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Best Practices for the Use of Prime in Texas Pavement Structures

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16. Abstract

The objective of this research project was to determine where, when, and why a prime or cure is needed for a pavement layer. Materials such as prime coats, curing materials, seal coats, and tack coats are typically considered nonstructural but integral to the pavement structure. Some materials can be used for multiple purposes, such as to prime, bond, or help cure; however, the rates and timing of use may change depending on why the material is being used. To aid decision-makers in determining whether a prime, cure, or bond material is needed, guidance was developed. Recommendations for where, when, and why to design and use the prime materials were developed.

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BEST PRACTICES FOR THE USE OF PRIME IN TEXAS PAVEMENT STRUCTURES

by

Darlene Goehl
Research Engineer
Texas A&M Transportation Institute

Stephen Sebesta
Research Scientist
Texas A&M Transportation Institute

Carl Bierman
Assistant Research Engineer
Texas A&M Transportation Institute

Kai-Wei Liu
Assistant Research Scientist
Texas A&M Transportation Institute

and

Jia-Lin Hsu
Research Associate
Texas A&M Transportation Institute

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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

DISCLAIMER

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This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Darlene C. Goehl, P.E. #80195.

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

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Prime and cure are terms that are frequently used when discussing pavements. Depending on the pavement layer, a material may act as both [*1*]. Unfortunately, these terms are used often without a full understanding of their purpose in the pavement structure, including why and when the material is used.

PRIME

The Texas Department of Transportation (TxDOT), in the *TxDOT Glossary*, defines prime as follows: "The prime coat (PC) is the initial application of a low viscosity liquid asphaltic material on a completed base course or other approved area for the purpose of promoting adhesion between the base course or area and the application of a subsequent layer of asphaltic material" [*2*]. The major purposes of prime coat are to:

- "protect the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer;
- reduce the drying rate of the compacted base;
- promote bond of the base to the subsequent asphalt pavement layer;
- seal the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder; and
- bind or stabilize the surface particles of the base" [*3*].

Figure 1 is an example of a prime coat in a flexible base with a seal coat surface.

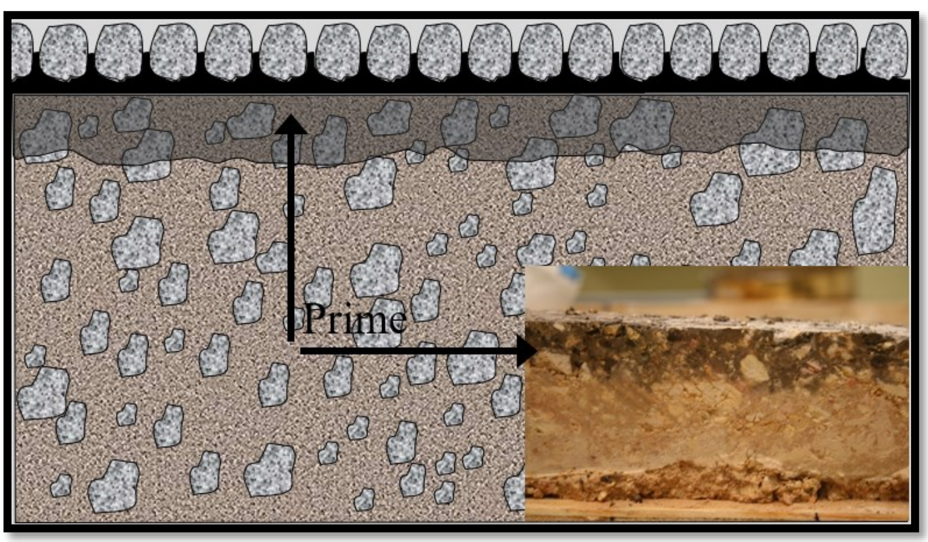

Figure 1. Prime Coat Illustration [3].

The first prime coat specification for TxDOT appeared in the 1950 *Standard Specifications for Road and Bridge Construction*. In 1962, a specification for emulsified asphalt treatment was added. TxDOT has consistently included prime coat specifications in its standard specification book ever since.

Current items with descriptions for use as a prime are Item 310, Prime Coat, and Item 314, Emulsified Asphalt Treatment. TxDOT's specification description for Item 310, Prime Coat, states, "Prepare and treat existing or newly constructed surface with an asphalt binder or other specialty prime coat binder material" [*4*]. While this is a description of the construction process, it does not really define a prime coat. The material used for a prime coat is usually an asphaltic material that has been cutback or emulsified, and in some cases both. The materials allowed are in accordance with Item 300, Asphalts, Oils, and Emulsions. The materials listed in TxDOT Item 300, Asphalts, Oils, and Emulsions, Table 18: Typical Material Use, as a prime are MC-30, AE-P, EAP&T, and PCE [*4*]. Additionally, TxDOT's online Material Producer List has prequalified specialty materials for use as prime coat binders:

- EC-30.
- Terra Prime.
- Envirotx Prime.

To access desired properties of prime, test methods can be applied in the laboratory and field. Table 1 summarizes different prime coat tests along with their functionalities.

Table 1. Summary of Test Methods for Prime Coats.

Category	Test	Lab	Field	Functionality
Penetration	Prime Penetration Test	Yes	Yes	Application rate and penetration time
Penetration	Ring Test	Yes	Yes	Application rate
Cohesion	Direct and Torsional Shear Test	Yes	No	Shear properties of the interface between a primed base and a subsequent layer
Cohesion	Cohesion Device	No	Yes	Shear properties at the surface
Adhesion	Pull-Off Test	Yes	Yes	Bond strength between the prime coat and the underlying base
Strength	Pocket Penetrometer	Yes	Yes	Strength of the prime coat

CURE

The *TxDOT Glossary* defines curing as follows: "Curing is the period of time during which concrete is subjected to favorable temperature and moisture conditions usually varying from three to 28 days for construction work" [*2*]. While the glossary's definition is specific to concrete, curing is used in several pavement-related specifications. The process of curing was not described in the TxDOT specification for flexible base until 1982. The 2014 pavement specification items with descriptions of curing are shown in Table 2.

Table 2. TxDOT Pavement Specifications for Curing.

Item	Name	Type of Cure	With Prime Coat	Other Material Allowed	Time to Cure
247	Flexible Base	Physical			Until moisture content is 2% below optimum.
251	Reworking Base Courses	Physical			Until moisture content is 2% below optimum.
260	Lime Treatment (Road-Mixed)	Chemical	Yes, asphalt material[1]	Item 204, "sprinkling"	2 days when PI ≤ 35 and 5 days when PI > 35 but not > 14 days.
263	Lime Treatment (Plant-Mixed)	Chemical	Yes, asphalt material[1]	Item 204, "sprinkling"	Minimum of 7 days but not > 14 days.
265	Fly Ash or Lime-Fly Ash Treatment (Road-Mixed)	Chemical	Yes, when permitted asphalt material[1]	Item 204, "sprinkling" or subsequent course	With FS, minimum of 7 days but not > 14 days. With CS, minimum of 24 hours. Dry for at least 48 hours before applying a prime coat.
275	Cement Treatment (Road-Mixed)	Chemical	Yes, when permitted asphalt material[1]	Item 204, "sprinkling" [2]	At least 3 days if microcracked plus 2 days after microcracking.
276	Cement Treatment (Plant-Mixed)	Chemical	Yes, when permitted asphalt material	Item 204, "sprinkling" [2]	At least 3 days if microcracked plus 2 days after microcracking.
351	Flexible Pavement Structure Repair	Both	Required after curing[3]		Cure in accordance with base item.
3088	Full-Depth Reclamation Using Foamed Asphalt (Road-Mixed)	Physical			Minimum of 2 hours.
3089	Full-Depth Reclamation Using Asphalt Emulsion (Road-Mixed)	Physical			Until moisture content is 2% below optimum.

1. Asphalt used solely for curing will not be paid for directly but will be subsidiary to this item. Asphalt placed for curing and priming will be paid for under Item 310, Prime Coat.
2. Continue until next course is placed, if prime coat is not used.
3. Protect the compacted, finished, and cured flexible, lime-treated, or cement-treated base (CTB) mixtures with a prime coat. Payment is subsidiary.

PRIME AND CURE

There is no consensus on whether a prime is needed, even within TxDOT. The Virginia Asphalt Association noted that the Virginia Department of Transportation (VDOT) has not required a prime coat since 2007 and that other state DOTs, county and municipal DOTs, state agencies, and engineers, like VDOT, are no longer specifying a prime coat on unbound aggregate base and subbase materials [*5*]. However, many still consider the prime coat to be a vital part of the pavement structure. The research team reviewed state department of transportation (DOT) standard specifications for construction posted on the 50 state DOTs' websites to determine the use of prime and cure for each DOT. The review consisted of investigating information for prime and cure applications, materials, and requirements. The following list provides highlights of the review, and a summary of the findings is shown in Table 3:

- Out of 50 DOTs, five states use prime on flexible base, nine states apply prime on cement-treated base, eight states require lime-treated base with prime, and nine states coat granular base with prime.
- Cutback (medium cure) and emulsified asphalt are the two major materials for prime coat. Among them, emulsified asphalt is used widely by 28 states, possibly due to its short cure time. However, the grade of the type of asphalt materials highly depends on the feature (e.g., texture) of the base and/or the season of the year that work is being performed.
- Prime coat seems to not only promote bonding to the subsequent pavement layers but also act as a curing membrane, especially for cement/lime-treated base.
- Out of 50 DOTs, five states (i.e., Arkansas, Louisiana, Nevada, North Dakota, and South Dakota) require the prime coat to be cured for a particular period before placing the pavement. Another 15 states indicate that the curing time for prime coat is based on the satisfaction of the engineer.
- Some states (13 out of 50) have no prime requirements, especially for thick pavement layers. Studies have shown that if the hot-mixed asphaltic (HMA) concrete is greater than 4 inches (100 mm), prime may not be necessary due to a lower chance of (a) surface water penetrating into the base, and/or (b) pavement slippage on the base.

Table 3. Summary of Prime and Cure Applications from State DOT Standard Specifications.

Application	Number of States	State
Prime on flexible base (FB) or granular base (GB)	12	FB: Texas, Alaska, Idaho GB: Florida, Georgia, Hawaii, Indiana, Iowa, Kansas, Louisiana, Oklahoma, Pennsylvania
Prime on cement-treated base	9	Texas, Arkansas, Arizona, Georgia, Kansas, Maryland, Oklahoma, Tennessee, Virginia
Prime on lime-treated base	8	Texas, Arizona, Colorado, Florida, Georgia, Kansas, Tennessee, Virginia
Cutback asphalt as prime	20	Texas, Arkansas, Alabama, Alaska, Georgia, Illinois, Kansas, Louisiana, Minnesota, Mississippi, Missouri, Nebraska, Nevada, North Dakota, Ohio, Oklahoma, Rhode Island, South Dakota, Utah, Virginia
Emulsified asphalt as prime	28	Texas, Alabama, Alaska, Arizona, Colorado, Florida, Hawaii, Idaho, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Missouri, Nevada, New Jersey, New Mexico, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont, Virginia, Wyoming
Cure time requirement for prime	20	Texas, Arkansas, Alabama, Alaska, Georgia, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Missouri, Nevada, New Mexico, North Carolina, North Dakota, Pennsylvania, South Dakota, Tennessee, Utah
No prime	13	California, Connecticut, Delaware, Maine, Massachusetts, Michigan, Montana, New Hampshire, New York, Oregon, Washington, West Virginia, Wisconsin

A review of other countries' use of prime was also performed. Researchers found that the penetration of the prime into the granular base is considered to be typically 0.25 to 0.5 inch (5 to 10 mm). A minimum 3-day curing period is required for cutback primes, and a minimum 1-day curing period is required for emulsion primes. It is recommended to apply a prime to a prepared granular base followed by a seal due to (a) more economical overall cost, (b) reduced absorption of seal coat binder into the pavement, (c) thicker waterproof layer, and (d) strong bond to the pavement. A prime can also assist with curing of stabilized pavement layers.

LITERATURE REVIEW SUMMARY

Standard Specifications of U.S. State DOTs

Standard specifications for construction posted on the 50 state DOT websites were reviewed to obtain information on prime and cure applications, materials, and requirements. In summary:

- Out of 50 state DOTs, five use prime on flexible base, nine apply prime on cement-treated base, eight require lime-treated base with prime, and nine coat granular base with prime.
- Cutback (medium cure) and emulsified asphalt are the two major materials for prime coat. Among them, emulsified asphalt is used widely by 28 states, possibly due to its short cure time. However, the grade of the type of asphalt materials highly depends on the feature (e.g., texture) of the base and/or the season of the year that work is being performed.
- Prime coat seems to not only promote bonding to the subsequent pavement layers but also act as a curing membrane, especially for cement/lime-treated base.
- Out of 50 state DOTs, five (i.e., Arkansas, Louisiana, Nevada, North Dakota, and South Dakota) require the prime coat to be cured for a particular period before placing the pavement. Another 15 states indicate that the curing time for prime coat is based on the satisfaction of the engineer.
- Some states (13 out of 50) have no prime requirements, especially for thick pavement layers. Studies have shown that if the HMA is greater than 4 inches (100 mm), prime may not be necessary due to a lower chance of (a) surface water penetrating into the base, and/or (b) pavement slippage on the base.

Technologies in Other Countries

The review of other countries' use of prime revealed that:

- The penetration of the prime into granular base is typically 0.25 to 0.5 inch (5 to 10 mm).
- A minimum 3-day curing period is required for cutback primes, and a minimum 1-day curing period is required for emulsion primes.
- It is recommended to apply a prime to a prepared granular base followed by a seal due to (a) more economical overall cost, (b) reduced absorption of seal coat binder into the pavement, (c) thicker waterproof layer, and (d) strong bond to the pavement.
- A prime can also assist with curing of stabilized pavement layers.

CHAPTER 2. TXDOT SURVEY

The researchers prepared and distributed a fact-based survey questionnaire to TxDOT employees to inquire about the state of practice regarding their experience and practices related to prime, curing, and bonding for the:

- General understanding of terminology.
- Design (when to specify on plans, specifications, and estimate [PS&E]).
- Specifications.
- Test methods.
- Materials.
- Construction practices, including:
    - Timing of application of material.
    - Application rates.
    - Timing for opening to traffic.
    - Climate conditions.
    - Quality control and acceptance.
- General perception of performance.

SURVEY

Those responding to the survey provided their names and contact information for follow-up questions as needed. Their responses were recorded anonymously for reporting purposes. Twenty-eight people representing 17 districts responded. The following districts responded to the survey, shown in Figure 2 in solid blue:

- AMA.
- ATL.
- BWD.
- BRY.
- CHS.
- LBB.
- SJT.
- LRD.
- PHR.
- SAT.
- CRP.
- PAR.
- DAL.
- WAC.
- TYL.

- LFK.
- YKM.

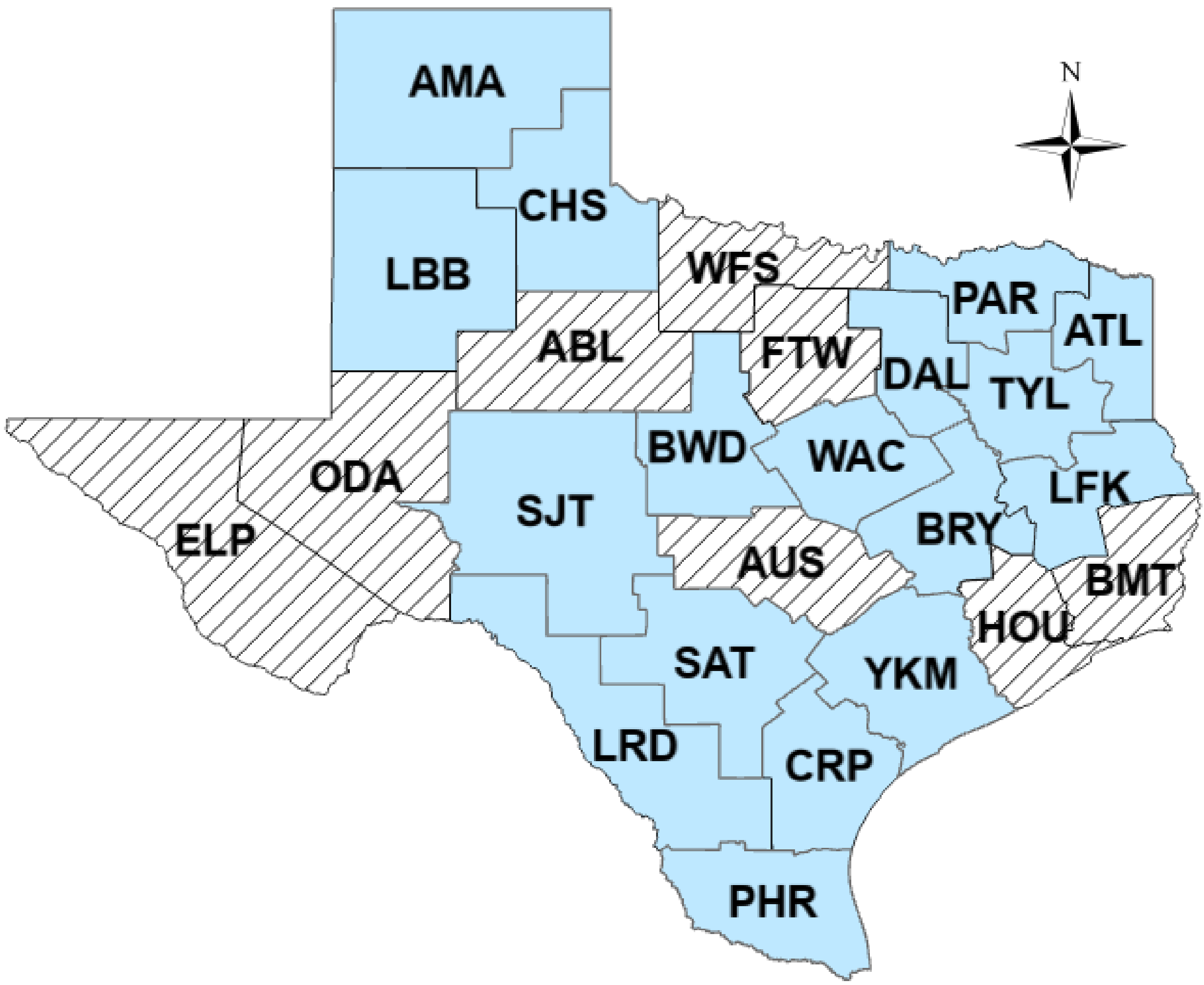

Figure 2. Responding Districts (Shown in Solid Blue).

Following is a presentation of each of the survey questions, along with a brief summary of the responses.

Question 1: Do you consider the description below to apply to a prime, cure or both?

- *Protect the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer.*
- *Reduce the drying rate of the compacted base.*
- *Promote bond of the base to the subsequent asphalt pavement layer.*
- *Seal the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder.*

- *Bind or stabilize the surface particles of the base.*
- *Protect the underlying subgrade from wet weather by providing a temporary waterproofing layer.*
- *Reduce the drying rate of subgrade.*
- *Bind or stabilize the surface particles of subgrade.*

As shown in Table 4, 89 percent indicated that prime is used to promote bond. The main use indicated for a cure is to reduce the drying rate.

Table 4. Question 1—Prime and Cure.

Description	Prime	Cure	Both	Neither	Not Sure
Protect the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer.	59.3%	3.7%	29.6%	7.4%	0.0%
Reduce the drying rate of the compacted base.	28.6%	42.9%	28.6%	0.0%	0.0%
Promote bond of the base to the subsequent asphalt pavement layer.	88.9%	0.0%	11.1%	0.0%	0.0%
Seal the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder.	75.0%	0.0%	14.3%	10.7%	0.0%
Bind or stabilize the surface particles of the base.	67.9%	7.1%	14.3%	7.1%	3.6%
Protect the underlying subgrade from wet weather by providing a temporary waterproofing layer.	33.3%	18.5%	29.6%	14.8%	3.7%
Reduce the drying rate of subgrade.	22.2%	48.2%	14.8%	7.4%	7.4%
Bind or stabilize the surface particles of subgrade.	48.2%	14.8%	11.1%	18.5%	7.4%

Question 2. Do you consider prime and cure to be the same?

Forty-eight percent indicated that prime and cure are not the same, and 52 percent said that maybe/sometimes they are the same. No one indicated that they are always the same.

Question 3. Based on the material below, would you specify a prime, cure or both?

- *Cement-Treated Base.*
- *Lime-Treated Base.*
- *Foam Asphalt–Treated Base.*
- *Emulsion-Treated Base.*
- *Other Treated Base.*

- *Cement-Treated Subgrade.*
- *Lime-Treated Subgrade.*
- *Other Treated Subgrade.*
- *Untreated Subgrade—Clayey.*
- *Untreated Subgrade—Sandy.*
- *Untreated Subgrade—Rocky.*

Respondents noted that prime would be specified more than 50 percent of the time for flexible base and treated bases but not as often on subgrades or treated subgrades. Figure 3 shows the results, which are summarized in Table 5.

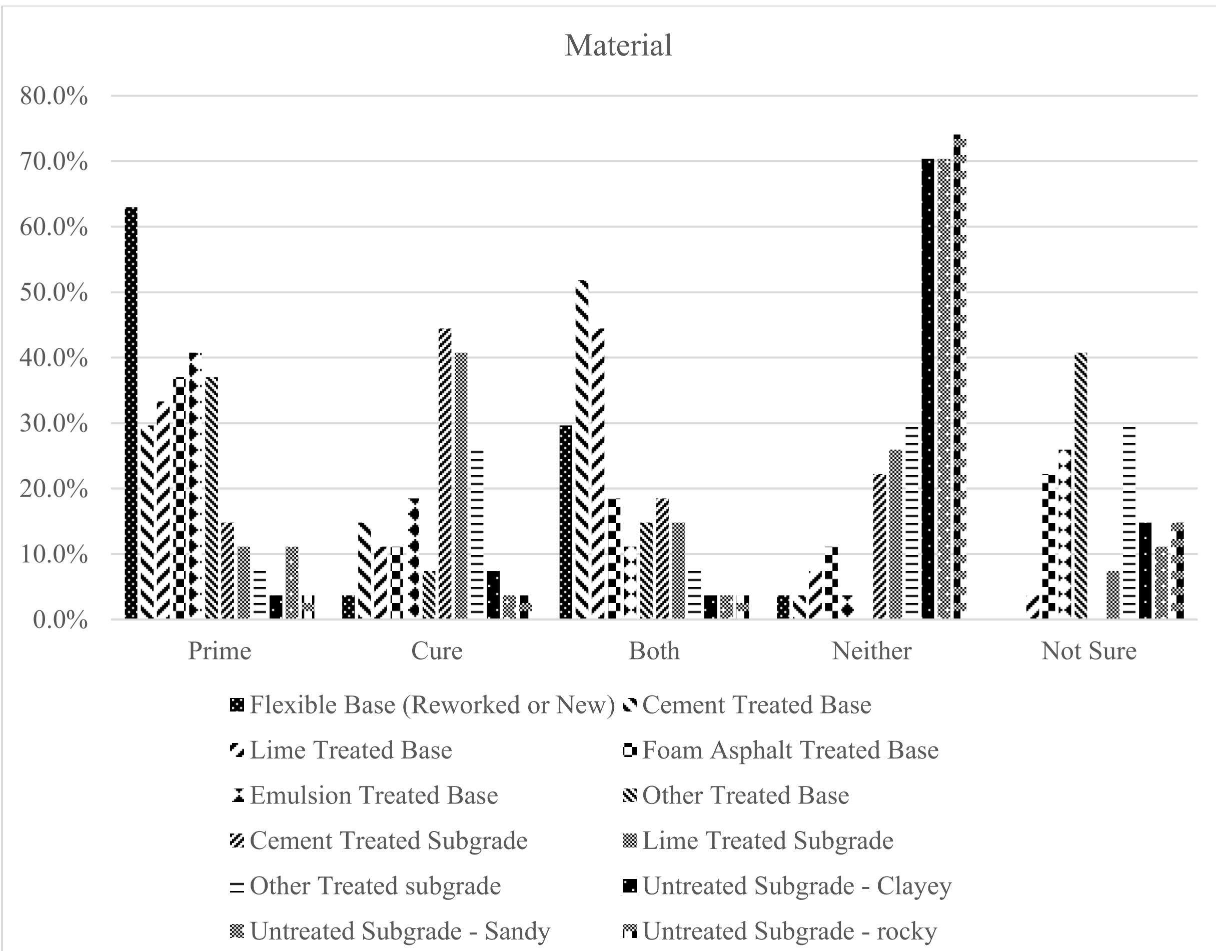

Figure 3. Question 3—Material.

Table 5. Question 3—Material.

Material	Prime	Cure	Both	Neither	Not Sure	Total
Flexible Base (Reworked or New)	63.0%	3.7%	29.6%	3.7%	0.0%	27
Cement-Treated Base	29.6%	14.8%	51.9%	3.7%	0.0%	27
Lime-Treated Base	33.3%	11.1%	44.4%	7.4%	3.7%	27
Foam Asphalt–Treated Base	37.0%	11.1%	18.5%	11.1%	22.2%	27
Emulsion-Treated Base	40.7%	18.5%	11.1%	3.7%	25.9%	27
Other Treated Base	37.0%	7.4%	14.8%	0.0%	40.7%	27
Cement-Treated Subgrade	14.8%	44.4%	18.5%	22.2%	0.0%	27
Lime-Treated Subgrade	11.1%	40.7%	14.8%	25.9%	7.4%	27
Other Treated Subgrade	7.4%	25.9%	7.4%	29.6%	29.6%	27
Untreated Subgrade—Clayey	3.7%	7.4%	3.7%	70.4%	14.8%	27
Untreated Subgrade—Sandy	11.1%	3.7%	3.7%	70.4%	11.1%	27
Untreated Subgrade—Rocky	3.7%	3.7%	3.7%	74.1%	14.8%	27

Question 4. Based on the material, what benefit will a prime provide? Select all that apply.

The materials are the same as question 3 and the benefits to choose from are as follows:

- *Waterproof.*
- *Reduce drying rate.*
- *Promote bond with next pavement layer.*
- *Seal surface to prevent absorption of surface treatment binder.*
- *Bind the surface particles.*
- *None.*

Figure 4 summarizes the responses, which are then given in Table 6. Most indicated that all things listed are benefits for flexible base, cement-treated base, and lime-treated base.

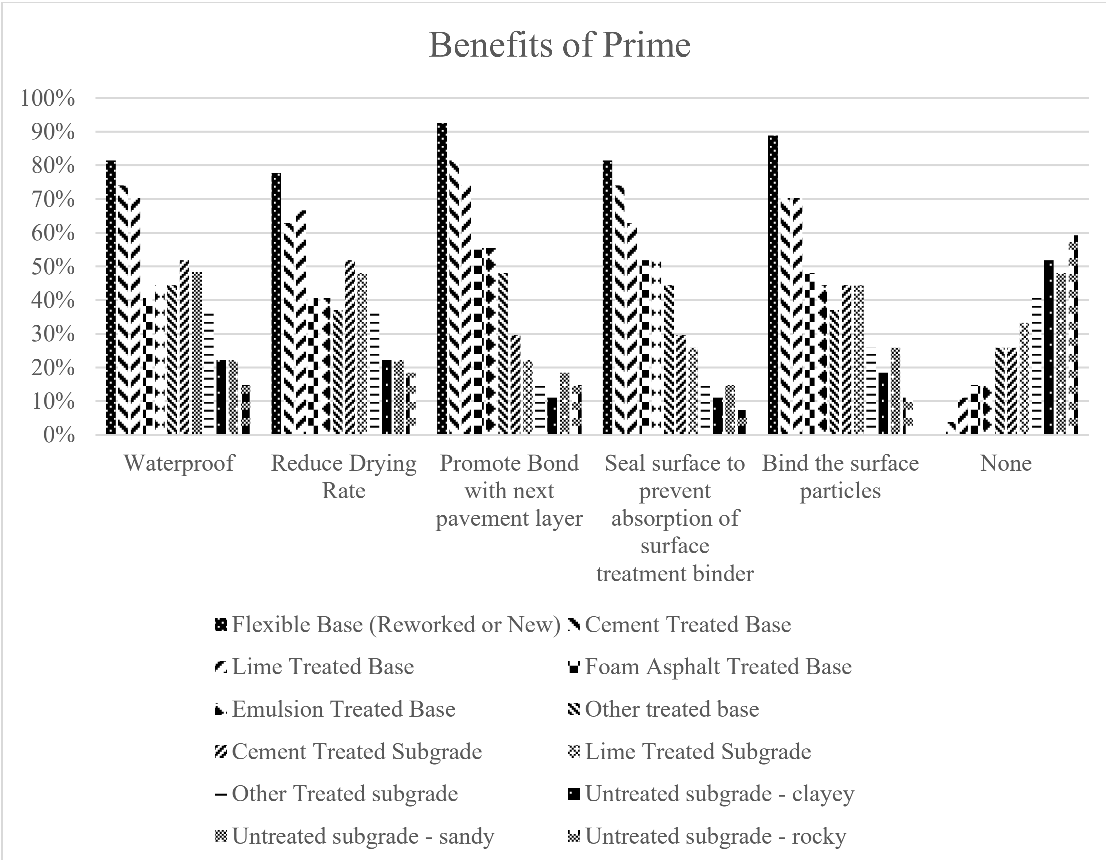

Figure 4. Question 4—Benefits of Prime.

Table 6. Question 4—Benefits of Prime

Material	Waterproof	Reduce drying rate	Promote bond with next pavement layer	Seal surface to prevent absorption of surface treatment binder	Bind the surface particles	None
Flexible Base (Reworked or New)	81.5%	77.8%	92.6%	81.5%	88.9%	0.0%
Cement-Treated Base	74.1%	63.0%	81.5%	74.1%	70.4%	3.7%
Lime-Treated Base	70.4%	66.7%	74.1%	63.0%	70.4%	11.1%
Foam Asphalt–Treated Base	40.7%	40.7%	55.6%	51.9%	48.1%	14.8%
Emulsion-Treated Base	44.4%	40.7%	55.6%	51.9%	44.4%	14.8%
Other Treated Base	44.4%	37.0%	48.1%	44.4%	37.0%	25.9%
Cement-Treated Subgrade	51.9%	51.9%	29.6%	29.6%	44.4%	25.9%
Lime-Treated Subgrade	48.1%	48.1%	22.2%	25.9%	44.4%	33.3%
Other Treated Subgrade	37.0%	37.0%	14.8%	14.8%	25.9%	40.7%
Untreated Subgrade—Clayey	22.2%	22.2%	11.1%	11.1%	18.5%	51.9%
Untreated Subgrade—Sandy	22.2%	22.2%	18.5%	14.8%	25.9%	48.1%
Untreated Subgrade—Rocky	14.8%	18.5%	14.8%	7.4%	11.1%	59.3%

Question 5. Is there another benefit of using a prime, besides those listed in the previous question? If so, please describe.

Table 7 provides the responses. The main other benefit described was dust control.

Table 7. Question 5—Other Benefits of Prime.

Response Number	Responses
1.	Dust control.
2.	Primary use of Prime would be to bond the layers. Waterproofing and reducing dry time are just added benefits.
3.	Dust control—loss of fines. Allow for construction traffic sooner.
4.	Keeps the dust down.
5.	We don't typically use asphalt overlays on cement treated base as the base layer tends to act more like a rigid pavement and causes the overlay to break apart. Not sure why you would ever lime treat base. We typically don't apply prime coats to subgrade whether treated or not. Secondary benefit from prime coat is by slowing the moisture loss in the material it helps with dust control.
6.	Moist cure the layer by sprinkling in accordance with ITEM 204, "Sprinkling" until primed or the next successive course is placed. The Engineer will measure the moisture content in the upper two inches of the layer using Tex-115E Part I, Nuclear Gauge Method. When the moisture content at any location within a land is more than 2 percent points below optimum the Contractor will prime or cover with the next successive course within three days unless approved otherwise. — Our general note that goes with most flexible base and cement treatment. We primarily use cement treated subgrade and base. We lime treat in order to adjust PI where it may be needed. I admit this doesn't give a set in stone timeframe as the way of days. This is for curing but is set back by priming in the note.
7.	Only two benefits to my knowledge is waterproofing and better bonding.

Question 6. When a pavement layer cures, it either goes through a physical action (such as evaporation) or a chemical reaction that results in a harder, tougher, or more stable linkage (such as an adhesive bond) or substance (such as concrete). What type of curing process do you consider to be occurring for the material listed below? Would you use a prime such as AE-P, MC-30, etc.? Would you use another curing aid besides a prime, such as moisture, if so please describe?

- *Flexible Base (Reworked or New).*
- *Cement-Treated Base.*
- *Lime-Treated Base.*
- *Foam Asphalt–Treated Base.*
- *Emulsion-Treated Base.*
- *Other Treated Base.*
- *Cement-Treated Subgrade.*
- *Lime-Treated Subgrade.*
- *Other Treated Subgrade.*
- *Untreated Subgrade—Clayey.*
- *Untreated Subgrade—Sandy.*
- *Untreated Subgrade—Rocky.*

Table 8 and Table 9 present the responses. Flexible base, lime-treated base, and cement-treated base were indicated as requiring a prime by more than 67 percent of those responding.

Table 8. Question 6—Base.

Material	Physical Action	Chemical Reaction	No Cure	Prime Required	Prime Optional	Prime Not Needed	Other Curing
Flexible Base (Reworked or New)	100%	30%	20%	84%	12%	4%	• Moisture. • Sunshine to remove the excess moisture. • Cure equals dry back. • Moisture. • Keep near optimal moisture until primed. No specified cure time.
Cement-Treated Base	90%	100%	8%	67%	29%	4%	• Moisture until prime can be placed. • Sunshine to remove the excess moisture. • Sprinkle if not priming quickly. 72 hour cure.
Lime-Treated Base	89%	100%	12%	70%	26%	4%	• No experience. • Sunshine to remove the excess moisture. • Mellowing. • Sprinkle. No defined curing period.
Foam Asphalt–Treated Base	84%	89%	20%	37%	47%	16%	
Emulsion-Treated Base	89%	69%	24%	40%	40%	20%	
Other Treated Base	86%	83%	12%	41%	47%	12%	• We do not have any other treated bases. • Sprinkle. No defined curing period.

Table 9. Question 6—Subgrade.

Material	Physical Action	Chemical Reaction	No Cure	Prime Required	Prime Optional	Prime Not Needed	Other Curing
Cement-Treated Subgrade	89%	100%	8%	32%	23%	45%	• Sunshine to remove the excess moisture. • Water. • We only put flexbase on top of our Subgrade. • Moisture.
Lime-Treated Subgrade	89%	100%	12%	29%	24%	48%	• Sunshine to remove the excess moisture. • Water. • Mellowing. • We only put flexbase on top of our Subgrade. • Moisture.
Other Treated Subgrade	87%	79%	12%	18%	24%	59%	• Water. • We do not have any other treated bases. • Moisture.
Untreated Subgrade —Clayey	82%	21%	36%	10%	25%	65%	• Moisture. • Sunshine to remove the excess moisture. • Water. • We treat all our clayey soils. • Moisture.
Untreated Subgrade —Sandy	76%	21%	40%	10%	20%	70%	• Sunshine to remove the excess moisture. • Water. • We only put flexbase on top of our Subgrade. • Moisture.
Untreated Subgrade —Rocky	80%	15%	40%	10%	10%	80%	• Sunshine to remove the excess moisture. • Water. • We do not have rocky soils. • Moisture.

Question 7. Assuming a prime is used, what is the maximum time after compaction that the prime should be placed? Use 0 if it is required by the end of the same day compaction is completed.

Table 10 presents the results. Four days on average is the timing to place a prime.

Table 10. Question 7—Timing of Prime Application.

Material	Minimum	Maximum	Mean
Flexible Base (Reworked or New)	0.9	7	3.44
Cement-Treated Base	0	7	3.78
Lime-Treated Base	1	7	4.24
Foam Asphalt–Treated Base	0	7	4.13
Emulsion-Treated Base	0	7	4.13
Other Treated Base	1	7	3.98
Cement-Treated Subgrade	1	7	4.19
Lime-Treated Subgrade	1	7	4.7
Other Treated Subgrade	1	7	4.16
Untreated Subgrade—Clayey	1	7	4.14
Untreated Subgrade—Sandy	1	7	4.14
Untreated Subgrade—Rocky	1	7	4.38

Question 8. How long after compaction does the material need to cure before the next pavement layer is placed?

A prime may or may not be used; however, for this question, prime was not considered the next pavement layer. Table 11 shows the results. The average cure time for all materials is 3 days.

Table 11. Question 8—Cure Time.

Material	Minimum	Maximum	Mean
Flexible Base (Reworked or New)	0	10	2.85
Cement-Treated Base	0	10	3.2
Lime-Treated Base	0	10	4.3
Foam Asphalt–Treated Base	0	5	2.1
Emulsion-Treated Base	0	7	2.79
Other Treated Base	0	7	3.71
Cement-Treated Subgrade	0	10	3.05
Lime-Treated Subgrade	0	10	4.53
Other Treated Subgrade	0	7	3.54
Untreated Subgrade—Clayey	0	10	2.08
Untreated Subgrade—Sandy	0	5	2.17
Untreated Subgrade—Rocky	0	4	1.56

Question 9. Assuming the material is curing, can it continue to cure with the next pavement layer placed the same day, regardless of whether or not a prime was placed?

The summary of results is presented in Table 12. There was a fairly even distribution of whether or not curing continued, which indicates this may be an area that needs further investigation.

Table 12. Question 9—Curing.

Material	Yes	Maybe	No
Flexible Base (Reworked or New)	30.8%	30.8%	38.5%
Cement-Treated Base	38.5%	26.9%	34.6%
Lime-Treated Base	30.8%	26.9%	42.3%
Foam Asphalt–Treated Base	36.0%	48.0%	16.0%
Emulsion-Treated Base	36.0%	44.0%	20.0%
Other Treated Base	16.0%	76.0%	8.0%
Cement-Treated Subgrade	38.5%	34.6%	26.9%
Lime-Treated Subgrade	34.6%	30.8%	34.6%
Other Treated Subgrade	16.0%	72.0%	12.0%
Untreated Subgrade—Clayey	26.9%	38.5%	34.6%
Untreated Subgrade—Sandy	30.8%	38.5%	30.8%
Untreated Subgrade—Rocky	34.6%	30.8%	34.6%

Question 10. What test or criteria is performed on the material to ensure that curing is complete? If there is another curing measure besides moisture content or a timeframe, please describe that in the last row.

Figure 5 displays the results, which are summarized in Table 13. Both moisture content and timeframe are used as measures; however, some do not have any requirements.

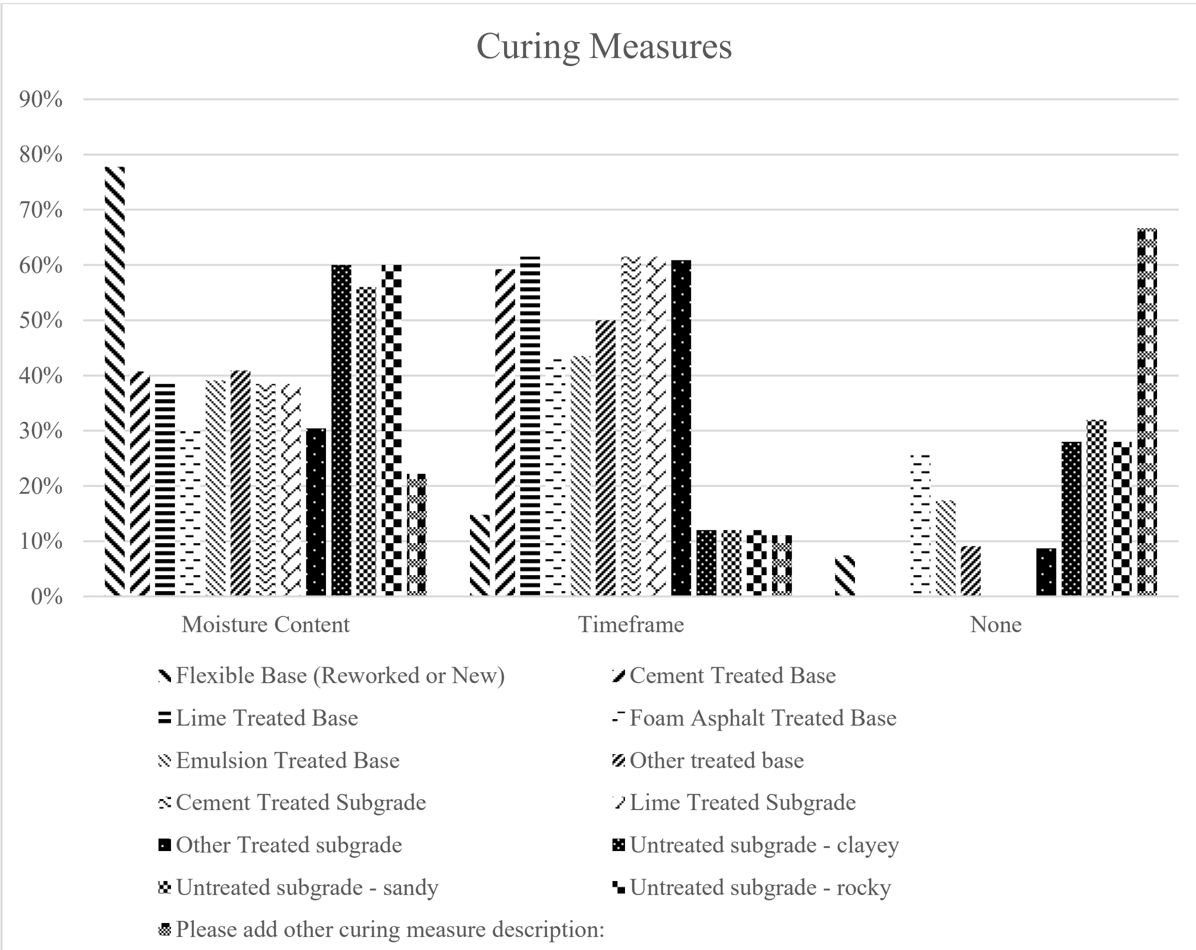

Figure 5. Question 10—Curing Requirements.

Table 13. Question 10—Curing Requirements.

Material	Moisture Content	Timeframe	None
Flexible Base (Reworked or New)	78%	15%	7%
Cement-Treated Base	41%	59%	0%
Lime-Treated Base	38%	62%	0%
Foam Asphalt–Treated Base	30%	43%	26%
Emulsion-Treated Base	39%	43%	17%
Other Treated Base	41%	50%	9%
Cement-Treated Subgrade	38%	62%	0%
Lime-Treated Subgrade	38%	62%	0%
Other Treated Subgrade	30%	61%	9%
Untreated Subgrade—Clayey	60%	12%	28%
Untreated Subgrade—Sandy	56%	12%	32%
Untreated Subgrade—Rocky	60%	12%	28%
Please add other curing measure description:	22%	11%	67%

Question 11. Assuming a prime is used, what material is typically used in your area?

Results are shown in Figure 6 and given in Table 14. AE-P, MC-30, and RC-250 with Grade 5 are the most commonly used primes. EAP&T, PCE, and other materials are not used.

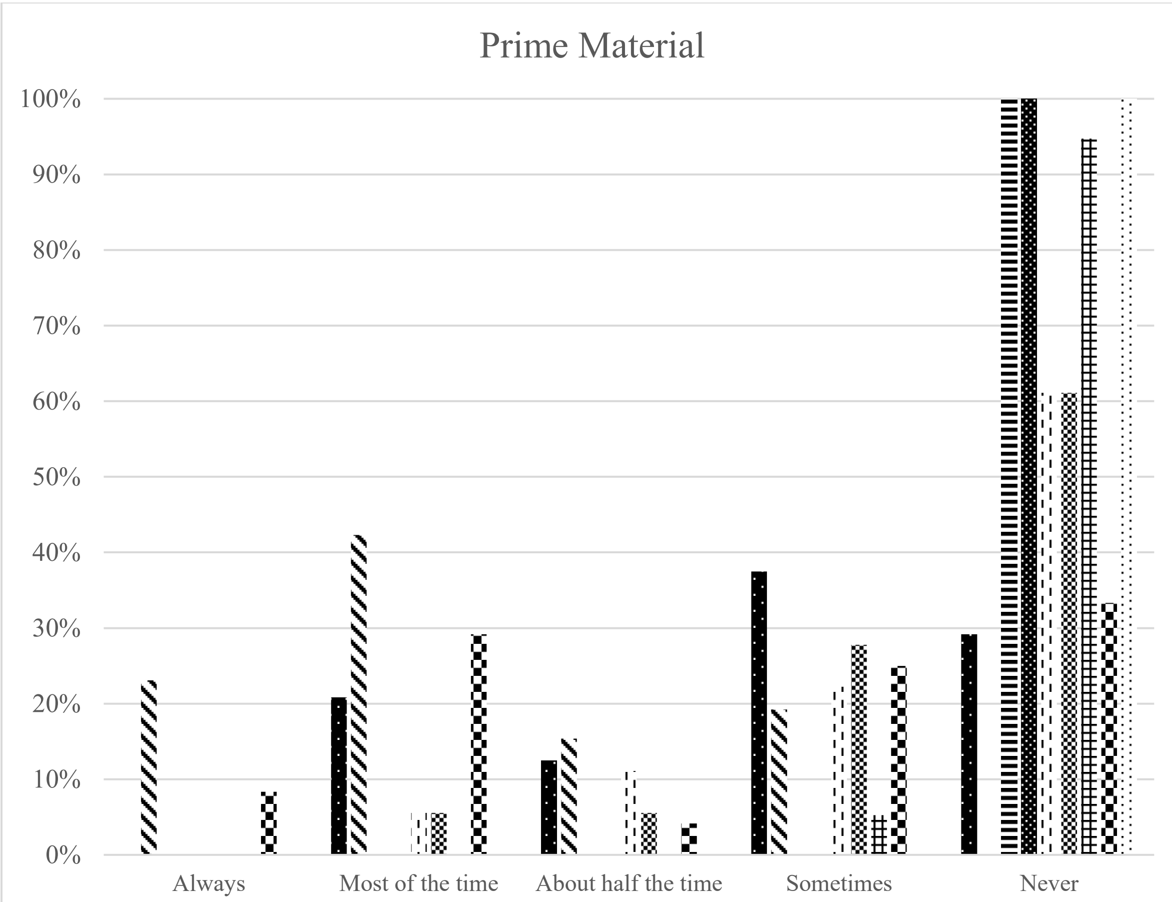

Figure 6. Question 11—Prime Material.

Table 14. Question 11—Prime Material.

Product	Always	Most of the time	About half the time	Sometimes	Never
AE-P	0%	21%	13%	38%	29%
MC 30	23%	42%	15%	19%	0%
EAP&T	0%	0%	0%	0%	100%
PCE	0%	0%	0%	0%	100%
Emulsion—Sprayed (please add emulsion name)	0%	6%	11%	22%	61%
Emulsion—Blended into Surface (please add emulsion name)	0%	6%	6%	28%	61%
EC 30	0%	0%	0%	5%	95%
RC-250 with Grade 5 (paid as seal coat)	8%	29%	4%	25%	33%
Other, please describe	0%	0%	0%	0%	100%

Question 12. Assuming a prime is used, how long does the prime need to cure before the next pavement layer is placed? If you are not familiar with the material listed, select "Not Applicable." For this question, only consider the prime material and not the layer it is covering for cure time.

Table 15 presents the results, with the time shown in days. CSS-1H is the most common emulsion used as prime. Cure times range from 0 to 21 days, with an average of 3½ days.

Table 15. Question 12—Prime Cure Time.

Prime	Minimum	Maximum	Mean
AE-P	0.3	7	2.98
MC-30	0	21	4.83
EAP&T	3	3	3
PCE	2.9	3	2.97
Emulsion—Sprayed CSS-1H, Trackless Tack	0	10	3
Emulsion—Blended into Surface CSS-1H, SS1	0	10	3.33
EC-30	0.1	3.1	1.8
RC-250 with Grade 5 (paid as seal coat)	0.5	21	7.42
Other (was not described)	3	3	3

Question 13. Assuming a prime is cured, how long can the prime remain uncovered and still perform.

Table 16 lists the results. Most material should perform in the 4- to 7-day timeframe; however, emulsion and EC-30 should be covered before it rains. Seventy-one percent indicated that RC-250 with Grade 5 can perform more than 7 days.

Table 16. Question 13—Prime Uncovered.

Prime	1 Day	1–3 Days	4–7 Days	>7 Days	Must Cover before Rain
AE-P	0%	10%	35%	45%	10%
MC-30	0%	8%	42%	46%	4%
EAP&T	0%	0%	67%	11%	22%
PCE	0%	11%	56%	11%	22%
Emulsion—Sprayed	11%	0%	44%	11%	33%
Emulsion—Blended	10%	0%	20%	20%	50%
EC-30	0%	0%	56%	0%	44%
RC-250 with Grade 5	0%	6%	6%	71%	18%

SUMMARY OF SURVEY

Twenty-eight people representing 17 districts responded to the survey. The main use indicated for a cure is to reduce the drying rate. The majority of those responding indicated that prime is used for the following (percent responding is shown in parentheses):

- Protect the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer. (59.3 percent)
- Promote bond of the base to the subsequent asphalt pavement layer. (88.9 percent)
- Seal the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder. (75.0 percent)
- Bind or stabilize the surface particles of the base. (67.9 percent)
- Dust control. (respondents added this item in Question 5)

No one considered prime and cure to be the same; however, just over 50 percent indicated that sometimes they serve the same purpose. Respondents noted that prime would be specified more than 50 percent of the time for flexible and treated bases but not as often on subgrades or treated subgrades. Curing would be specified for cement- and lime-treated bases.

Four days on average is the timing to place a prime, with a range of the same day to 7 days. The average cure time for all materials is 3 days, ranging from 0 to 10 days. Both moisture content and timeframe are used as measures of curing; however, some agencies do not have any requirements to verify that curing is complete.

AE-P, MC-30, and RC-250 with Grade 5 are the most commonly used primes. CSS-1H is the most common emulsion used as prime. Cure times range from 0 to 21 days, with an average of 3½ days. Most prime material should perform in the 4- to 7-day timeframe before covering; however, emulsion and EC-30 should be covered before it rains. Seventy-one percent indicated that RC-250 with Grade 5 can perform more than 7 days.

CHAPTER 3. LABORATORY EXPERIMENTS

The research team developed a testing plan for both the laboratory experiments and field observations that best addressed the research goals. The research team revised the testing plan based on findings from the literature review and input from TxDOT. Since a testing protocol for bonding between hot-mix layers has been established, the research team performed a limited evaluation to further validate the testing thresholds. The research team established testing to determine the most viable tests to evaluate material properties based on the following performance factors for prime and cure:

- Prime:
  - Protect the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer.
  - Reduce the drying rate of the compacted base.
  - Promote bond of the base to the subsequent asphalt pavement layer.
  - Seal the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder.
  - Bind or stabilize the surface particles of the base.
- Cure:
  - Physical action (such as control evaporation in flexible base).
  - Chemical reaction that results in a harder, tougher, or more stable linkage (such as an adhesive bond) or substance (such as stabilized base).

The research team performed a laboratory study to help identify and develop test methods and procedures used for the field testing sites and potentially for product evaluation. A testing plan was developed to provide reliable data over the range of test variables deemed sufficient to arrive at general, relevant, and useful conclusions from the data analysis. Additionally, the research team developed a correlation to define the criteria thresholds for the test results to apply to applicability of material and application rates. To assess the desired properties of prime, researchers applied test methods in the laboratory and field. Table 17 summarizes different prime coat tests along with their functionalities.

Table 17. Summary of Test Methods for Prime Coats.

Category	Test	Lab	Field	Functionality
Penetration	Prime Penetration Test	Yes	Yes	Application rate and penetration time
Penetration	Ring Test	Yes	Yes	Application rate
Cohesion	Direct and Torsional Shear Test	Yes	No	Shear properties of the interface between a primed base and a subsequent layer
Cohesion	Cohesion Device	No	Yes	Shear properties at the surface
Adhesion	Pull-Off Test	Yes	Yes	Bond strength between the prime coat and the underlying base
Strength	Pocket Penetrometer	Yes	Yes	Strength of the prime coat

LABORATORY TESTING

Table 18 presents the laboratory test matrix. All laboratory tests were conducted at the Texas A&M Transportation Institute facility in accordance with the laboratory test plan. The plan was established to predict the allowable timeframe for applying the material and the optimal application rates. It was based on the following:

- Time of application.
- Substrate moisture.
- Application rate.

The prime was placed at three rates: manufacturer's rate (MR), lower limit (LL), and upper limit (UL). The prime materials used in the lab testing were MC-30, AE-P, CSS-1H, RC-250 with Grade 5, and EBL. The substate at which the prime was placed was as follows:

1. Flexible base at 2 percent below optimum moisture content (FB@BO).
2. Flexible base at optimum moisture content (±0.5 percent) (FB@O).
3. CTB at optimum moisture content ±0.5 percent.

Table 18. Testing of Prime/Cure with Flexible and Cement-Treated Base Substrate.

Phase	Test Description	Method	Rate	Substrate Moisture	Overlay Type	Conditions	Estimated Quantity
1	Particle Size Analysis	Tex-110-E	n/a	n/a	n/a	n/a	400 lb for all tests in Phase 1
1	Plasticity Index	Tex-104-106-E	n/a	n/a	n/a	n/a	400 lb for all tests in Phase 1
1	Max. Density & Optimum Moisture Content	Tex-113-E	n/a	n/a	n/a	n/a	400 lb for all tests in Phase 1
2	Determine Recommended Prime/Cure Rate	Input from supplier(s) or subject matter experts	n/a	n/a	n/a	n/a	Varies
3A	Moisture Loss/Drying Rate	Tex-103-E	MR, LL, UL	1, 2, & 3	n/a	68°F (20°C) @ 50% RH 39.2°F (4°C) @ 50% RH 104°F (40°C) @ ~30% RH	900 lb (assumes 36 specimens per prime/cure treatment for a total of 180 (6×2) specimens)
3B	Permeability	Mod. Tex-246-F	MR, LL, UL	1, 2, & 3	n/a	68–77°F (20–25°C)	Use FB substrates from 3A
3C	Penetration Depth of Prime	Image analysis	MR, LL, UL	1, 2, & 3	n/a	68–77°F	Use CTB substrates from 3A and FB substrates from 3B
4	Bond Strength	Modified Surface Treatment Bond Test, Product 0-6271-P3	MR, LL, UL	1, 2, & 3	SP-D HMA	(20–25°C)	Use CTB substrates from 3A before performing 3C 1600 lb (6 slabs per prime/cure treatment for a total of 30 slabs)
5	Durability/Raveling	Modified three-wheel polisher Macro and micro texture (ARTS/laser texture scanner)	MR, LL, UL	1, 2, & 3	n/a	68–77°F	1600 lb (6 slabs per prime/cure treatment for a total of 30 slabs)

Note: n/a = not applicable.

Phase 1

Three major tests were involved in this phase:

- Particle size analysis (Tex-110-E).
- Plasticity index (Tex-104-106-E).
- Density and optimum moisture content (Tex-113-E).

Prior to testing, all materials were oven-dried and sampled to meet the requirements as described in each test. The particle size analysis quantitatively determines the distribution of particle sizes in materials to better understand the materials' contributions on the mechanical properties and response of unbound aggregates. Plasticity index (PI) indicates the range of the moisture content at which the materials remain plastic. The relationship between the water content and the dry unit mass (density) of base materials was established by following Tex-113-E. Specimens were prepared at different moisture contents and compacted in a 6-inch × 8-inch mold in four equal layers. The resulting weights of materials per unit volume at different moisture contents were plotted to establish the maximum dry density and optimum moisture content values.

Phase 2

The objective of this phase was to determine recommended prime/cure rate using input from suppliers or subject matter experts. For example, one of the findings from the literature review was that one producer determines rates of fog seal by using a ring test, which has the potential to be a test for rate determination of prime coat.

Phase 3

This phase was divided into three sub-phases (3A, 3B, and 3C). Moisture loss/drying rate (3A) and permeability (3B) of base materials before and after prime/cure treatments were determined using Tex-103-E and the modified ring test, respectively. Penetration depth of prime (3C) was determined by image analysis after completion of testing in 3B.

Phase 4

In this phase, bond strength after prime/cure treatments was determined by modifying the surface treatment bond test originally established in TxDOT 0-6271-P3. Three prime/cure treatment rates (i.e., below recommended, recommended, and above recommended rate by manufacturer) were applied on the base materials with varying moisture contents (i.e., 2 percent below optimum and ±0.5 percent optimum content) under normal lab conditions. This also helped establish the upper and lower limits (thresholds) of the rates. Around 1600 lb of base (six 16-inch × 20-inch × 2-inch) was used to fabricate slabs. A total of 30 slabs were used to complete the tests.

Phase 5

Durability/raveling after prime/cure treatments was determined by a modified three-wheel polisher and micro/macro texture scanners. Three prime/cure treatment rates were applied on the base materials with varying moisture contents (i.e., 2 percent below optimum and ±0.5 percent optimum content) under normal lab conditions. Around 1600 lb of base material (six 16-inch × 20-inch × 2-inch slabs per prime/cure treatment, for a total of 30 slabs) was used to complete the tests.

SELECTION OF MATERIALS

Base Materials

Two base materials were collected: FB 642 and FB 607. Materials from the Austin District (Texas Materials stockpiles 642 and 607) were selected for the use of FB materials and material to be stabilized, respectively, and were tested with full factorial experimental design (Table 18). For each source, the required amounts of materials (determined based on the full factorial experimental design) were collected. Table 19 presents available information provided by the producers on the collected materials, while Table 20 shows the sieve analysis.

Table 19. Properties of Materials.

Testing Description	Austin District (Stockpile 642)	Austin District (Stockpile 607)
Maximum Dry Unit Weight, pcf	148.4	150.9
Optimum Moisture, %	5.5	5.5
Liquid Limit	23	n/a
Plastic Limit	18	n/a
Plasticity Index	5	2

Table 20. Sieve Analysis Percentage Passing.

Sieve Size	Austin District (Stockpile 642)	Austin District (Stockpile 607)
1¾ inch	0	0
⅞ inch	17	25
⅜ inch	39	50
#4	55	63
#40	80	86

Prime/Cure Materials

Based on the literature review and the survey conducted with TxDOT, five materials were selected to cover commonly used prime/cure materials in Texas, as shown in Table 21.

Table 21. Prime Products Used during Laboratory Testing.

Type of Emulsion	Abbreviation
Medium-Curing Cutback Asphalt	MC-30
Anionic Asphalt Emulsion	AE-P
Cationic Slow-Setting Asphalt Emulsion	CSS-1H
Rapid Curing Cutback Asphalt	RC-250
Cationic Modified Asphalt Emulsion (Polymerized)	EBL

Each material was applied on three substrate types (i.e., new HMA, FB, and CTB) at different rates and timeframes for different tests in Phases 3 to 5.

PHASE 1—TESTING MATERIALS FOR SAMPLE FABRICATION

Particle Size Analysis (Tex-110-E)

It has been proven that gradation, or particle size distribution, significantly influences the mechanical properties and response of unbound aggregates. A densely packed configuration enhances shearing resistance and reduces the compressibility of unbound soil aggregates. Therefore, more than 550 lb of each sample was oven-dried and analyzed according to the procedures described in Tex-110-E for sieve analyses. Table 22 presents the particle size distribution of the samples received, along with the distribution curves (Figure 7) for all the aggregate materials.

Table 22. Sieve Analysis (Tex-110-E).

Sieve Sizes	Austin District (Stockpile 642) Individual % Retained	Austin District (Stockpile 607) Individual % Retained
1¾ inch	0	0
1¼ inch	2.5	3.6
⅞ inch	10	14.5
⅝ inch	9.8	14.5
⅜ inch	13.6	16.9
#4	14.3	15.8
#40	34.8	23.4
< #40	14.9	11.4

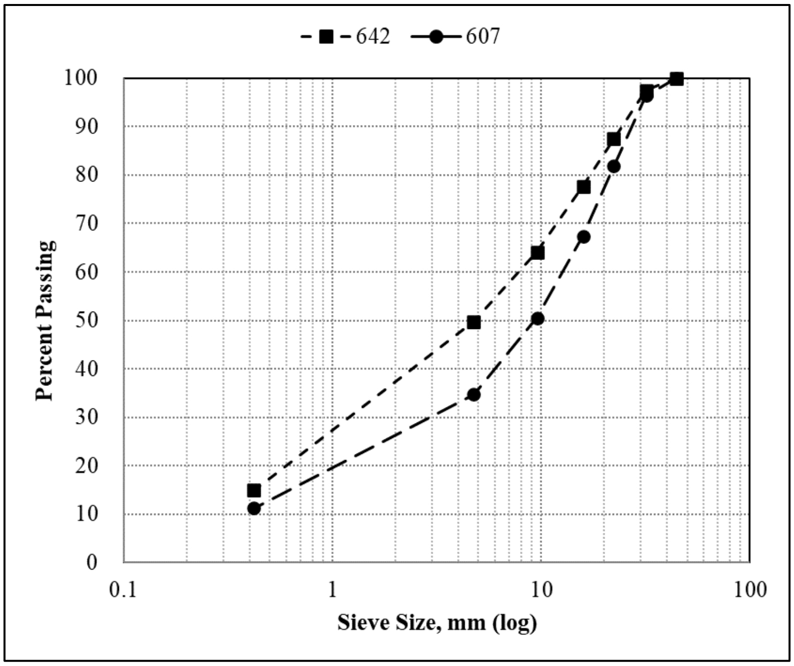

Figure 7. Aggregate Gradation Curve.

Plasticity Index (Tex-104-106-E)

Atterberg limit tests (liquid limit, plastic limit, and plasticity index) following Tex-104-106-E were conducted on the material fraction finer than 0.425 mm (passing No. 40 sieve). Results from the Atterberg limit tests are presented in Table 23. In general, a high value of plasticity index represents soil that remains plastic due to a large amount of clay content. It is commonly accepted that PI values less than or equal to 6 can be used as pavement unbound aggregate base courses, though non-plastic fines are preferred. TxDOT's Item 247, Flexible Base, maximum PI is 10 for Grade 1–2 and Grade 5 bases. Older foundation base courses found in existing pavements can have higher PIs, such as 12 or 14.

Table 23. Index Properties of Materials.

Description	Austin District (Stockpile 642)	Austin District (Stockpile 607)
Liquid Limit, %	23	19
Plastic Limit, %	9	8
Plasticity Index, %	14	11

Maximum Density and Optimum Moisture Content (Tex-113-E)

In this test, aggregate specimens were prepared at different moisture contents and compacted in a 6-inch × 8-inch mold in four equal layers with a 10-lb rammer and 18-inch drop height. Four tests were performed and used to draw a curve to establish the maximum dry density and optimum moisture content values. Table 24 summarizes the maximum dry density and optimum moisture content values of the tested aggregate materials. In general, a high maximum dry density indicates denser packing.

Table 24. Moisture-Density Relationship.

Description	Austin District (Stockpile 642)	Austin District (Stockpile 607)
Maximum Dry Density, pcf	150.1	150.4
Optimum Moisture Content, %	5.4	5.9

PHASE 2—APPLICATION RATES

The objective of this phase was to determine recommended prime/cure rate using input from suppliers or subject matter experts. The following methods were investigated:

- Tex-246-F, Permeability or Water Flow of Hot Mix Asphalt.
- Ring Test, Determination of Rates of Fog Seal.

Based on preliminary results, the ring test is the most promising; however, it will need to be modified to remove subjectivity. Cody Chambliss with Ergon Asphalt Inc. provided a test set with instructions to the research team. Following is a description of the ring test:

1. Equipment (see Figure 8):
    a. One 6-inch diameter template.
    b. One binder, for example, PASS QB (diluted at 1:1) 6 oz (175 ml/cc).
    c. One marker.
    d. One at least 0.5-oz (12-ml/cc) pipette.
    e. Two applicator brushes.

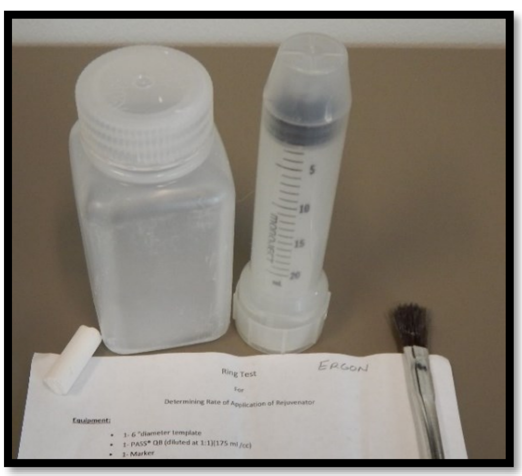

Figure 8. Ring Test Equipment.

2. Procedure:
    a. Using the 6-inch template and marker, draw out three test plots and mark each with a prescribed rate of application in gallons per square yard (gal/sy).
    b. From Table 25, determine the quantity of prime (ml/cc) for appropriate application rate in gal/sy, corresponding to ml/cc for the target application rate in gal/sy.

Table 25. Ring Test Conversion Table.

Rate (gal/sy)	Quantity per Sample Plot (ml)	Quantity per Sample Plot (oz)	Pipette Quantity[1] (ml/cc)	Pipette Quantity[1] (oz)
0.07	5.8	0.196	6.1	0.206
0.08	6.6	0.223	6.9	0.233
0.09	7.4	0.250	7.8	0.264
0.1	8.3	0.281	8.7	0.294
0.11	9.1	0.308	9.5	0.321
0.12	9.9	0.335	10.4	0.352
0.14	11.6	0.392	12.1	0.409

    c. Account for material retained on brush and in pipette 5 percent:
        i. Using the pipette, withdraw the number of ml/cc of liquid from the 6-oz (175-ml) container.
        ii. Distribute material using the pipette for each test plot initially with the corresponding amount of material (clean pipette after use).
        iii. Finish application by using the applicator brush to evenly distribute over the test plot area.
3. Test Report:
    a. Note the following on the test report:
        i. Location.
        ii. Weather: temperature, wind, and humidity.
        iii. Pavement: type, age, and condition.
        iv. Recommendation: include brief description along with pictures.

Figure 9 shows an example of the ring test from an American Association of State Highway and Transportation Officials (AASHTO) Transportation System Preservation Technical Services Program (TSP2) presentation [*6*]. This test is subjective since it is based on the visual observation of a "good" rate.

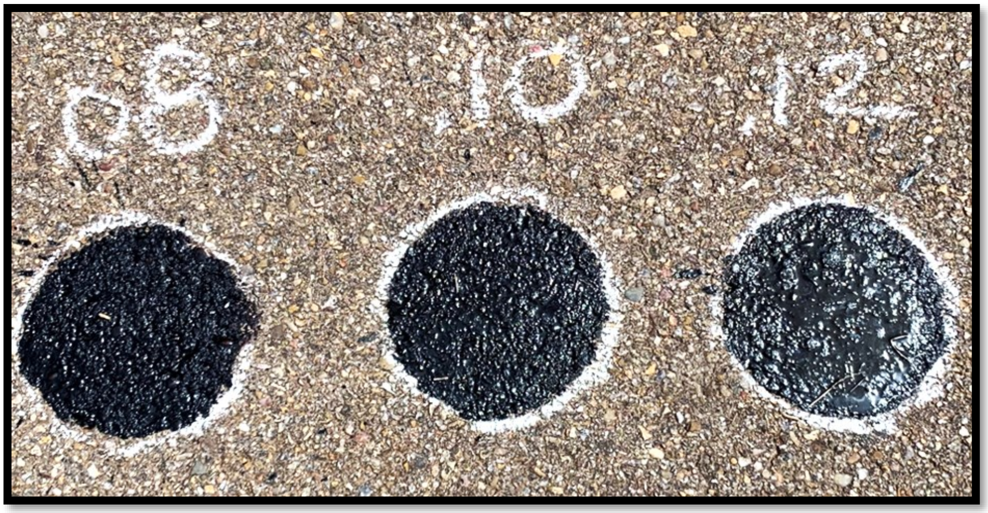

Figure 9. Ring Test Example [*6*].

One of the issues with measuring the rate is that when applying the rate, changes are very small (< 1⁄64 inch), such that they cannot be detected through the normal site glass on the permeability test devices. The research team experimented with water flow over a 6-inch diameter sample. Figure 10 is an example of the apparatus setup. The apparatus consists of a funnel and plumber's putty. The funnel is a 3-inch (75-mm) diameter PYREX® funnel that has a short, wide stem with a 0.67-inch (17-mm) outer diameter opening. Actual measurements of the funnel are shown in Table 26.

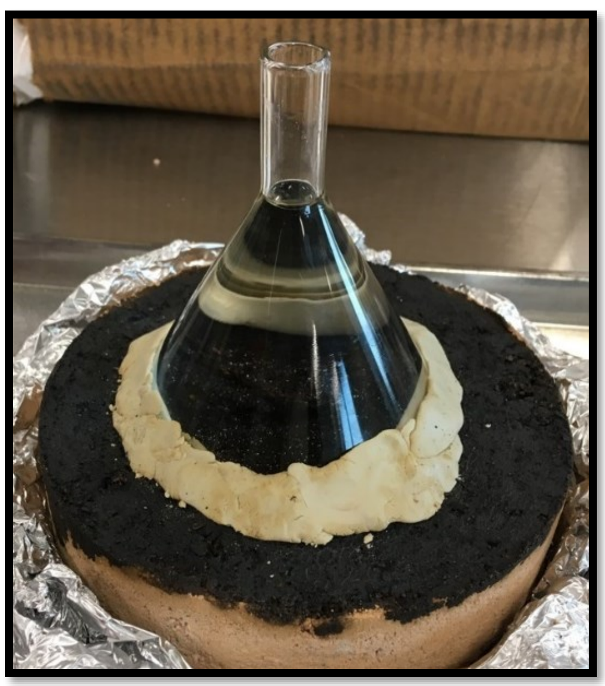

Figure 10. Modified Ring Test with Plumber's Putty.

Table 26. Funnel Dimensions.

Description	Manufacturer (in.)	Measured (in.)
Height	3.6614 (93 mm)	5.5850
Stem Inside Diameter	0.6693 (17 mm)	0.6466
Top Inside Diameter	2.9528 (75 mm)	3.1636

The proposed procedure is as follows:

1. Place plumber's putty around the perimeter of the test area.
2. Place the funnel into the putty to seal the area and prevent water leakage.
    a. The plumber's putty leaked on a primed base sample. The research team changed to an oil clay (clay used for modeling; see Figure 11).
    b. Oil clay is a cost-effective alternative and solved the problem of water leaking through the seal to the side.
3. Fill the device to a set level of 4.3 oz (125 ml) and wait a set time of 2 hours.
4. Use a graduated syringe to refill the device to the set level.
    a. Based on typical adjustments and the test area size, a 20-ml graduated syringe was used.
5. Record the amount added.
    a. It was assumed that the amount added was the same as the amount absorbed by the pavement. Table 27 contains conversions used to determine the amount absorbed in terms of application rates.

Figure 11. Modified Ring Test with Oil Clay.

Table 27. Binder Application Volume.

Rate (gal/sy)	Height (in.)	6-in. Ring Area (sq. in.)	Volume (in^3)	Volume (cc or ml)
0.02	0.0065	28.27	0.1833	3.0
0.03	0.0097	28.27	0.2749	4.5
0.04	0.0130	28.27	0.3665	6.0
0.05	0.0162	28.27	0.4582	7.5
0.06	0.0194	28.27	0.5498	9.0
0.07	0.0227	28.27	0.6415	10.5
0.08	0.0259	28.27	0.7331	12.0
0.09	0.0292	28.27	0.8247	13.5
0.10	0.0324	28.27	0.9164	15.0

PHASE 3—MOISTURE LOSS, PERMEABILITY, AND PENETRATION DEPTH

This phase was divided into three sub-phases (3A, 3B, and 3C). Moisture loss/drying rate (3A) and permeability (3B) of base materials before and after prime/cure treatments were determined using Tex-103-E and the modified ring test (Figure 11), respectively. Penetration depth of prime (3C) was determined by image analysis after completion of testing in 3B. Three prime/cure treatment rates were applied on the base materials with varying moisture contents (i.e., 2 percent below optimum and ±0.5 percent of optimum content). The moisture loss/drying rate tests were performed at 39.2°F (50 percent relative humidity [RH]), 68°F (50 percent RH), and 104°F (~30 percent RH). The permeability tests and penetration depth of prime were performed under normal lab conditions.

Phase 3A—Moisture Loss

The research team applied Tex-103-E to determine moisture loss or drying rate in base materials after applying prime/cure materials. One lift of base materials (6 inch × 2 inch) was prepared and compacted with two desired moisture contents (i.e., at least 2 percent below optimum and optimum ± 0.5 percent) prior to application of prime/cure for the FB substrates. For the CTB substates, a single lift of base materials, measuring 6 inches × 2 inches, was prepared and compacted with 4 percent Type I/II cement.

The 4 percent cement was determined by the rapid mix design developed in TxDOT 0-7027 (proposed as Tex-120-E Part III) and was verified using Tex-120-E [*7*]. Test specimens were compacted to a 4-inch diameter and 2-inch height using a Superpave gyratory compactor. The specimens were cured 72 hours and then moisture-conditioned 24 hours prior to indirect tensile strength (IDT) testing. The automatic tamper (compaction) device was used for compacting samples to a 6-inch diameter and 8-inch height for determining the unconfined compressive strength (UCS) of samples molded in accordance with Tex-113-E and cured for 7 days. Table 28 shows the average IDT strength for moisture-conditioned test specimens as a function of cement content and the UCS of the sample containing the cement content determined by IDT.

Table 28. Strength of Cement-Treated Base.

Description	1% Cement Content	2% Cement Content	3% Cement Content	4% Cement Content
Average IDT (psi)	5.7	14.7	35	74.9

Once specimens achieved the desired moisture content, the best side (top or bottom) was selected to apply prime/cure. The remaining exposed specimen faces were wrapped in a plastic wrap, and then the prime/cure material was applied to the sample (Figure 12). After applying the prime/cure, specimens were placed in the environmental conditions (Figure 13) required for the test, as shown in Table 29.

Figure 12. Specimen after Prime.

Figure 13. Specimens in the Test Environmental Condition (20°C and 50% RH).

Table 29. Summary of Prime Rate.

Prime	Residue by Distillation	LL Rate (gal/sy)	MR Rate (gal/sy)	UL Rate (gal/sy)
MC-30	58.5%	0.1	0.15	0.2
AE-P	43.95%	0.13	0.19	0.25
CSS-1H	61.5%	0.09	0.14	0.19
EBL	67.5%	0.08	0.13	0.17
RC-250 with Grade 5	73%	0.15	0.20	0.25

The mass of specimens was measured over time, and at least two replicates for each testing condition were tested. To observe the mass changes of the prime itself, 6-inch diameter metal disks coated with the same rate of prime (Figure 14) were prepared. Table 30 shows the average mass changes of the prime itself at different temperatures: 39.2°F (4°C), 68°F (20°C), and 104°F (40°C). The weight was measured each day for 14 days, and the percent loss was calculated. The day at which the weight loss stabilized was noted as the cure time. A summary of the mass change for the prime only is shown in Table 30, and an example graph of the mass change for MC-30 is shown in Figure 15.

Figure 14. A 6-inch Metal Disk Coated with Prime.

Table 30. Mass Changes for Prime Only.

Prime	39.2°F (4°C) Loss	68°F (20°C) Loss	104°F (40°C) Loss	39.2°F (4°C) Cure Days	68°F (20°C) Cure Days	104°F (40°C) Cure Days
MC-30	4.7%	5.1%	5.8%	10	3	3
AE-P	6.8%	8.9%	9.2%	13	9	5
RC-250	2.7%	3.5%	4.4%	7	10	7
CSS-1H	6.3%	4.8%	5.4%	3	5	1
EBL	5.3%	6.0%	5.4%	2	1	1
Average Cure	—	—	—	7	5.6	3.4
FB No Prime	2.2%	3.0%	4.1%	14	5	5

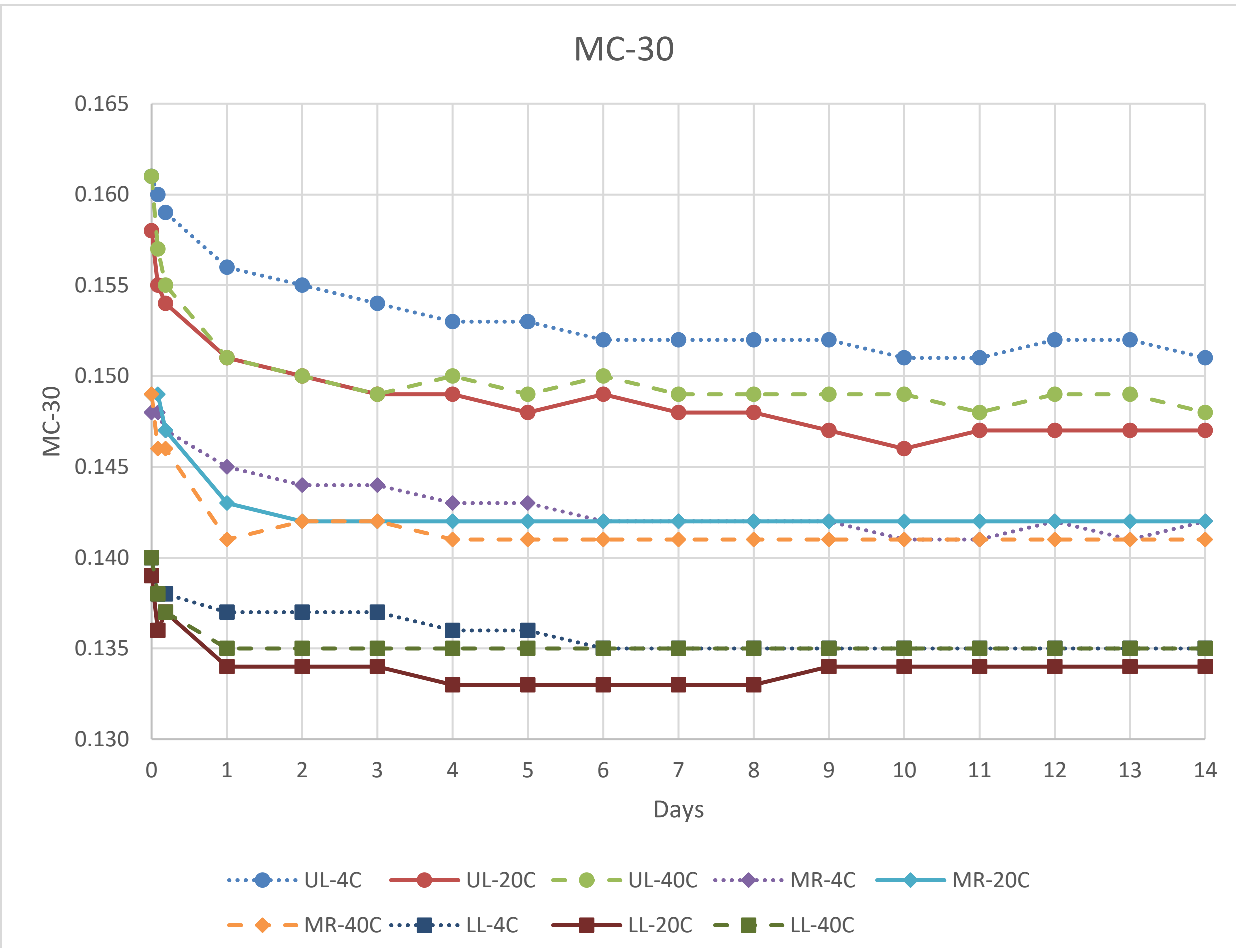

Figure 15. MC-30 Cure Time.

For each sample, the moisture loss at day 14 was compared to the untreated base without prime to determine whether the prime prevented or slowed the moisture loss. Table 31 contains the prime products tested and shows that the moisture loss of the sample with prime was less than the loss without prime (the prime weight loss was deducted from the combined sample). The

CTB moisture loss was less with each prime used except for RC-250. AE-P was successful for 56 percent of the FB samples, MC-30 and RC-250 for 50 percent of the FB samples, EBL for 6 percent of the FB samples, and CSS-1H for none of the FB samples. For FB samples meeting construction specifications of 2 percent below optimum before being primed, AE-P worked for 89 percent to prevent additional moisture loss.

Table 31. Minimizing Moisture Loss.

Sample Condition	FB@BO	FB@O	CTB
UL-4C	AE-P	AE-P, RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL, RC-250
UL-20C	AE-P, RC-250, MC-30	RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL, RC-250
UL-40C	AE-P	RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL
MR-4C	AE-P	AE-P, RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL, RC-250
MR-20C	AE-P, RC-250, MC-30	RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL, RC-250
MR-40C	AE-P	none	AE-P, MC-30, CSS-1H, EBL
LL-4C	AE-P	RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL, RC-250
LL-20C	RC-250, MC-30	RC-250, MC-30	AE-P, MC-30, CSS-1H, EBL, RC-250
LL-40C	AE-P, EBL	none	AE-P, MC-30, CSS-1H, EBL

Phase 3B—Water Permeability

The research team employed the modified ring test (Figure 11) to assess the water permeability of FB materials subjected to each prime/cure treatment within the context of Phase 3A. This specialized testing approach was chosen to delve into the intricacies of water permeability dynamics, offering a comprehensive understanding of how prime/cure treatments influence the permeability characteristics of the base materials. For this test, materials that were measured to be less than 0.001 oz per minute are shown in Table 32. MC-30 was impermeable for 94 percent of the samples, while EBL was impermeable for 39 percent, CSS-1H and RC-250 for 33 percent, and AE-P for 17 percent.

Table 32. Permeability Summary.

Sample Condition	Impermeable Prime on FB@BO	Impermeable Prime on FB@O
UL-4C	MC-30	MC-30
UL-20C	MC-30, EBL	MC-30, CSS-1H, EBL
UL-40C	MC-30, RC-250	MC-30, AE-P, EBL, RC-250
MR-4C	MC-30, CSS-1H	MC-30, CSS-1H
MR-20C	MC-30, EBL	MC-30, CSS-1H
MR-40C	MC-30, AE-P, EBL	MC-30, CSS-1H, EBL, RC-250
LL-4C	MC-30, CSS-1H	MC-30, RC-250
LL-20C	MC-30, EBL	n/a
LL-40C	MC-30, RC-250	MC-30, AE-P, RC-250

Phase 3C—Prime Penetration

The research team investigated prime penetration depth with image analysis using the procedure summarized below. Figure 16 and Figure 17 show examples of the prime penetration image for FB and CTB, respectively. The results of average thickness determinations at different temperatures—39.2°F (4°C), 68°F (20°C), and 104°F (40°C)—are provided in Table 33. The results obtained from this analysis were compiled to provide an average value of the measured depths, contributing to understanding of prime penetration characteristics.

1. Capture images containing the prime layer within an opened specimen, ensuring a ruler is included in the frame. This photographic documentation is facilitated by employing a commercial camera.
2. Utilize dedicated software tools, in this case ImageJ, to obtain images of the prime layer at specific sites, ensuring they are of identical size. Additionally, capture images at known-distance sites from the ruler, maintaining a consistent orientation.
3. Employ the image software to establish the unit of length measurement by utilizing the known distance from the ruler. This calibration ensures accurate and standardized measurements, typically set at a unit such as 1 mm (0.04 inch).
4. Improve the clarity of the images by adjusting contrast settings, facilitating more accurate measurements for the images of the prime layer's specific sites.
5. Leverage software capabilities to calculate the prime area. Subsequently, divide this area by the length of the prime layer, yielding the average prime thickness.

Figure 16. Example of Prime Penetration Depth in the Flexible Base.

Figure 17. Example of Prime Penetration Depth in the Cement-Treated Base.

Table 33. Penetration Depth Summary.

Condition	UL 39.2°F (4°C)	UL 68°F (20°C)	UL 104°F (40°C)	MR 39.2°F (4°C)	MR 68°F (20°C)	MR 104°F (40°C)	LL 39.2°F (4°C)	LL 68°F (20°C)	LL 104°F (40°C)
MC-30 FB@BO (in.)	0.126	0.0811	0.0958	0.0588	0.0771	0.1091	0.035	0.0651	0.1061
MC-30 FB@O (in.)	0.0504	0.023	0.0248	0.0445	0.0667	0.0883	0.0255	0.0645	0.1429
MC-30 CTB	0.0105	0.0562	0.0631	0.0069	0.0129	0.0087	0.0045	0.0087	0.0128
AE-P FB@BO (in.)	0.322	0.2048	0.1604	0.2623	0.2128	0.1514	0.1597	0.136	0.1745
AE-P FB@O (in.)	0.2168	0.3458	0.2906	0.1618	0.2393	0.2923	0.2591	0.2649	0.1504
AE-P CTB	0.0494	0.0622	0.0857	0.0369	0.0426	0.0172	0.0076	0.0073	0.0085
CSS-1H FB@BO (in.)	0.0087	0.0081	0.0138	0.0077	0.0129	0.0164	0.016	0.0162	0.0215
CSS-1H FB@O (in.)	0.0064	0.0166	0.0117	0.0167	0.009	0.016	0.0163	0.022	0.0243
CSS-1H CTB	0.0119	0.0131	0.0121	0.0083	0.0105	0.0096	0.0026	0.0066	0.0077
EBL FB@BO (in.)	0.3458	0.2128	0.136	0.2168	0.1604	0.2623	0.2923	0.1597	0.1745
EBL FB@O (in.)	0.2048	0.2393	0.2649	0.322	0.2906	0.1618	0.1514	0.2591	0.1504
EBL CTB	0.0167	0.0096	0.0146	0.0121	0.0083	0.0134	0.0091	0.0076	0.0050
RC-250 FB@BO (in.)	0.1146	0.1063	0.1891	0.1589	0.0645	0.0139	0.1064	0.0723	0.1276
RC-250 FB@O (in.)	0.0533	0.0644	0.0571	0.127	0.0296	0.0837	0.1117	0.0845	0.1268
RC-250 CTB	0.0327	0.0397	0.0484	0.0158	0.0295	0.0349	0.0152	0.0180	0.0205

Phase 3 Discussion

Prime

Based on the test results, the following observations can be drawn:

- Generally, higher environmental temperatures correlate with a faster curing process for the prime coat.
    - Notably, it appears that on average the prime achieves curing within a span of 7 days, irrespective of the prime type, application rate, and temperature and humidity variations. The average rates are 3½ days for high temperatures, 5½ days for moderate temperatures, and 7 days for low temperatures.
    - A consistent trend was observed where the prime cured within the first week, and the mass changes in most base substrates remained minimal after 14 days following the prime application.
- The rate at which the prime coat dries or cures is susceptible to the influence of environmental temperature. Elevated temperatures expedite the drying or curing process, potentially limiting the time available for the coating to thoroughly penetrate the substrate and establish a robust layer. This acceleration, while quickening the process, may inadvertently result in increased water loss over time because the coating may become less stable and more susceptible to degradation. Conversely, lower temperatures may impede the drying process, providing a more extended period for the coating to penetrate into the substrate and create a durable layer. However, if the temperature falls below the minimum required for prime coat curing, it may hinder proper curing, leading to insufficient film build and potential performance issues.
    - This finding was illustrated by the fact that AE-P took the longest to cure, and AE-P successfully minimized moisture loss on 56 percent of the FB samples; however, it was only 17 percent successful in allowing moisture to penetrate (impermeability) into the sample. For the FB meeting construction specifications of 2 percent below optimum before being primed, AE-P worked for 89 percent of the samples to prevent additional moisture loss.
    - MC-30 and RC-250 were comparable for minimizing moisture loss. MC-30 was impermeable for 94 percent of the samples, while RC-250 was impermeable for only 33 percent.
    - EBL minimized moisture loss for only 6 percent of the FB samples and CSS-1H for none of the FB samples. EBL was impermeable for 39 percent of the samples, and CSS-1H was impermeable for 33 percent of the samples.

Flexible Base

For samples at optimum moisture content (OMC), the following observations were made:

- At 104°F (40°C) and 68°F (20°C), the mass change of the base is minimal when applying RC-250 with Grade 5, regardless of the application rate.
- At 104°F (40°C), the prime penetration depth is relatively high when applying AE-P, regardless of the application rate.
- At 68°F (20°C), AE-P achieves relatively high penetration depths at the UL and LL rates. EBL achieves relatively high penetration depths at the MR rate.
- At 39.2°F (4°C), the mass change is lowest with the application of MC-30 at the UL rate, AE-P at the MR rate, and RC-250 with Grade 5 at the LL rate. AE-P results in relatively high penetration depths at the UL and LL rates, and EBL achieves relatively high penetration depths at the MR rate.

For samples at 2 percent below optimum moisture content (OMC − 2 percent), the following observations were made:

- At 104°F (40°C), the mass change of the base is minimal when applying MC-30, regardless of the application rate. The prime penetration depth is relatively high when applying RC-250 with Grade 5 at the UL rate. EBL achieves relatively high penetration depths at the MR and LL rates.
- At 68°F (20°C), the mass change is lowest with the application of MC-30 at the UL rate, RC-250 with Grade 5 at the MR rate, and AE-P at the LL rate. EBL achieves relatively high penetration depths at the UL and LL rates. AE-P achieves relatively high penetration depths at the MR rate.
- At 39.2°F (4°C), the mass change is lowest with the application of MC-30 at the UL rate and AE-P at the MR and LL rates. EBL results in relatively high penetration depths at the UL and LL rates, and AE-P achieves relatively high penetration depths at the MR rate.

Cement-Treated Base

For CTB samples, the following observations were made:

- At 104°F (40°C), the mass change of the base is minimal when applying AE-P, regardless of the application rate. The prime penetration depth is relatively high when applying AE-P at the UL rate and RC-250 with Grade 5 at the MR and LL rates.
- At 68°F (20°C), the mass change is lowest with the application of EBL at the UL rate, CSS-1H at the MR rate, and RC-250 with Grade 5 at the LL rate. AE-P achieves relatively high penetration depths at the UL and MR rates but not at the LL rate.

- At 39.2°F (4°C), the mass change is again minimal with the application of AE-P, irrespective of the application rate. AE-P consistently results in relatively high penetration depths at the UL and MR rates.

It is essential to recognize that the selection of prime coat material plays a role in influencing the mass changes in FB substrates. Certain materials, like asphalt emulsions, might necessitate a higher application rate, whereas others, such as polymer-modified emulsions, may require a lower application rate. Careful consideration of the specific properties inherent to the chosen prime coat material is paramount when determining the optimal application rate.

Beyond influencing the temperature-dependent behavior of the prime coat, temperature can also affect the physical properties of both the prime coat and the substrate. Specifically, higher temperatures may induce expansion or contraction in substrates, potentially resulting in issues like cracking or damage if the coating lacks adequate flexibility to accommodate these changes. Such limitations in flexibility can contribute to increased moisture infiltration from the substrates.

The tested results of water permeability revealed that MC-30 performed the best. It is crucial to emphasize that the efficacy of a prime coat in mitigating water permeability hinges on various factors. These factors encompass the substrate porosity, the specific type of coating employed, and the prevailing environmental conditions to which the coating will be exposed.

Evaluation of the penetration depths of the prime coat in the base materials through image analysis suggested that elevated temperatures typically contribute to improved penetration, while colder conditions may impede the effectiveness of the cutback prime coat. Nonetheless, multiple factors contribute to the penetration depth of the prime coat, with the type of prime coat material, temperature during application, and characteristics of the underlying surface all playing pivotal roles. When comparing the penetration depths of all primes, the research team found that all depths in CTB materials were less than 0.09 inches and lower than those in FB materials, regardless of the application rate and temperature. This finding indicates that, in this study, prime materials penetrated FB more easily than CTB.

PHASE 4—BOND STRENGTH

The objective of this phase was to determine the effect of different prime materials on the bond strength between the base layers and the subsequent surfacing. Preliminary testing was carried out to determine the most suitable test for bond strength on FB and CTB using the following tests:

- Modified surface treatment bond test established in TxDOT 0-6271-P3.
- Simple torque test.

Although the initial project plan recommended using cored specimens from compacted slabs for this phase of the project, initial trials showed that the FB disintegrated during the coring process. Therefore, similar to Phase 3, one lift of base material (6 inches × 2 inches) was prepared and compacted at OMC with 55 blows from a 10-lb hammer with an 18-inch drop height. The desired prime was applied immediately for specimens to be tested at OMC ± 0.5 percent and applied after 4 hours (at 104°F, 40°C) for specimens to be tested at OMC – 2 percent.

The research team investigated the feasibility of compacting a 2-inch SP-D HMA surfacing on the FB layers. It was found that the specimens dried back to 2 percent below OMC would crumble under the gyratory compaction effort, destroying the specimens. As an alternative, the pull-off and torque tests were trialed without the use of any surfacing. During these trials, it was found that the glue or epoxy used to stick the puck on the specimens penetrated the surface of the FB and strengthened the material. The strength added by the glue or epoxy exceeded that of the prime; therefore, the results were not an accurate measure of the influence of the prime. Figure 18 shows the pucks sticking to an unprimed surface.

To overcome this challenge, a thin layer of asphalt was applied to the primed surface of the FB specimen. The asphalt layer acted as a seal coat, isolating the glued puck from the FB surface while providing an accurate representation of typical field conditions. During both the pull-off and torque tests, the failures occurred on the primed surface and within the FB, indicating that the bond strength between the asphalt and FB was being tested and that the effect of the prime could be determined. Specimens were primed before being allowed to dry for at least 24 hours at 77°F (25°C). Figure 19 shows four sets of primed specimens after application of 0.846 oz (25 ml) of asphalt as a surfacing. The application rates for the various prime products are shown in Table 34.

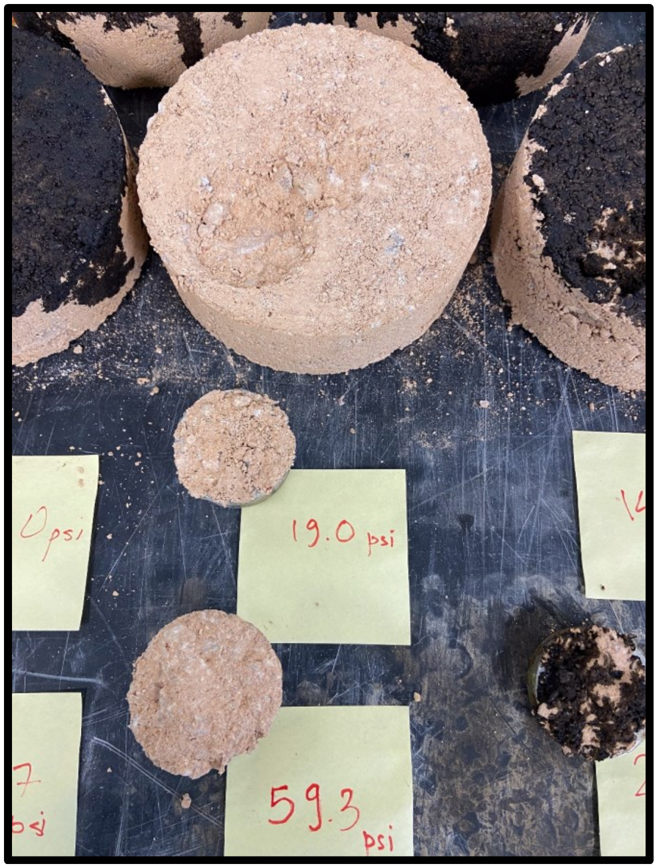

Figure 18. Glue Acting as a Prime on Unprimed Specimen.

Figure 19. Primed Specimens with Asphalt Surfacing.

Table 34. Prime Application Rates for Phase 4.

Prime	LL Prime Rates (gal/sy)	MR Prime Rates (gal/sy)	UL Prime Rates (gal/sy)
MC-30	0.1	0.15	0.2
AE-P	0.13	0.19	0.25
CSS-1H	0.09	0.14	0.19
RC-250	0.15	0.20	0.25
EBL	0.08	0.13	0.17

After application of the prime and asphalt surfacing layer, the specimens were kept at 77°F (25°C) for at least 4 hours to allow the asphalt to cool. The asphalt layer on each specimen was then cored using a 2-inch core barrel to the surface of the FB. Special care had to be taken during the coring because drilling too deep into the FB would break the specimens. The space created by the coring was filled with a fine sand to avoid flowing of the asphalt and to isolate the testing area. Pucks were then glued to the surface of the asphalt layer using a Devcon 5-minute epoxy gel, as shown in Figure 20. The epoxy was allowed to set for at least 24 hours before the specimens were tested.

Figure 20. Pucks Glued to Asphalt Surfacing.

Modified Surface Treatment Bond Test (Pull-Off Test)

The pull-off test entails gluing a metal puck on the surface of a specimen using an epoxy or glue. After a 24-hour setting period, the test is conducted using a Proceq pull-off tester. This procedure tests adhesive strength between two layers of a specimen—in this case, the bond strength between the asphalt surfacing and the FB—in order to test the influence of a prime coat.

During the feasibility investigation of the pull-off test for this study, researchers found that the pull-off strength measured on the FB was very inconsistent. The measured pull-off strength was between 0 psi and 60 psi, whereas the manufacturer's recommended working range is between 44 psi and 443 psi. Additionally, the nature of the pull-off test creates a tensile condition, which is not representative of in-field conditions. Due to these concerns, the research team decided to investigate the feasibility of using a simple torque test.

Torque Test

The simple torque test is set up using the same method described for the pull-off test, including application of the asphalt surfacing, coring, and gluing of a puck. After the 24-hour setting period, the test is conducted by rotating the puck using a digital torque wrench, capable of recording the maximum torque applied during a test in lbf.in before failure, as shown in Figure 21. By using the simple torque test, the research team better simulated in-field conditions in that the surfacing was sheared by turning wheels. This test proved to provide a representative measure of the effect on bond strength of the various prime products.

Figure 21. Simple Torque Test.

The average results of the simple torque test (per products listed in Table 34) were analyzed and grouped into comparable results for each product at a designated application rate and moisture condition and are presented in Figure 22 and Figure 23.

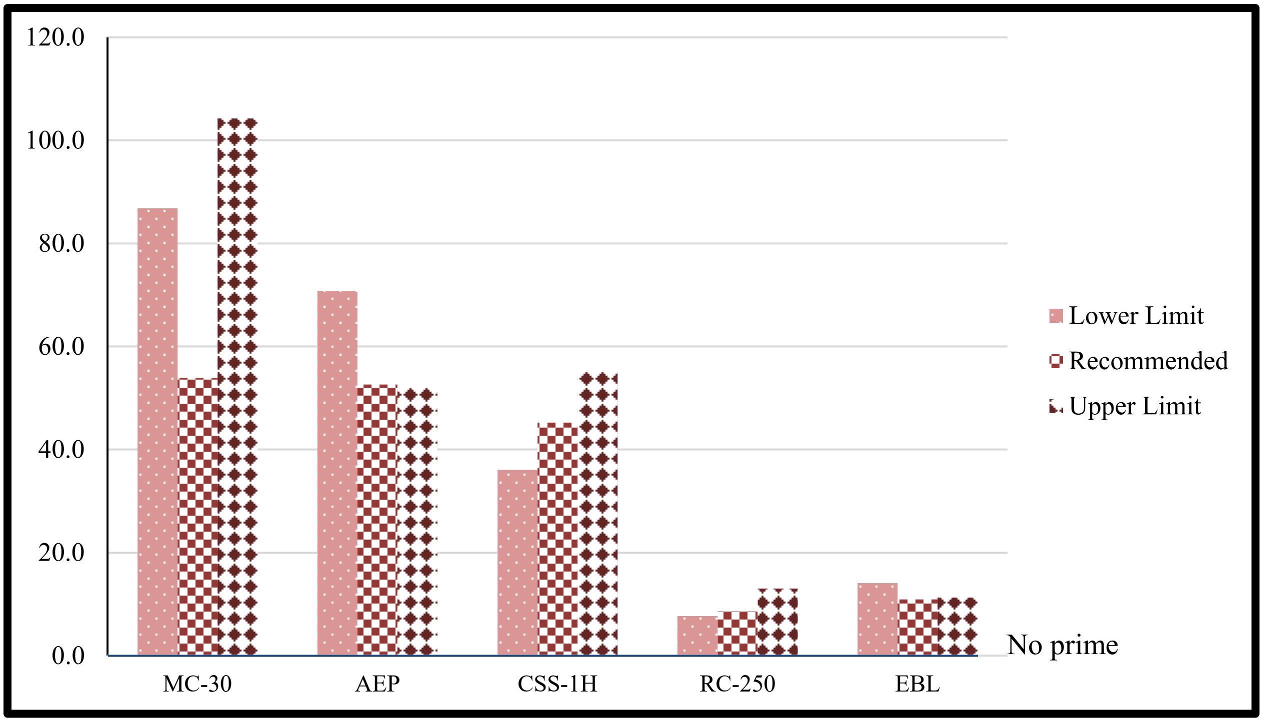

Figure 22. Torque Strength at Different Application Rates for Flexible Base.

Table 35. Torque Strength at Different Application Rates for Flexible Base.

Application Rate	MC-30	AE-P	CSS-1H	RC-250	EBL
Lower Limit	86.8	70.8	36.1	7.7	14.1
Recommended	53.9	52.6	45.2	8.6	10.9
Upper Limit	104.3	52.3	55.3	13.0	11.3

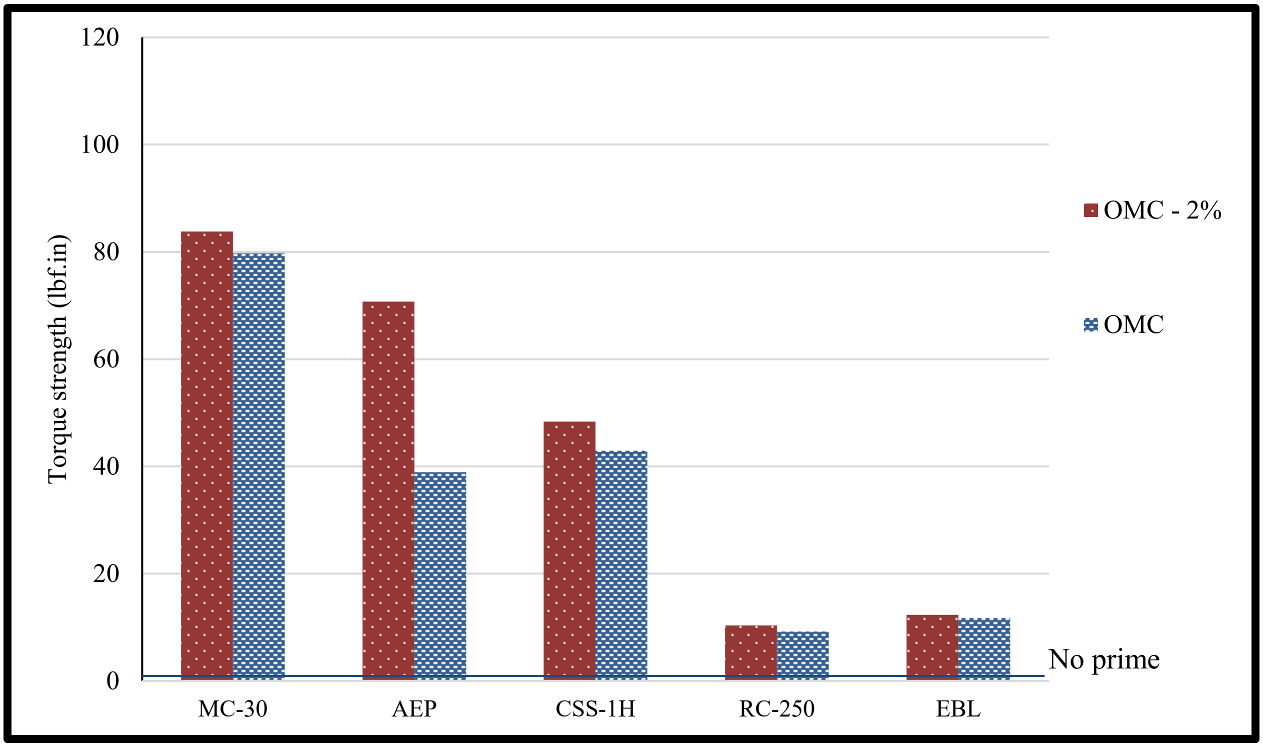

Figure 23. Torque Strength at Different Moisture Contents for Flexible Base.

Table 36. Torque Strength at Different Moisture Contents for Flexible Base (lbf.in).

Moisture	MC-30	AEP	CSS-1H	RC-250	EBL
OMC − 2%	84	71	48	10	12
OMC − 2%	80	39	43	9	12

Flexible Base Bond Discussion

During this phase of the laboratory study, both the pull-off test and the simple torque test were utilized to evaluate the bond strength of various asphalt products at different application rates and two moisture conditions. The following observations were made based on the results of the simple torque test on the FB, as depicted in Figure 22 and Figure 23:

- The simple torque test effectively simulates in-field conditions experienced under turning traffic and provides representative results that can be used to assess the effect of prime on bonding strength between the base and surfacing.
- A clear advantage was observed when applying any of the products included in this study, as opposed to not applying any prime. Specimens that were not primed and asphalt that was applied directly to the FB exhibited very low shear strength, and in many cases, the asphalt delaminated before testing could commence.
- A clear reduction in bond strength was observed for all products applied at OMC compared to specimens dried to 2 percent below OMC, as shown in Figure 23.

- For MC-30, a clear advantage was observed when applied at higher dosages than the manufacturer's recommendation on the FB. However, lower strengths were recorded at the recommended rate than at the lower limit. This may be attributable to the variability between specimens.
- The results of the torque test were generally lower for AE-P compared to MC-30 and showed little sensitivity to the application rate. However, significantly lower results were observed for the specimens primed at OMC, indicating that AE-P is highly sensitive to the moisture condition of the FB.
- The torque test results were generally lower for the CSS-1H samples, with a clear increase in strength as the application rate increased. Specimens treated at OMC – 2 percent showed slightly higher results compared to those treated at OMC.
- The bond strength of EBL was significantly lower than any of the other products, with little sensitivity to application rate or moisture condition. This material, similar to the hot-applied asphalt, did not appear to penetrate the surface of the FB to create a stronger bond.
- While the torque test provided repeatable and representative results for most products, RC-250 showed more variability due to texture depth changes after applying Grade 5 aggregate. This variability suggests that the RC-250 results should not be directly compared to other materials despite overall positive outcomes.

The following observations were made from the simple torque test on cement-treated specimens, as depicted in Figure 24:

- The bond strength of all the primed specimens to the cement-treated specimens was significantly higher than that of the FB specimens. The primary reason for this is that the prime bound effectively to the fine aggregates on the surface of the cement-treated specimens, which were bound to the rest of the material, unlike the unbound fines in the FB. A notable conclusion is that since the penetration depth of the prime was minimal, this test may be testing the cement bond and not the prime.
- Notably, the torque strength of cement-treated specimens without any prime applied was still higher than that of the FB specimens with any of the prime products tested.
- All asphalt products tested showed a significant increase in bond strength for cement-treated specimens, with low sensitivity to application rate, except for RC-250 with Grade 5 aggregate, which exhibited considerable sensitivity to changes in application rate and texture variability.
- The highest bond strengths were achieved with MC-30 and CSS-1H applied to cement-treated materials.

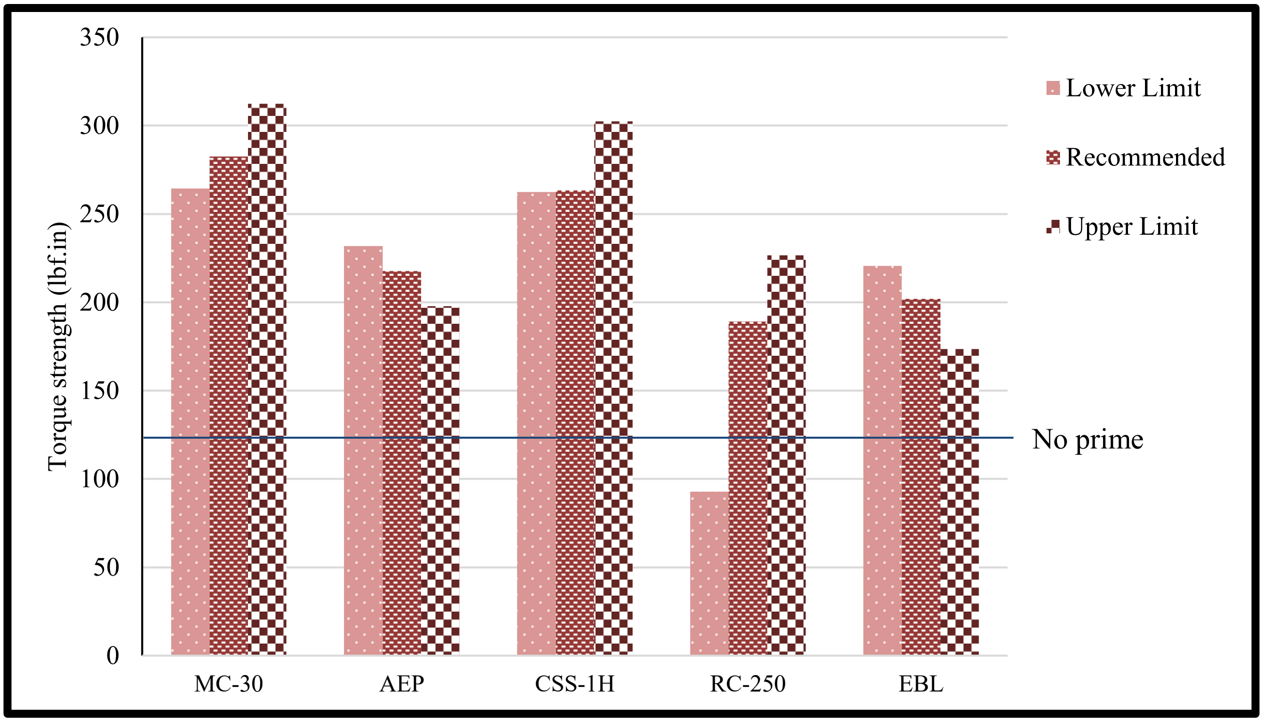

Figure 24. Torque Strength at Different Application Rates for Cemented Materials.

Table 37. Torque Strength at Different Application Rates for Cemented Materials (lbf.in).

Application Rate	MC-30	AEP	CSS-1H	RC-250	EBL
Lower Limit	264	232	262	93	221
Recommended	282	218	263	189	202
Upper Limit	312	198	303	227	174

Cemented Slab Torque Test

The bond strength investigation was expanded to cement-treated materials primed with various asphalt products and at different curing conditions. As part of this investigation, torque tests were conducted on four compacted slabs treated with 4 percent cement. Two of these slabs were treated with 2 percent CSS-1H as well to simulate the practice of mixing emulsion into the top 1 to 2 inches of a cement-treated layer. These slabs were prepared for Phase 5 of this study and tested with the three-wheel polisher but were also used to determine the bond strength in this phase.

These slabs were subjected to two distinct curing conditions:

- Two slabs were primed immediately after molding and the sides sealed off to simulate the use of these products to delay drying out of the curing layer.
- Two slabs were cured at 77°F and 100 percent humidity for 7 days before applying the prime.

The application rates used were the recommended (MR) rates for CSS-1H, MC-30, EBL, and AE-P, as presented in Table 29. Each prime product was applied in a quadrant of the slab, and the torque test was performed three times per quadrant. The torque test locations are depicted in Figure 25. The overall results are shown in Figure 26, and Figure 27 shows averaged results for each product and explores the effect of curing regime for cemented materials.

Figure 25. Torque Test Locations on Cemented Slabs.

Cement-Treated Bond Discussion

During this phase of the laboratory study, the torque test was utilized to evaluate the bond strength of various asphalt products used on cement-treated specimens at two curing conditions, with and without asphalt emulsion. The following observations were made based on the results of the torque test, as depicted in Figure 26 and Figure 27:

- The bond strength achieved with all products was significantly higher on the cement-treated samples compared to the flex base without cement. However, since the penetration depth of the prime was minimal, this test may be testing the cement bond and not the prime.
- There was no substantial difference in bond strength between the products, but on average, the highest to lowest strength was MC-30, CSS-1H, EBL, and AE-P.
- For each prime product, the cement- and emulsion-treated slab had a greater bond strength than the cement slab; however, for CSS-1H, the difference was negligible.
- For cement-treated slabs, a higher bond strength was achieved if the slab was primed immediately after molding. This held true for all prime products.

- For cement- and emulsion-treated slabs, the bond strength was greater for all prime products if the slab was left to cure for 7 days in a moisture-controlled room.
- Priming immediately for both cement-treated slabs and cement- and emulsion-treated slabs provided similar average strengths.
- A 7-day cure for the cement- and emulsion-treated slab yielded the highest bond strength of all the tested slab and curing conditions.

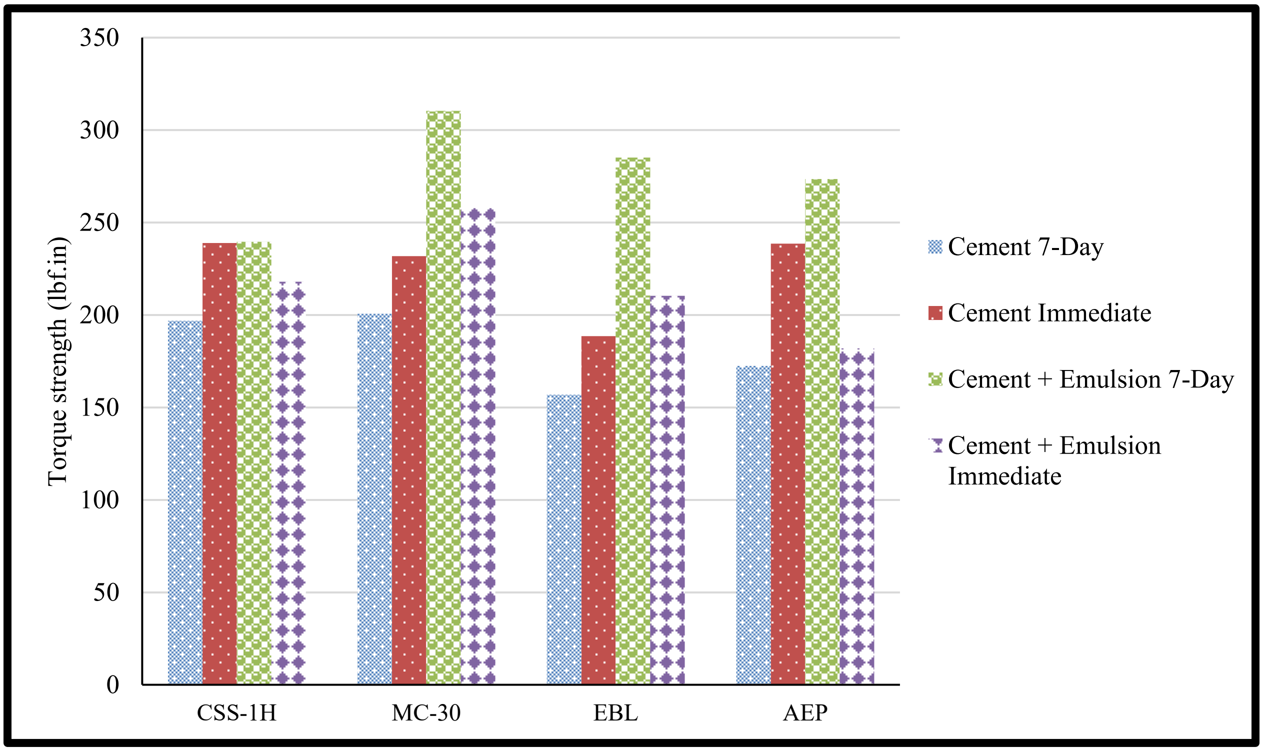

Figure 26. Effect of Curing and Emulsion on Torque Strength of Cemented Slabs.

Table 38. Effect of Curing and Emulsion on Torque Strength of Cemented Slabs (lbf.in).

Curing Condition	CSS-1H	MC-30	EBL	AEP
Cement 7-Day	197	201	157	172
Cement Immediate	239	232	189	239
Cement + Emulsion 7-Day	240	310	285	274
Cement + Emulsion Immediate	218	258	210	182

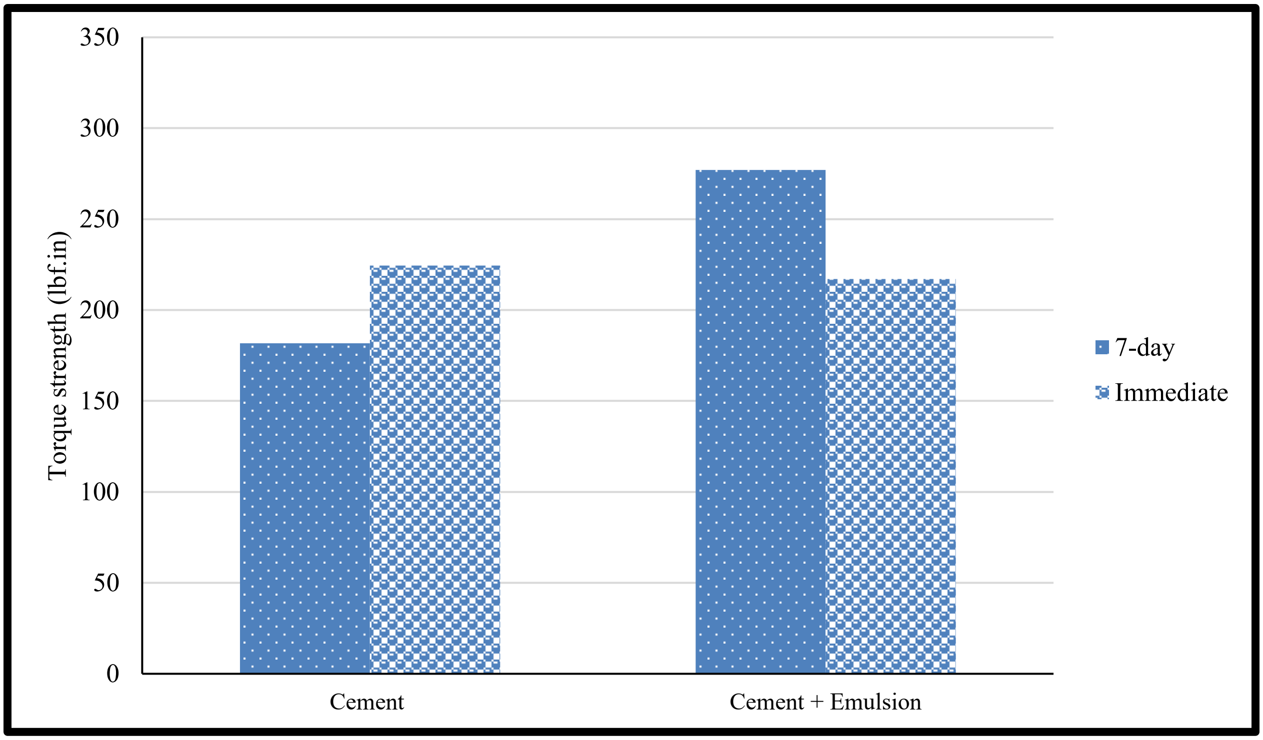

Figure 27. Effect of Curing and Emulsion on Torque Strength of Cemented Slabs (Average of Four Prime Products).

Table 39. Effect of Curing and Emulsion on Torque Strength of Cemented Slabs (Average of Four Prime Products) (lbf.in).

Curing	Cement	Cement + Emulsion
7-day	182	277
Immediate	224	217

PHASE 5—DURABILITY

Phase 5 of the research testing plan was designed to evaluate the durability properties of both the FB and CTB that had been treated with different prime materials. The durability properties of the treated material offer a reliable estimate of the material's resistance to raveling when exposed to construction traffic and when it is opened to the public before the application of a surfacing layer.

During this phase, FB slabs were prepared using an asphalt slab compactor. These slabs were subsequently dried to the desired moisture content before the application of the asphalt product. Once dry, the slabs underwent testing using a three-wheel polisher, and aggregate loss was measured at set intervals using the circular track meter (CTM).

The results provide valuable insight into surface deterioration over time at different moisture conditions, asphalt products, and application rates.

Slab Preparation

Slabs were prepared by reconstituting the sieved and dried aggregate, replacing all fractions larger than ⅞ inch with an equivalent amount retained on the ⅝-inch sieve. This ensured that the largest aggregate particles were less than half the slab thickness of 1.5 inches. The material was covered and left overnight before compaction commenced. Moisture was checked and corrected before beginning the molding process by comparing the initial weight to the weight before molding. The mold for the slab compactor was assembled, and a ¼-inch base plate was inserted to facilitate handling of the slab after compaction. The flex base was then evenly placed in the slab before it was compacted to 100 percent of the maximum dry density (MDD). Larger and oddly shaped aggregate pieces were removed from the direct wheel path and placed elsewhere in the slab to ensure one aggregate piece did not skew the results. This process is depicted in Figure 28.

Figure 28. Slab Preparation.

Once the slabs were compacted to the required height, they were dried to the desired moisture level. Slabs to be primed at OMC were primed directly after compaction. In contrast, slabs to be primed at OMC − 2 percent were placed in a room with a constant temperature of 104°F (40°C) and constant airflow. This process normally took 4 hours; however, the slab was weighed periodically to ensure the proper moisture content before priming. Once the slabs reached the desired moisture level, they were divided into four equal quadrants, each primed with the selected application rate, as shown in Figure 29. The prepared slabs were kept at room temperature for 3 to 7 days to dry out before testing.

Figure 29. Priming of Slabs in Four Quadrants.

Raveling (Three-Wheel Polisher) Test

After the compaction, priming, and drying of the slabs, they were subjected to the three-wheel polisher to simulate early trafficking on the newly constructed layer. It is important to note that this test was not conducted using water because doing so significantly weakens the flex base and does not yield representative results. The CTM was used to establish the texture depth in the same track as the three-wheel polisher. The texture depth was determined before testing, followed by increments of 100 revolutions up to 1000, and finally in increments of 500 up to 5000. The testing process is depicted in Figure 30, while an example of a tested slab at various intervals is shown in Figure 31.

The CTM measurements for each slab were collected and processed. The CTM measured the texture depth at 1024 points along this track, and those data were then processed to provide an average depth for each of the four quadrants of the slab. The data points obtained within 1 inch of the boundary between the quadrants were discarded, and only the points in the center were used to establish the average depth.

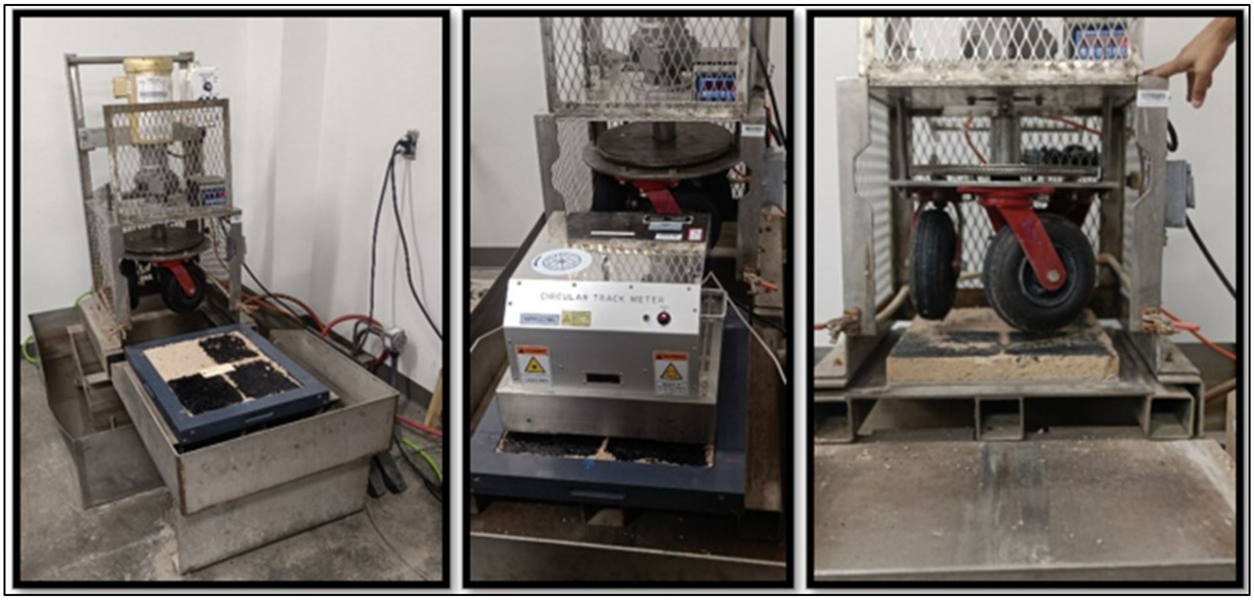

Figure 30. Three-Wheel Polisher Testing and CTM Measurement.

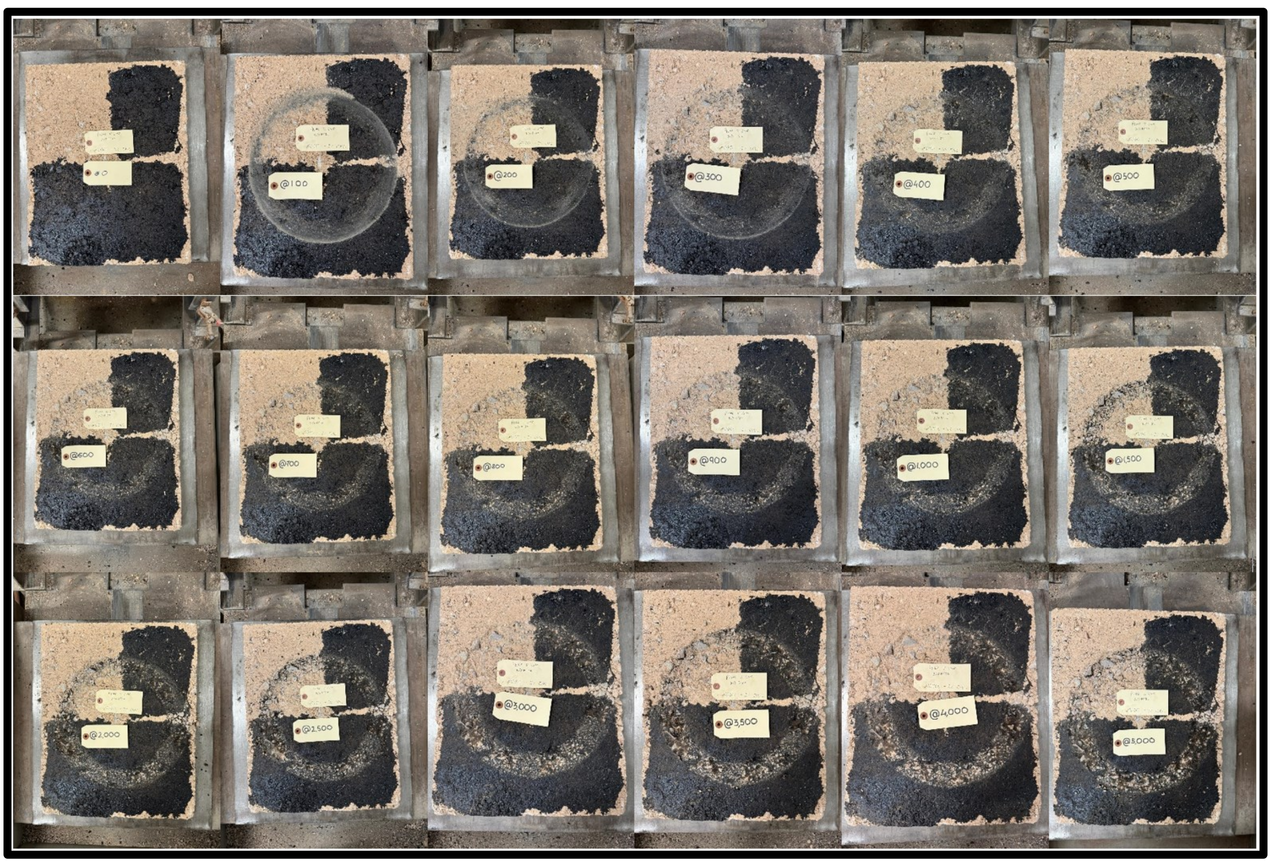

Figure 31. Three-Wheel Polisher Test of Slabs at Various Stages.

Durability Discussion

The three-wheel polisher test, executed at set intervals and tracking aggregate loss with the CTM, offers a durability metric that is responsive to the application of asphalt products. The outcomes of the test varied considerably based on the type of asphalt product, rate of application, and moisture conditions. The results from these tests, summarized in Figure 32 and Figure 33, led to the following key insights:

- Although there was variability between and within slabs, the effects of the different asphalt products and moisture conditions were clear and repeatable. Generally, a clear benefit of using the asphalt products could be observed.
- LL application rate frequently performed worse and led to significant aggregate loss compared to the higher application rates, suggesting a lack of effectiveness in preventing long-term aggregate loss.
- The untreated quadrant mostly performed worse than the treated quadrants; however, in certain cases (AE-P at OMC, for example), the untreated quadrant performed better than the treated quadrants. This finding was possibly due to the impervious nature of the material that traps moisture in the layer, weakening its structural integrity. This is a certain disadvantage for FB but can prove to be an advantage for cement-treated layers.
- UL application rates often exhibited a slower rate of aggregate loss, indicating moderate yet consistent protection against aggregate loss over time.
- MC-30, EBL, and CSS-1H performed very well during this test, showing low degradation even after 5000 cycles.
- In almost all cases, the specimens dried to OMC − 2 percent before applying the asphalt products performed better than those primed at OMC. This implies that prime applied to the surface of the dried specimens can penetrate the surface and flow deeper into the material, increasing its resistance to raveling. This finding is in line with and confirms the current state of the practice.

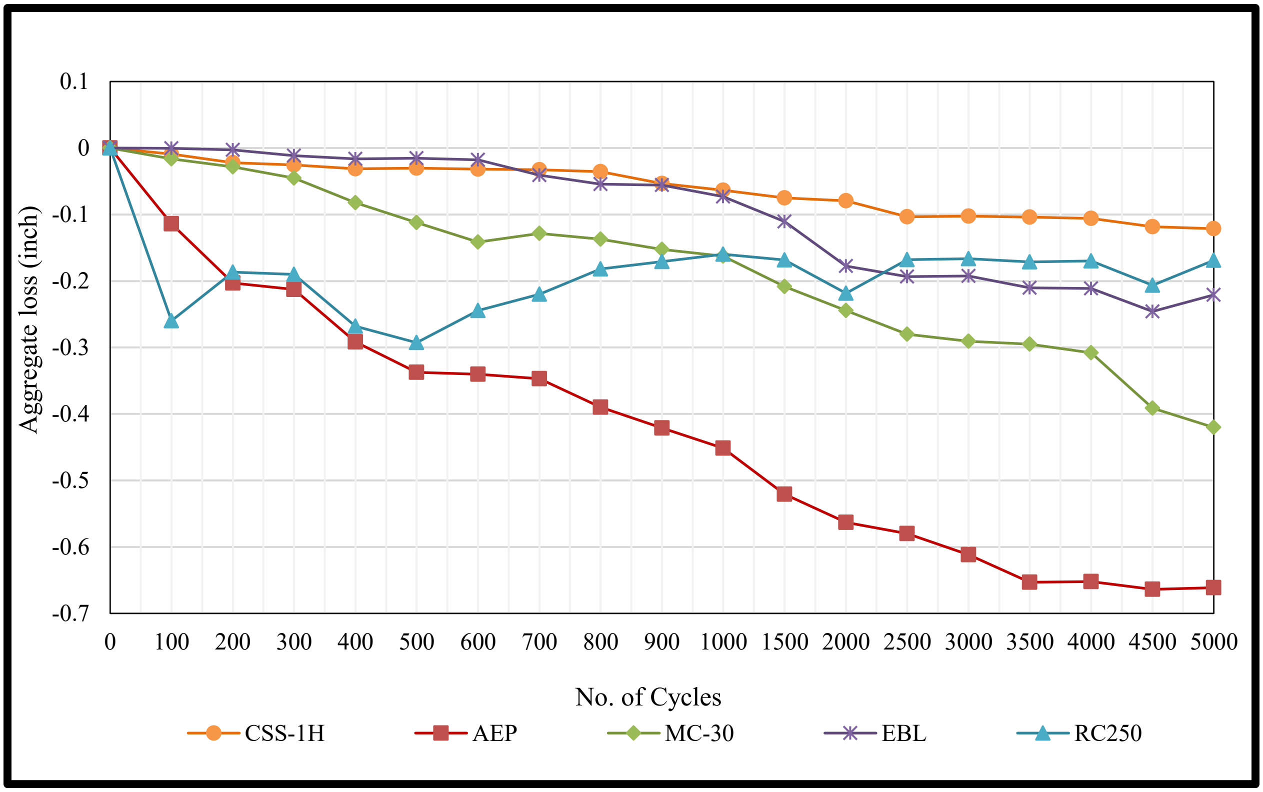

Figure 32. Raveling Test at MR, Tested at OMC.

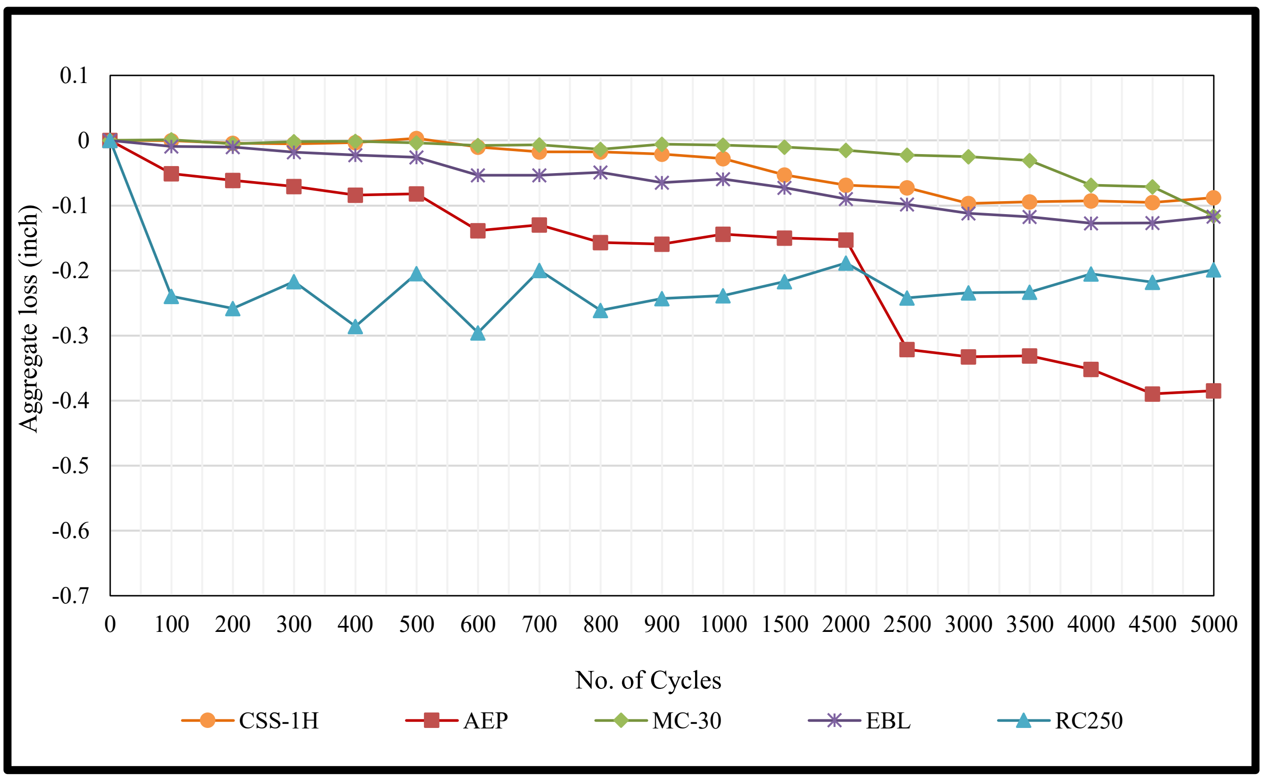

Figure 33. Raveling Test at MR, Tested at OMC − 2%.

Cement-Treated Slabs

The resistance to raveling investigation was expanded to cement-treated materials primed with four of the asphalt products and subjected to different curing conditions. Slabs were prepared by mixing 4 percent cement with the aggregate at OMC before compacting to 100 percent of MDD using the slab compactor. Two of these slabs were treated with 2 percent CSS-1H as well to simulate the practice of mixing emulsion into the top 1 to 2 inches of a cement-treated layer to promote adhesion.

These slabs were subjected to two distinct curing conditions:

- Two slabs were primed immediately after molding and the sides sealed off to simulate the use of these products to delay drying out and curing of the layer.
- Two slabs were cured at 77°F and 100 percent humidity for 7 days before applying the prime.

The recommended (MR) application rates used were for CSS-1H, MC-30, EBL, and AE-P, as presented in Table 29. Each prime product was applied in a quadrant of the slab and allowed to cure before testing. Figure 34 shows the preparation of the cement-treated slabs. Figure 35 shows the four different slabs after 1000 revolutions of the three-wheel polisher, from the top left, clockwise:

1. Cement treated, primed immediately and sides sealed.
2. Cement treated, primed after 7 days in the wet room.
3. Cement and emulsion treated, primed immediately and sides sealed.
4. Cement and emulsion treated, primed after 7 days in the wet room.

Figure 34. Cemented Slab Preparation.

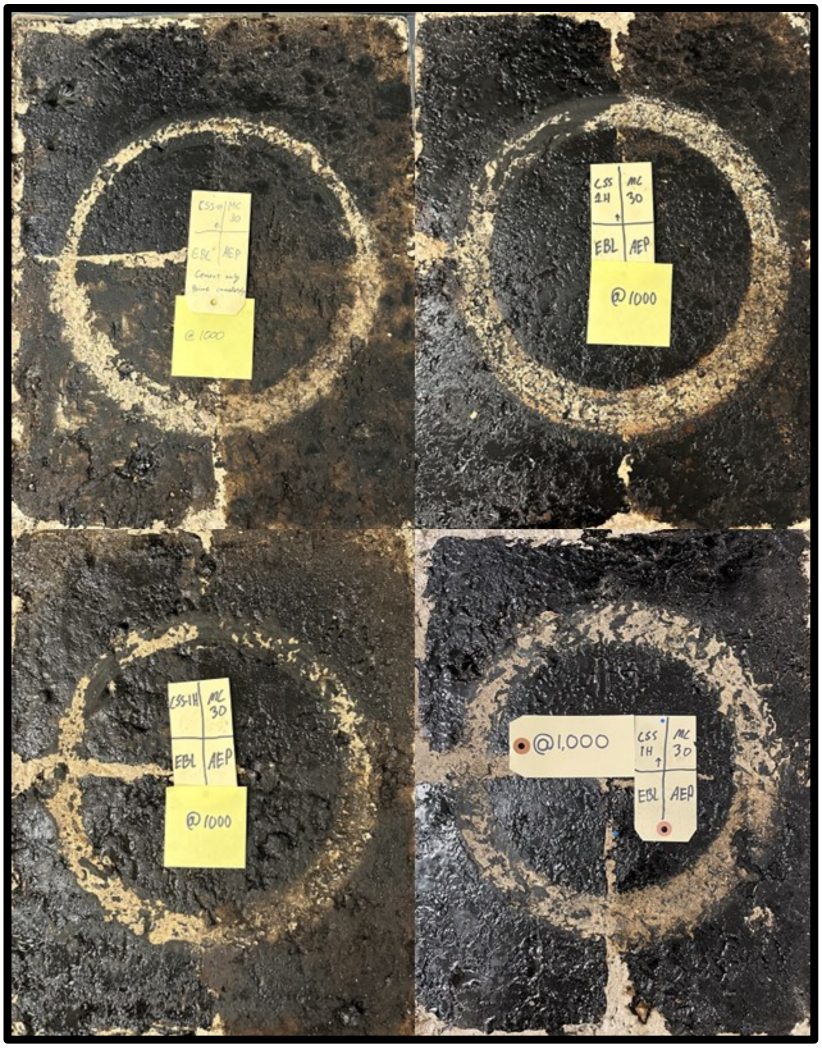

Figure 35. Cemented Slabs after 1000 Rotations with the Three-Wheel Polisher.

Raveling Discussion

Surface aggregate loss was simulated using the three-wheel polisher to ravel the surface of the cemented slabs. The aggregate loss was measured using the CTM, and the results for each quadrant, along with its prime product, for each slab are shown in Figure 36 to Figure 39. These results led to the following observations and conclusions:

- The amount of raveling for all cement-treated slabs was significantly lower than that of the flex base slabs. After 5000 cycles, the flex base specimens lost between 0.2 and 0.5 inches, whereas the cement-treated specimens lost between 0.001 and 0.05 inches.
- It was observed that, in some cases, the aggregate loss was negative, indicating that the specimen increased in height from raveling. This counterintuitive phenomenon was investigated, and it was found that some of the rubber on the tires of the three-wheel polisher started to melt and stuck to the surface of the specimen. The main reason for the high temperatures was due to tests conducted without wetting the surface of the

specimen, leading to high friction and high temperatures. These deposits were scraped off where possible and ignored during the analysis of the results.

- For specimens treated with cement only, all prime products tested performed similarly, and little distinction could be made between the four products. However, the specimen primed immediately and treated with MC-30 showed much poorer results. The reason for these results may be that the diluted asphalt was not able to penetrate the surface due to the moisture in the specimen.
- Specimens treated with cement and emulsion performed similarly, and both showed more variation and performed slightly worse compared to specimens treated with only cement.
- As shown in Figure 35, it appears that the quadrant treated with AE-P discolored the material more than any other product in all four cases. This finding indicates better penetration into the layer and may lead to improved bond strength and resistance to raveling.
- The high resistance to raveling and high bond strength showed by all products tested indicate a much lower sensitivity to product type for cement-treated materials. Therefore, it can be concluded that the choice of prime product for cement-treated materials is much less critical than for FB.

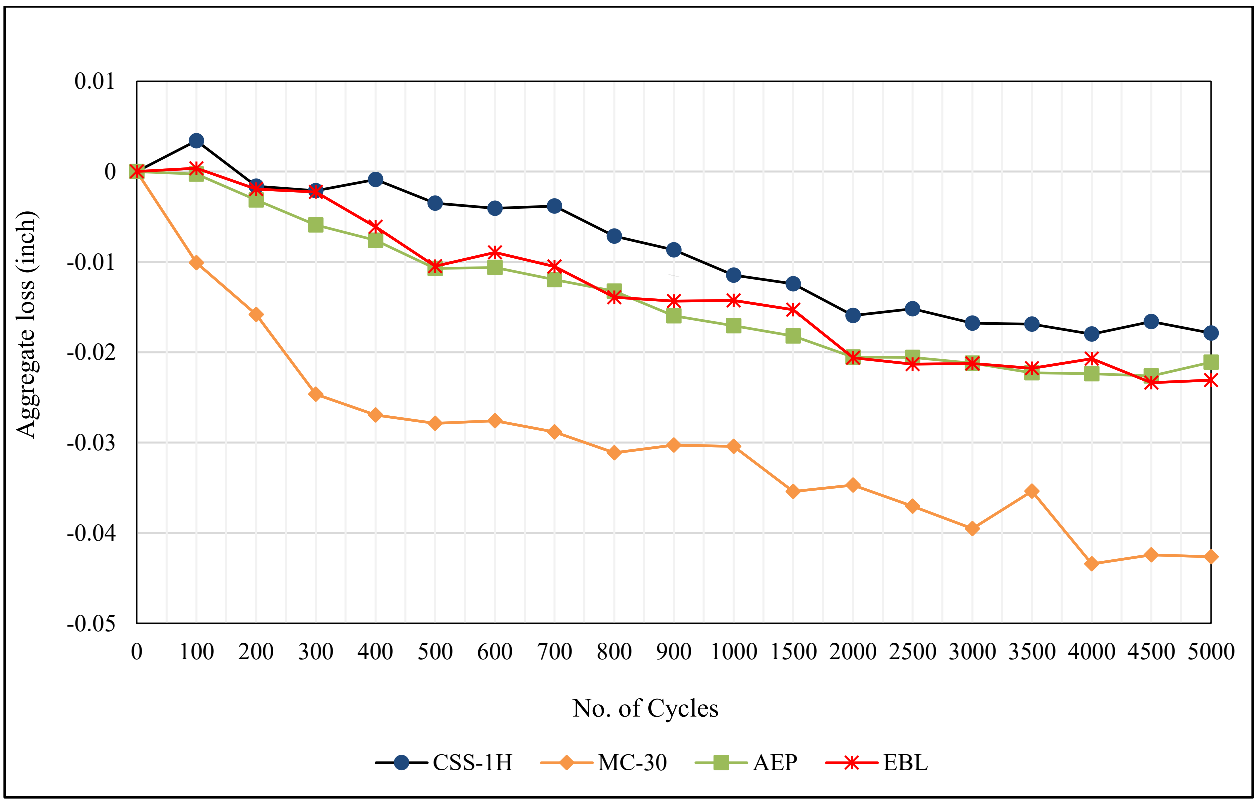

Figure 36. Raveling Results for Cement-Treated Slab Primed Immediately.

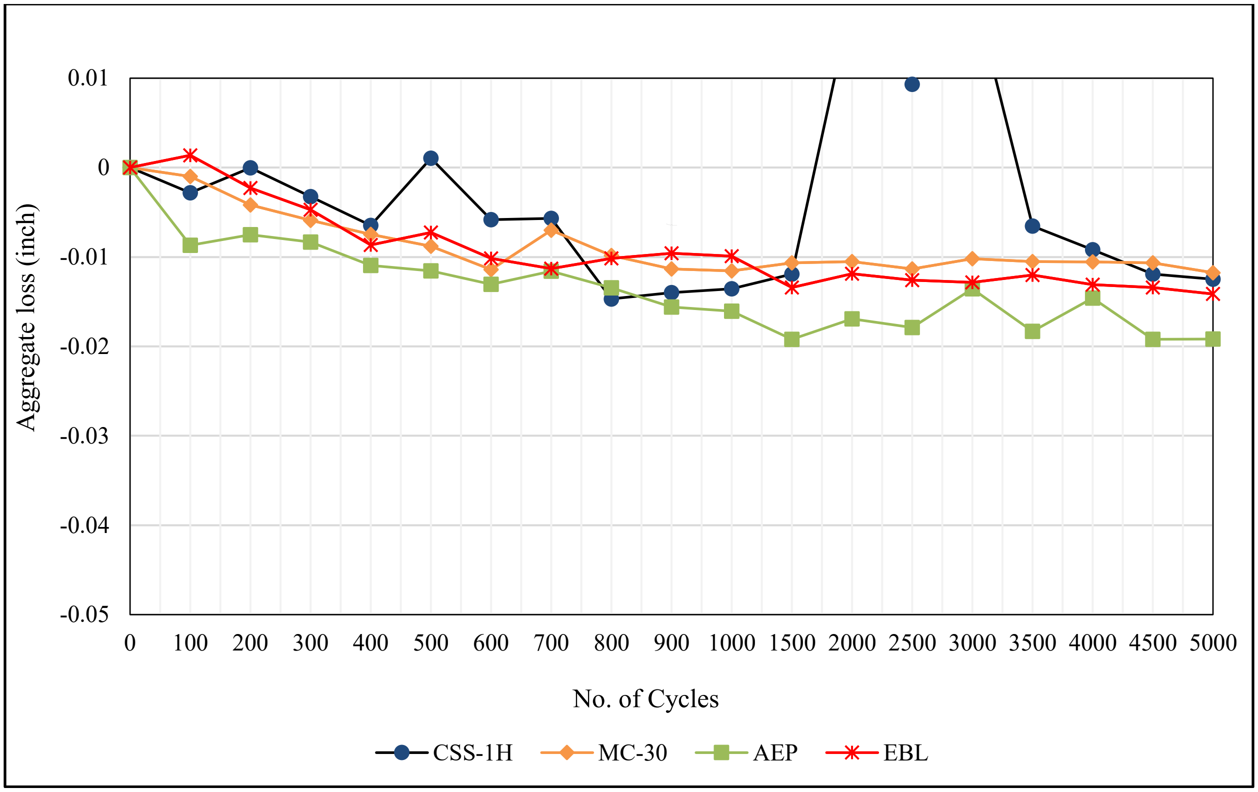

Figure 37. Raveling Results for Cement-Treated Slab Primed after 7 Days.

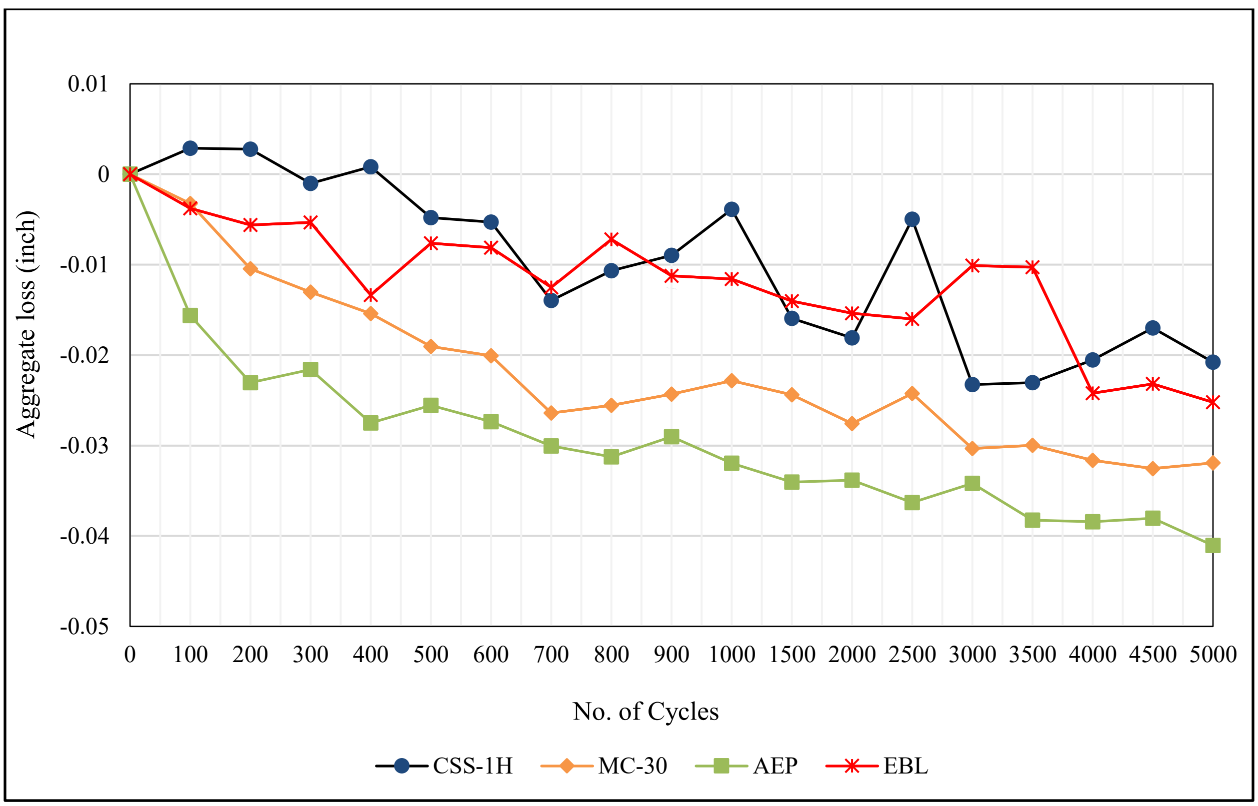

Figure 38. Raveling Results for Cement- and Emulsion-Treated Slab, Primed Immediately.

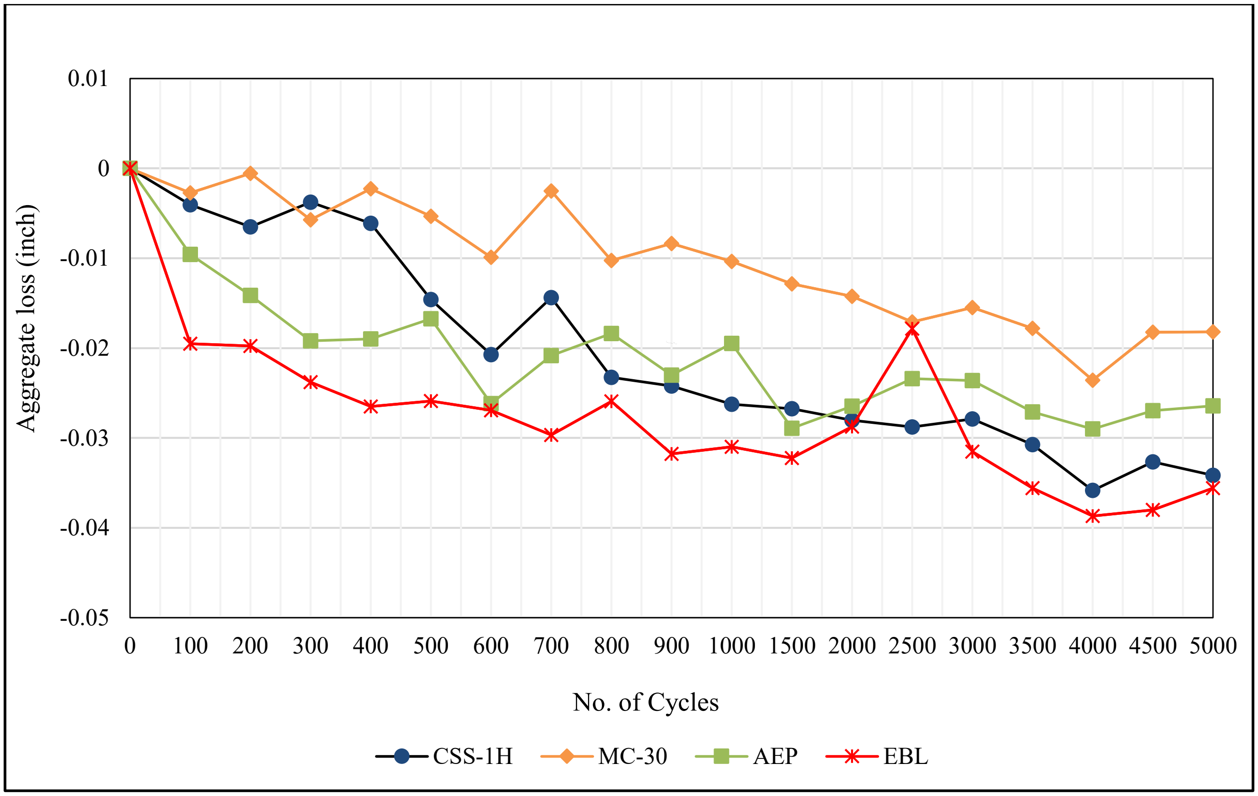

Figure 39. Raveling Results for Cement- and Emulsion-Treated Slab, Primed after 7 Days.

CONCLUSIONS FROM LABORATORY INVESTIGATION

This section contains conclusions made from the laboratory investigation concerning moisture loss, permeability, and penetration depth, as well as bond strength and durability.

Moisture Loss, Permeability, and Penetration Depth

On average, the prime achieved curing within a span of 7 days, irrespective of the prime type, application rate, and variations in temperature and humidity, with an average of 3½ days for high temperatures, 5½ days for moderate temperatures, and 7 days for low temperatures. A consistent trend was observed where the prime cured within the first week, and the mass changes in most base substrates remained minimal after 14 days following the prime application.

For flexible bases, at OMC, RC-250 with Grade 5 generally resulted in minimal mass change across different temperatures, while MC-30 and AE-P showed more effective results at specific temperatures and rates. When the moisture content was OMC − 2 percent, MC-30 consistently minimized mass change, particularly at higher temperatures. For cement-treated bases, AE-P demonstrated consistent performance in minimizing mass change across all temperatures, with EBL and CSS-1H also showing effectiveness at moderate temperatures, depending on the application rate.

The penetration depth of prime coats varied with base type and temperature. For flexible bases at OMC, AE-P generally provided higher penetration depths, especially at elevated temperatures (104°F) and across various application rates. EBL also showed good performance, particularly at moderate temperatures (68°F) and specific rates. When the moisture content was OMC – 2 percent, RC-250 with Grade 5 showed better penetration at higher temperatures, while EBL consistently delivered deeper penetration across different temperatures and application rates. For cement-treated bases, AE-P performed well at higher temperatures (104°F) and at specific rates, achieving relatively high penetration depths. At lower temperatures (39.2°F), AE-P remained effective, particularly at higher application rates.

The curing and penetration of prime coats were significantly influenced by environmental temperatures, with higher temperatures accelerating the process but potentially compromising coating stability and moisture retention. Prime coats generally cured within 7 days, but the drying rate varied with temperature, affecting how well the coating penetrated and formed a durable layer.

Material selection and application rates must be carefully tailored to these temperature effects since some materials may require different rates to optimize performance. Despite these variables, penetration in flexible bases was generally better than in cement-treated bases, with temperatures playing a crucial role in determining penetration depth. Additionally, the study found no clear trend in water permeability, emphasizing the complex interplay of factors like substrate porosity, coating type, and environmental conditions on prime coat effectiveness.

Based on the laboratory investigation, Table 40 summarizes the optimal prime coats and application rates for minimal mass change (moisture prevention), while Table 41 summarizes recommended prime products for maximum penetration depth across various temperatures and base types.

Table 40. Summary of the Optimal Prime Coats and Application Rates for Moisture Prevention.

Base Type	Temperature	Recommended Prime	Application Rate	Rationale
FB (OMC)	104°F (40°C)	RC-250 with Grade 5	Any	Minimal mass change
FB (OMC)	68°F (20°C)	RC-250 with Grade 5	Any	Minimal mass change
FB (OMC)	39.2°F (4°C)	MC-30, AE-P, RC-250 with Grade 5	UL (MC-30) MR (AE-P) LL (RC-250 with Grade 5)	Lowest mass change
FB (OMC − 2%)	104°F (40°C)	MC-30	Any	Minimal mass change
FB (OMC − 2%)	68°F (20°C)	MC-30, RC-250 with Grade 5, AE-P	UL (MC-30) MR (RC-250 with Grade 5) LL (AE-P)	Lowest mass change
FB (OMC − 2%)	39.2°F (4°C)	MC-30, AE-P	UL (MC-30) MR and LL (AE-P)	Lowest mass change
CTB	104°F (40°C)	AE-P	Any	Minimal mass change
CTB	68°F (20°C)	EBL, CSS-1H, RC-250 with Grade 5	UL (EBL) MR (CSS-1H) LL (RC-250 with Grade 5)	Lowest mass change
CTB	39.2°F (4°C)	AE-P	Any	Minimal mass change

Table 41. Summary of the Optimal Prime Coats and Application Rates for Penetration Depth.

Base Type	Temperature	Recommended Prime	Application Rate	Rationale
FB (OMC)	104°F (40°C)	AE-P	Any	Consistent high penetration depth
FB (OMC)	68°F (20°C)	AE-P, EBL	UL and LL (AE-P) MR (EBL)	High penetration depth
FB (OMC)	39.2°F (4°C)	AE-P, EBL	UL and LL (AE-P) MR (EBL)	High penetration depth
FB (OMC − 2%)	104°F (40°C)	RC-250 with Grade 5, EBL	UL (RC-250 with Grade 5) MR and LL (EBL)	High penetration depth
FB (OMC − 2%)	68°F (20°C)	EBL, AE-P	UL and LL (EBL) MR (AE-P)	High penetration depth
FB (OMC − 2%)	39.2°F (4°C)	EBL, AE-P	UL and LL (EBL) MR (AE-P)	High penetration depth
CTB	104°F (40°C)	AE-P, RC-250 with Grade 5	UL (AE-P) MR and LL (RC-250 with Grade 5)	High penetration depth
CTB	68°F (20°C)	AE-P, RC-250 with Grade 5	UL and MR (AE-P) LL (RC-250 with Grade 5)	High penetration depth
CTB	39.2°F (4°C)	AE-P, RC-250 with Grade 5	UL and MR (AE-P) LL (RC-250 with Grade 5)	High penetration depth

Bond Strength

The simple torque test revealed several key insights into the effectiveness of different prime coats. Applying any prime coat significantly improved bond strength compared to unprimed specimens, where asphalt often delaminated before testing. The simple torque test effectively simulated in-field conditions and provided reliable data on bond strength.

For MC-30, a clear advantage could be observed when applied in higher dosages than recommended by the manufacturer. However, lower strengths were recorded at the recommended rate versus the lower limit. No clear difference was observed between the specimens primed at OMC and OMC − 2 percent.

AE-P showed lower bond strength overall compared to MC-30 and showed little sensitivity to the application rate. However, much lower results were observed for the specimens primed at OMC, showing that AE-P is very sensitive to the moisture condition of the FB.

Bond strength was found to be lower for CSS-1H, with a clear increase as the application rate increased. Specimens treated at OMC − 2 percent showed slightly lower results compared to those treated at OMC.

The bond strength of EBL was significantly lower than any of the other products, with little sensitivity to application rate or moisture condition. This material, like the hot-applied asphalt, did not appear to penetrate the surface of the FB but bonded to dust and loose fines on the surface of the flex base.

Bond strength measurements for RC-250 with Grade 5 aggregate were inconsistent and much lower than expected. The aggregates on the surface resulted in uneven application of torque, and the test results were not deemed representative of in-field performance.

The bond strength of all the cement-treated primed specimens was significantly higher than that of the FB specimens. The primary reason for this is that the prime bound effectively to the fine aggregates on the surface of the cement-treated specimens, which were bound to the rest of the material, unlike the unbound fines in the FB.

Durability

The three-wheel polisher test revealed key insights into the durability and effectiveness of various asphalt products in preventing aggregate loss under different conditions. The test demonstrated that applying asphalt products generally enhanced the durability of the FB layers, though results varied based on product type, application rate, and moisture conditions.

LL application rate frequently performed worse and led to significant aggregate loss compared to the other application rates, suggesting a lack of effectiveness in preventing long-term aggregate loss.

UL application rates often exhibited a slower rate of aggregate loss, indicating moderate yet consistent protection against aggregate loss over time.

The untreated quadrant mostly performed worse than the treated quadrants; however, in certain cases (AE-P at OMC, for example), the untreated quadrant performed better than the treated quadrants. This result is possibly due to the impervious nature of the material that traps moisture in the layer. This is a certain disadvantage for flexible base but can prove to be an advantage for cement-treated layers.

MC-30, EBL, and CSS-1H performed particularly well during this test, showing minimal degradation even after extensive testing.

Specimens dried to OMC − 2 percent before asphalt application generally exhibited better raveling resistance since the prime coat could penetrate deeper into the flex base, aligning with current best practices.

The high resistance to raveling and high bond strength showed by all products tested on the CTB indicated a much lower sensitivity to product type. Therefore, it can be concluded that the choice of prime product for cement-treated materials is much less critical than for FB.

CHAPTER 4. FIELD OBSERVATIONS

Several sites using different types of prime materials were studied. This chapter contains descriptions of selected field observations.

FIELD EVALUATION OF ULTRATACK® AS A PRIME IN THE BRYAN DISTRICT

TTI researchers traveled to Huntsville, Texas, on October 12, 2021, to observe and document the installation of a new type of prime coat marketed by Blacklidge called UltraTack®. This product was selected instead of the conventional prime material because it was touted as requiring only a 30-minute cure time prior to application of the next pavement course.

Project Location

The project was located on FM 2821 in Huntsville just east of SH 75. There were two short sections only a few hundred feet in length—one on FM 2821 and another on Rosenwall Road—as in Figure 40 as circled and identified in red.

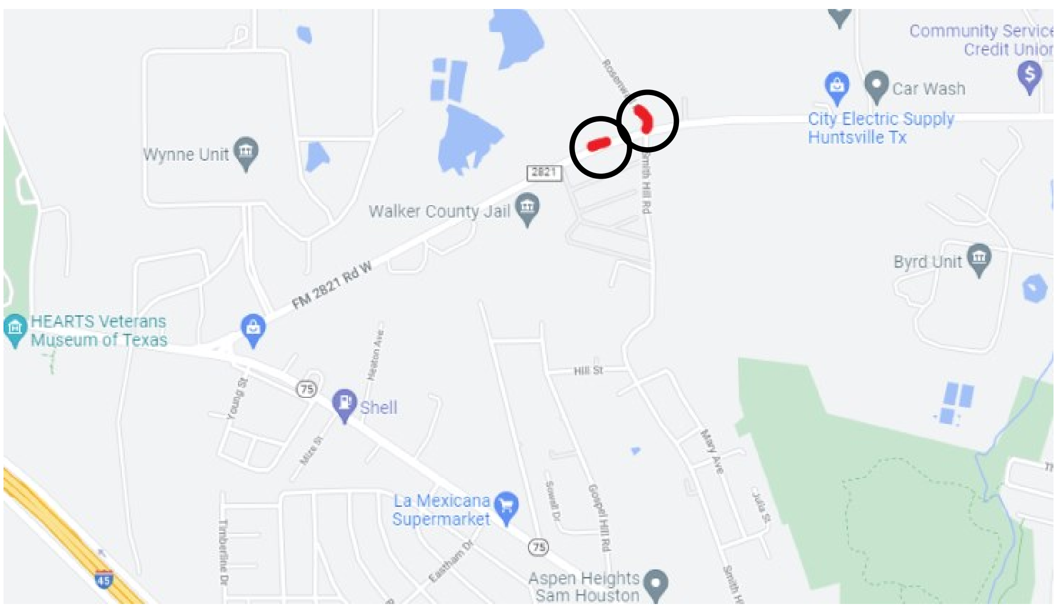

Figure 40. Section Locations Where UltraTack® Was Placed.

Base Course Condition

The pavement section consisted of 8 inches of crushed limestone flex base over 8 inches of stabilized subgrade. After placement of the prime, 2 inches of Type B followed by 2 inches of Type D hot mix were applied. Photos of the base course for the two sections prior to priming are shown in Figure 41.

Figure 41. Base Course prior to Priming.

Application of Prime

The contractor attempted to place the prime on Tuesday, October 12, 2021; however, the product was clogging the nozzles. By the next day, corrections were made and the product was sprayed without any more clogging issues. The contractor thought the problem was twofold:

1. The prime was only heated to 140°F when it should have been at 170°F.
2. When it was diluted (at a 2:1 ratio, with two parts oil to one part water), cold water was added, and this also contributed to the product clumping in the tank.

No changes were made to the product in the tank for day 2 except that the oil was heated thoroughly and to a higher temperature. The diluted prime was applied at a rate of 0.20 gal/sy (see Figure 42). In the photo on the left in Figure 42, no traffic would be on this section until it was paved, but in the photo on the right (Rosenwall Road), traffic needed to be placed after curing so that traffic could be switched and the other direction primed. Traffic was kept off the Rosenwall Road section for about 2 hours until it appeared dry and not tacky.

Figure 42. Base Course with Fresh Applied Prime.

Performance with Application of Traffic

Traffic was allowed onto the primed surface on Rosenwall Road after a couple of hours of cure time. With the passage of a few light vehicles, the prime performed well. Then a slow-moving pickup hauling a trailer loaded with some equipment trafficked on the primed surface, and the prime started to pick up on the tires (Figure 43). There appeared to be no penetration of the prime material into the base course, as evidenced in Figure 44. Once this occurred, the contractor bladed off the material, and the area engineer was contacted to establish a new course of action (refer to Figure 45).

Figure 43. Prime Picking Up on Vehicle Tires.

Figure 44. No Penetration of the Prime into the Base.

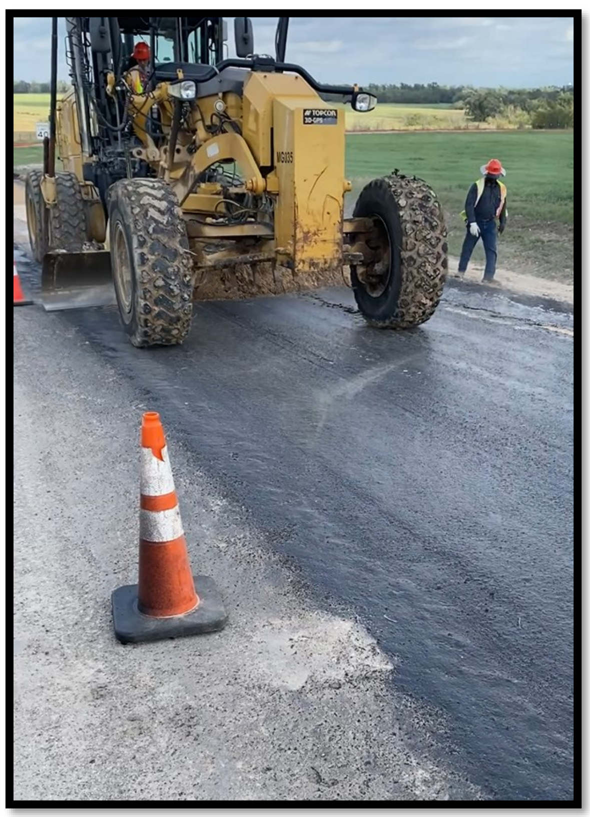

Figure 45. Removal of Prime with Blade.

FIELD EVALUATION OF CSS-1H AS A PRIME IN THE BEAUMONT DISTRICT

TTI researchers traveled to Chester, Texas, on August 10, 2022, to observe and document the installation of CSS-1H prime on an emulsified asphalt-treated base.

Project Location

The project was located on US 287 from FM 1745 to Russell Creek, for a total length of 2.2 mi (Figure 46).

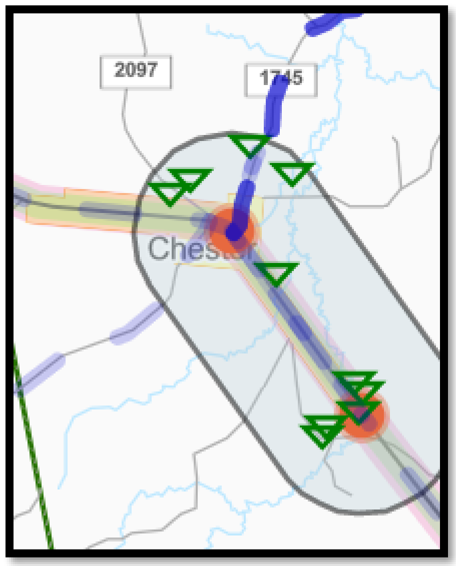

Figure 46. US 287 Location.

Base Course Condition

The pavement section consisted of 8 inches of full-depth reclamation (FDR) treated with 1 percent cement plus 3.5 percent CSS-1H emulsion. FDR took place the week of August 1, with all FDR on one side of the road completed by August 5. Traffic was allowed onto the FDR section at the end of each day. Figure 47 shows the unprimed FDR layer under traffic.

Figure 47. FDR Base Course on US 287 under Traffic prior to Prime.

Application of Prime

The contractor prepared the section by first blading and brooming the shoulder, which was also treated with the FDR process. Next, the contractor applied a skeet of water, followed by the distributor applying CSS-1H (with 40 percent residue) at a rate of 0.07 gal/sy. The distributor applied the oil within less than 10 minutes after the water truck. The contractor performed an adjacent pass with the water truck followed by the distributor to prime the shoulder. Figure 48 shows this second pass.

Figure 48. Applying CSS-1H on US 287 FDR Layer.

Performance with Application of Traffic

Traffic was allowed onto the primed surface after a couple of hours of cure time. No issues were encountered; Figure 49 shows traffic on the section.

Figure 49. Traffic on US 287 after Placing CSS-1H.

FIELD EVALUATION OF AE-P AS A PRIME IN THE BRYAN DISTRICT

This project was located in the Bryan District, in Grimes County south of Navasota, Texas (see Figure 50) near the SH 6 and FM 2 intersection. The plans called for an RC-250 with a Grade 5 aggregate; however, it was field changed to AE-P. The portion under construction that was primed was the detour pavement. The typical section from the plans is shown in Figure 51, and the plan view is shown in Figure 52.

Figure 50. SH 6 at FM 2.

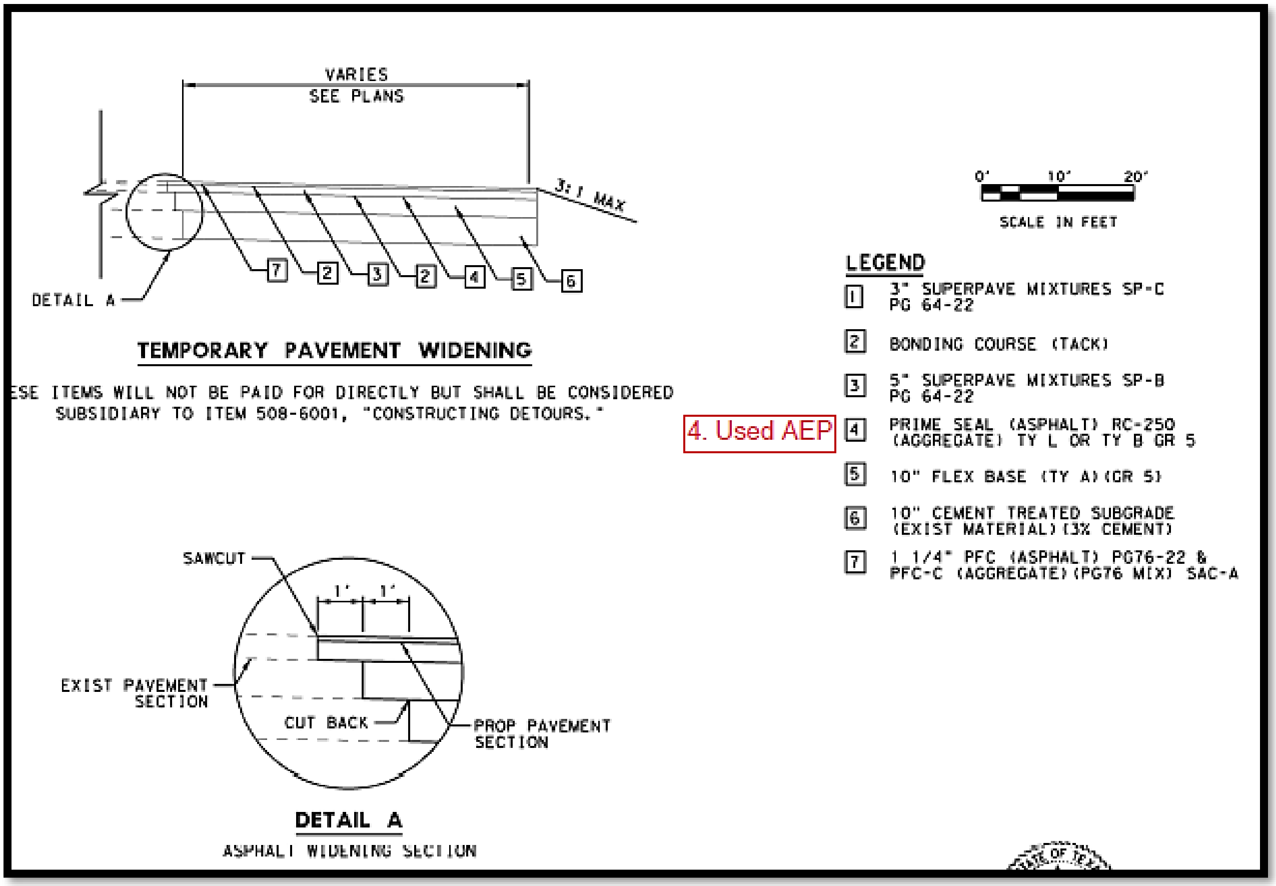

Figure 51. SH 6 Typical Section.

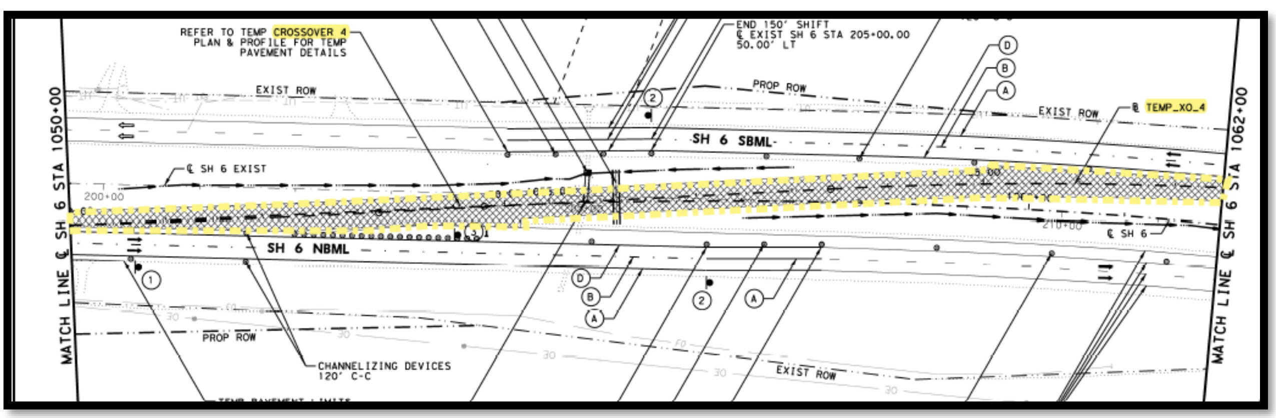

Figure 52. SH 6 Temporary Crossover 4.

The research team cored the primed pavement; however, the material that was cored did not provide good information since the coring operation affected the ability to remove an undamaged core (damaged from coring operation). The core location is shown in Figure 53. The prime could not be seen on the material obtained from the cores, as shown in Figure 54. Due to the problems obtaining field sites and retrieving testable samples, the research team documented the current state of practice on TxDOT construction projects without retrieving additional core samples.

Figure 53. SH 6 Coring Location.

Figure 54. SH 6 Cores.

FIELD EVALUATION OF AE-P AS A PRIME IN THE ODESSA DISTRICT

This project was located on US 385 in the Odessa District. The project was an FDR project where AE-P was used as prime. The FDR project had an 8-inch layer of treated material, 4 percent emulsion, and 1 percent cement. The AE-P was diluted at a 50 percent to 50 percent ratio of water to emulsion. The plan rate of 0.20 gal/sy was used and found to provide adequate coverage. Sections of the FDR layer were primed on June 16, 2023, and June 27, 2023. Material cured approximately 1 day to allow the 2 percent moisture dry back, and prime was placed, but the seal coat nor final surface had been placed at the time of review. The next layer was to be a seal coat and then an SMAR-F. Figure 55 shows the details.

Figure 55. US 385 Odessa District AE-P Prime.

CHAPTER 5. RECOMMENDATIONS

The objective of this research project was to determine where, when, and why a prime or cure is needed for a pavement layer. Materials such as prime coats, curing materials, seal coats, and tack coats are typically considered nonstructural but integral to the pavement structure. Some materials can be used for multiple purposes; however, the rates and timing of use may change depending on why the material is being used. Through a series of laboratory and field testing, guidance was developed to help designers, inspectors, and construction personnel understand the materials and where, when, and why to use them.

WHERE

Place prime on the top of a base course, both flexible and treated bases, for TxDOT base course Items 247, 251, 260, 275, 276, 290, 291, 292, and 351.

WHEN

For untreated materials—TxDOT base course Items 247, 251, or 351—place prime after density is achieved and curing is complete.

For cement- or lime-treated materials—Items 260, 275, 276, 351—place prime after density is achieved and before curing starts.

For asphalt-treated materials—Items 290, 291, 314, 351—place prime as soon as practical after density is achieved at a rate low enough to not impede curing.

WHY

As part of the flexible pavement design process, layers are assumed to be bonded. When comparing a prime to an unprimed base, the prime improved the bond in all laboratory testing. The use of the prime minimizes the risk of debonding, which can lead to premature pavement failures. The major purposes of prime coat are as follows:

- For untreated materials, TxDOT base course Items 247, 251, or 351:
    - Prime promotes bond to the next successive layer.
    - Prime helps minimize raveling by binding or stabilizing the surface particles of the base course.
    - Prime seals the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder.
    - Prime protects the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer.
- For treated materials, TxDOT base course Items 260, 275, 276, 290, 291, 314, or 351:
    - Prime promotes bond to the next successive layer.

- Prime helps minimize raveling by binding or stabilizing the surface particles of the base course.
- Prime helps prevent moisture loss from the treated base during the curing process (reduces the drying rate).
- Prime seals the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder.
- Prime protects the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer.

SELECTION OF PRIME TYPE

The recommendations presented here are based on the testing performed in this study and show the suggested primes and benefits for FB and CTB layers. Guidance for selection of a prime product is as follows:

- Flexible Base:
  - MC-30 and RC-250 with Grade 5 show high penetration and bonding strength across different temperatures, particularly effective in reducing water penetration.
  - AE-P has moderate effectiveness and is sensitive to moisture conditions, especially at higher application rates.
  - CSS-1H provides quick curing but lower bond strength compared to other primes, making it suitable for less demanding applications.
- Cement-Treated Base:
  - AE-P consistently provides high penetration and moisture prevention, particularly effective across a wide range of temperatures.
  - MC-30 and RC-250 with Grade 5 show strong performance in bonding and moisture control, especially in warm conditions.
  - CSS-1H is recommended as a good option due to its cost-effectiveness, though it has lower bond strength under high moisture conditions.

Table 42 through Table 44 contain a summary of the recommendations based on the following performance levels:

- 1—Desirable Level: suitable for standard conditions where the best performance is expected.
- 2—Acceptable Level: suitable for standard conditions where better-than-basic performance is expected.
- 3—Tolerable Level: minimum suitable for standard conditions where basic performance is sufficient.

Table 42. Prime Selection Based on Performance Factor for Flexible Base.

Condition	MC-30	AE-P	CSS-1H	RC-250	EBL
Moisture Loss	1	1	n/a	1	n/a
Permeability	1	3	2	2	2
Bond	1	2	2	3	3
Durability	1	3	2	2	2

Table 43. Prime Selection Based on Performance Factor for Treated Base.

Condition	MC-30	AE-P	CSS-1H	RC-250	EBL
Moisture Loss	1	1	1	2	1
Permeability	n/a	n/a	n/a	n/a	n/a
Bond	1	2	1	Not tested	3
Durability	1	3	1	Not tested	2

Table 44. Prime Selection Recommendations.

Base Type	Performance Level	Prime Type	Application Rate (gal/sy)	Key Benefits
FB	3	CSS-1H	0.15	Cost-effective, quick curing, suitable for dried base
FB	2	AE-P	0.19	Moderate bonding, better moisture resistance
FB	1	MC-30	0.15	High penetration, excellent waterproofing and bonding
FB	1	RC-250 with Grade 5	0.20	Superior durability, seals surface pores effectively
CTB	3	CSS-1H	0.14	Low cost, adequate bonding in moderate conditions
CTB	2	AE-P	0.19	Prevents moisture loss, improves bond strength
CTB	1	MC-30	0.15	High penetration depth, superior moisture control
CTB	1	RC-250 with Grade 5	0.2	Excellent bonding and penetration, especially in warm temperatures

MODIFICATIONS TO TXDOT 2024 SPECIFICATIONS

The specifications typically used for prime are Items 310 and 314. Item 316 is used for a prime—typically employing RC-250 and a Grade 5 aggregate—that is placed with the same requirements as a seal coat. In the plans, a prime being placed under Item 316 may be referred to as a seal coat, inverted prime, or prime. For future use with the proposed specification modifications, the material paid for under Item 316 that is intended to be a prime should be noted as such on the plans. The following are proposed modifications to TxDOT 2024 Specifications, written in special provision formatting:

Item 247

- Remove and replace 247.4.5 with:
    - **247.4.5, Curing**. "Cure the finished section until the moisture content is at least 2 percentage points below optimum or as directed before applying prime coat. Prime application rates shown on the plans are for estimating purposes only. Adjust the rates for existing conditions as directed. Allow the prime coat to cure as per the plans or the requirements in Item 310, Item 314, or Item 316 before applying the next successive course."

- **247.6, Payment**. Add the following to the second paragraph:
    - "When prime is shown on the plans or directed, it will be paid for in accordance with Item 310, 314, or 316."

Item 251

- Remove and replace 251.4.6 with:
    - **251.4.6, Curing**. "Cure the finished section until the moisture content is at least 2 percentage points below optimum or as directed before applying prime coat. Prime application rates shown on the plans are for estimating purposes only. Adjust the rates for existing conditions as directed. Allow the prime coat to cure as per the plans or the requirements in Item 310, Item 314, or Item 316 before applying the next successive course."

- **251.6, Payment**. Add the following to the third paragraph:
    - "When prime is shown on the plans or directed, it will be paid for in accordance with Item 310, 314, or 316."

Item 260

- Remove and replace 260.2.5 with,
  - "Asphalt. When asphalt or emulsion is shown on the plans or directed to be placed as a prime, furnish materials that meet the requirements of Item 300, 'Asphalts, Oils, and Emulsions.'"

- Remove and replace 260.4.10 with the following:
  - **260.4.10, Curing**. "When sprinkling is shown on the plans or directed, cure for the minimum number of days shown in Table 2 by sprinkling in accordance with Item 204. Maintain moisture during curing. Upon completion of curing, maintain the moisture content in accordance with Section 132.3.5., 'Maintenance of Moisture and Reworking,' for subgrade and Section 247.4.5., 'Curing,' for bases before placing subsequent courses. Do not allow equipment on the finished course during curing except as required for sprinkling, unless otherwise approved. Apply seals or additional courses within 14 calendar days of final compaction.

    When asphalt or emulsion is shown on the plans or directed instead of sprinkling, apply an asphalt material at a directed rate after finishing. Continue to maintain moisture by sprinkling until asphalt is applied. Prime application rates shown on the plans are for estimating purposes only. Adjust the rates for existing conditions as directed. Do not allow equipment on the finished course during curing unless otherwise approved. Apply additional courses within 14 calendar days of final compaction."

- **260.6, Payment**. Remove and replace the sixth paragraph with:
  - "When prime is shown on the plans or directed, it will be paid for in accordance with the applicable bid item."

Item 275

- Remove and replace 275.2.5 with:
  - "Asphalt. When asphalt or emulsion is shown on the plans or directed to be placed as a prime, furnish materials that meet the requirements of Item 300, 'Asphalts, Oils, and Emulsions.'"

- Remove and replace 275.4.10 with the following:
  - **275.4.10 Curing**. "When sprinkling is shown on the plans or directed, cure for at least 3 days by sprinkling in accordance with Item 204. When a section is microcracked, cure section for an additional 2 days after microcracking. Maintain the moisture content during curing at no lower than 2 percentage points below optimum. Continue curing until placing another course.

When prime is shown on the plans or directed, maintain the moisture by sprinkling in accordance with Item 204 until prime asphalt is applied. Apply prime after finishing is complete, at a directed rate. Prime application rates shown on the plans are for estimating purposes only. When a section is shown on the plans to be microcracked, cure section by sprinkling in accordance with Item 204 until microcracked. Continue to maintain moisture by sprinkling until prime asphalt is applied. After microcracking, apply prime asphalt as shown on the plans or directed in accordance with applicable bid items. Prime application rates shown on the plans are for estimating purposes only. Adjust the rates for existing conditions as directed."

- **275.6, Payment**. Remove and replace the sixth paragraph with:
  - "When prime is shown on the plans or directed, it will be paid for in accordance with the applicable bid item."

Item 276

- Remove and replace 276.2.4 with:
  - "Asphalt. When asphalt or emulsion is shown on the plans or directed to be placed as a prime, furnish materials that meet the requirements of Item 300, 'Asphalts, Oils, and Emulsions.'"

- Remove and replace 276.4.6 with the following:
  - **276.4.6, Curing**. "When sprinkling is shown on the plans or directed, cure for at least 3 days by sprinkling in accordance with Item 204. When a section is microcracked, cure section for an additional 2 days after microcracking. Maintain the moisture content during curing at no lower than 2 percentage points below optimum. Continue curing until placing another course.

    When prime is shown on the plans or directed, maintain the moisture by sprinkling in accordance with Item 204 until prime asphalt is applied. Apply prime after finishing is complete, at a directed rate. Prime application rates shown on the plans are for estimating purposes only. When a section is shown on the plans to be microcracked, cure section by sprinkling in accordance with Item 204 until microcracked. Continue to maintain moisture by sprinkling until prime asphalt is applied. After microcracking, apply prime asphalt as shown on the plans or directed in accordance with applicable bid items. Prime application rates shown on the plans are for estimating purposes only. Adjust the rates for existing conditions as directed."

- **276.6, Payment**. Remove and replace the fourth paragraph with:
  - "When prime is shown on the plans or directed, it will be paid for in accordance with the applicable bid item."

Item 290

- Item 290.6.7, remove and replace the first and second paragraph with:
  - "Cure the finished section until the moisture content is a minimum of 2 percent below the optimum moisture content, or as directed, before applying the next successive course. The Engineer may allow traffic on the finished section during curing when proof rolling indicates adequate stability. Apply fog seal daily at a rate between 0.05 and 0.10 gal per square yard in accordance with Item 315, "Fog Seal," when traffic is allowed on the finished section during curing, unless otherwise directed.

    Proof roll the roadbed in accordance with Item 216. If deformation occurs, do not allow traffic to return to the finished section until the mixed material is firm enough to accommodate traffic without deformation. Apply prime coat, seal coat, or additional courses within 14 calendar days of final compaction."

Item 291

- Item 291.6.7, remove and replace the second paragraph with:
  - "Proof roll the roadbed in accordance with Item 216. If deformation occurs, do not allow traffic to return to the finished section until the mixed material is firm enough to accommodate traffic without deformation. Apply prime coat, seal coat, or additional courses within 14 calendar days of final compaction."

Item 351

No changes recommended.

CHAPTER 6. VALUE OF RESEARCH

The savings determined for the value of research (VOR) assume that the seal coat is constructed with good application rates that are being adjusted as conditions along the roadway change. This will lead to improved quality of seal coats with significantly fewer premature failures. The VOR is determined by the assumption that monies currently being spent on immediate maintenance will be significantly reduced as the research is implemented.

The expected value duration is based on the expected average life (20 years) of a seal coat. Discount rate is based on the Office of Management and Budget Circular No. A-94 for the 20-year nominal interest rates on treasury notes and bonds, which is 4.7 percent. The expected value per year is based on a savings of maintenance costs for control of flushing and bleeding.

For this estimated VOR, it was assumed that TxDOT rehabilitation projects with base courses to be primed for each district are 20 mi in length, with an average width of 28 ft (conservative estimate of base used per year). This results in 8,213,333 sy/yr, when it is assumed that 1 percent of projects have immediate maintenance needs. The additional maintenance is estimated to be flexible pavement repair ($115.00/sy). The expected savings will be a result of reduced repairs due to base failures.

Table 45 contains the basic project values and the savings per year. Figure 56 is a graph of the change in value over time with the net present value shown for each year. Table 46 contains the VOR benefit areas.

Table 45. TxDOT VOR Form Basic Data.

Description	Value	Years	Expected Value	Years	Expected Value
Project #	0-7103	0	$9,445,333.33	11	$15,654,196.74
Project Name	Investigating Prime versus Curing: Where, When, and Why	1	$9,889,264.00	12	$16,389,943.98
Agency	TTI	2	$10,354,059.41	13	$17,160,271.35
Project Duration (yr)	3.0	3	$10,840,700.20	14	$17,966,804.10
Expected Value Duration (yr)	20	4	$11,350,213.11	15	$18,811,243.90
Project Budget	$525,000.25	5	$11,883,673.13	16	$19,695,372.36
Exp. Value (per yr)	$9,445,333.33	6	$12,442,205.76	17	$20,621,054.86
Discount Rate	4.7%	7	$13,026,989.43	18	$21,590,244.44
Economic Value Total Savings	$122,133,143	**8**	$13,639,257.94	19	$22,604,985.93
Payback Period (yr)	0.055583	**9**	$14,280,303.06	20	$23,667,420.27
Net Present Value (NPV)	$99,234,639	**10**	$14,951,477.30		
Cost Benefit Ratio (CBR, $1 :$_)	$189				

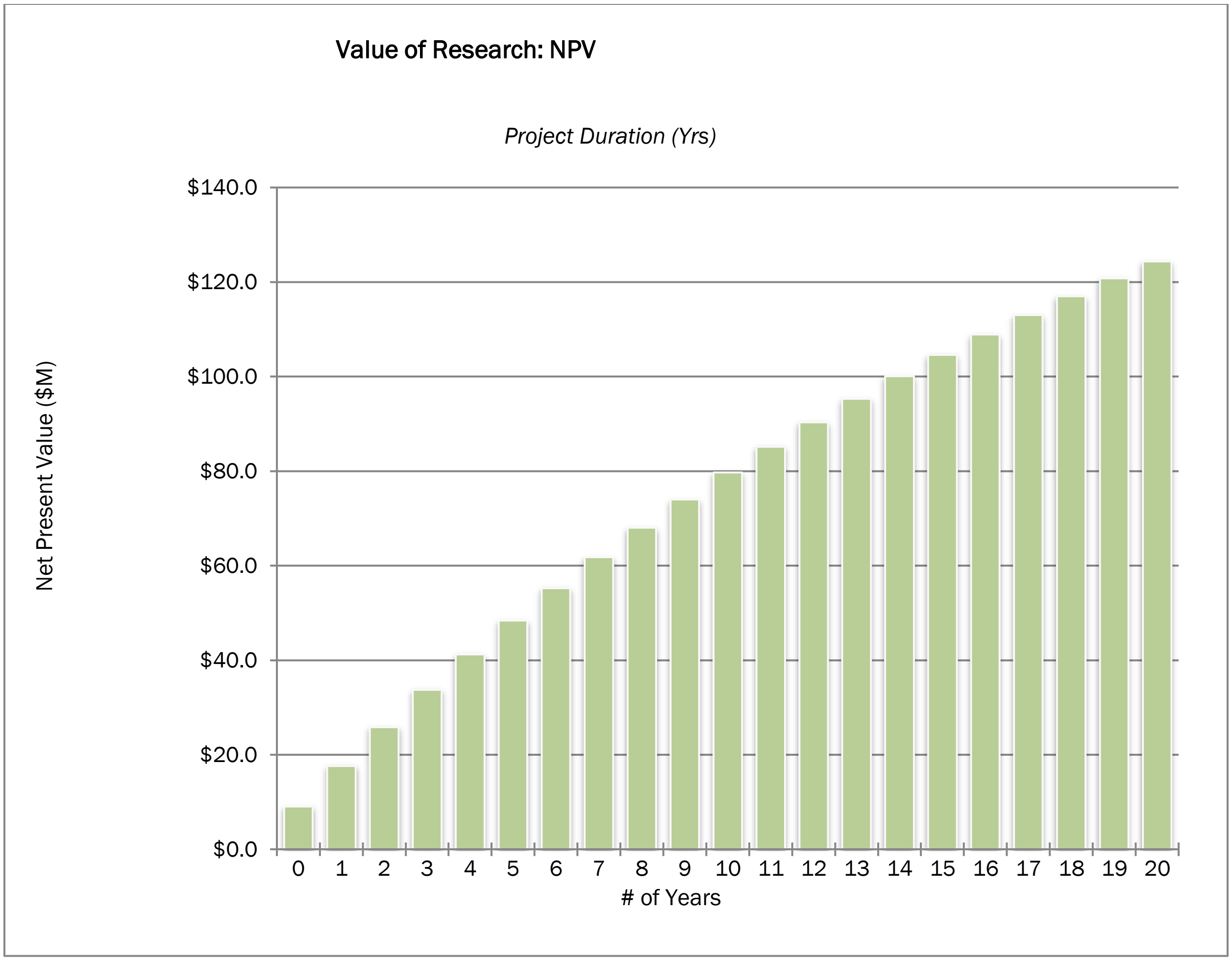

Figure 56. VOR, Net Present Value.

Table 46. VOR Benefit Areas.

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in Context to the Project Statement
Level of Knowledge	X			X			This project will significantly increase TxDOT's understanding of prime, including when, where, and why it is used.
System Reliability		X		X			This project will promote improving overall pavement structure, which will minimize early maintenance treatments, thereby reducing user delays and unforeseen costs to TxDOT.
Increased Service Life		X		X			By using prime appropriately, the service life will be as expected without premature failures.
Reduced User Cost		X			X		By constructing a good pavement structure, the user cost will decrease by avoiding lane closures and delays due to repairs of premature failures.
Reduced Construction, Operations, and Maintenance Cost		X			X		A reduction in premature failures will save on unexpected maintenance costs.
Materials and Pavements		X			X		This project will provide a better understanding of prime material.
Infrastructure Condition		X				X	This project will improve the condition of the existing structure by maintaining the expected service life. Quality of construction will improve the infrastructure network condition.

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