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Constructability Review of Surface Treatments Constructed on Base Courses

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Texas Department of Transportation

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Constructability Review of Surface Treatments Constructed on Base Courses

A Final Report

By

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Abstract

It is common practice for TxDOT to construct surface treatments (1-, 2- or 3- course) directly over base courses. Such surface treatments may act as either wearing surfaces or underseals (or interlayers). The decision to use surface treatments is based on a number of factors including low life-cycle cost, low initial construction cost, inexpensive maintenance, historically favorable experience, availability of experienced contractors, and availability of sound local materials. Problems associated with surface treatments include flushing/bleeding in the wearing courses, debonding at the interface with the base layer, poor ride quality, loss of aggregate (raveling) and ineffective sealing of the pavement. When a surface treatment is used as an underseal, its failure may lead to accelerated failure of the overlying surface layer.

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Information collected from the constructability review was used to develop a district training workshop and to develop a design and construction guide for surface treatments. The workshop was delivered by researchers at eight regional locations, and each workshop was attended by TxDOT professionals from at least 3 districts. This report highlights the key findings from the constructability review and its related tasks. Chapter 1 provides an introduction to the research project and chapter 2 provides an overview of the constructability review conducted. This is an abbreviated version of the interim report 0-5169-1 for this research project. Though not a part of the original project agreement, a limited laboratory testing program was undertaken to evaluate the impact of factors influencing prime coat effectiveness. Details of this laboratory program, along with its results and a discussion are presented in Chapter 3. Chapter 4 provides an outline of the regional training workshops and the feedback that was received from participants. Chapter 5 provides the overarching conclusions from this research project.

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Chapter 1

Introduction

A surface treatment is defined as a single application of asphalt binder, followed by a single application of cover aggregate, both placed on a prepared flexible or stabilized base. In Texas, surface treatments are used as surface courses in low volume roads in the form of either one or multiple course treatments. One-course surface treatments are rare, and they are typically used for only a short period of time before covered by another one-course surface treatment or other type of surface course. In the case of multiple treatments, two or three courses of surface treatments are applied to provide a durable surface course. These surface treatments provide an economical pavement surfacing alternative compared to hot mix asphalt concrete. A surface treatment used as a pavement wearing surface has to be strong enough to withstand the traffic and climate-induced stresses. It also has to be durable. However, most importantly, it seals the pavement base and foundation.

In many instances, surface treatments are also used as interlayers, which are also referred to as underseals, between the base and surface courses. Some examples of such applications are *cape seals* (a combination of an underseal and a microsurfacing) and *stress-absorbing membrane inter-layers* (SAMI's). A surface treatment underseal has several functions in a pavement. An underseal can provide a stronger bond between the base and the HMAC layer, that will significant reduce the stress levels in the HMAC, resulting in a longer fatigue life of that layer. Similar to a surface treatment wearing course, it is a very effective method to seal the base course and foundation of the pavement from moisture. This can significantly extend the service life of pavement. A flexible underseal can also act as a Stress Absorbing Membrane Interlayer (SAMI) that can reduce reflective cracking in the HMAC layer. Hot rubber asphalt surface treatments have shown more effectiveness as a SAMI. Since the underseals are eventually covered with HMAC, they can be used in pavements with high traffic levels.

The application of surface treatment produces a small increase in thickness of the road surface, but it is not intended to provide additional structural capacity to the pavement. Therefore, all the structural strength in such a pavement is provided by the base course, which makes its role in the pavement very crucial. Such a pavement structure cannot be effectively used in high traffic volume roadways because the base and subbase layers are unable to provide strength that is sufficient for such pavement structures. However, ASTs provide a variety of benefits; they make the pavement waterproof, provide a skid-resistant wearing surface and lower life-cycle costs.

Most of the rural and farm-to-market roads in Texas experience relatively low traffic volume. Each year, the construction and maintenance of the state managed road network require a significant appropriation of funds from the state. Therefore, effective utilization of these funds is of utmost importance. Asphalt Surface Treatment (AST) is an

appropriate, economical and reliable technique, particularly for low volume roads. Also, ASTs are commonly used by highway agencies in other states and countries.

This report highlights the key findings from the constructability review and its related tasks. Chapter 1 provides an introduction to the research project and chapter 2 provides an overview of the constructability review conducted. This is an abbreviated version of the interim report 0-5169-1 for this research project. Though not a part of the original project agreement, a limited laboratory testing program was undertaken to evaluate the impact of factors influencing prime coat effectiveness. Details of this laboratory program, along with its results and a discussion are presented in Chapter 3. Chapter 4 provides an outline of the regional training workshops and the feedback that was received from participants. Chapter 5 provides the overarching conclusions from this research projects.

Chapter 2

Constructability Review

2.1 Background

A number of factors can significantly influence the performance of a surface treatment. Many practitioners involved in surface treatment and seal coat work consider them to be more of an “art” than a science. Such reflections give indications of the strong influence construction practices have on the performance of surface treatments. A large body of research has already been done on various technical aspects of surface treatment materials and their properties. However, a very good understanding of the “physics” of the problem does not always translate to a satisfactory surface treatment because the field personnel directly involved in construction and inspection are routinely called upon to make pivotal, often subjective decisions that may have a long-lasting effect on the performance of the surface treatment. Success in making such critical decisions requires sound technical judgment and a wealth of experience under local conditions. Therefore, the practice of producing high quality surface treatments requires a good training program for the inexperienced practitioner, and a continuing education program for the seasoned practitioner to keep up with the latest technologies and materials.

A sound specification is a prerequisite to producing a good quality surface treatment, but that alone cannot ensure consistent quality in a construction process. Field personnel who must both apply and enforce the terms of the specification must be trained to recognize good and bad construction procedures. More importantly, they must fully understand the capabilities of equipment used in the industry to complete projects. Seemingly insignificant details such as the moisture content of a finished base, and the amount of dust accumulated on the base surface can alert the contractor to remedy the problem on the spot and make the difference between a successful surface treatment and one that fails due to insufficient bonding between the asphalt and the finished base. Thus, the primary focus of this project will be to identify construction practices that consistently produce good surface treatments, and create a training program for TxDOT practitioners who are responsible for the execution, inspection, and acceptance of surface treatment projects.

2.2 Constructability Review Process

The methodology to be used for this purpose is a formal constructability review of the surface treatment construction process, similar to the method adopted in TxDOT research project 0-1787: *Seal Coat Constructability Review* (Senadheera et al. 1999).

Constructability is a term of art which has come to encompass a detailed review of design drawings, specifications, and construction processes by a highly experienced construction engineer before a project is put out for bids. It is defined as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII, 1986). The purpose of the constructability review is to identify the following five items:

- Design errors, both material selection and dimensional
- Ambiguous specifications
- Project features which will be difficult or exceedingly costly to construct as designed
- Project features which exceed the capability of industry to properly build
- Project features which are difficult to interpret and will be hard to accurately bid

The researchers picked apart, piece by piece, the surface treatment process from planning to construction completion looking for those portions of the processes that are inherently variable and difficult to replicate in the field. The performance of a surface treatment is often a function of the following broadly classified factors:

- Appropriate project selection
- Quality of design
- Quality and consistency of construction
- Quality and consistency of materials
- Environmental conditions
- Traffic conditions

The study focused primarily on construction and materials. These are the two factors that show the most promise for control through better training of field personnel. The quality of a surface treatment or seal coat project's performance is influenced by at least eight construction process variables (McLeod, 1960):

- Preparation of the surface of base layer
- Uniform distribution of binder
- Time between applying binder and aggregate application
- Time between the application of successive treatments
- Material variation
- Compaction method and duration
- Embedment of aggregate
- Climatic conditions prior to, during and after construction
- Interval between completion and opening to traffic

As a part of this constructability review, a vast volume of research material was collected in this research project. During the literature review and state-of-practice review of this research, researchers contacted state DOTs and also reviewed information from several countries. The state-of-practice review focused primarily on communicating with surface treatment practitioners from other highway agencies.

The researchers made attempts to contact all 50 states to obtain information on their surface treatment practices. Information requested from other state DOTs was not nearly as extensive as that of TxDOT districts. Repeated attempts to obtain the required information resulted in only 28 states responding to the request. Appendix A presents the questionnaire that was used when interviewing other State DOTs.

Six of the 28 states indicated extensive use of surface treatments directly on base courses. Three other states indicated limited use of surface treatments and 19 states do not use surface treatments directly on base as a general practice.

The researchers also investigated surface treatment practices by other countries. It was found that surface treatments (on base) are used by many countries worldwide. South Africa, Australia and New Zealand were three countries that showed extensive surface treatment use in their highway networks.

2.3 Statewide Constructability Review

The research team visited and interviewed surface treatment practitioners from all twenty five TxDOT districts. The district constructability review consisted of the following two phases.

- A face-to-face interview on the subject of surface treatments (constructed on base) with a team of personnel assembled by each district
- Visits to surface treatment construction projects

The face-to-face district interview was guided by a questionnaire consisting of 83 questions that covered topics related to surface treatments ranging from project selection to continuous improvement. The surface treatment process can be broken down into the following three parts.

- Design
- Construction
- Performance

2.3.1 Design of Surface Treatments

Asphalt surface treatments are typically classified as either one-course, two-course or three-course applications. In Texas, surface treatments are constructed as a thin bitumen–aggregate application on a prepared road base. The construction method typically involves the finishing of the base layer and spraying a heated prime coat binder. The prime coat is typically a sprayed asphalt binder that has a sufficiently low viscosity and surface tension contact angle with the base material that will allow it to penetrate into the base and create a strong bond (hold) on the base. A prime coat can also be applied by mixing an emulsified asphalt binder to the top of the base material. Such a prime coat is called a cut-in, worked-in or a mixed-in prime.

The application of prime coat is followed by the application of the surface treatment. The objective of the prime coat is to act as a bonding agent between the finished base and the surface treatment binder. The prime coat binder, which is typically a low-viscosity material, penetrates into the base and establishes bonding with its particles. Figure 2.1

shows a schematic of a typical penetration pattern of a prime coat binder into the base layer.

After applying the prime coat, typically, a curing time is allowed. Then the surface treatment binder is applied over the prime coat using an asphalt distributor. The cover aggregate is then applied uniformly using an automated aggregate spreader. A pneumatic-tired roller is used to push the cover aggregates into the soft asphalt binder before it cool (or cures in the case of emulsified asphalt) and hardens. The asphalt and aggregate application rates are designed such that approximately one half of the height of each aggregate particle is embedded into the asphalt binder to prevent lost of cover aggregate. It is recommended that the voids space between individual particles when looking from the top is kept at approximately 30 percent. The final product with a one-course surface treatment is similar to that shown in Figure 2.1.

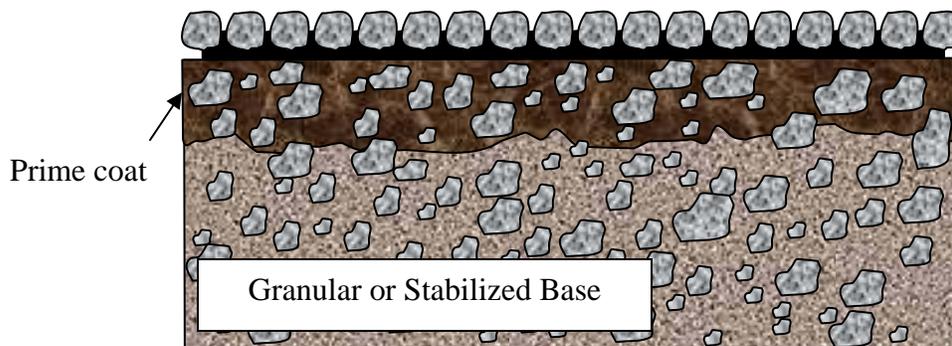


Figure 2.1 Schematic of a Typical One-Course AST

The design process of a surface treatment comprises of the following steps.

- Project selection
- Design of prime coat method
- Design of the surface treatment

The statewide constructability revealed that 2-course surface treatment (2-CST) is by far the most popular surface treatment in the state. It is used by 18 districts. The underseal is used by 9 districts. Three districts use 3-course surface treatments. In some of these districts, it ends up being a 4-course surface treatment when a 1-course ST is applied late in the fall, which is followed by a 3-CST during the next asphalt season. One district indicated that in a few instances, they have been able to use a 1-CST for an extended period of time in roadways with a very low traffic volume. The statewide use of surface treatment types is illustrated in Figure 4.1 below.

It is very important that appropriate projects are selected for surface treatment work. A number of factors are considered in the project selection process. TxDOT districts use a

number of criteria to decide if a surface treatment wearing surface is to be used for a pavement construction project. The top nine such criteria identified by districts are listed below. The number in parenthesis indicates the number of districts that consider that particular criterion in surface treatment project selection decisions.

- ADT of highway (19)
- Highway section location (10)
- Percent trucks (8)
- Cost (8)
- Highway classification (6)
- Existing pavement type and condition (4)
- Traffic control plan (3)
- Presence of turning traffic (2)

The next topic in the design process is the prime coat. It includes the selection of an appropriate prime coat method, selection of a binder type and an application rate. The design of the prime coat is done with serious consideration given to its constructability. All TxDOT districts that use surface treatments either as a wearing course or as an underseal use prime coat. The following section provides an introduction to the prime coats used by districts.

The prime coat plays a very important role in pavement structures. Its primary benefit is the facilitation of bond between the surface treatment and the base layer. The binders that are used in the surface treatment courses need to be strong and durable. Such binders do not have the low viscosity needed to penetrate the base layer and grip it, to prevent it from debonding due to shear stresses exerted by traffic and due to other factors. A prime coat which uses a low viscosity binder can act as an intermediary between the surface treatment binder and the base. The gripping effect of the prime coat onto the base strengthens the base layer by providing more cohesion to the top of the base.

There is usually a time lag between the completion of base layer construction and the application of surface treatment. A well-applied prime coat can protect the base layer from adverse weather conditions and from wear due to construction and regular traffic until the surface treatment is applied. This is particularly useful in situations where surface treatments are constructed under traffic with no satisfactory method of traffic control. It can also either prevent or slow down the formation of dust on the surface that will have a serious negative impact on the bonding of binder to base.

The penetration of the prime coat into base is very important to get the maximum benefit from the prime coat. The amount of penetration would depend on a number of factors including the prime coating method, prime coat binder, base material, base finishing technique and the porosity of the base course. Typical penetration of a sprayed cutback prime could be in the range of 1/8-3/8 inches.

At least four different prime coat types are used by TxDOT districts. The most common is a spray prime coat. The most commonly used spray prime coat binders are MC-30,

AE-P and RC-250. The typical spray prime binder application rate is 0.2 gal/sy, which may be adjusted depending on the tightness of base finish and if construction traffic has to be allowed on the primed surface. When construction of a spray prime coat is done under traffic, blotting sand may be spread on the prime coat binder within minutes after the binder is sprayed, and traffic can be allowed on the primed base within a fraction of an hour.

A worked-in (sometimes referred to as cut-in) prime coat application involves the spraying of a diluted emulsified asphalt, which is then covered with a thin coating of fine base material dust by working the windrow with the motor grader. This process is usually repeated 2-3 times to get a total emulsion application rate of 0.2 gallon per square yard. The emulsions commonly used for this purpose are SS-1, CSS-1h and MS-2. This leaves a asphalt-sand layer on the finished base that is approximately 1/8 in. thick (see inset).

The third type of prime coat is a covered (or inverted) prime. This covered prime is similar to a course in the surface treatment where RC-250 cutback is first applied on the finished base, which is covered by spreading Grade 5 rock. This 'priming' technique is particularly useful when traffic has to be allowed on the primed surface before the other half of the roadway is primed. This type of a prime can provide 2-3 months of satisfactory service as a very temporary wearing course under favorable traffic conditions including little or no turning traffic or heavy traffic.

The type of prime coat not shown in these pictures and videos is the "mixed-in prime". This is when one the base density is achieved and the base is completed up to the blue-tops, the top 2-3 inches of base is remixed with a diluted emulsion and then re-compacted. It must be mentioned that 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 where the prime coat binder, which is a 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 re-compacted.

The third and final step in the design process is the design of the surface treatment itself. This involves the decision on the number of surface treatment courses (including their construction sequence), the selection of aggregate type & grade, selection of binder type & grade and the design of material application rates. In many situations, a one-course surface treatment is applied in late fall, which is used as a temporary wearing surface for several months until the next warm weather season arrives when the subsequent course(s) are applied. If a covered prime, which is really a single course with grade 5 aggregate, the service life one can expect to get as a temporary wearing course may be no more than 3 months.

The aggregate rate used for a surface treatment course is an important part of the surface treatment rate design, and it is often the first item that is designed. The general guideline

is to leave sufficient room (i.e. 15-25% in plan view) between rock particles so that they can ‘wiggle’ and settle to the most stable position when rolled. A ‘Board Test’ is used by some districts to help determine the rock rate. The board test uses a 1 yard by 1 yard board on which aggregate is spread to the required coverage level, and then determines the application rate by using the calculation method outlined in the TxDOT Seal Coat and Surface Treatment Manual (2004).

Typically, a correction has to be made to the rock rate determined using the board test to suit field conditions. The key is to avoid over-application of stone. If ‘too much’ rock is applied, rock particles may not be seated in a stable manner, and result in rock loss due to lack of embedment.

A variety of binder types and grades are used by districts in surface treatment courses. These binders can be classified into binders used in warm weather and cool weather. AC-20 5TR is the most commonly used warm weather ST binder, followed by AC-15P and AC-5. The emulsion grade CRS-1P is the most commonly used cool weather ST binder, followed by AC-5 and AC-12 5TR.

The design of surface treatment binder rates begins with seal coat binder rate design. Districts do seal coat binder rate design in several ways. The most commonly used method is based on the aggregate type & grade, aggregate rate, % embedment needed and traffic level (ADT and % trucks). The procedure to perform the binder rate design is outlined in the TxDOT Seal Coat and Surface Treatment Manual of 2004. Binder rate designed in this manner is used in the preparation of plans.

Some districts determine the binder rate based on experience, but this approach is recommended only when sufficient experience is gained by the designer for the conditions under which the seal coat is used (i.e. binder grade, source, aggregate and traffic level). At the time of seal coat construction, the binder rate used in the plans are adjusted to suit field conditions including pavement surface condition, ADT, percent trucks and aggregate type/grade.

The binder rate design in seal coats is closely related to the percent embedment of aggregate into the binder. Typically, a 30% embedment is used for high traffic volume roads and a 40% embedment is recommended for low traffic roads. The percent embedment depends on the binder type and grade, aggregate type and grade and the traffic level. Generally, a higher % embedment is used when a larger rock is used, because more binder is needed to retain the aggregate. Since the asphalt binder is the most expensive item in a surface treatment, the strategy is to use the lowest quantity (i.e. application rate) of binder without allowing rock loss. If too much binder is used, the surface treatment may experience flushing and/or bleeding with time, creating maintenance problems.

Even though seal coat binder rate design can be used to guide the binder rate design for multiple-course surface treatments, some key adjustments need to be made to account for the design and construction sequence of the surface treatment. If successive courses are

applied quickly one after the other, allow for drain-down of binder (i.e. use a lighter rate for lower course, and heavier for the upper course). This may be achieved by considering the existing surface to be highly textured (coarse). If upper course is applied months later, use a heavier rate at the bottom and lighter at the top

2.3.2 Construction of Surface Treatments

The next phase of the surface treatment system is the construction process, and it can be divided into the following five parts.

- Construction Management
- Base Finishing
- Prime Coat
- Surface Treatment Application
- Quality Control

The construction management process plays a very important role in the performance of surface treatment. A lot of discussion has been centered on the possibility of using specifications other than methods specifications for repetitive processes such as surface treatments. Districts were asked whether surface treatment projects are good candidates for performance-based or warranty specifications. Sixteen districts indicated that STs would be good candidates for such specifications and, and many of them indicated that research is needed to explore ways to move in that direction. A warranty period of one year was considered to be an appropriate warranty period by many. Eight districts indicated that they don't think performance-based or warranty specifications are feasible for surface treatments due to likely obstacles to implementation. There seemed to be some overlap in thinking between those who responded as either "yes" or "no". The differences between them appear to be whether they think this is a feasible endeavor or not.

Districts were asked about the problems they commonly experienced with contractors. The issues most often mentioned were;

- Contractor's expertise, both in general and that of equipment operators
- Contractor's work load. i.e. several contracts handled by the contractor result in some districts getting a sub-standard workforce (B-Team)
- Timely availability of materials, particularly aggregates
- Finish quality of the surface treatment
- Poor condition of contractor's equipment
- Contractors' inability to adhere to established asphalt rates

Other problem topics included contractor not mobilizing on time, work-zone safety issues and contractor unfamiliarity with materials used in surface treatment (in particular the binder).

Finishing of the base is extremely important to the bonding of surface treatment to base. In this section, several aspects related to base finishing are discussed. The base materials most commonly used with surface treatments are listed below in the order of decreasing use.

- Limestone
- Caliche
- Iron Ore Gravel
- Gravel
- Fly Ash Stabilized Base
- Cement Treated Base
- Asphalt Stabilized Base

Limestone is by far the most common, with fourteen districts using them. The next most common base material is caliche with six districts using it. Of the stabilized bases, cement and fly ash stabilized bases are most common. Asphalt stabilized bases were not included in this research because of its unique interaction with an underseal compared to other stabilized and flexible base materials.

Both the pneumatic roller and the steel wheel roller are used to finish the base. The pneumatic roller is used first, followed by the steel-wheel roller. The kneading action of the pneumatic roller helps the initial rolling to even-out the bladed surface. The steel-wheel roller helps to get an even and less rocky surface before the prime coat is applied.

TxDOT districts use three base finishing methods.

- Slush rolling
- Blade and roll
- Trimming

Slush rolling is the most common method with twelve districts using it. However, this base finishing technique varies among districts depending on the amount of water used. Some districts use little water, whereas others use a lot of water.

The blade-and-roll technique is the next most common technique with seven districts using it.

The trimming technique uses the subgrade trimmer used by districts to finish the base. Excess base is used to compact the base 1-2 inches above the blue-top level, and then, the trimmer is used to cut it down to the required finish level. Then, the trimmed surface is rolled. This eliminates the need to do slush rolling. The excess material is used in other miscellaneous construction operations.

One of the most critical elements of surface treatment construction is the priming of base. The prime coat helps the surface treatment binder to adhere to the base course by

penetrating and sticking to the base. In this section, some findings on the construction of the prime coat are presented.

Several conditions may be identified as “optimum” for a base to have before a prime coat is applied. Under these conditions, the base should be

- Reasonably smooth,
- Reasonably porous
- Not dusty
- Structurally strong

The base should not have standing dust when the prime is applied, and the finished base is broomed to remove the dust. However, brooming must be done carefully so as not to disturb the base layer particles.

These “optimum” conditions for the base may not necessarily be “compatible” with each other.

For example, a “reasonably smooth” finished base is required to achieve a desirable ride quality in the finished surface treatment. However, an overly smooth base can prevent the prime coat binder from penetrating into the base and achieve a good bond between the base and the prime. Therefore, some porosity (fine or small pores) is needed for this bond to be developed. The desirable pore size is determined by the prime coat binder and its wettability of the base material.

In many instances, slush rolling is used to obtain a smooth finished base surface. However, unless care is taken to control the ‘slushing’ water content, excess water can weaken the base significantly by making its density lower.

The timing of the prime coat application is of great significance in achieving a good bond with the base. The moisture content in the base has to be “just right” for the prime to penetrate into the base. 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, base must be allowed to dry to some extent after finishing before the prime coat is applied. However, too dry a base can 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. Therefore, ‘skeeting’, which involves light sprinkling of water on an overly dry surface to make it more suitable to apply the prime coat binder, is done. Shaded areas, which are common in east Texas, dry slower than non-shaded areas. If the prime coat is applied under these conditions, it may not effectively stick to the base and eventually delaminate.

The worked-in prime coat layer is strong enough to run traffic for several days when applied under the ‘right’ circumstances which are given below:

- Prime applied under appropriate base moisture condition
- Do not allow traffic on the primed surface for at least one day
- Allow reduced-speed traffic for the first couple of days, particularly at the intersection approaches

When a “worked-in” prime is used and if traffic is allowed on the primed base for several days, it is recommended that there are drainage paths for storm water.

The first decision that a TxDOT project manager or inspector has to make with regard to surface treatment application is whether the primed pavement is ready for surface treatment application. The researchers asked the districts how long they would wait after the priming before applying the surface treatment. The responses received to that question varied from same day to 10 days. This time lag between the prime and the surface treatment depends on the following factors:

- Type and grade of binder (i.e. provide time for cutback volatiles to evaporate and for emulsions to cure and penetrate)
- Type of base (allow prime to penetrate)
- Contractor’s construction schedule
- Work-zone management

However, the following general practices emerged from the survey.

- Wait at least 3 days when the prime coat binder is an emulsion
- Wait at least 7 days if the prime coat binder is a cutback.

The district response to the question ‘What should the minimum time lag be between first and second courses of a multiple-course surface treatment (MCST) when the binder is AC?’ varied from 1 day to 14 days (and more). The variation in responses appeared to be based on the district’s belief on whether it is more desirable to allow traffic on the first course for some time before the second course is applied. There were a few districts that applied the first and second courses the same day.

The response to the same question for emulsified asphalt ranged from 1 day to several months.

The variation in responses appeared to be based on the following factors.

- Allow sufficient time for emulsion in the first course to cure, and the opinions on this seems to vary somewhat from 1 to 7 days.
- Use the emulsion in the first course towards the latter part of the asphalt season or during winter to obtain several months of service so that the next course could be applied during the asphalt season using AC binder

For cutback asphalts, the responses we received depended on the type of “first” course used. Several districts use a ‘covered (or ‘inverted’) prime, which can be considered as a

first course in a ST. In this case, RC-250 cutback asphalt is used as the binder, and 7 days appear to be sufficient for the volatiles to escape the rapid curing RC-250. In the case of surface cutback surface treatment binders such as MC-2400 or MC-3000, a minimum of 90 days is recommended before the second course is applied.

Quality control is arguably the most important part of any construction process. It encompasses many aspects of construction including materials used in construction, conformance to plans and specifications and workmanship. Due to the 'low-bid' contract method adopted by TxDOT, the inspector has to be mindful about the contractor's expertise and the skill set, particularly if the inspector has no prior experience working with the contractor. In such a situation, certain key adjustments have to be made in the inspection of surface treatment process.

The chief inspector in a construction project has to provide effective leadership to the inspection crew as well as to the construction project itself. It is important that the construction crew establish an effective working relationship with contractor's personnel. The first step in achieving a good rapport with the contractor is to establish effective lines of communication between the inspection crew and the contractor's crew. This will minimize miscommunication at the construction site between the two parties.

During district interviews, researchers asked TxDOT district interview subjects for general comments regarding the quality control process., and the following comments were often repeated by districts.

- Inspection forces are dwindling
- TxDOT is losing a lot of experience in inspection staff
- Some surface treatment inspectors handle multiple jobs, and therefore, some some project tasks cannot be inspected effectively
- Surface treatment training is needed for new inspector hires
- In many cases, surface treatment work is contractor-driven primarily due to lack of inspector expertise

Over the past several years, the Department has seen a significant depletion of the inspection pool, particularly the experienced inspectors. This has placed a significant burden on the remaining inspectors, and they are often asked to handle several concurrent jobs as a result. Therefore, these inspectors have to manage their time effectively among different projects, or within various work locations within one project to ensure that all key work tasks are inspected in a timely and an effective manner.

Also, in some situations, the Department is compelled to place newly hired inspectors with limited training, on positions of authority, which may put them in 'difficult-to-handle' situations. This can also cause problems in a project. The inspector is the client's representative at the project site. Therefore, he/she has to establish the client's authority at the construction site. If the inspector is unable to resolve certain situations or disputes at site, the inspector has to make the judgment whether or not to call the Engineer to resolve the issue. It is important for the inspector to recognize that the

contractor is a partner in a construction project, and that it is reasonable to expect them to make a decent return on their investment in the business. Therefore, the inspector must make every effort to resolve questions or issues that arise in a timely manner, so that the contractor can make satisfactory progress.

Often, contractors have a wealth of experience in the construction work they do. Therefore, it is in the client's best interest to effectively utilize such expertise to the benefit of the project.

Allowing contractors some freedom to handle certain construction situations on which they are experts, will facilitate a positive working relationship between the inspector and the contractor

It is the inspector's duty to ensure that the contractor is performing the work in conformity with the specifications and plan notes that are a part of the construction agreement. The general workmanship of the contractor has to be in accordance with reasonable norms. Furthermore, the inspector has to ensure that contractor personnel who operate key equipment, have the requisite skills.

Two inspection tasks that are unique to the surface treatment construction process are the finishing of base and the prime coat. These two processes often are related to each other. The base finishing method is a very important part of the surface treatment construction process. This does not include the construction of base and the achievement of required density. Generally, the base is constructed for a certain roadway length (often referred to as the construction land) at one time, before the base finishing and prime coat of that section is undertaken.

The use of an effective method to finish the base is of utmost importance. The base finishing method has to be done without compromising the quality of the base, and it has to be compatible with the prime coating method. It is also important to consider the constructability of the activity, particularly if the contractor has the expertise to do the base finishing work as stipulated in the plans. The finish quality of the base has to be checked by the inspector, because it dictates the final ride quality of the surface treatment. It would be a much easier to ask the contractor to refinish the base rather than having to ask the whole surface treatment to be re-done. Traditionally, most inspectors conduct a "seat of the pants" test to ensure the quality of base finish. However, a few districts (ATL, BWD, ODA, SJT, YKM in particular) are using the International Roughness Index (IRI) calculated using the profiler measurements to check the finish quality of the finished (or primed) base. Several other districts are also taking a serious look at this method. This will provide inspectors with a much easier task of evaluating the base finish, but it is important to ensure that the contractor is using appropriate methods to achieve the base finish.

The prime coating process also involves several key steps that require inspector involvement, and the most important of them is checking the readiness of the finished base to be primed. The attainment of the right moisture content of the base is of utmost importance. Most experienced inspectors may be able to check the moisture content

using simple techniques such as by looking the base surface and by digging into the base at several locations. However, it is recommended that a moisture content measurement be made to verify the state. The new 2004 TxDOT specification recommends a moisture content of base optimum moisture content (OMC) minus 2% to be optimum before prime coating. Having too much water in the base may prevent effective bonding of the prime, and can trap too much moisture in the base making it weaker (low modulus) than it was designed for. Too much drying of the base generally creates a thin coating of dust that will also reduce the effectiveness of bonding. In such a situation, a light spray of water (skooting) can help alleviate the situation.

The other key items in the inspection of prime coating process are the use of an appropriate prime coat binder rate and the prime coating technique itself. The inspector must also ensure that the contractor takes all possible precautions to protect the prime coat. These may include the use of cutouts to prevent water-logging of the primed base (when base material windrows are used in the priming process) and to minimize traffic on the primed base which may wear the prime. Wearing of the prime can prevent the surface treatment binder from bonding to the base.

Once the prime coat is applied on base, the next step is to apply the first course of the surface treatment. The inspector has to ensure that the contractor applies the surface treatment course at the most optimum time. If traffic has to be put on the primed base, the surface treatment must be applied as soon as possible to prevent potential damage to the primed base. However, the inspector must ensure that the contractor allows sufficient time for the prime to cure before the surface treatment is applied. If emulsified asphalt is used for the prime, it must be cured appropriately (all the water is evaporated). When cutback asphalt is used, all the volatiles must be evaporated from it, and otherwise, the surface treatment will be weakened once applied.

The surface treatment binder must be applied at the proper rate and temperature. The inspector must check the nozzle angles and the spray bar height to ensure proper binder rate application. The shots must be marked, and the distributor must be periodically strapped to ensure that the computer readings are accurate.

Aggregate (rock) must be applied as soon as possible for both hot asphalt and emulsified asphalt. The inspector must check the aggregate stockpiles for dust, and debris, and ensure that aggregate gradation is appropriate. In the case of precoated aggregate, proper precoating coverage must be ensured. The inspector must mark rock lands, and ensure that the loader operator loads trucks consistently so that proper application rate can be checked using rock lands. Rolling of the aggregate is very important to ensure that aggregate particles are seated on the pavement in their most stable position (lowest center of gravity). This will ensure that aggregates will maintain a satisfactory bond with the binder. The inspector must pay particular attention to the roller coverage of the surface treatment and if the specified number of roller passes is used. When surface treatment is done in the morning and later afternoon, particular attention must be made to the binder temperature, and the number of roller passes could be increased in such situations to ensure that design embedment is achieved.

Loose rock on the pavement can cause numerous problems to the traveling public as well as construction personnel. It is a safety hazard, and it may also contribute to windshield damage. On the other hand, having loose rock on the primed base can damage the prime (and the base), and timely removal of loose rock is very important. One way to reduce damage to prime due to loose rock is to shoot the surface treatment binder a little wide, and then to overlap it with the adjoining binder shot.

Almost all surface treatment construction projects require that the contractor effectively manage work zone traffic and access to nearby property. Safety of the traveling public and construction personnel during construction is of supreme importance, and therefore, the inspector must ensure that the contractor abides by the plans and specifications in this regard. The inspector should also check, on a daily basis, if continuous access is provided to personal and commercial property from the construction zone. When access to property has to be curtailed to allow construction activity to proceed, the inspector must ensure that the public is notified of such activity well in advance to minimize inconvenience.

Under current TxDOT specifications, the acceptance of the job after the completion of surface treatment construction is a key milestone. Once accepted, the roadway becomes the client's (TxDOT) responsibility, and therefore, the inspector must ensure that the job is accepted in good condition. The inspector must ensure that quality of completed construction project is checked as per specifications. An important part of this process is checking the completed structure for any damage during construction. The inspector must ensure that such damage is repaired by the contractor as stipulated in the contract prior to the acceptance of the job by TxDOT.

2.3.3 Performance of Surface Treatments

The next section of the surface treatment process is its performance aspects. Surface treatments have some unique performance characteristics, and in this section, surface treatment distresses, and how they are rectified, are discussed.

The following four distresses are associated with surface treatments. The number in parentheses indicates the number of districts that identified that distress as one they have encountered.

- Peeling of Prime (3)
- Peeling of ST (4)
- Bleeding/Flushing (22)
- Raveling/Rock Loss (20)

Even though bleeding and flushing are two different distresses, they are identified together due to similarities in the way they develop. These distresses can occur both in the short-term (during construction) and long-term (during performance of the surface treatment). Both these types of distresses are discussed in the next few slides.

Figure 4.10 shows a prime coat that peeled during brooming. Generally, a light brooming is done on the primed surface to remove any dust accumulated on it before the surface treatment binder is sprayed. In this case, the peeling of prime may have been due to the following two factors:

- Turning traffic at this location that exert higher shear stresses on the primed base
- Shaded area may have contributed to the prime to cure slowly

Traffic should only be allowed on the prime coated base when it is absolutely necessary. Traffic has to be allowed early on some primed roadways because it is an existing two-lane roadway. However, opening for traffic for too long, particularly when significant heavy traffic is present, it can cause the prime coat to wear off and cause problems. In such situations, the surface treatment will not stick well in the area where the prime is worn out. Re-priming of the affected area must be done in such situations.

When rainstorms occur on an exposed primed base that is open to traffic, both the prime and the base are likely to get damaged. This is particularly true when drainage paths are not allowed for storm water during construction. Roadside base material windrows can create such situations. The inspector must ensure that when primed (or un-primed) base is opened to traffic, proper drainage channels are provided.

Damage may be caused to a prime coat because of loose rock on the primed base. Loose bounced-off rock from the chip spreader can be the cause of prime coat damage when traffic on the primed base drives the loose rock into the base. Therefore, it is important to minimize the presence of loose rock on the primed base. One way to achieve this is by shooting the surface treatment binder about 6 inches wide, such that any bounced off-rock from the chip spreader can be retained. Since this extra width of asphalt is to the end of the distributor, it leaves a lighter asphalt coating, and it can be overlapped when the next lane is shot.

The pickup of the newly constructed prime can be caused by sudden movement of tires in construction vehicles. It can also be caused by poor bonding between the base and the prime or between the prime and the surface treatment. Failure may occur between the base and the prime. Failed areas need to be quickly repaired by the contractor.

Flushing and bleeding are common distresses of asphalt surface treatments. Flushing of a surface treatment shows the loss of macro-texture in the pavement surface. Bleeding is when excess soft and sticky asphalt is present on the pavement surface, and it causes a loss of aggregate-tire contact. Both flushing and bleeding are caused by aggregate particles driven into the soft pavement by traffic. Bleeding is the advanced stage of the flushing distress. Losing rock from surface treatments referred to as raveling. Rock loss generally occurs outside of the wheel-paths because at these locations, traffic usually helps in the bonding of aggregate to the binder.

Loss of rock is typically an indication of one of the following:

- Incompatibility between the aggregate and the binder

- Insufficient binder to hold the rock
- Cold and/or wet weather arriving too soon after the surface treatment
- Dusty aggregate
- Application of aggregate too late after binder is sprayed
- Application of surface treatment in cooler weather
- Insufficient rolling (particularly in the case of hot asphalt)

2.3.4 Field Projects

The district interviews were combined with visits to surface treatment construction projects to observe construction operations and to interview field personnel. Sixty-six projects were earmarked for possible site visits during construction, and the researchers were able to visit thirty seven of them when construction work was in-progress. During each visit, data on the project including materials used, material application rates and the construction process were collected. Informal interviews were conducted with TxDOT field personnel (inspectors) and contractor personnel at the project site. The construction process was also recorded on digital pictures and video. Several other pavement sections were visited after the construction was completed. Figure 2.2 shows the statewide distribution of construction projects visited by researchers when surface treatment work was in-progress. Table 2.1 shows some of the key elements of each construction project visited by the researchers.

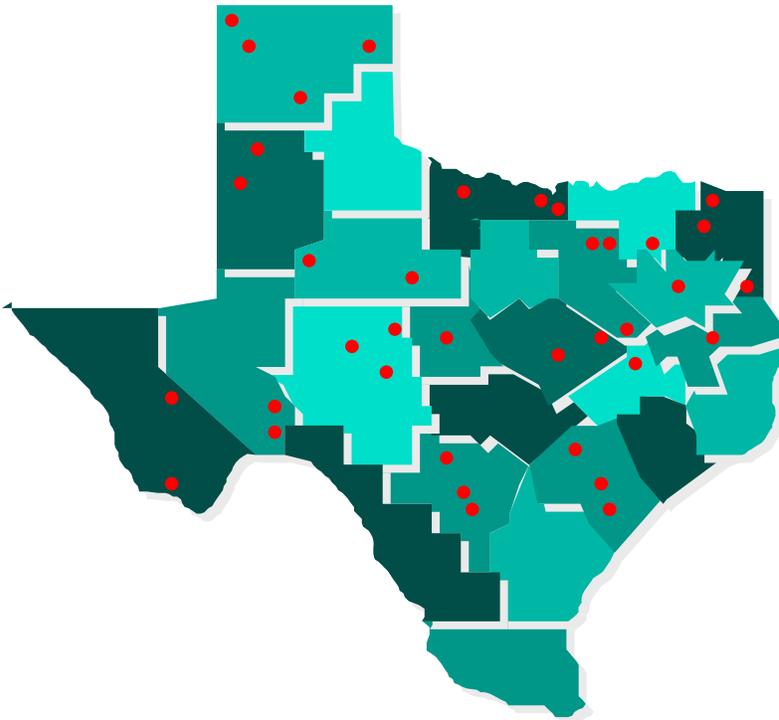


Figure 2.2 Locations of Surface Treatment Projects Visited by Researchers

A large volume of construction project data, along with video footage and still pictures of construction activities was collected during these project visits. The important elements of a few selected projects are highlighted in this chapter to illustrate unique surface treatment practices.

Table 2.1 Summary of Surface Treatment Construction Projects Visited by Researchers

District	Project (County)	Remarks
ABL	FM 204 (Taylor) FM 1054 (Borden) FM 669 (Howard)	Contract Paving - 1st and 2nd courses of 2CST Jones Bros - LS base;AE-P prime; 1st of 2CST Price Construction
AMA	FM 1727 (Dallam) SH 33 (Hemphill) US 287 (Armstrong) US Hwy 87 (Dallam)	J. Lee Milligan - LS base finished using Trimmer Gilvin-Terrill - Finished base for MC-30 prime J. Lee Milligan - Trimmed LS base with AE-P J. Lee Milligan - Primed LS base with MC-30
ATL	FM 699 (Panola) US 259 (Cass) FM 576 (Bowie)	Pinto Const. - LS base finish; MC-30 prime; IRI DL Lennon - Iron Ore Gravel (IOG) base finish; SS-1 prime; underseal Widening - IOG base; MC-30 prime
BWD	FM 3064 (Brown) FM 2214 (Eastland)	Prater Equipment – Underseal Jay Mills Contracting
BRY	FM 489 (Freestone) PR 40 (Walker) SH 40 (Brazos) FM 2 (Grimes) SH 7 (Leon)	A.L. Helmcamp - LS base finish; inverted prime Ajax Equipment Glenn Fuqua Glenn Fuqua Young Contractors
DAL	FM 1394 (Navarro) FM 2194 (Collin) FM 75 (Collin)	Big Creek Construction - Limestone (LS) flex base installation; considering use of base laydown machine and premixed base & prime 2nd course of 2CST prior to HMA overlay; evaluated 2 sections (6 and 12 months old) 2nd course of 2CST prior to HMA overlay
ELP	FM 170 (Brewster) SH 17 (Jeff Davis)	Gilvin-Terrill - LS base treatment (full depth) finishing with MS-2; 1st and 2nd courses of 2CST (in place) Jones Bros - 1st course of 2CST (in place); remove existing pavement section to subgrade
FTW	FM 8 (Erath)	Jay Mills Contracting
LRD	US 277 (Maverick) FM 624 (LaSalle)	Price Construction Foremost Paving
LBB	SH 214 (Bailey) SH 194 (Castro)	Amarillo Road - MC-30 prime; 1st course/2CST Amarillo Road - Completed 3CST in one day
LFK	SH 103 (Angelina)	Pinto Construction - Inverted prime; base finishing on cement-treated iron ore base; first course of 2CST + HMAC
ODA	SH 349 (Terrell)	Jones Bros - MS-2 prime cut-in; 1st and 2nd courses of 2CST

Table 2.1 Summary of Surface Treatment Construction Projects Visited by Researchers
(continued)

District	Projects (County)	Remarks
PAR	SH 276 (Rains) I-30 Frontage Road (Hopkins) FM 3236 (Hopkins)	D.L. Lennon - LS Base finish; SS-1 cut-in prime D.L. Lennon - Cement treated sandstone (SS) base finish; SS-1 cut-in prime A.K. Gillis & Sons - 2CST on CTB
SJT	SH 208 (Tom Green) US 67 (Runnels) US 87 (Concho) RM 337 (Real)	Reece-Albert - Primed base with AE-P Reece-Albert - 1st and 2nd course of 2CST Stephens-Martin - LS base finish; MC-30 prime Allen Keller
SAT	SH 16 (Bandera) SH 173 (Atascosa) SH 16 (Atascosa) RM 1051 (Uvalde) Spur 98 (Kerr) FM 1688 (Uvalde) FM 624 (McMullen) FM 3175 (Atascosa) FM 1343 (Medina) FM 471 (Medina) FM 1052 (Uvalde) FM 1957 (Medina)	Capital Excavation - LS base; AE-P; peeling u/s Ray Faris - Inverted prime (underseal) using AC-5 and Grade 5 rock Salinas Construction - MS-2 prime on LTB E.E. Hood & Sons Capital Excavation E.E. Hood & Sons - Inverted prime over cement treated LS base (CTB) Foremost Paving E.E. Hood & Sons E.E. Hood & Sons (new project - not started) E.E. Hood & Sons (new project - not started) E.E. Hood & Sons E.E. Hood & Sons
TYL	Loop 49 (Smith)	Young Contractors - LS base finish
WAC	FM 638 (Limestone) FM 1695 (McLennan) SH 195 (Bell)	Young Contractors - Cut-in CMS-2 prime Big Creek Construction - LS base using Ingersoll-Rand base laydown machine; prime with pugmill premixed base & emulsion Woodard Const. (asphalt subcontractor) Marvin Dean Whittingburg
WFS	FM 51 (Cooke) FM 372 (Cooke) US 277 (Wichita)	AUI Contractors - Base finish Rushing Paving - LS base slushed; MC-30 Duininc Bros - LS base finish; MC-30 prime
YKM	FM 153 (Fayette) FM 616 (Jackson) FM 2433 (Calhoun) FM 1163 (Wharton) FM 3131 (Jackson) FM 1291 (Fayette)	Hunter Ind. - Covered prime; 1st of 2CST Brannan Paving Garey Construction Faltisek Paving Brannan Paving Big Creek Construction

2.4 Summary of the Constructability Review

The application of a surface treatment is a simple and straightforward process. However, its success depends to a great degree on the effectiveness with which the base layer is finished and on the method used to ensure sufficient bonding between the surface treatment and the base. In Texas, all surface treatment construction projects use a prime

coat on base to achieve this end. The techniques used to construct prime coats vary significantly both within and between districts.

Two of the most important topics related to the surface treatment process are base finishing and prime coating. Many districts use the slush rolling technique to finish the base primarily to achieve a smooth base finish that is critical to the final ride quality of the surface treatment. The research team noted that there are several interpretations of what slush rolling really is. Some districts refer to a light sprinkling of water to wet a dry base as slush rolling. Others use slush rolling techniques that involve the virtual flooding of the compacted base to drive the fines in the base to the top during rolling. Such a practice, though resulting in a smooth finish, is definitely harmful for the pavement in the long run because of the weakening of the base that results. Several districts have been very successful at producing smooth pavements without using slush rolling. These practices are highlighted as best practices in this report and they will also be incorporated in the design and construction guide that will be published later as a part of this research.

Even the most effective design may not ensure a satisfactory surface treatment due to the strong influence construction practices have on performance. Similar to the preventive maintenance seal coat operations, the surface treatment process is not that complicated. However, they both consist of systems whose satisfactory functioning depends heavily on the conditions under which they are constructed. Therefore, the designers of both these systems are constrained by not knowing the field conditions for which to design for. This puts a tremendous burden on the field project manager to make critical adjustments and decisions in the field. Most practitioners call seal coat and surface treatment work more of an “art” than a science for this reason. However, this research team firmly believes that there is more to the science of surface treatments and seal coats than it appears to be.

Construction of surface treatments, unlike seal coat projects, comprise of a small part in a larger construction contract. The surface treatment in such projects could either be an underseal or a wearing course which is the culmination of a larger project. This sometimes creates a situation where a prime contractor may not have the skilled personnel required to complete the surface treatment work at a satisfactory quality level. For example, the motor grader operator and other surface treatment equipment operators need to be skilled in operating such equipment which are crucial to project quality. In some cases, the prime contractor may subcontract the work to a surface treatment specialist, and this practice should always be encouraged.

The design and construction of surface treatments require careful consideration of several factors. These include sound project selection for ST work, required ride quality and how to achieve it, number of courses in the ST and their construction sequence, prime coating method, and constructability and material selection application rates.

The selection of projects for surface treatments should be judiciously made. An underseal must be recommended practice for most HMAC surfacing projects in the state due to inherent benefits gained from their application. It protects the base from moisture, and ensures satisfactory bonding of the hot mix to the base below. This will in turn

reduce the stresses generated in the HMAC layer and is likely to provide longer fatigue life. Surface treatments can be used as wearing courses in pavements that may carry traffic as high as 5000 ADT. The researchers came across a few instances where STs have been effectively used as wearing courses in ADT levels as high as 12,000. Overlays applied on cracked pavement surfaces may not be suitable candidates for surface treatments because of the likelihood of crack reflection. However, some surface treatments such as hot rubber seals have proven to be satisfactory crack arresters. A two- or three-course surface treatment, when properly constructed, may be as effective if not more effective than HMAC wearing courses at lower traffic levels.

The prime coating method is another important aspect of surface treatment. TxDOT districts use four prime coating methods that were described earlier in this chapter. All prime coating methods indicated earlier are capable of providing good bonding between the prime coat and the finished base. One important factor is to ensure that the prime coat binder is sprayed at the appropriate base moisture content. The 2004 TxDOT specification calls for a base moisture content 2 percentage points below the optimum moisture content as appropriate for good prime penetration and adhesion. Even though different base material-binder combinations may have different optimum moisture levels, the specification value appears to be a good rule-of-thumb to adopt. The researchers observed a couple of surface treatment projects that failed during construction because the prime coat was applied too wet.

The material rate design for surface treatments begins with the rate design for seal coats. Even though seal coat binder rate design can be used to guide the binder rate design for multiple-course surface treatments, some key adjustments need to be made to account for the design and construction sequence of the surface treatment. If successive courses are applied quickly one after the other, allowances must be made for drain-down of binder (i.e. use a lighter rate for lower course, and heavier for the upper course). This may be achieved by considering the existing surface to be highly textured (coarse). If upper course is applied months later, use of a heavier rate at the bottom and a lighter rate at the top are recommended.

Tire-pavement noise is often a concern with surface treatments, but proper selection of aggregate grades and application rates combined with low-noise asphalts such as tire rubber asphalt can reduce these noise levels significantly. Another important area of application of surface treatment wearing courses is in pavements that are built on moving subgrade. The investments made on HMAC may not be justified under such conditions where the HMAC may not last very long due to excessive stresses caused by subgrade movements. A surface treatment, particularly hot rubber asphalt or multiple-course surface treatment can be both cost effective and easily replaceable.

The industry has been moving towards better control of ride quality for surface treated pavements. The use of IRI is a very effective way to control the ride quality. The IRI can be calculated using profilograph measurements on the finished base, first course or the final course of the surface treatment. Some districts tried IRI specifications of 120 on finished base, but experience suggests that these values can be reduced much further for

the finished base. The question then arises as to how these ride quality values can be achieved. Many districts have allowed contractors to use the practice of slush rolling for the purpose of achieving ride quality. Even though this can provide good ride quality, when excessive amount of water is used, slush rolling can be a recipe for premature base failure. Slush rolling drives the fines in the base material to the top, thus creating voids in the flexible base and destroying its integrity. Therefore, the researchers recommend that other methods such as 'blade-and-roll' and the use of base lay-down machine be adopted for this purpose. The 'blade-and-roll' technique requires a very good blade operator and most districts insist that it is becoming harder and harder to find contractors with good blade operators. A base lay-down machine can be a good substitute for this scenario. These factors make it imperative that control mechanisms be adopted by districts to ensure that contractors have appropriate methods in place to achieve the required ride quality without compromising the integrity of the pavement.

One of the most critical issues for the immediate future in surface treatment practice is the role of project management and inspection. TxDOT is becoming increasingly dependent on inspectors and project managers with little experience. This is caused by the high rate of turnover of experienced inspectors and project managers over the past several years. This appears to be leading towards an era of surface treatment practices at construction sites dictated to a significant extent by the contractors. Good contractors have a lot of experience and wisdom that TxDOT projects can benefit from. However, the time is right for TxDOT to re-evaluate the inspection process. With a booming construction market and an expanding economy, it is unlikely that TxDOT will have experienced inspectors and project managers in sufficient numbers in the foreseeable future. The alternatives for TxDOT to consider may be either to invest in accelerated inspector training programs or to become innovative and creative in the way specifications are written and designs are done. Innovative contracting methods could also be a possibility.

Chapter 3

Laboratory Evaluation of Prime Coat Effectiveness

3.1 Overview

The main objective of this research was to identify best practices for asphalt surface treatments constructed on base. The asphalt surface treatments and their effectiveness depend on a number of factors including characteristic of the underlying base material, characteristics of the prime coat, depth of prime penetration into base, effective aggregate bonding and stiffness of the base. In typical Texas surface treatment applications, the prime coat is applied on a finished base to act as an intermediary between asphalt surface treatment and base. A prime coat is used on top of the finished base layer and it can carry temporary traffic during construction in situations where the existing right-of-way is not sufficient to divert traffic during the construction phase.

The effectiveness of the prime coat depends on many factors including base material, finish type and moisture content at priming. When prime coat is applied over a prepared base, it infiltrates into the base. The more infiltration it has, the better the performance is likely to be. The depth of prime infiltration depends on the viscosity of prime coat binder and the suction developed in the porous base course. The finished granular base which is at a partly saturated state begins to dry after compaction it continues to develop negative pore pressure (soil suction) and will facilitate the penetration of prime coat binder into the base layer. Therefore, an accurate prediction of suction in the base material can provide a better estimate of prime coat infiltration.

It is believed that prime coat is not only used for sealing the prepared base to prevent moisture escape but also helps to build an intermediate layer between base material and asphalt layer. Penetrated prime coat mixes with base material and acts as a transition layer which gives some rigidity. The usefulness of this layer becomes transparent when the prime penetrate much deeper into the base. One of the key points of this research is to determine the most effective base material – prime coat combinations. In Texas, variety of base materials and prime coat methods/materials are used. Table 3.1 shows the commonly used material combinations in TxDOT districts as obtained from district constructability reviews. From Table 3.1, it is clear that limestone base and MC-30, AE-P, RC-250 and CSS-1h are the most commonly used base material-prime coat binder combinations used in the State.

The evaporation of water vapor from the base material increases the soil suction. Experimental and theoretical procedures have been developed in the past to estimate the moisture flow from a porous soil material. Hydrologists, soil scientists and engineers have studied the evaporation from unsaturated soils for several decades. Wilson et al. (1997) report the work of Holmes (1961) and Gray (1970) indicating that actual evaporation (AE) is equal to potential evaporation (PE) at the initial drying state in a soil having high water contents (i.e. when AE/PE is approaching unity).

Table 3.1 Material Selection Guidance

District	Prime coat binder	Prime coat binder rate (gal/sy)	Base material
Pharr	MC-30	0.20 – 0.40	Caliche
Tyler	MC-30	0.18 – 0.20	Limestone
San Antonio	MS-2,AE-P,RC-250	0.20 – 0.22	Limestone
LBB	MC-30	0.15 – 0.20	Limestone
Beaumont	AE-P	0.20	Limestone
Lufkin	RC-250, MC-30	0.10	Limestone
Laredo	RC-250, MC-30	0.20	Cement-Treated Base
El Paso	CSS-1h	0.20	Limestone
Dallas	MC-30	0.25	Limestone
Atlanta	MC-30	0.15 – 0.25	Iron ore gravel
Fort Worth	AE-P, MC-30	0.20 – 0.25	
Paris	SS or MS	0.20	
Amarillo	MC-30	0.15 – 0.25	
	MS-2	0.45	
Odessa	MS-2	0.17	
	AE-P	0.17	
	MC-30	0.17	
Bryan	RC-250	0.22	
	MC-30, AE-P	0.22	

When the water content in the base material is reduced, the AE/PE ratio is also significantly reduced (see Figure 3.1). This reduction depends on the soil texture (gradation) and drying rate. It is extremely difficult to predict soil properties that influence evaporation from an unsaturated soil surface, and that has resulted in the development of empirical methods. Hillel (1980) suggests that drying of soil surface may be simulated using a square root time method. The equation they developed is purely empirical and the actual mechanisms that control soil evaporation are not reflected in that. Yanful et al. (1993) adopted an empirical approach to evaluate the performance of a soil cover system for acid generating waste rock.

Some other attempts have been made to study the effects of parameters that control evaporation from unsaturated soil. Barton (1979) suggested that soil evaporation can be estimated on the basis of pore relative humidity and water content of the near surface of soil. Hammel et al. (1981) also modeled the actual evaporation from soil using the soil water content as a variable and included water flow process in the soil with combined moisture and temperature gradients. Granger (1989) stated that evaporation from unsaturated soil surface is a function of actual vapor pressure at the soil surface.

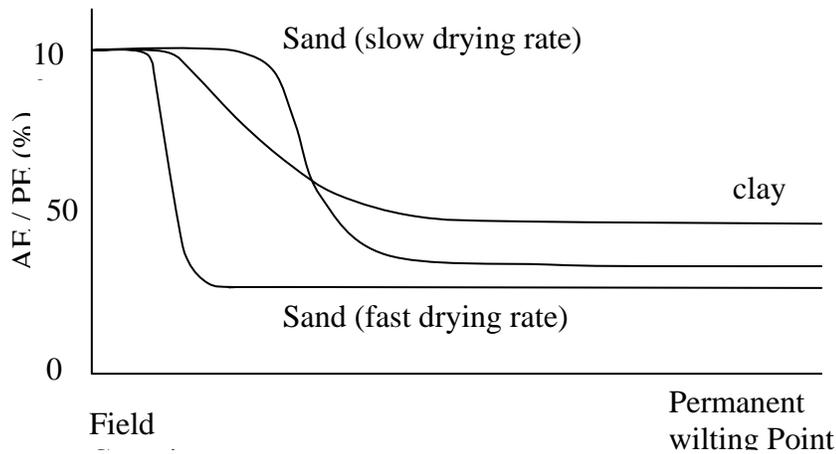


Figure 3.1 Typical Drying Curve for Sand and Clays (AE/PE vs Water Content)

The suction in unsaturated soil (or porous material) can be defined as free energy of water (Hammel et al. 1981; Hillel 1980). Suction can also be considered as negative pore pressure. Under isothermal conditions, the total suction (h_t) is comprised of osmotic suction (h_p) and matric suction ($u_a - u_w$) components (Hammel et al. 1981; Hillel 1980). The osmotic suction results from the dissolved salts in the pore fluid (usually water) and matric suction results from the capillary action.

$$h_t = (u_a - u_w) + h_p$$

The relationship between soil suction and relative humidity at a certain temperature T is given by

$$h_t = \frac{RT}{v_0 \varpi} \ln(RH)$$

R is the universal gas constant, T is the absolute temperature, RH is the relative humidity, v_0 is the specific volume of water, and ϖ is the molecular mass of water vapor.

An experimental procedure was developed to obtain the soil-water characteristics curve based on water content and pore humidity measurements made on laboratory base material samples. The curve was developed using the theoretical framework indicated above.

Laboratory test procedures were also developed to evaluate the effects of factors that influence prime coat effectiveness. These include characteristic of the underlying base material, characteristics of the prime coat, depth of prime penetration into base and the effectiveness of base-prime adhesion. The laboratory test program comprised of the following three tests that measured the effectiveness of base-prime bond.

1. Prime coat penetration depth

2. Flexural strength
3. Pullout strength

3.2 Specimen Preparation

Many studies have identified the moisture content, which is related to suction, as the key parameter that governs prime coat penetration into the base material. The first part of the experimental procedure was to develop dry density-moisture content relationship for each base material tested using the ASTM D1557 standard test procedure. Table 3.2 summarizes the dry density-moisture content data for each base material tested.

Laboratory base material specimens were prepared in 1ft square, 4 inches high plywood boxes shown in Figure 3.2(a). The specimen was compacted at the optimum moisture content determined in the laboratory to obtain the maximum dry density. As indicated earlier, the moisture-density curve for each base material was obtained using the standard ASTM D1557 procedure. A special compactor, shown in Figure 3.2(a), was fabricated to provide the same compaction energy as in the standard laboratory compaction procedure. The specimen was compacted in three equal layers, and the compaction was controlled using specimen height as the basis, and a final compaction density equal to 95% of the laboratory maximum dry density was achieved.

Table 3.2 Dry-Density - Moisture Content Relationship for Base Materials Tested

Test No.	Description	m (%)	γ_d (pcf)
1	Limestone (source 1) OMC = 8.00 %	5.96	117.67
		7.23	129.58
		10.27	128.90
		11.06	128.10
2	Iron ore gravel (IOG) OMC = 8.40 %	5.10	121.20
		8.10	135.37
		9.60	133.16
		10.98	128.95
3	Limestone (source 2) OMC = 6.20 %	4.90	137.62
		5.87	139.43
		6.38	139.31
		8.24	134.26
		8.72	132.97

It was deemed important to use base finishing methods that simulate actual field conditions because of its strong influence on the bonding characteristics of the prime. The constructability review revealed two primarily base finishing techniques used by districts. The first is a ‘blade and roll’ technique which provides a ‘regular’ base finish, first by tight-blading the compacted base layer, followed by compaction first using a pneumatic roller, and then by a heavyweight steel-wheel roller. The ‘regular’ base finish was achieved in the laboratory by dry-rolling the compacted specimen using a solid steel cylinder. The second base finishing technique is the ‘slush rolling’ method where the

compacted base is first ‘slushed’ with water and rolled to get a paste of base material fines to migrate to the surface. The base is then ‘tight-bladed’ to achieve a smooth surface finish. The ‘slush-rolled’ finish was attained in the laboratory by slushing the compacted specimen with water, and then rolling it with the solid steel cylinder. approximately 300ml of water was sprayed uniformly over the specimen surface area of 1ft². Water drainage was allowed through holes in the plywood molds on the sides. The finished base material sample had the dimensions 12 in. x 12 in. x 3 in (Fig.1b).



(a) Specimen mold



(b) Compacted specimen

Figure 3.2 Testing Mold and Prepared Specimen

Once finishing was done on the base material specimen, it was primed using the appropriate prime coat binders. A liquid sprayer with adjustable nozzle opening was used to spray the prime coat on the base specimen. Since the constructability review revealed that base moisture content has a significant influence on prime coat bonding and penetration, prime coat was sprayed at four base moisture contents; optimum moisture content (OMC) of the base material, OMC-1%, OMC-2% and OMC-4%. Due to the uneven variations in the ambient climatic conditions in the laboratory, to keep laboratory test conditions as uniform as possible, the finished base material specimens were placed in a room with both temperature and humidity control. Specimens earmarked for priming at OMC were primed immediately after compaction was completed for ‘regular’ compaction specimens, and after subsequent drying to the OMC in the case of ‘slush-rolled’ specimens.

Once finishing was done on the base material specimen, it was primed using different prime coat binders indicated in the next section. A liquid sprayer with adjustable nozzle opening was used to spray the prime coat on the finished base specimen. Since the constructability review revealed that the moisture content in the base when prime coat is applied, has a significant influence on prime coat bonding and penetration, prime coat was sprayed at several base moisture contents; optimum moisture content (OMC) of the base material, OMC-1%, OMC-2% and OMC-4%. Due to the uneven variations in the ambient conditions in the laboratory, the base material specimens were placed in a room with environment control (both temperature and humidity) to attain the required moisture state. Specimens earmarked for priming at OMC were primed immediately after compaction was completed for ‘regular’ compaction specimens, and after subsequent drying to the OMC in the case of “slush-rolled” specimens. The prime coat binder

application was 0.2 gal/yd², which was the rate used by almost all the TxDOT districts. After spraying the primed coat, it was allowed to cure and penetrate into the base material for at least 24 hours (Figure 3.3).



Figure 3.3 Prime Coated Specimen after Curing

3.3 Experimental Design

3.3.1 Drying Characteristics of Finished Base Material

The first experimental procedure involved the study of drying patterns in the base material after compaction and finishing. The moisture content of the base material specimens were monitored by measuring the pore humidity in the base material. However, to estimate the moisture content, a calibration curve was developed for each base material relating the moisture content to pore humidity. Specimens were made with limestone and iron ore gravel, and after applying the appropriate surface finish, they were kept in the environmentally-controlled chamber, and the pore humidity inside the base material at depths of 0.5 inches and 1 inch were continuously recorded for ten hours by automatically capturing the temperature and pore humidity data onto a computer. One additional sensor was used to monitor the temperature and relative humidity in the environmental chamber. To monitor humidity and temperature, a set of wired sensors (Sensirion[®] SHT71) were used. As recommended by the sensor manufacturer, a correction to the measured *RH* was applied if the *RH* value was above 90%. After applying this correction, the total suction in the base material was calculated. Once the suction is known, the soil–water characteristic curve and the variation of suction with time were determined.

Periodic manual measurements of the water content were conducted at regular intervals by extracting small amounts of base material from the outer fringes of the specimen. The

collected data was used to investigate the drying characteristics of the base material and the matric suction vs. water content relationship

3.3.2 Test Factorial

A partial test factorial shown in Table 3.3 was prepared for the test program. It included the base material, base finish, prime coat binder and the base material moisture content at the time of prime application as experimental variables. The experimental combinations that were conducted are shown by shading in Table 3.3. The symbol 'Dx' indicates a diluted emulsified asphalt binder with x% of emulsion in the emulsion-water blend.

Table 3.3 Test Combinations

Material	Finish	Moisture	Prime Coat Binder					
			MC- 30	RC- 250	AE-P	CSS -1h	CSS - 1h D50	MS -2 D5
Limestone	REGULAR	OMC						
		OMC - 1						
		OMC - 2						
		OMC - 4						
	SLUSHED	OMC						
		OMC - 2						
OMC - 4								
Iron-ore gravel (IOG)	REGULAR	OMC						
		OMC - 2						
		OMC - 4						
	SLUSHED	OMC						
		OMC - 2						
		OMC - 4						

3.4 Testing Procedures

3.4.1 Prime Coat Penetration Test Procedure

In the prime coat penetration test, each sprayed specimen was cut into four identical beams using a power saw (Figure 3.4). These cut specimens were cleaned carefully to ensure accurate measurement of penetration depths. The beams were used to measure the prime coat penetration. Measurements were taken at six locations in the middle part of each beam and averaged.



Figure 3.4 Cut Specimen Beams

3.4.2 Flexural Strength Test Procedure

In order to determine the flexural strength of each prime coated beam, two replicate beams (*out of four*) from each test specimen were selected to perform three-point flexural bending test. A triaxial loading frame was used to load the beam under strain controlled loading (Figure 3.5). A strain rate of 0.01 in/min was used in this test and specimen deformation and corresponding load increments were recorded. Two of the beams were tested while keeping the primed surface on top and two others when the primed surface was at the bottom. The failure load was obtained from the resulting load-displacement curve and used to calculate flexural strength.



Figure 3.5 Flexural Strength Testing Arrangement

3.4.3 Pullout Strength Test Procedure

One of the remaining beams from each sample was tested to determine the pullout bond strength of the prime coat. A wooden block (1.5in cube) attached with a nail was glued on the top of the beam (Figure 3.6) and kept for at least seven hours such that a strong bond between prime coat and the wooden block was attained. A minimum of two

wooden cubes were glued to each beam specimen to obtain replicate measurements. The nails on the wooden blocks were pulled out using a tensile testing machine. A Dyno AFG 500 force gauge with 110lb capacity mounted on an automated loading frame was used with a loading rate of 2 in/min. The resulting force-displacement curve was automatically recorded into the computer and the failure load was obtained.



Figure 3.6 Pullout Strength Testing Arrangement

3.5 Results and Discussion

3.5.1 Drying Characteristics of Base Material

The specimens were prepared at OMC and dried in an environmentally controlled room until it reached the desired moisture content. Pore humidity and moisture content measurements were taken simultaneously at depths of 0.5 inches and 1.0 inches to obtain a correlation between pore humidity and moisture content. Automated pore relative humidity measurements were taken for six days. The results are shown in Figure 3.7 below. The drying patterns for the ‘regular finish’ and the ‘slush finish’ showed similar trends for each depth. This shows a steep drop in the initial stage and keeps drying with a slower rate.

The temperature variation in the soil mass, shown in Figure 3.7, illustrates an interesting phenomenon. Initially, at both depths, the temperature starts to drop, and the trend continues for approximately six to eight hours irrespective of the surface finish adopted. This rather sharp reduction in temperature also increased the relative humidity at the two depths in the soil specimen. Initially, at the time of compaction, the air mass trapped inside the soil pores has a slightly higher temperature than that of the compacted soil. The authors believe that moisture movement in the upward direction in the soil specimen would have induced a cyclic gas flow. This phenomenon has the potential to decrease the soil pore-wall temperature (Wilson et al. 1997). This reduction in wall temperature will induce a heat flow into the soil particles, and then drop-wise condensation will occur on the particle surfaces (Yanful 1993). Basically, the soil pore wall acts like a cooled

surface. When suitable sub-cooling conditions are available, the condensation of water begins (Yanful 1993). This is an area where further studies may be needed.

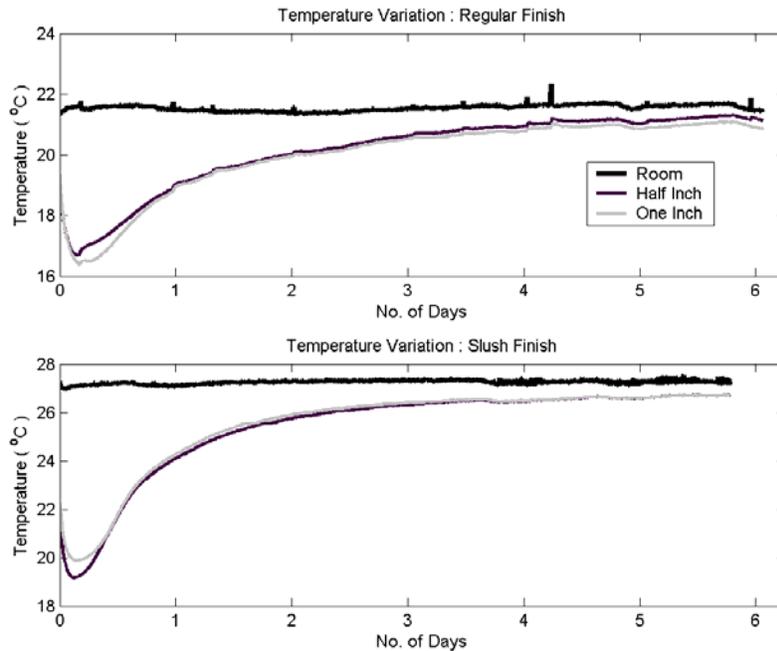


Figure 3.7 Variation of Temperature in Base Material with Time

Figure 3.8 shows the variation of pore relative humidity (PRH) inside the two soil specimens prepared using the two finishing methods, during the first six days after the specimens were molded. At the 1.0 in. depth, the PRH increases for approximately 1.5 days, and then gradually decreases. This is because more moisture is moving upwards towards that location from below, than the moisture that moves up from that depth. At the 0.5 inch depth, the PRH for the “regular finish” specimen stays constant for almost three days before starting to increase. On the other hand, for the “slush finish” specimen, the increase in PRH started much sooner (i.e. 1.5 days).

The variation in gravimetric water content (GWC), which was determined manually using samples of soil removed from the specimen, is shown in Figure 3.9. It shows that the GWC decreases rapidly for approximately 2 days before reaching an asymptotic level of 3%. The soil suction values were calculated at the same instances when the GWC was determined, by substituting the PRH and temperature measurements in Equations presented earlier. This variation of suction is shown in Figure 3.10. The suction increases rapidly for approximately two days (the same period when the GWC was decrease). This plot of suction vs. time provides useful information to determine the most appropriate time to apply the prime coat (i.e. when the suction is high). It is

important to note that under field conditions, such variation may be either accelerated or decelerated depending on the ambient conditions.

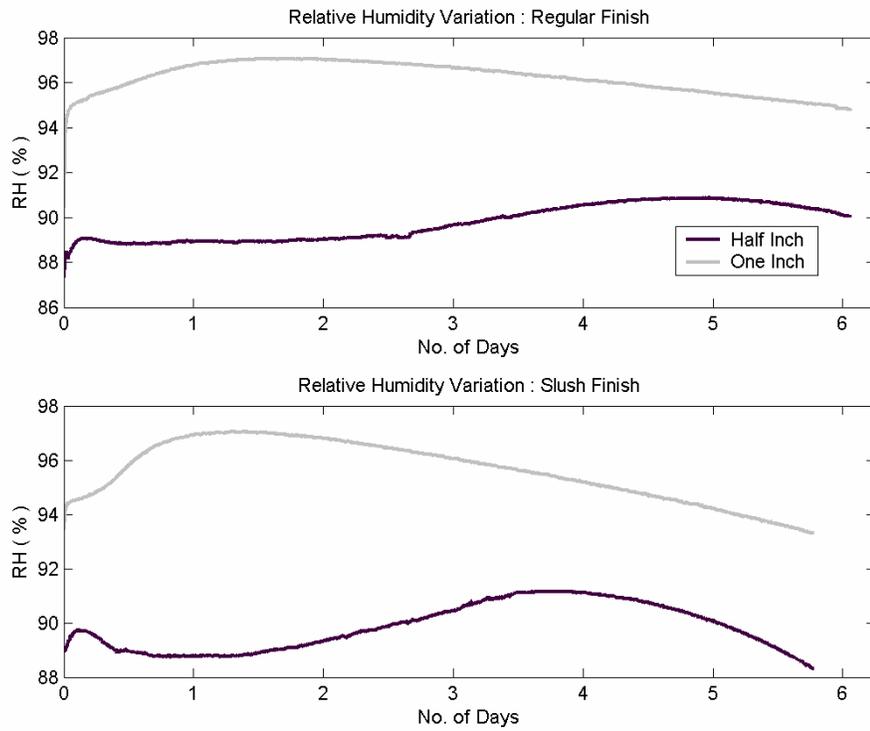


Figure 3.8 Variation of Pore Relative Humidity with Time (Ion Ore Gravel)

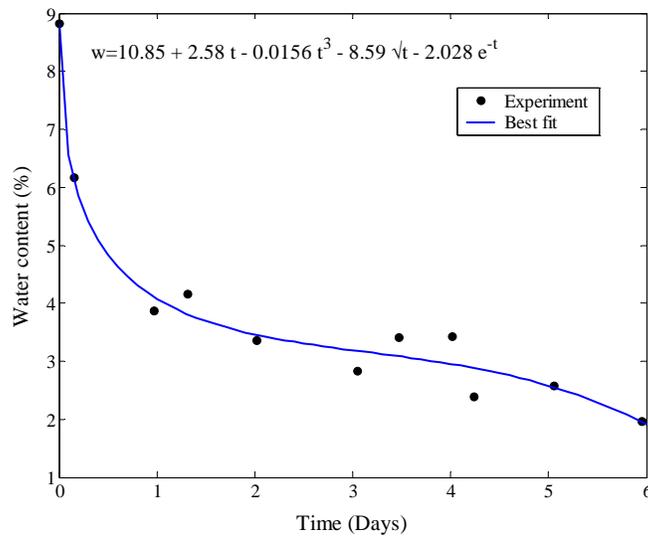


Figure 3.9 Variation in Gravimetric Water Content in Soil Specimen at 0.75 Inch Depth

3.5.2 Prime Coat Penetration

The results for prime coat penetration measurements are presented in Table 3.4 and in Figures 3.12 and 3.13. In terms of prime coat penetration, the MC-30 cutback and the AE-P custom prime binder displayed similar and high penetration depths for the specimen with ‘regular’ (i.e. REG) finish. The RC-250 cutback binder and the CSS-1h emulsion provided minimal penetration numbers. As expected, for all binders tested, the penetration into the ‘regular finish’ specimen was higher than for the specimen with ‘slush’ (SLU) finish. For the AE-P binder, this difference was much higher than for others. The ‘slush rolling’ technique generates a layer of fine base material particles on the surface, thus creating a barrier to slow down penetration of the prime coat.

For ‘regular finish’ specimens, the optimum moisture content (OMC) showed the lowest penetration, and OMC-1% the highest. The ‘slush finish’ specimens were tested at OMC and OMC-2%, and the penetration was lower for OMC-2% condition. As expected, the ‘slush finish’ specimens indicated lower penetration depths than ‘regular finish’ specimens.

Table 3.4 Prime Coat Penetration Summary

Base Material	Prime Coat Binder	Base Finish	Base Moisture at Priming (%)	Prime Penetration (in)
Limestone	MC-30	REG	OMC -4	0.2760
Limestone	MC-30	REG	OMC	0.3594
Limestone	CSS-1h	REG	OMC	0.0365
Limestone	AE-P	REG	OMC	0.3802
Limestone	MC-30	REG	OMC -1	0.6979
Limestone	RC-250	REG	OMC	0.0417
Limestone	AE-P	SLU	OMC	0.1458
Limestone	MC-30	REG	OMC-2	0.5391
Limestone	MC-30	SLU	OMC-2	0.1406
Limestone	MC-30	SLU	OMC	0.2917
Limestone	CSS-1h	SLU	OMC	0.0339
Limestone	RC - 250	SLU	OMC – 2	*
Limestone	RC - 250	SLU	OMC – 4	*
Limestone	AE - P	SLU	OMC – 2	*
Limestone	AE - P	SLU	OMC – 4	*
Limestone	RC-250	SLU	OMC	0.0313
Limestone	MS-2 D5	REG	OMC	0.1042
Limestone	MS-2 D5	REG	OMC-2	0.0885
Limestone	MS-2 D5	SLU	OMC-2	0.0313
Limestone	CSS-1h D50	SLU	OMC-4	0.0885
Iron ore gravel	CSS-1h	REG	OMC	0.0469
Iron ore gravel	CSS-1h D50	REG	OMC	0.0885
Iron ore gravel	CSS-1h D50	SLU	OMC-4	0.0625
Iron ore gravel	CSS-1h D50	SLU	OMC-2	0.0521

Note: * - Samples with zero penetration (not tested against flexural and pullout tests).

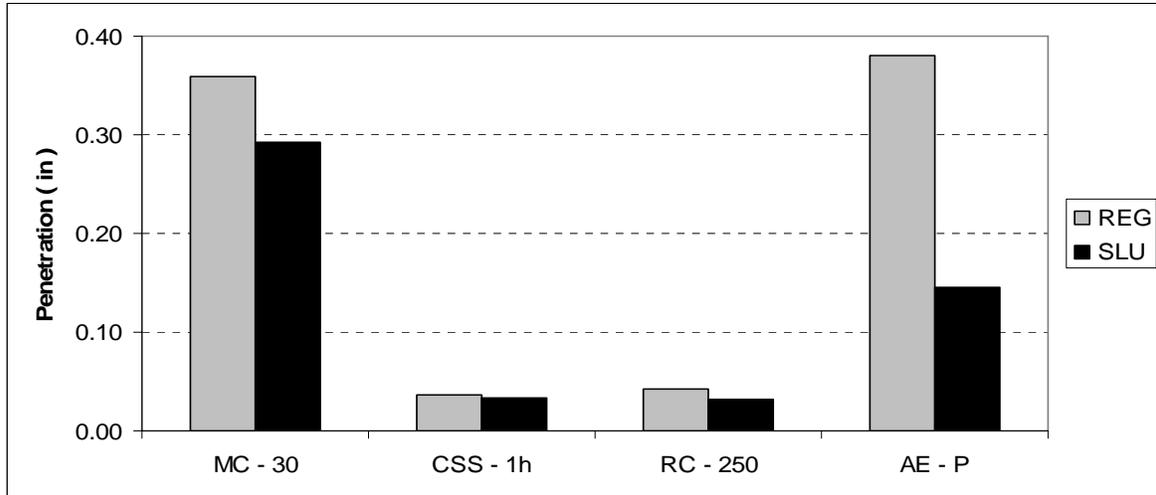


Figure 3.12 Prime Coat Penetrations for Four Binders and Two Surface Finishes

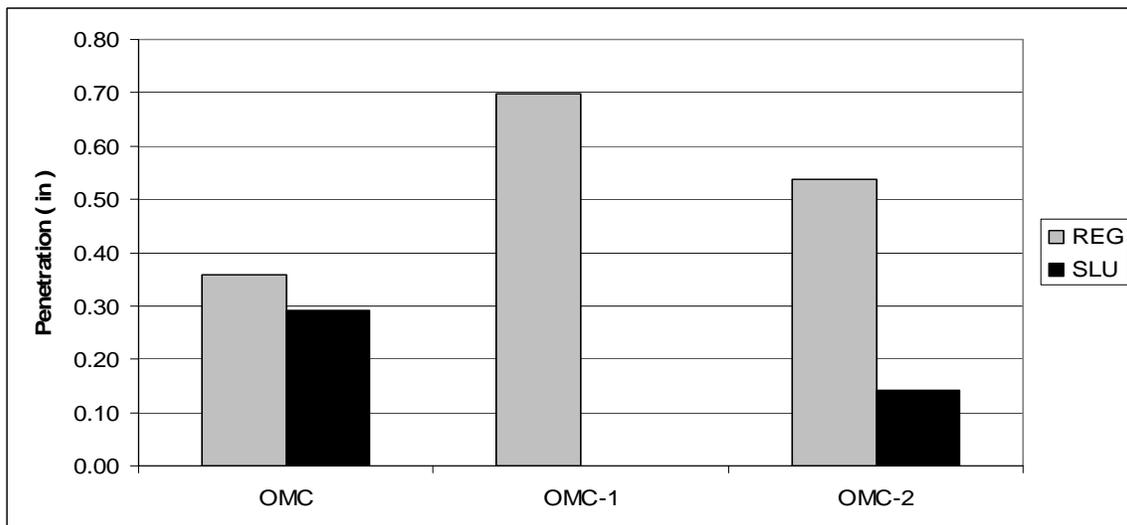


Figure 3.13 Prime Coat Penetrations for Three Moisture Contents and Two Surface Finishes

3.5.3 Flexural Strength

Results from the flexural strength tests are presented in Table 3.5. In Figure 3.14, results are presented for four prime coat binders and two surface finishes. It shows similar flexural strength values for MC-30, RC-250 and CSS-1h binders on ‘regular finish’ specimens. For ‘slush finish’ specimens, the MC-30 provided the highest flexural strength and RC-250 provided the lowest. Lack of effective penetration of RC-250 would have likely contributed to this.

The effect of moisture condition at the time of priming is illustrated in Figure 3.15. Limited data for flexural strength showed that in the case of ‘regular finish’ specimens, the OMC-4% moisture state provided the highest strength and OMC-1% provided the lowest. For ‘slush finish’ specimens, OMC-2% provided lower flexural strength compared to OMC specimens. These results appear to be somewhat inconclusive, and additional tests are needed before more concrete conclusions can be made.

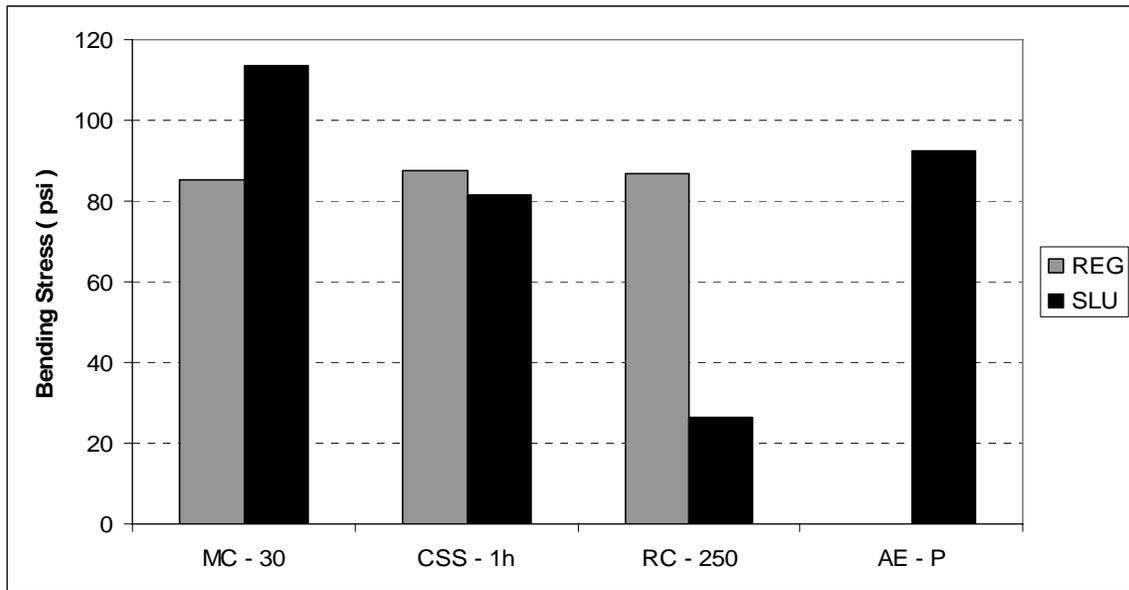


Figure 3.14 Flexural Strength of Primed Base for Four Binders and Two Surface Finishes

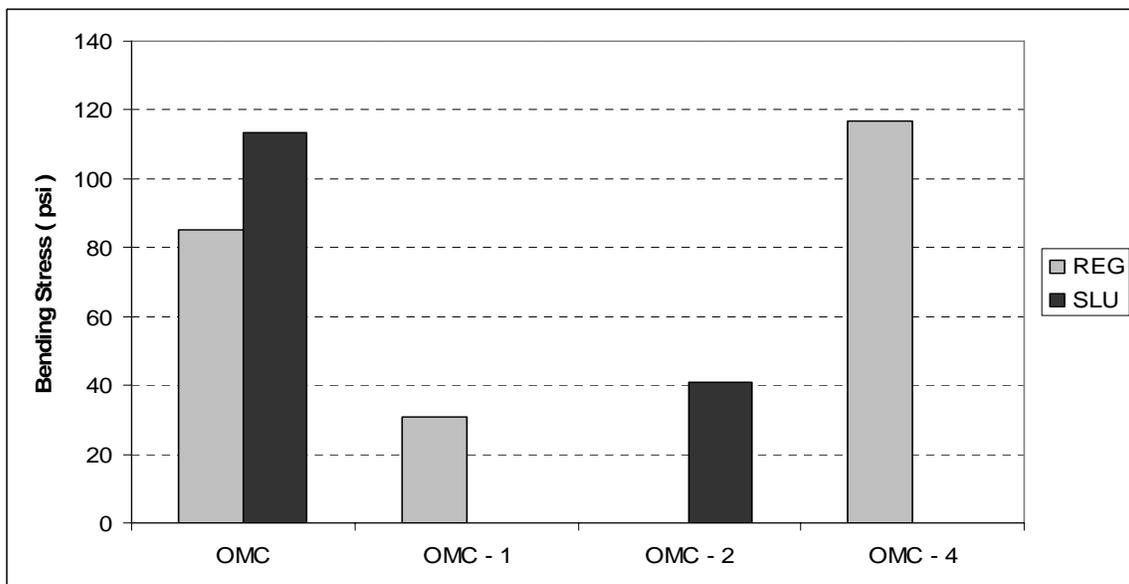
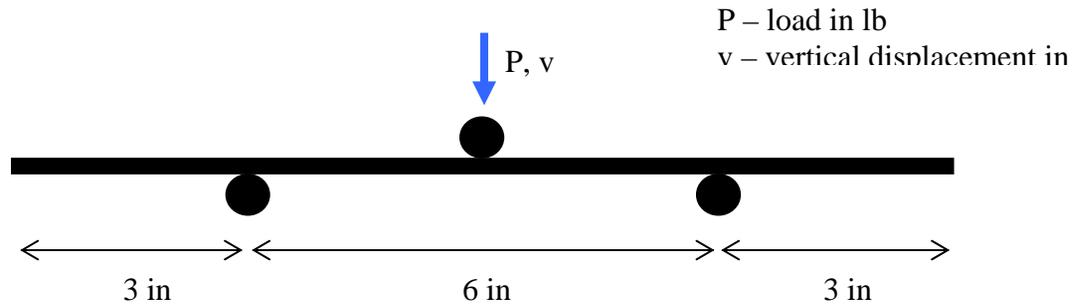


Figure 3.15 Flexural Strength for Four Base Moisture States and Two Surface Finishes



Base Material	Prime Coat Binder	Base Surface Finish	Base Moisture Content at Priming	Beam Tested with Prime on Top			Beam Tested with Prime at the Bottom		
				Failure Load (lb)	Vertical Displacement (in)	Flexural Strength (psi)	Failure Load (lb)	Vertical Displacement (in)	Flexural Strength (psi)
Limestone	MC-30	REG	OMC -4	291.6	0.144	116.64	253.4	0.068	101.36
Limestone	MC-30	REG	OMC	255.3	0.126	85.10	272.8	0.150	90.93
Limestone	CSS-1h	REG	OMC	175.0	0.085	87.50	232.5	0.104	116.25
Limestone	AE-P	REG	OMC	*			*		
Limestone	MC-30	REG	OMC -1	92.0	0.106	30.67	143.0	0.094	40.86
Limestone	RC-250	REG	OMC	216.8	0.101	86.72	290.5	0.123	96.83
Limestone	AE-P	SLU	OMC	276.9	0.161	92.30	119.4	0.090	53.07
Limestone	MC-30	REG	OMC-2	*			*		
Limestone	MC-30	SLU	OMC-2	82.2	0.112	41.10	219.9	0.154	73.30
Limestone	MC-30	SLU	OMC	283.9	0.134	113.56	417.7	0.167	128.52
Limestone	CSS-1h	SLU	OMC	224.1	0.141	81.49	223.6	0.128	81.31
Limestone	RC-250	SLU	OMC	79.2	0.093	26.40	91.6	0.120	36.64
Limestone	MS-2 D5	REG	OMC	88.2	0.081	39.20	158.3	0.081	63.32
Limestone	MS-2 D5	REG	OMC-2	256.2	0.147	102.48	230.8	0.154	76.93
Limestone	MS-2 D5	SLU	OMC-2	111.0	0.048	34.15	127.4	0.090	42.47
Limestone	CSS-1h D50	SLU	OMC-4	196.2	0.088	65.40	172.3	0.071	68.92
Iron ore gravel	CSS-1h	REG	OMC	41.7	0.080	16.68	156.7	0.096	44.77
Iron ore gravel	CSS-1h D50	SLU	OMC-2	*			*		

Table 3.5 Summary of Flexural Strength Test Results

Note: * - indicates unusual crack defect while testing for flexure. Few other unrealistic results have been removed as outliers.

3.5.4 Pullout Strength

Results from the pullout strength test are presented in Table 3.6. Figure 3.17 shows the variation in pullout strength for four prime coat binders and two surface finishes. For ‘regular finish’ specimens, the RC-250 binder provided the highest adhesive strength and CSS-1h provided the lowest. For ‘slush finish’ specimens, MC-30 binder provided the highest adhesive strength and CSS-1h provided the lowest. For all binders, the ‘slush finish’ specimens provided higher pullout strengths than for ‘regular finish’ specimens. Observation of the failure mode showed that for ‘regular finish’ specimens, due to higher penetration of the prime, the pullout failure occurred deeper into the specimen compared to the ‘slush finish’ specimens. The shallower penetration in the ‘slush finish’ specimens would likely have a higher concentration of binder at the surface, thus providing a more concentrated adhesive bond.

Figure 3.18 shows the variation in pullout strength for three base moisture contents and two surface finishes. Results showed the highest adhesive strength at OMC-2% for the “regular finish” specimens and the results were roughly the same for OMC and OMC-1% specimens. In the case of “slush finish” specimens, the OMC showed a higher adhesive strength than the OMC-2% specimen. It is not clear as to why the OMC and OMC-2% specimens showed different trends with regard to surface finish. The “slush finish” specimen showed higher pullout strength at OMC, but slightly lower strength at OMC-2%. This may have been due to random error in experimentation.

Table 3.6 Summary of Pullout Strength Test Results

Base Material	Prime Coat Binder	Base Surface Finish	Base Moisture Content at Priming	Pullout Load for Beam 1 (lb)	Pullout Load for Beam 2 (lb)	Pullout Load for Beam 3 (lb)	Average Pullout Load for All Beams (lb)
Limestone	MC -30	REG	OMC	43.40	23.92	33.66	33.66
Limestone	CSS-1h	REG	OMC	21.60	16.16	18.88	18.88
Limestone	AE-P	REG	OMC	29.79	30.10	29.95	29.95
Limestone	MC-30	REG	OMC - 1	33.28	28.78	35.12	32.39
Limestone	RC-250	REG	OMC	49.33	58.90	*	54.12
Limestone	AE-P	SLU	OMC	55.50	58.90	34.84	49.75
Limestone	MC-30	REG	OMC - 2	51.34	58.38	64.58	58.10
Limestone	MC-30	SLU	OMC - 2	61.06	60.36	41.34	54.25
Limestone	MC-30	SLU	OMC	91.16	49.72	62.74	67.87
Limestone	CSS-1h	SLU	OMC	32.68	25.78	*	29.23
Limestone	MS-2 D5	SLU	OMC	27.24	15.66	*	
Limestone	MS-2 D5	REG	OMC - 2	2.75	8.92	*	
Iron ore gravel	CSS-1h	REG	OMC	23.12	32.40	36.24	30.59
Iron ore gravel	CSS-1h D50	SLU	OMC - 2	15.1	18.98	*	

Note: * - indicates unusual failure (block did not stick with the surface due to the dust present. See Figure 3.16)



Figure 3.16 Unusual Failure in Pullout Test (See note in Table 3.6)

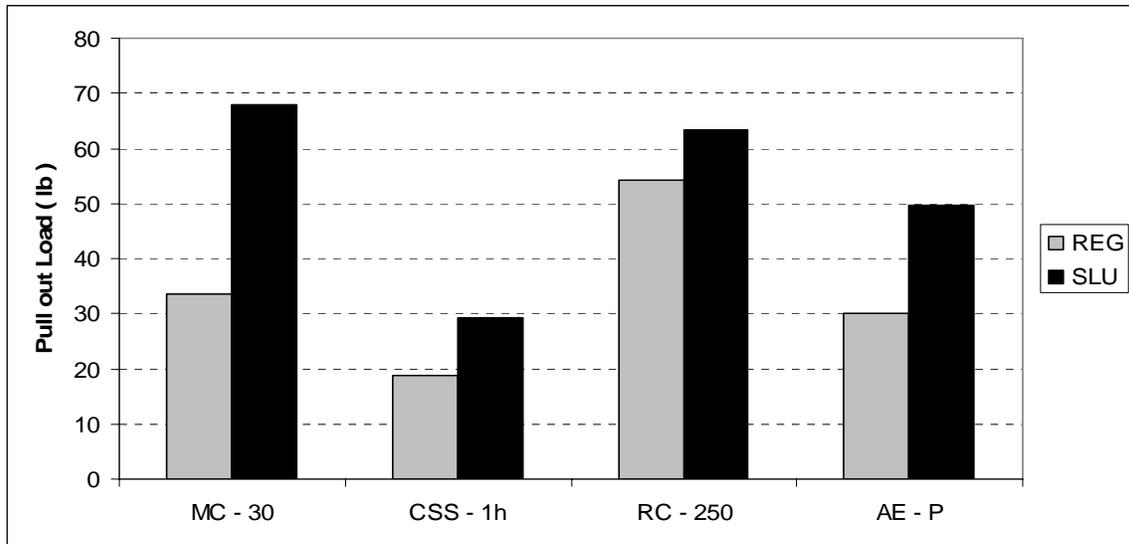


Figure 3.17 Pullout Strength of Primed Base for Four Binders and Two Surface Finishes

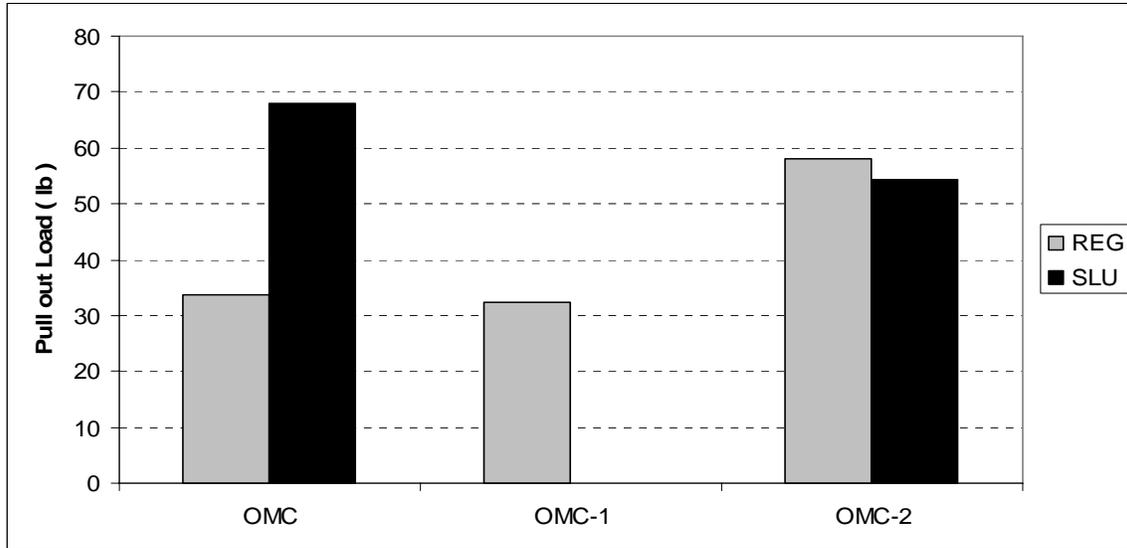


Figure 3.18 Pullout Strength for Four Base Moisture States and Two Surface Finishes

3.6 Conclusions

There is very little research done on the subject of prime coat effectiveness in surface treatment construction, even though its influence on surface treatment performance has been well established for some time. A limited laboratory program was undertaken to investigate the effects of factors that have long known to influence prime coat effectiveness in surface treatments. The emerging conclusions from this experimental program are presented in this report.

The effectiveness of a prime coat depends on a number of factors including its penetration, prime coat binder and the prime coat technique. In addition, the prime coat performance also depends on factors such as the base material, its moisture content at the time of priming and the surface finish of the base on which the prime is applied. In Texas, three primary techniques are used for prime coat application; spray prime, worked-in prime and covered prime. In addition, base finishing techniques such as blade and roll, slush roll, trimming and laydown machine are used. With regard to base moisture content at the time of priming, a value of OMC minus 2 percentage points is recommended in specifications.

Results obtained in this research program clearly showed that base moisture condition that is optimum for priming depends on a variety of factors including the base material, surface finish and the prime coat binder. Also, there appear to be a set of a very complex relationships between the factors indicated above, and additional research is needed to conduct a comprehensive research program to develop a testing protocol that will allow the highway professionals to evaluate the effectiveness of their material combinations that are effective under local construction conditions.

Chapter 4

Regional Training Workshops

4.1 Overview

Based on the training workshop that was development from information collected in the constructability review, the researchers developed a regional workshop and delivered a ‘pilot’ workshop at the Abilene district. This workshop was attended by the project advisors as well as other surface treatment practitioners from the Abilene district. Based on the feedback received at this ‘pilot’ workshop, the workshop was ‘tweaked’ and the eight regional workshops were delivered by researchers. Basic information on each workshop including the districts attended and the number of attendees at each workshop is presented in Table 4.1. These workshops were all conducted according to the originally proposed schedule. At least three workshops were scheduled to be represented in each workshop. A total of 281 TxDOT professionals took part in these eight workshops. All district workshops were held at the district headquarters except in Lufkin where due to the large group of attendees, the workshop was held at the Lufkin Pitser Garrison Civic Center (Figure 4.1).

Table 4.1 Regional Workshop Information Summary

No.	Location	Date	Other Districts	No. of Attendees
1	Laredo	Feb 06	PHR, CRP	46
2	Yoakum	Feb 09	SAT, AUS	29
3	Lubbock	Feb 15	AMA, CHD	44
4	Lufkin	Mar 01	BRY, BMT, HOU	59
5	Odessa	Mar 06	SJT, ELP	22
6	Atlanta	Mar 09	PAR, TYL	35
7	Waco	Mar 29	DAL, FTW	31
8	Abilene*	Apr 05	BWD, WFS	15
Total				281

Table 4.2 shows the typical schedule for each regional workshop. Each workshop began at 10am and a two hour presentation was made by the researchers that encompassed surface treatment basics, constructability review findings and a summary of construction project information. Information presented during this session included data on statewide surface treatment practices as well as pictures and video clips from selected surface treatment projects. A copy of this presentation is included in Appendix A of this report. The afternoon session began with an overview of surface treatment best practices. The material presented in this segment was selected by researchers and project advisors. They included surface treatment best practices for project selection, surface treatment design, prime coating, surface treatment construction and performance. A separate section on continuous improvement of surface treatment practices was also included. A copy of this presentation is included in Appendix B of this report.



Figure 4.1 Location of Lufkin Regional Workshop

Table 4.2 Typical Schedule for Regional Workshop

Time	Workshop Agenda Item
10:00am-12:00pm	Surface treatment basics Constructability review findings Construction project information
12:00-1:00pm	Lunch (on your own)
1:00-1:45pm	ST best practices
1:45-3:00pm	Discussion/interactive activities
3:00-3:30pm	Workshop evaluation/wrap-up

The third and final segment of the workshop was an interactive segment in which the workshop attendees were divided into groups of approximately five to seven participants. Each group was assigned a topic to discuss for 10 minutes and one spokesperson was appointed for each group to present the viewpoints of the group for the larger audience. At the end of presentation by each group, the topics were opened for discussion by all participants. This interactive segment generated a lot of useful discussion. The topics for this interactive session were selected from the following list. The number topics selected at a particular workshop depended on the number of participants at the workshop and other regional considerations.

1. Spray prime vs. cut-in (or worked-in) prime
2. What would be an appropriate surface treatment (ST) specification type (method vs. performance-based vs. warranty)?
3. Design and construction of underseals
4. Importance of quality control in STs (role of the inspector, specifications/plan notes, etc.)
5. A ride quality spec for ST job acceptance (on finished base or finished first course)
6. Slush rolling technique to finish base

7. Alternate methods of finishing base (base lay-down machine, trimmer, etc.)
8. Timing of prime coat application on finished base (base moisture, etc.)
9. Contractor expertise/operator skills

The workshop was concluded with the workshop evaluation. Each participant was asked to fill out a workshop evaluation form prepared by the researchers. A copy of this evaluation form is presented in Appendix C of this report. Findings from this workshop evaluation are summarized in the section below.

4.2 Workshop Evaluation Summary

The following section summarizes the workshop participants' responses to the evaluation questionnaire. The questionnaire requested participants to provide a 'short' (Yes/No/OK) answer and an optional 'long' answer to each question raised. The following eleven tables (Tables 4.3 through 4.13) provide a summary of short responses provided. These responses indicate that the participants at these workshops were overwhelmingly satisfied with the workshop organization, content and delivery.

4.2.1 Summary of Short Responses to Workshop Evaluation Questions

Table 4.3 Question: Was the workshop format (slides, pictures, video, discussions) effective?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	14	13	0	1
Atlanta	31	28	0	3
Laredo	44	40	0	2
Lubbock	38	30	2	5
Lufkin	41	36	0	5
Odessa	23	22	0	1
Yoakum	22	9	8	3

Table 4.4 Question: Was the workshop of sufficient length?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	14	14	0	0
Atlanta	31	28	2	1
Laredo	44	36	5	1
Lubbock	37	34	2	1
Lufkin	42	38	1	3
Odessa	23	19	1	3
Waco	26	22	2	2
Yoakum	27	25	0	0

Table 4.5 Question: Did you find the number of topics covered to be adequate?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	14	14	0	0
Atlanta	31	30	1	0
Laredo	42	39	1	0
Lubbock	39	37	1	0
Lufkin	41	38	1	2
Odessa	22	22	0	0
Waco	26	26	0	0
Yoakum	27	25	1	0

Table 4.6 Question: Was adequate information provided in the 'Best Practices' portion?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	12	10	1	1
Atlanta	30	28	0	2
Laredo	42	38	0	1
Lubbock	38	33	4	1
Lufkin	38	37	1	0
Odessa	22	21	1	0
Waco	25	21	2	1
Yoakum	22	18	3	0

Table 4.7 Question: Did the workshop increase your understanding of the subject?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	14	13	0	1
Atlanta	30	28	1	1
Laredo	43	41	0	0
Lubbock	34	27	4	2
Lufkin	42	35	4	2
Odessa	23	21	0	2
Waco	25	25	0	0
Yoakum	25	23	1	0

Table 4.8 Question: Do you think more focused (details) training should be provided to TxDOT employees on this subject?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	13	13	0	0
Atlanta	27	25	2	0
Laredo	43	38	2	0
Lubbock	37	36	0	0
Lufkin	39	36	1	2
Odessa	22	19	2	1
Waco	24	22	2	0
Yoakum	25	20	3	0

Table 4.9 Question: Do you think the handouts provided will be useful?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	14	14	0	0
Atlanta	30	28	0	1
Laredo	44	39	1	1
Lubbock	37	35	1	1
Lufkin	41	38	0	3
Odessa	23	23	0	0
Waco	26	26	0	0
Yoakum	24	22	0	0

Table 4.10 Question: Did the quality of slides, pictures and videos meet your expectations?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	14	14	0	0
Atlanta	30	29	0	1
Laredo	44	40	0	2
Lubbock	39	36	1	2
Lufkin	41	36	1	3
Odessa	23	23	0	0
Waco	26	26	0	0
Yoakum	26	23	2	0

Table 4.11 Question: Did you wish to have more information in some areas?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	9	3	6	0
Atlanta	28	10	18	0
Laredo	32	9	19	0
Lubbock	30	11	18	1
Lufkin	29	7	20	1
Odessa	18	2	15	1
Waco	17	5	11	0
Yoakum	17	10	6	0

Table 4.12 Question: Did this workshop make you look at STs differently?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	13	9	4	0
Atlanta	27	18	9	0
Laredo	39	23	15	0
Lubbock	34	20	12	0
Lufkin	37	14	19	2
Odessa	20	8	12	0
Waco	22	15	7	0
Yoakum	25	13	11	0

Table 4.13 Question: Is your district currently using STs effectively?

Workshop Location	Total Number of Responses	Responses Indicating 'Yes'	Responses Indicating 'No'	Responses Indicating 'OK'
Abilene	13	13	0	0
Atlanta	28	27	0	1
Laredo	40	37	1	0
Lubbock	36	33	3	0
Lufkin	35	32	3	0
Odessa	22	19	3	0
Waco	25	21	2	2
Yoakum	26	22	2	1

4.2.2 Summary of Long Responses to Workshop Evaluation Questions

The section below provides a summary of long responses provided by the workshop attendees. They are arranged as a bulleted list for each question in the workshop evaluation questionnaire. Long responses to these questions are fairly self-explanatory and a brief synopsis of them is provided at the end of this section. These responses were identified as optional and do not reflect the total number of attendees at the workshops.

Question: Was the workshop format effective?

- Videos were good (3)
- Was good (2)
- Workshop is great (1)
- Very effective (1)
- Very good (1)
- OK for length (1)
- Easy to understand (1)
- Somewhat (1)

Question: What topics/information interested you the most?

- Prime (32)
- All (23)
- Comparison of others' practices (20)
- Base work (12)
- Construction videos and pictures (12)
- Group discussion (11)
- New technologies (7)
- Laydown machine (6)
- IRI, Ride Spec (5)
- Best Practices (5)
- Design, aggregate embedment, rates (4)

Question: What topics/information did not interest you?

- None (35)
- Slush rolling (8)
- Finishing (5)
- Priming (4)
- Base laydown machine/trimmer (4)
- Design (3)
- Basic seal coat info (2)

Question: Did you wish to have more information in some areas? What are they?

- Prime coating (9)
- Materials and properties (5)
- Actual ST applications (4)
- Design (4)
- Coated vs. non-coated rock (3)
- Base laydown (3)
- Research (2)
- Inspection (2)
- More statistics (2)
- More in depth info (2)
- Seal coat (2)

Question: Was adequate information provided in "Best Practices" portion?

- Very informative (1)
- Rates (2)
- Need solutions (1)
- Seemed to be rushed (1)
- More details on applications (2)
- Seemed skewed to West Texas (1)
- More would be better (1)

Question: Did the workshop increase your understanding of the subject?

- Very Much (1)
- This was my first exposure (1)
- Somewhat (1)
- Not Really (1)
- Better understanding of prime (1)
- How STs are used differently (1)
- Multi course treatments (1)
- Reemphasized some areas (1)
- New methods (1)
- Learned about different types of prime and base finishes (1)

Question: Did this workshop make you look at STs differently? Explain.

- Different ways of placement (4)
- It all starts with protecting the base (3)
- Little previous experience (3)
- Focus better on inspection (3)
- My experience leaves little surprises (2)

- Importance of ST (2)
- Made me more aware of my job (1)
- The different situations it can be used for (1)
- Use cut-in prime to increase penetration (1)

Question: Did this workshop make you look at STs differently? Explain.

- Need to look at ST differently (1)
- Learned things I had never thought before (1)
- Will be more careful when finishing bases (1)
- Same info taught by experienced inspectors (1)
- New methods (1)
- Clarified some issues (1)
- A lot of factors (1)
- Reinforced understanding of STs (1)
- Importance of penetrating depth (1)

Question: Is your district currently using STs effectively?

- Do not use/Used very little (5)
- So so, Can use more (4)
- Most of the time (3)
- Use primarily as underseal (3)
- Lack experienced inspectors (2)
- Having fairly good results (2)
- Rely on contractors that don't know what they are doing.

Question: Is your district currently using STs effectively?

- Have developed consistency in the district (1)
- Need to be aware of others successes (1)
- Difficulties with base finishing (1)
- Need improved ride quality (1)
- See a lot of rutting and flaking (1)

Question: Do you think more focused training should be provided to TxDOT employees on this subject?

- More inspector training (22)
- More engineer training (7)
- New employee training (5)
- Review training (2)
- More training (2)
- Top priority, focused training for employees (1)

- Equations calculations and strengths (1)
- More real life situations and problem solving (1)
- Needs to be within district (1)
- Split into separate issues (1)

Question: Do you think more focused training should be provided to TxDOT employees on this subject?

- Base finishing and priming (1)
- Design (1)
- Will help of lack of experience (1)
- Contractors are not that good (1)
- Need more research (1)
- Maybe add field exercises (1)
- Contractor knows more than we do (1)
- If the district uses it (1)
- Not for this type of presentation (1)

Based on these long responses, several factors can be highlighted. The respondents overwhelmingly indicated that the workshop was a valuable learning experience and most of the workshop contents were very useful. Information on base finishing and prime coats appeared to have interested many participants, and some indicated a need for more information on that topic. It was quite interesting to see that some participants indicated that the workshop made them look at surface treatments differently and wished that their districts would use more of it. A large number of participants indicated that more focused training is needed for inspection personnel, particularly those with limited field experience.

Chapter 5

Conclusions

It is common practice for TxDOT to construct surface treatments (1-, 2- or 3- course) directly over base courses. Such surface treatments may act as either wearing surfaces or underseals (or interlayers). The decision to use surface treatments is based on a number of factors including low life-cycle cost, low initial construction cost, inexpensive maintenance, historically favorable experience, availability of experienced contractors, and availability of sound local materials. Constructability issues related to surface treatments often dictate their performance. However, a formal statewide constructability review of surface treatments over base has not been conducted either by TxDOT or by other state highway agencies in the recent past. The objective of this research project was to conduct a comprehensive constructability review of surface treatment as practiced by TxDOT districts and to identify best practices. A comprehensive survey of existing surface treatment practices was conducted, both by interviewing and contacting highway professionals and by visiting construction projects. Interviews were conducted with TxDOT district personnel, contractors, material suppliers and other State DOT personnel. Information collected from the constructability review was used to develop a district training workshop and to develop a design and construction guide for surface treatments. The workshop was delivered by researchers at eight regional locations.

As a part of this constructability review, a vast volume of research material was collected in this research project. During the literature review and state-of-practice review of this research, researchers contacted state DOTs and also reviewed information from several countries. The state-of-practice review focused primarily on communicating with surface treatment practitioners from other highway agencies.

The researchers made attempts to contact all 50 states to obtain information on their surface treatment practices. The researchers also investigated surface treatment practices by other countries. It was found that surface treatments (on base) are used by many countries worldwide. South Africa, Australia and New Zealand were three countries that showed extensive surface treatment use in their highway networks.

The application of a surface treatment is a simple and straightforward process. However, its success depends to a great degree on the effectiveness with which the base layer is finished and on the method used to ensure sufficient bonding between the surface treatment and the base. In Texas, all surface treatment construction projects use a prime coat on base to achieve this end. The techniques used to construct prime coats vary significantly both within and between districts. Many districts use the slush rolling technique to finish the base primarily to achieve a smooth base finish that is critical to the final ride quality of the surface treatment. The research team noted that there are several interpretations of what slush rolling really is. Some districts refer to a light sprinkling of water to wet a dry base as slush rolling. Others use slush rolling techniques that involve the virtual flooding of the compacted base to drive the fines in the base to the top during rolling. Such a practice, though resulting in a smooth finish, is definitely harmful for the pavement in the long run because of the weakening of the base that results. Several

districts have been very successful at producing smooth pavements without using slush rolling. These practices are highlighted as best practices in this report and they will also be incorporated in the design and construction guide that will be published later as a part of this research.

Even the most effective design may not ensure a satisfactory surface treatment due to the strong influence construction practices have on performance. Similar to the preventive maintenance seal coat operations, the surface treatment process is not that complicated. However, they both consist of systems whose satisfactory functioning depends heavily on the conditions under which they are constructed. Therefore, the designers of both these systems are constrained by not knowing the field conditions for which to design for. This puts a tremendous burden on the field project manager to make critical adjustments and decisions in the field. Most practitioners call seal coat and surface treatment work more of an “art” than a science for this reason. However, this research team firmly believes that there is more to the science of surface treatments and seal coats than it appears to be.

Construction of surface treatments, unlike seal coat projects, comprise of a small part in a larger construction contract. The surface treatment in such projects could either be an underseal or a wearing course which is the culmination of a larger project. This sometimes creates a situation where a prime contractor may not have the skilled personnel required to complete the surface treatment work at a satisfactory quality level. For example, the motor grader operator and other surface treatment equipment operators need to be skilled in operating such equipment which are crucial to project quality. In some cases, the prime contractor may subcontract the work to a surface treatment specialist, and this practice should always be encouraged.

The design and construction of surface treatments require careful consideration of several factors. These include sound project selection for ST work, required ride quality and how to achieve it, number of courses in the ST and their construction sequence, prime coating method, and constructability and material selection application rates.

The selection of projects for surface treatments should be judiciously made. An underseal must be recommended practice for most HMAC surfacing projects in the state due to inherent benefits gained from their application. It protects the base from moisture, and ensures satisfactory bonding of the hot mix to the base below. This will in turn reduce the stresses generated in the HMAC layer and is likely to provide longer fatigue life. Surface treatments can be used as wearing courses in pavements that may carry traffic as high as 5000 ADT. The researchers came across a few instances where STs have been effectively used as wearing courses in ADT levels as high as 12,000.

The prime coating method is another important aspect of surface treatment. TxDOT districts use four prime coating methods that were described earlier in this chapter. All prime coating methods indicated earlier are capable of providing good bonding between the prime coat and the finished base. One important factor is to ensure that the prime coat binder is sprayed at the appropriate base moisture content. The 2004 TxDOT specification calls for a base moisture content 2 percentage points below the optimum moisture content as appropriate for good prime penetration and adhesion. Even though different base material-binder combinations may have different optimum moisture levels, the specification value appears to be a good rule-of-thumb to

adopt. The researchers observed a couple of surface treatment projects that failed during construction because the prime coat was applied too wet.

The material rate design for surface treatments begins with the rate design for seal coats. Even though seal coat binder rate design can be used to guide the binder rate design for multiple-course surface treatments, some key adjustments need to be made to account for the design and construction sequence of the surface treatment. If successive courses are applied quickly one after the other, allowances must be made for drain-down of binder (i.e. use a lighter rate for lower course, and heavier for the upper course). This may be achieved by considering the existing surface to be highly textured (coarse). If upper course is applied months later, use of a heavier rate at the bottom and a lighter rate at the top are recommended.

The industry has been moving towards better control of ride quality for surface treated pavements. The use of IRI is a very effective way to control the ride quality. The IRI can be calculated using profilograph measurements on the finished base, first course or the final course of the surface treatment. Some districts tried IRI specifications of 120 on finished base, but experience suggest that these values can be reduced much further for the finished base. The question then arises as to how these ride quality values can be achieved. Many districts have allowed contractors to use the practice of slush rolling for the purpose of achieving ride quality. Even though this can provide good ride quality, when excessive amount of water is used, slush rolling can be a recipe for premature base failure. Slush rolling drives the fines in the base material to the top, thus creating voids in the flexible base and destroying its integrity. Therefore, the researchers recommend that other methods such as 'blade-and-roll' and the use of base lay-down machine be adopted for this purpose. The 'blade-and-roll' technique requires a very good blade operator and most districts insist that it is becoming harder and harder to find contractors with good blade operators. A base lay-down machine can be a good substitute for this scenario. These factors make it imperative that control mechanisms be adopted by districts to ensure that contractors have appropriate methods in place to achieve the required ride quality without compromising the integrity of the pavement.

One of the most critical issues for the immediate future in surface treatment practice is the role of project management and inspection. TxDOT is becoming increasingly dependent on inspectors and project managers with little experience. This is caused by the high rate of turnover of experienced inspectors and project managers over the past several years. This appears to be leading towards an era of surface treatment practices at construction sites dictated to a significant extent by the contractors. Good contractors have a lot of experience and wisdom that TxDOT projects can benefit from. However, the time is right for TxDOT to re-evaluate the inspection process. With a booming construction market and an expanding economy, it is unlikely that TxDOT will have experienced inspectors and project managers in sufficient numbers in the foreseeable future. The alternatives for TxDOT to consider may be either to invest in accelerated inspector training programs or to become innovative and creative in the way specifications are written and designs are done. Innovative contracting methods could also be a possibility.

There is very little research done on the subject of prime coat effectiveness in surface treatment construction, even though its influence on surface treatment performance has been well established for some time. A limited laboratory program was undertaken to investigate the effects of factors that have long known to influence prime coat effectiveness in surface treatments. The emerging conclusions from this experimental program are presented in this report.

The effectiveness of a prime coat depends on a number of factors including its penetration, prime coat binder and the prime coat technique. In addition, the prime coat performance also depends on factors such as the base material, its moisture content at the time of priming and the surface finish of the base on which the prime is applied. In Texas, three primary techniques are used for prime coat application; spray prime, worked-in prime and covered prime. In addition, base finishing techniques such as blade and roll, slush roll, trimming and laydown machine are used. With regard to base moisture content at the time of priming, a value of OMC minus 2 percentage points is recommended in specifications.

Results obtained in this research program clearly showed that base moisture condition that is optimum for priming depends on a variety of factors including the base material, surface finish and the prime coat binder. Also, there appear to be a set of a very complex relationships between the factors indicated above, and additional research is needed to conduct a comprehensive research program to develop a testing protocol that will allow the highway professionals to evaluate the effectiveness of their material combinations that are effective under local construction conditions.

Feedback provided by regional training workshop participants responses indicate that they were overwhelmingly satisfied with the workshop organization, content and delivery. The respondents overwhelmingly indicated that the workshop was a valuable learning experience and most of the workshop contents were very useful. Information on base finishing and prime coats appeared to have interested many participants, and some indicated a need for more information on that topic. It was quite interesting to see that some participants indicated that the workshop made them look at surface treatments differently and wished that their districts would use more of it. A large number of participants indicated that more focused training is needed for inspection personnel, particularly those with limited field experience.

References

- [1] Barbour, S.L., Wilson, G.W., and St-Arnaud, L.C. 1993. Evaluation of the saturated – unsaturated ground water conditions of a thickened tailing deposit. *Canadian Geotechnical Journal*, 30: 935 – 946
- [2] Barton, I.J. 1979. A parameterization of the evaporation from nonsaturated surfaces. *Journal of Applied Meteorology* 18: 43 – 47
- [3] Granger, R.J. 1989. Evaporation from non-saturated surfaces, *Journal of Hydrology*, 111: 21 – 29
- [4] Gray, D.M. 1970. Handbook on the principles of hydrology. Canadian National Committee for the International Hydrological Decades. National Research Council of Canada.
- [5] Hammel, J.E., Papendick, R.I. and Campbell, G.S. 1981. Fallow tillage effects on the evaporation and the seed zone water content in a dry summer climate. *Soil Science of America Journal*, 45: 1016 – 1022
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0-5169-2
Appendix A

Constructability Review of Surface Treatments Constructed on a Base Course



Research Project 0-5169

Constructability Review of Surface Treatments Constructed on Base Courses

Regional Training Workshop for TxDOT Districts

Conducted by
Sanjaya Senadheera, Ph.D.
Michael Leaverton, P.E.

TechMRT
Texas Tech University Center for Multidisciplinary Research in Transportation



Research Project Overview



Workshop Timeline

Time	Workshop Agenda Item
10:00am-12:00pm	Surface treatment basics Constructability review findings Construction project information
12:00-1:00pm	Lunch (on your own)
1:00-1:45pm	ST best practices
1:45-3:00pm	Discussion/interactive activities
3:00-3:30pm	Workshop evaluation/wrap-up



Project 0-5169:
Constructability Review of Surface Treatments Constructed on Base Courses

- Two-year study
- Ending in August, 2006

Project Monitoring Committee:

Program Coordinator: Lynn Passmore, P.E. (BWD)
Project Director: David Seago, P.E. (DAL)
Project Advisors: Doug Eichorst, P.E. (ODA)
John Jasek, P.E. (WAC)
Gary Mizer, P.E. (CHD)



Outline of PowerPoint Presentation

- Research Project Overview
- National and International Outlook on STs
- Specifications, Manuals & Publications
- Role of Surface Treatments in Pavements
- Design of Surface Treatments (STs)
- Construction & Performance of STs
- Statewide Constructability Review Findings



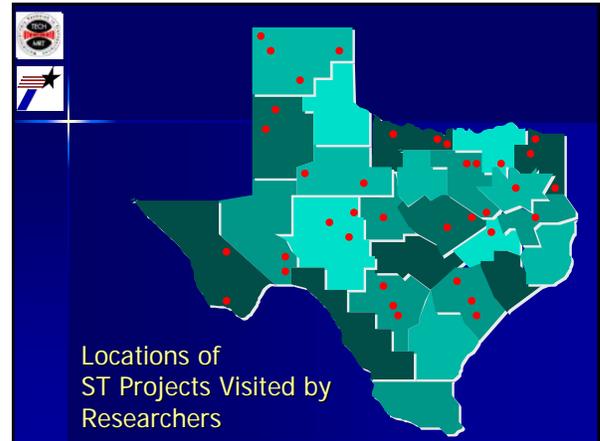
Research Products

- **Regional Workshops**
- Design and Construction Guide
- Suggested Changes to Specifications

Constructability Review of Surface Treatments Constructed on a Base Course

Sources of Workshop Presentation Material

- Literature review
- State-of-Practice review
- Phone interviews (or E-mail) with DOTs
- District Constructability Reviews
- Interviews
- Project Visits



District Constructability Review

- District Interview
 - Visited all 25 districts
 - Questionnaire discussed
 - Interview team assembled by district
- Construction project visits
 - 66 projects identified
 - 37 projects visited

National and International Outlook

District Questionnaire

83 Questions under 10 Categories

- General information on District ST program
- Planning & design
- Contract-related Information
- Materials
- Base courses and their preparation
- Construction of ST
- Quality Control
- Equipment
- Performance of surface treatments
- Continuous improvement of ST practices

Use of Surface Treatments on Base by other State DOTs

Category	No. of States	Remarks
Significant ST Activity	6	GA, AK, AR, WA, SC, WI
Some ST Activity	3	KS, NM, OH
Don't use STs	19	CA, CT, DE, FL, IA, ID, IL, MA, MD, MN, MO, NE, NV, NH, NJ, NY, OK, VT, WY

Constructability Review of Surface Treatments Constructed on a Base Course



Use of Surface Treatments on Base by other Countries

- Australia
- France
- New Zealand
- South Africa
- United Kingdom
- Many others



Other Publications

- Norman W. McLeod, "Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalts and Asphalt Cements," Proceedings of The Association of Asphalt Paving Technologists, 1960.
- Robert L. McHattie, *Asphalt Surface Treatment Guide*, Alaska Department of Transportation and Public Facilities, 2001.
- Department of Transport, "Surfacing Seals for Rural and Urban Roads" Republic of South Africa, 1998.



Specifications, Manuals & Publications



Role of Surface Treatments in Pavements



Specifications and Manuals

- TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges, Adopted June 1, 2004 ([ftp://ftp.dot.state.tx.us/pub/txdot-info/des/specs/specbook.pdf](http://ftp.dot.state.tx.us/pub/txdot-info/des/specs/specbook.pdf))
 - Item 316: Surface Treatments
 - Item 300: Asphalts, Oils, and Emulsions
 - Item 301: Asphalt Antistripping Agents
 - Item 302: Aggregates for Surface Treatments
 - Item 310: Prime Coat
 - Item 314: Emulsified Asphalt Treatment
 - Item 318: Hot Asphalt-Rubber Surface Treatments
- TxDOT Seal Coat and Surface Treatment Manual, 2004 (<http://manuals.dot.state.tx.us/docs/collinfra/forms/scm.pdf>)



Introduction to Pavement Engineering

What is a Pavement?

A structure built on existing ground to facilitate rapid, safe, reliable & comfortable traffic movement

What is the Role of ST in a Pavement?

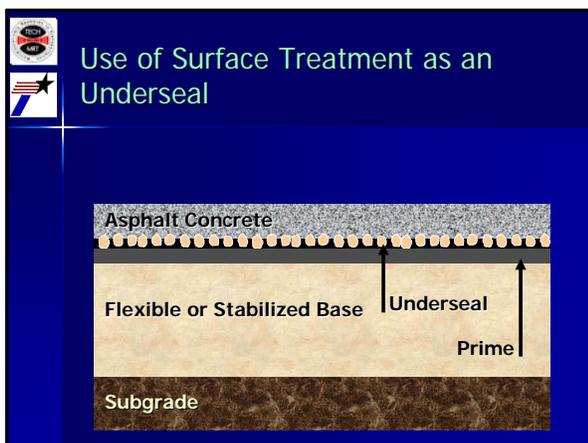
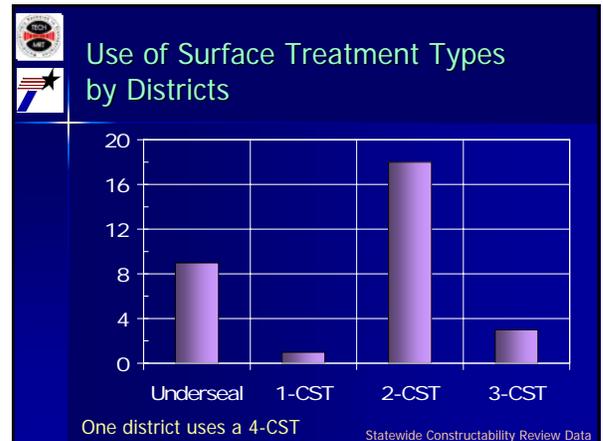
As a "wearing surface" or as an "interlayer"

Constructability Review of Surface Treatments Constructed on a Base Course



- ## Functions of a ST Used as an Underseal
- Seal the pavement base and foundation
 - Act as a temporary wearing course (and protect the base)
 - Provide a strong bond between hot mix and base
 - Prevent reflective cracking by acting as a Stress Absorbing Membrane Interlayer (SAMI)
 - Can be used with any traffic level

- ## Functions of a ST Used as Wearing Surface
- Seal the pavement base and foundation
 - Provide a strong wearing surface
 - Provide a durable wearing surface
 - ST does not add significant strength to the pavement structure
 - Generally used in low-volume roads

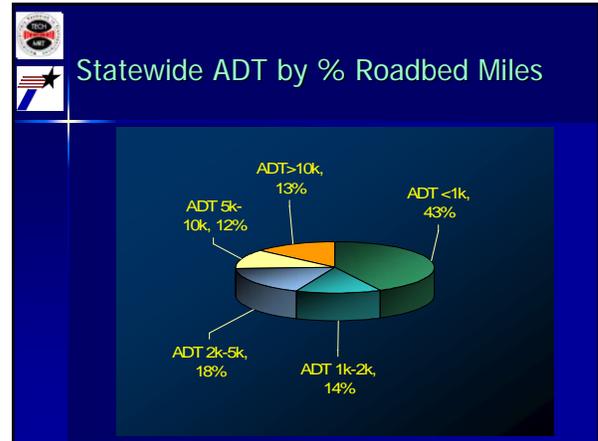


- ## Surface Treatment Process
- Design
 - Construction
 - Performance

Constructability Review of Surface Treatments Constructed on a Base Course

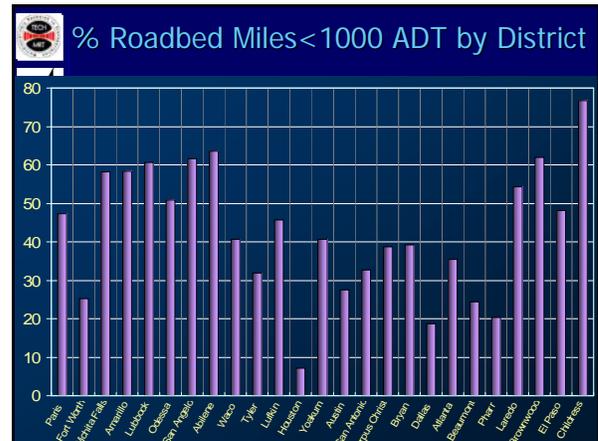


Design of Surface Treatments




Design of Surface Treatments

- Project selection
- The prime coat
 - Type of prime coat
 - Prime coat binder type and application rate
 - Constructability
- Design of the surface treatment
 - Number of courses in ST/Construction sequence
 - Aggregate type(s)/grade(s)/rate(s)
 - Binder type(s)/grade(s)/rate(s)




ST Project Selection Criteria

- ADT (19)
- Location (10)
- % Trucks (8)
- Cost (8)
- Highway Class (6)
- Traffic Control Plan (3)
- Existing Pavement (2)
- What's around It (2)
- Turning Traffic (2)

Statewide Constructability Review Data

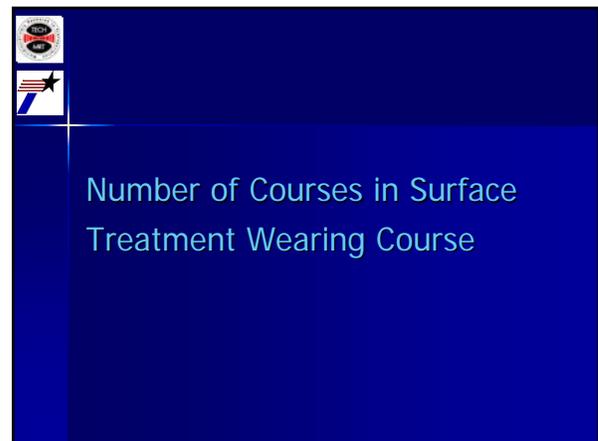
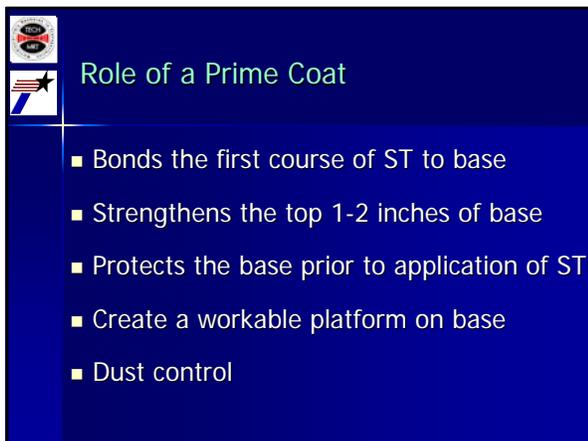
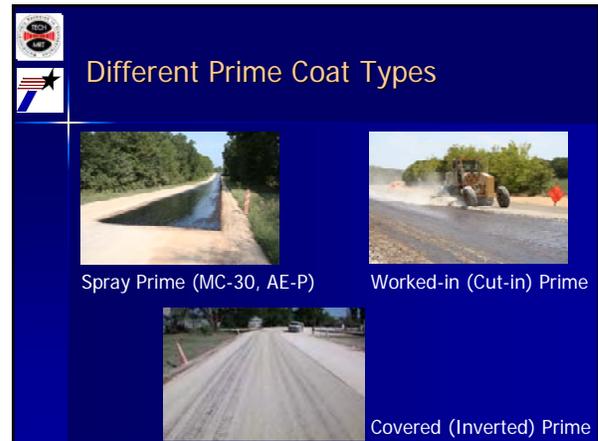
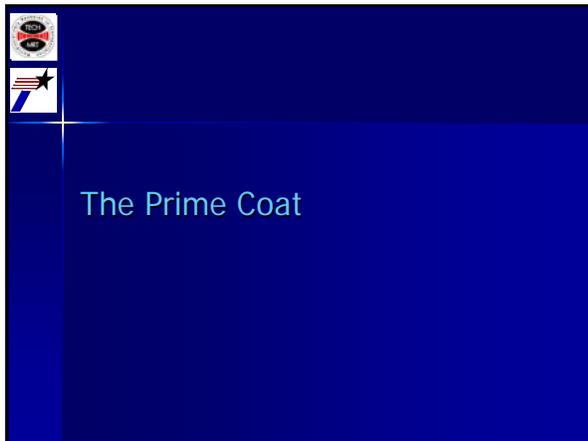
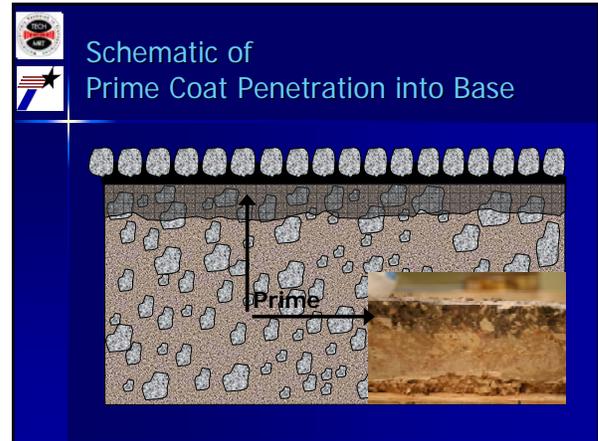


Is Roadway Noise a Consideration in Selecting STs as Wearing Course?

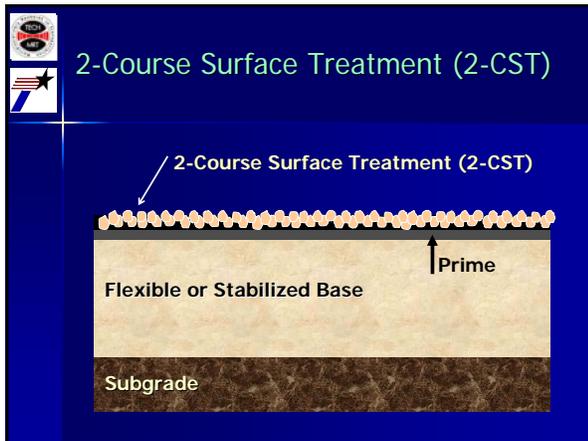
- No (20)
- Yes (3)

Statewide Constructability Review Data

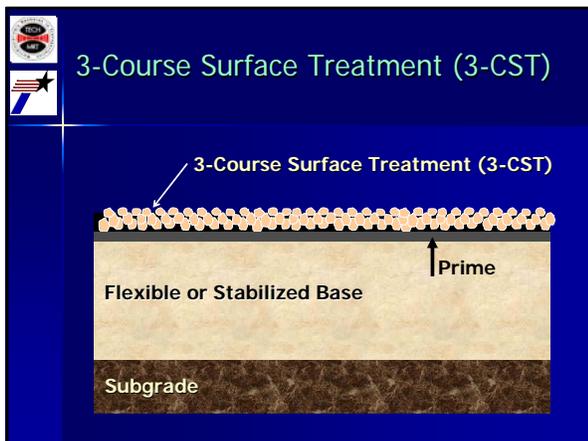
Constructability Review of Surface Treatments Constructed on a Base Course



Constructability Review of Surface Treatments Constructed on a Base Course



- ### Construction Sequence of Multiple Courses
- Covered prime service life approx. 3 months
 - A late season first course serves as wearing course until next summer, and truck traffic and turning traffic can pose challenges in such situations
 - Subsequent courses applied in summer could be one, two or three courses
 - If two or three courses are applied, they could be done on the same day

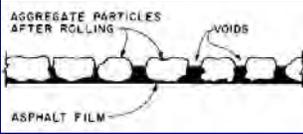


Aggregate Grades and Rates

Constructability Review of Surface Treatments Constructed on a Base Course

Design of Aggregate Rates

- Leave sufficient room (15-25%) between rocks for them to settle to the most stable position when rolled.



AGGREGATE PARTICLES AFTER ROLLING
VOIDS
ASPHALT FILM

- Can use "Board Test" in the lab and calibrate it in the field
- Avoid over-application of stone.

Can you guess the % voids for this aggregate spread?



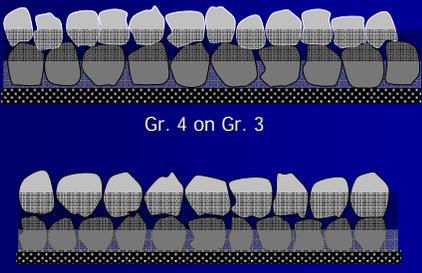
It is 21.5% Voids!

Shoulder-to-Shoulder Matrix in South African Surface Treatments



Dense Matrix Medium-Dense Matrix
Open Matrix

2-Course Surface Treatments Commonly used Aggregate Grades

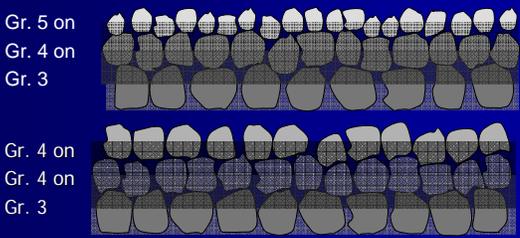


Gr. 4 on Gr. 3
Gr. 3 on Gr. 4

Over-Application of Stone

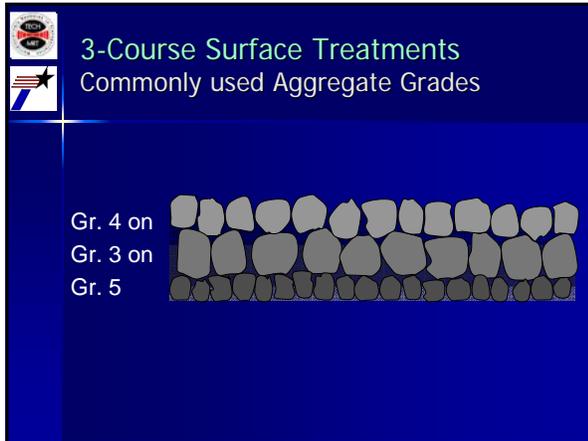


3-Course Surface Treatments Commonly used Aggregate Grades



Gr. 5 on Gr. 4 on Gr. 3
Gr. 4 on Gr. 4 on Gr. 3

Constructability Review of Surface Treatments Constructed on a Base Course



3-Course STs District Use of Aggregate Grades

Aggregate Grade Sequence Bottom-Middle-Top	No. of Districts
2 - 3 - 4	1
3 - 3 - 4	1
3 - 3 - 5	1
3 - 4 - 4	1
3 - 4 - 5	1
4 - 4 - 5	1

Statewide Constructability Review Data

District Use of ST Aggregate Grades

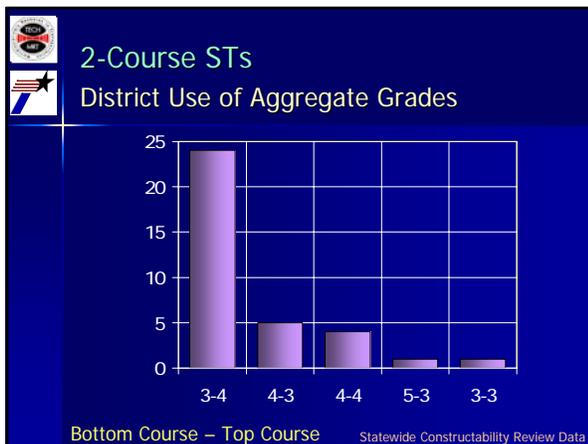
ST Type	Course	No. of Districts		
		Gr 3	Gr 4	Gr 5
1CST		4	8	2
2CST	1 st Course	19	9	1
	2 nd Course	3	19	1
3CST	1 st Course*	4	4	1
	2 nd Course	4	2	0
	3 rd Course	1	4	1

* - One district uses Gr. 2 rock in 1st course Statewide Constructability Review Data

Use of ST Aggregate Rates by Districts (sq. yd /cu. yd)

Grade	≤80	81-90	91-100	101-110	111-120	121-130	>130
Gr. 2	1	-	-	-	-	-	-
Gr. 3	1	7	5	2	2	-	-
Gr. 4	-	1	7	3	5	2	-
Gr. 5	-	-	-	2	2	1	1

Statewide Constructability Review Data



Asphalt Binder Grades and Rates

Constructability Review of Surface Treatments Constructed on a Base Course

Warm Weather Asphalt Use

- AC-20 5TR (14)
- AC-15P (6)
- AC-5 (3)
- AC-10+Ltx (2)
- AC-5+Ltx (2)
- AC-15 XP (2)
- CRS-2P (2)

Statewide Constructability Review Data

Percent Embedment

LOW TRAFFIC VOLUME
Voids 40 Percent Full

HIGH TRAFFIC VOLUME
Voids 30 Percent Full

Cool Weather Asphalt Use

- CRS-1P (14)
- AC-5 (6)
- AC-12 5TR (3)
- AC 10+Ltx, (2)
- AC 5+Ltx, (2)
- CRS 2P, (2)
- MC-2400, (2)
- MC-3000, (2)

Statewide Constructability Review Data

% Embedment of Aggregate Range from 30-40%

Grade 5 Aggregate

Grade 4 Aggregate

Grade 3 Aggregate

% Embedment depends on: binder type & grade
aggregate type & grade
traffic

Seal Coat Binder Rate Design

- Procedure outlined in the TxDOT Seal Coat and Surface Treatment Manual, 2004
- First, a base binder rate is designed based on
 - Aggregate type and grade
 - Aggregate rate
 - Design % Embedment
 - Traffic (ADT, % Trucks)
- Then, field adjustments are made based on the pavement surface condition

Design of Binder Rates for Multiple Course Surface Treatments (MCST)

- Decide on a total binder rate (for all courses)
- If successive courses are applied quickly one after the other, allow for draindown (i.e. use a lighter rate for lower course, and heavier for the upper course)
- If upper course is applied months later, use a heavier rate at the bottom and lighter at the top

Constructability Review of Surface Treatments Constructed on a Base Course



Surface Treatment Construction

- Construction Management
- Base Finishing
- Prime Coat
- Surface Treatment Application
- Quality Control



% Construction of ST by Prime Contractor

- More than 70% of the Time – 14 Districts
- Between 40-70% of the Time – 3 Districts
- Less than 40% of the Time – 8 Districts

Statewide Constructability Review Data



Construction Management



Problems Experienced with Contractors

- Expertise of contractor personnel
- Work load contractor handles for all districts
- Timely availability of materials
- Finished (Ride) quality of ST
- Equipment condition
- Asphalt rates
- Other: Mobilization timing, work zone safety, unfamiliar with materials

Statewide Constructability Review Data



Are STs good candidates for performance-based/warranty specs?

- Yes (16)
- No (8)

Statewide Constructability Review Data



Base Finishing

Constructability Review of Surface Treatments Constructed on a Base Course

  Types of Base Material Used

- Limestone
- Caliche
- Iron Ore Gravel
- Gravel
- Fly Ash Stabilized Base
- Cement Treated Base
- Asphalt Stabilized Base

Statewide Constructability Review Data

  Cement-Treated Limestone Base



Statewide Constructability Review Data

  Limestone Base



Statewide Constructability Review Data

  Rollers Used to Finish Base

 Pneumatic (17)

 Steel wheel (20)

Statewide Constructability Review Data

  Iron Ore Gravel Base



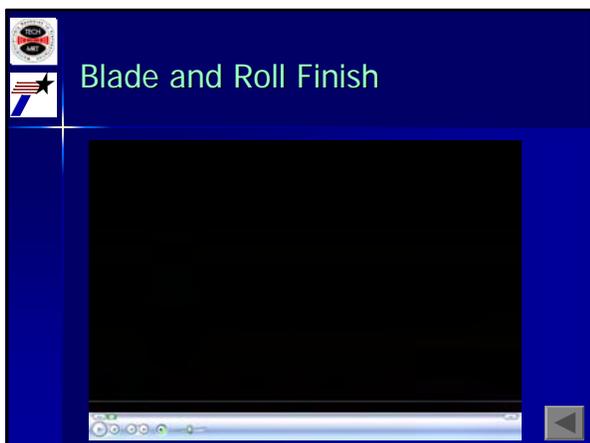
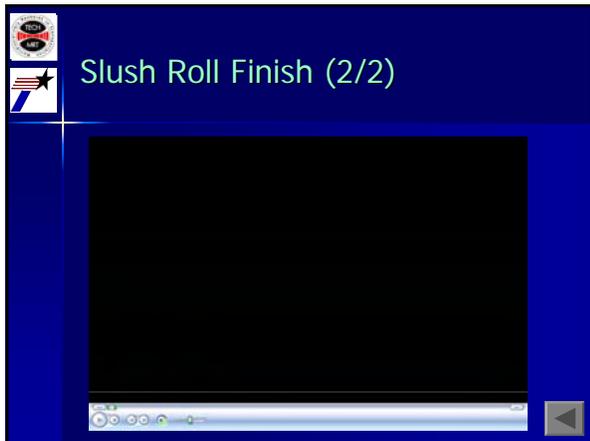
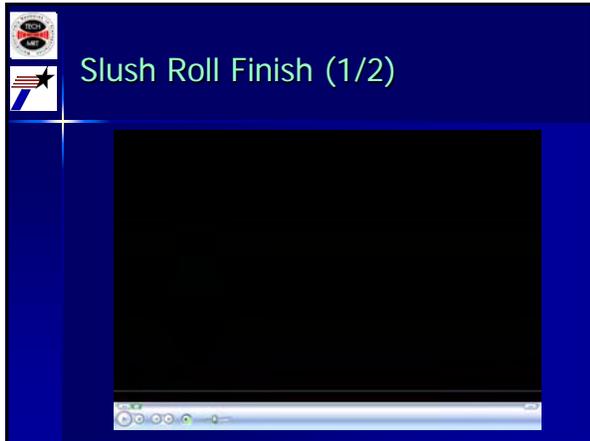
Statewide Constructability Review Data

  District Use of Base Finishing Techniques

- Slush Roll (12)
- Blade and Roll (7)
- Trimmer (3)

Statewide Constructability Review Data

Constructability Review of Surface Treatments Constructed on a Base Course



Constructability Review of Surface Treatments Constructed on a Base Course

 Prime Coat Method

- MC-30 Spray (17)
- AE-P (9)
- RC-250 Covered Prime (6)
- MS-2 or MS-1 Cut-in (6)
- SS-1 or CSS-1H Cut-in (4)
- Dirty Water (1)

Statewide Constructability Review Data

 Shaded Areas



 Optimum Conditions in Base for Prime Coat Application

- A "no-dust" base
- A "reasonably smooth" finished base
- A "reasonably porous" finished base
- A "strong" base
- "Appropriate" moisture condition in base

 MC-30 Prime Coat



 Skooting Prior to Prime



 MC-30 Prime Coat



Constructability Review of Surface Treatments Constructed on a Base Course

 Penetration of MC-30 Prime into Limestone Flex Base



 Sprayed-on AE-P Prime on Limestone Base



 Dilution of Emulsion Prime



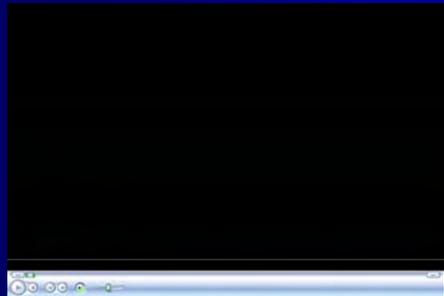
 Sprayed-on Diluted MS-2 Prime on Limestone Base



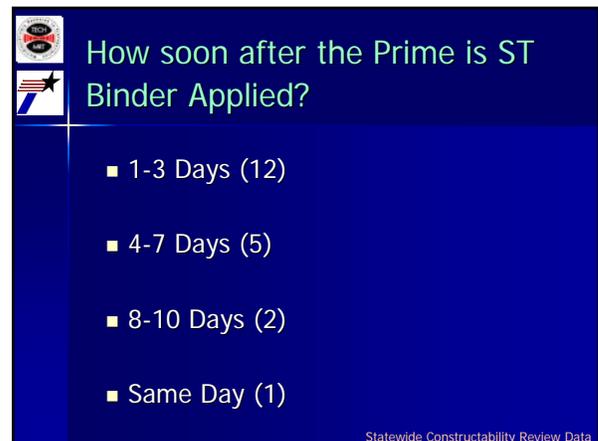
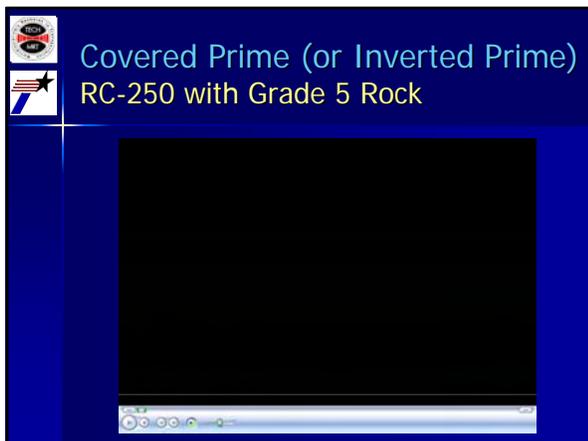
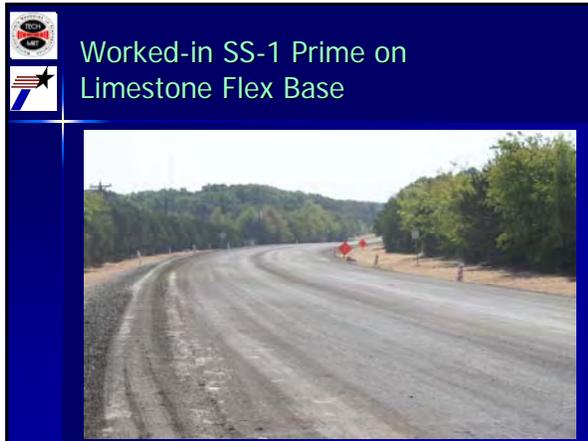
 Worked-in SS-1 Prime on Iron Ore Gravel Base



 Worked-in SS-1 Prime on Limestone Flex Base



Constructability Review of Surface Treatments Constructed on a Base Course



Constructability Review of Surface Treatments Constructed on a Base Course

 Aggregate Spread Timing on Emulsion

- ASAP (14)
- When emulsion is starting to break (5)
- As emulsion is breaking (4)
- After emulsion breaks (3)

Statewide Constructability Review Data

 Minimum Time Lag from 1st to 2nd Course of MCST - Cutbacks

- RC-250
 - Minimum 7 days
- MC-2400
 - 90 days
 - 120 days

Statewide Constructability Review Data

 Minimum Time Lag from 1st to 2nd Course of MCST - AC Binders

- 1 Day (6)
- 3 Days (4)
- 7-10 Days (2)
- 14 Days or more (2)
- For a 3-CST, will shoot 3rd course within hours of the 2nd course

Statewide Constructability Review Data

 Drag Broom Used for Grade 2 Rock



 Minimum Time Lag from 1st to 2nd Course of MCST - Emulsion

- 1 – 2 days
- Minimum 3 days
- Minimum 7 days
- Wait for asphalt season
- Wait for next 80°F week

Statewide Constructability Review Data

 Drag Broom Used for Grade 2 Rock



Constructability Review of Surface Treatments Constructed on a Base Course

 Transition Area Between Two Rock Truckloads



 Tasks for the Inspector (2/5)

- Get contractor to conform to specs/plan notes
- Workmanship
 - General workmanship
 - Expertise of personnel such as equipment operators
- Materials
 - Quality (stockpile evaluation of aggregate, etc.)
 - Application of proper rates
- Equipment calibration

 Quality Control

 Tasks for the Inspector (3/5)

- Finishing of Base
 - Use of an effective method
 - Finish quality
- Prime Coat
 - Timing of Prime (water content in base)
 - Prime coat method
 - Prime coat binder rate
 - Precautions (cutouts, keeping traffic off, reduced speed traffic)

 Tasks for the Inspector (1/5)

- Establish a good rapport with contractor's personnel
- Establish effective lines of communication with the contractor
- Manage limited inspector time and use it effectively
- Resolve contractor's questions/issues in a timely manner
- Establish inspector's (client's) authority
- Make effective use contractor's expertise

 Tasks for the Inspector (4/5)

- Surface Treatment
 - Timing of the first course
 - Binder application checklist
 - Temperature, spray bar height, nozzle angles, marking of shots
 - Rock application checklist
 - Timing of rock application, rock lands, stockpile checks, loading of trucks to consistent volume, check for debris
 - Rolling (primarily for hot asphalt)
 - Control of loose rock

Constructability Review of Surface Treatments Constructed on a Base Course

 **Tasks for the Inspector (5/5)**

- Work-Zone control
 - Safety
 - Access to Property
- Job Acceptance
 - Execute previously agreed repair policy
 - Finish quality of surface treatment

 **Performance of Surface Treatments**

 **Wetting of Aggregate Stockpiles**



 **Common ST Distresses**

- Peeling of Prime (3)
- Peeling of ST (4)
- Bleeding/Flushing (22)
- Raveling/Rock Loss (20)

Statewide Constructability Review Data

 **Quality Control**

- Inspection forces are dwindling
- TxDOT is losing a lot of experience
- Some ST inspectors handle multiple jobs
- ST Training needed for new hires
- In many cases, ST work is contractor-driven

Statewide Constructability Review Data

 **Driveway Turnout; AE-P on Limestone Prime Picked-up after Brooming**



Constructability Review of Surface Treatments Constructed on a Base Course

 Wearing of Prime Coat by Traffic



 Failure of Prime Coat Due to Loose Rock on the Road (2/2)



 Failure of Prime Coat before ST is Applied



 Pick-up of Prime and Surface Treatment by Construction Traffic



 Failure of Prime Coat Due to Loose Rock on the Road (1/2)



 Peeling of Prime/ST
AE-P Prime Coat on Limestone Base



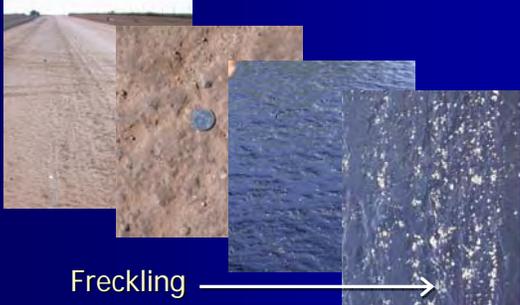
AC-15P Underseal Applied the day after prime coat

Constructability Review of Surface Treatments Constructed on a Base Course

 Bleeding Surface Treatment



 Underseal (Covered Prime)
AC-5 Binder Applied Directly on CTB



Freckling →

 Flushing Surface Treatment



 Surface Treatment Failure at Intersection



 Raveling Surface Treatment



 Tracking of Surface Treatment at Intersection



Constructability Review of Surface Treatments Constructed on a Base Course

 **Shoulder Drop-off**
3-CST in Main Lane, 2-CST in Shoulder

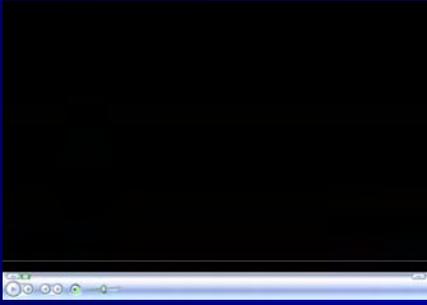


 **How to Correct Raveling/Rock Loss?**

- Fog Seal (13)
- Re-shoot (5)
- Strip Seal (2)

Statewide Constructability Review Data

 **Problems due to Heavy Traffic**



 **Correct Action for Bleeding**

- Chatting/Ice Rock (12)
 - A very short-term solution
 - Porous aggregate may work better
- Lime Water (10)
 - Cools pavement
 - Pavement absorbs less heat
 - Chemically reacts with asphalt and stiffens binder

Statewide Constructability Review Data

 **A Problem waiting to Happen?**



 **End of the Morning Session !**

Any questions or comments?

Constructability Review of Surface Treatments Constructed on a Base Course



Researchers' Contact Information

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0-5169-2
Appendix B

Constructability Review of Surface Treatments Constructed on a Base Coat



Surface Treatment Best Practices



Asphalt Emulsion Spray Applications



Presentation Outline

- Asphalt Emulsion Spray Applications
- A Ride Quality Requirement for STs
- Base Finishing and Prime with no Slushing
- TTU Lab Tests to Study Prime Coat Penetration
- New Equipment in the Market
- Continuous Improvement of ST Practices



A Ride Quality Requirement for Finished Surface

- May be applied on
 - Finished base
 - Primed base
 - After first course of ST is applied
- TxDOT Special Provision 247-011 for Flexible Base
 - Within 3 days after placing the covered prime coat (RC-250+ Gr. 5 rock), run profiler and check if IRI is less than 125 per mile for each wheel path
- Preliminary observations suggest that the IRI requirement could be reduced further



Asphalt Emulsion Spray Applications

Obtained (with permission) from Video published by The Asphalt Institute, Lexington, Kentucky



Limestone Base w/Slush Roll Finish IRI = 112, Ready for MC-30 Prime



Constructability Review of Surface Treatments Constructed on a Base Coat


 Limestone Base w/Slush Roll Finish
IRI = 112, Ready for MC-30 Prime




 Worked-in Prime Coat (Step 2/3)




 Base Finishing (with No Slushing) and Priming


 Worked-in Prime Coat (Step 3/3)




 Worked-in Prime Coat (Step 1/3)




 Good Ride is Possible without Slushing



Constructability Review of Surface Treatments Constructed on a Base Coat

 Laboratory Tests

 Monitoring of Specimen Drying



 Laboratory Test Program

- 24 Combinations
 - 3 Base Materials (LS, IOG, FATB)
 - 5 Prime coat materials (MC-30, AE-P, RC-250, SS-1, MS-2)
 - 2 Surface finishes (regular, slushed)
 - 3 Moisture states (OMC, OMC-2%, OMC-4%)
- Moisture level monitored with moisture sensors placed 1 and 2 inches below specimen surface

 Application of Prime



 Specimen Preparation

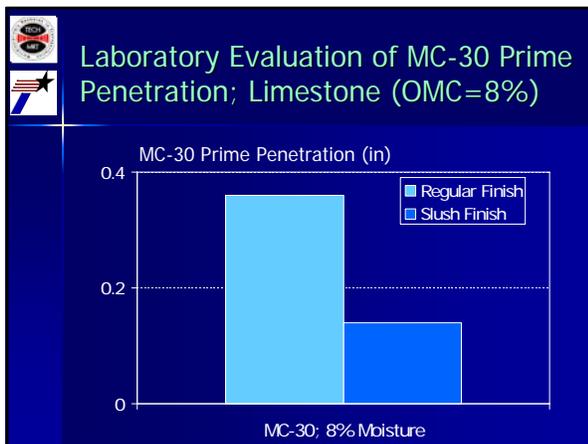
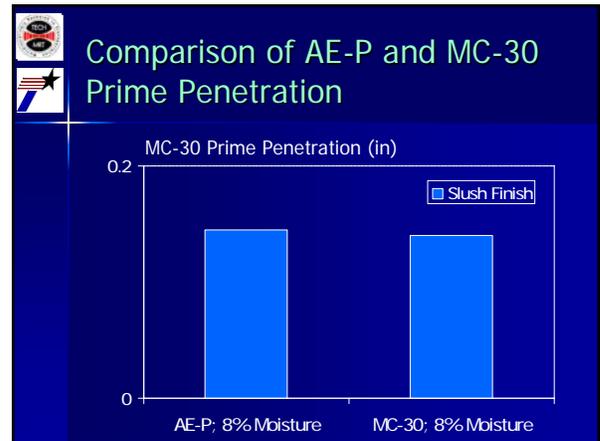
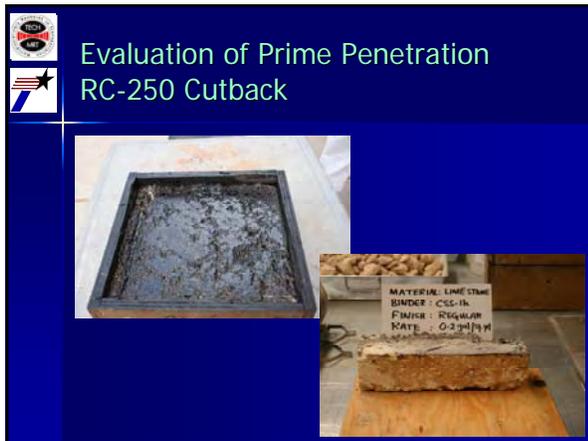
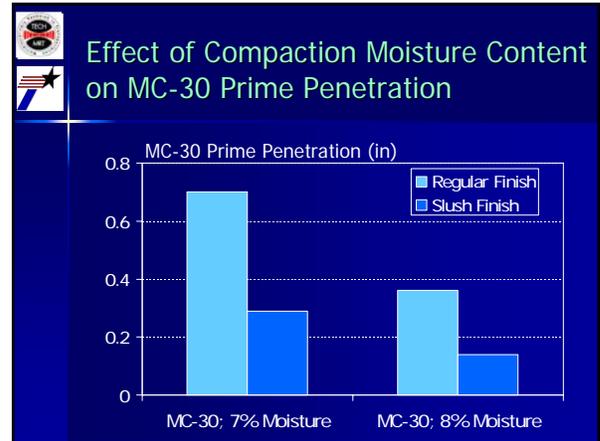
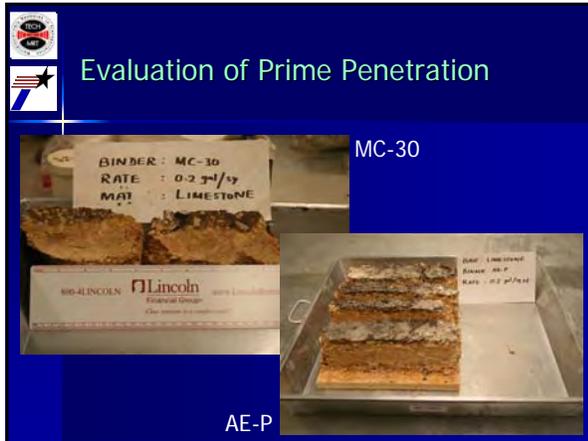


- 1'X1' wooden box; 4" height; Removable sides

 Evaluation of Prime Penetration



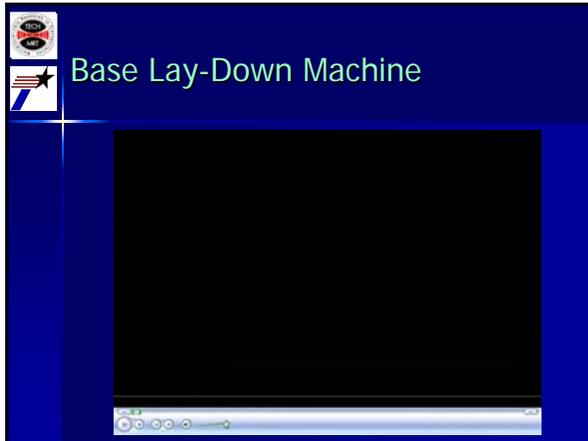
Constructability Review of Surface Treatments Constructed on a Base Coat



New Equipment in the Market: Base Material Lay-Down Machine

Contractor: Big Creek Construction

Constructability Review of Surface Treatments Constructed on a Base Coat

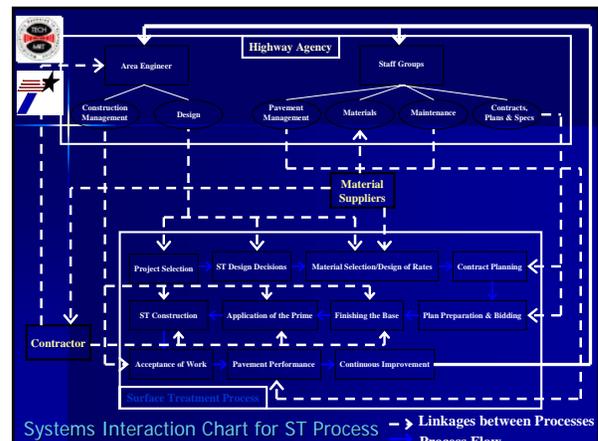


- ## How to Construct ST if Money was not an Issue
- Use Best Available Materials
 - Use TR Binders
 - Work only in Summer
 - Use Better/Harder Rock
 - Cover With Hot Mix
 - Others (Do Away with Slushing, Use Larger Rock)
- Statewide Constructability Review Data

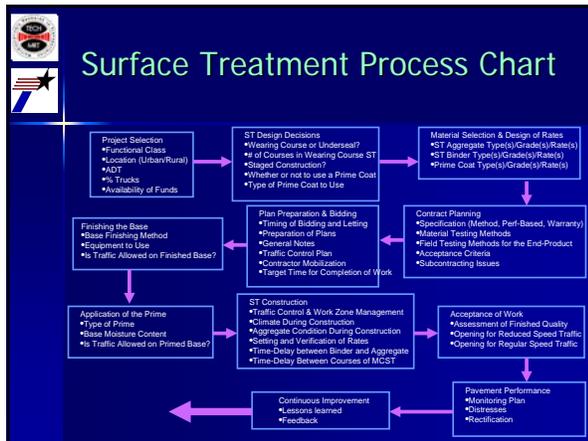
Continuous Improvement of ST Practices

- ## Improvements Suggested by Districts to the ST Process
- Train Inspectors
 - Certify Contractors/Personnel
 - Share ST Best Practices
 - Don't Accept Poor Construction
 - Try to Keep Traffic off the Job
 - Shoot Early in the Season
 - Calibrate Equipment
 - Spend More Time Finishing Surface
 - Get a Handle on Asphalt
- Statewide Constructability Review Data

- ## Importance of Continuous Improvement
- Learn from experiences
 - Benefit from contractor's experience
 - Bring-in new materials
 - Bring-in new equipment and technologies
 - Training of personnel



Constructability Review of Surface Treatments Constructed on a Base Coat



Do Surface Treatments have a Place in Pavements?

- Yes!
- It is the best way to seal base and foundation of any type of pavement
- Why/Where?
 - A cost-effective wearing surface
 - Good temporary wearing surface before paving hot mix
 - In high traffic roadways, underseal can be used to bond HMAc to base
 - Effective in high PI expansive soil areas
- Base is the key !

End of Section on Best Practices

0-5169-2
Appendix C

TxDOT Research Project 0-5169
Constructability Review of Surface Treatments Constructed on Base Courses

Regional Training Workshop

Abilene District Headquarters, April 5, 2006

Workshop Evaluation Form

Thank you very much for your participation in this regional training workshop on surface treatments. We appreciate your feedback on this workshop to help us understand your thoughts on both the workshop and the TxDOT surface treatment practice in general. Please provide your contact information to us if you wish to do so.

Name	Contact E-mail	Contact Phone Number

You may provide feedback on the following aspects of the workshop. If you need additional space, you can write on the back of this form.

		Short Response	Additional Comments
1	What do you think about limiting the number of workshop participants to approximately 15 from each District?		
2	Was the workshop format (slides, pictures, video, discussions) effective?		
3	Would you have delivered the workshop differently? If YES, how?		
4	Was the workshop of sufficient length?		
5	What topics/information interested you the most?		
6	What topics/information did not interest you?		
7	Did you find the number of topics covered to be adequate?		
8	Did you wish to have more information in some areas? What are they?		
9	Was adequate information provided in the "Best Practices" portion?		
10	Did the workshop increase your understanding of the subject?		
11	Did this workshop make you look at STs differently? Please explain.		
12	Is your district currently using STs effectively? If NO, please explain.		
13	Do you think more focused (details) training should be provided to TxDOT employees on this subject?		
14	Do you think the handouts provided will be useful?		
15	Did the quality of slides, pictures and videos meet your expectations?		



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