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TEXAS PAVEMENT PRESERVATION CENTER
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Evaluation of the Curing Time and Other Characteristics of Prime Coats Applied to a Granular Base

Our Mission

The mission of the TPPC, in joint collaboration with the Center for Transportation Research (CTR) of the University of Texas at Austin and the Texas Transportation Institute (TTI) of Texas A&M University, is to promote the use of pavement preservation strategies to provide the highest level of service to the traveling public at the lowest cost. The executive sponsor for the TPPC is the Texas Department of Transportation (TxDOT).

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Past and Upcoming Events

TPPC Microsurfacing Courses

Microsurfacing training courses will be offered by the TPPC. The course is designed for engineers and inspectors and is entitled “Guidelines on the use of Microsurfacing.” The course recapitulates the pavement preservation concepts, specifically with reference to microsurfacing. It focuses on proper mix design selection and application of microsurfacing. TxDOT’s experience with microsurfacing is also discussed. This course also includes discussion on the use and applications of cape seals.

TPPC Seal Coat Training Courses

Seal Coat training courses will continue to be offered by the TPPC. The course designed for inspectors, entitled “Seal Coat Inspection and Applications,” focused on proper inspection methods and the equipment used during chip seal construction. The other, “Seal Coat Planning and Design,” instructed engineers on planning, designing, and constructing chip seals.

For more information on the Seal Coat and Microsurfacing courses, please contact Dr. Yetkin Yildirim, P.E. at yetkin@mail.utexas.edu or (512) 232-3084.

Introduction

Background information

The overall performance and stability of pavements are of utmost importance to meet the needs of the growing population. To reduce the risk of premature failure and improve the stability of flexible pavements, prime coats are applied as a coating of low viscosity binder on top of a compacted granular base before application of subsequent courses (Freeman, Button and Estakhri, 2010). The application of prime coat material to the top of compacted granular bases is a standard operating procedure in the construction of asphalt pavements and is even considered mandatory at times.

Prime coat applied on the top of the prepared soil base is often left exposed to the weather for a few days so that the carrier evaporates, thereby curing the prime coat. Prime coat curing requirements vary significantly from state to state. In some cases, only a visual assessment is done to determine whether the prime coat has cured or not, but this practice is not satisfactory. Thus, it is extremely important to determine the minimum time required for curing and how the curing time would vary under different weather conditions for different prime coats.

Flexible pavements

An understanding of the importance and function of prime coats begins with an understanding of flexible pavements as a whole. A typical cross section of a flexible pavement with a prime coat which consists of five layers is presented below in Figure 1.

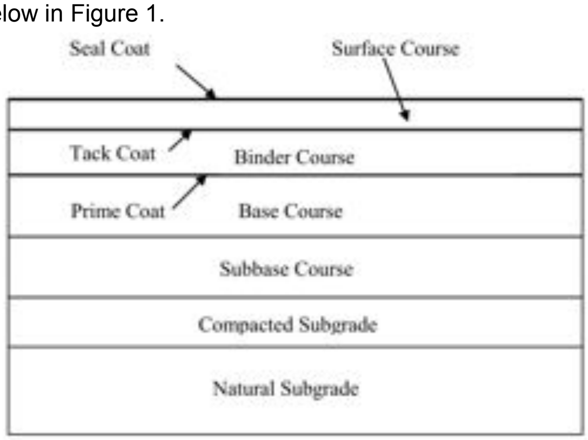

Figure 1 Cross section of a flexible pavement (Modified from Huang, 2004)

The surface course comes in direct contact with the traffic loads and mainly consists of multiple layers of hot mix asphalt (HMA). A seal coat is generally provided on top of the HMA layers to prevent infiltration of water or to provide skid resistance (Huang, 2004). The binder course also called the asphalt base course is mainly provided for two reasons: 1. HMA is too thick to be compacted to one layer so the binder course provides an additional layer. 2. Use of a binder course results in a more economical design.

A tack coat is provided between the surface course and the binder course to ensure a good bond between the layers. The base course consists of aggregates which cannot be damaged by moisture or frost. It should be stiff and thick enough to provide overall stiffness to the pavement structure as a whole. A prime coat is provided on top of the base course to protect the integrity of the granular base during construction and bind the granular base to the asphalt layer. The subbase course provides structural support, minimizes frost action damage and improves the drainage. The subgrade refers to the existing soil and it can be treated to improve its properties if it is not suitable for construction.

Prime Coats

After outlining all the layers of a flexible pavement, the function and importance of proper prime coat application can be better appreciated. ASTM defines prime coat as "an application of a low-viscosity bituminous material to an absorptive surface, designed to penetrate, bond, and stabilize the existing surface and to promote adhesion between it and the construction course that follows."

The main purpose of providing a prime coat is to prevent water from penetrating into the base, thus waterproofing the base. Along with this purpose, a prime coat performs various functions such as:

1. Binding the surface fines together so as to provide a good bond with the HMA layer
2. Increasing the bond strength between the compacted base and the HMA layer
3. Providing a stabilized base by penetrating and filling voids present in the base
4. Strengthening the base by binding together the finer particles of aggregate and permeating into the base
5. Temporarily protects the surface from unfavorable weather conditions and light traffic until the overlying courses are constructed
6. Preventing the lateral movement of the base during construction activities.

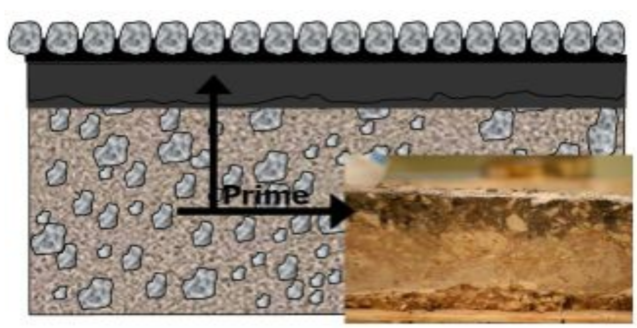

Figure 2 Schematic Showing Prime Coat Penetration into Base with Photographic Inset Showing Actual Penetration in a Laboratory - Compacted Limestone Base

Prime coat materials mainly consist of cutback asphalt, emulsions/emulsified asphalt or polymer based chemicals. Cutback asphalt is manufactured by blending asphalt cement with petroleum solvent, and emulsified asphalt consists of a suspension of asphalt cement in water.

For stabilized bases, the most widely used prime coat material worldwide is MC-30, a cutback, (Ishai and Livneh, 1984), due to its high penetration capacity. Cutback asphalts have been the most widely used prime coat materials for a long time, but when compared to other prime coats, cutbacks release a higher amount of volatile organic compounds (VOCs) into the atmosphere. For this reason, emulsions and polymer based materials are becoming more and more popular due to their less harmful effects on the environment. As per the information obtained from TxDOT, in Texas the most commonly used prime coat materials are MC-30, AEP, EC-30, CSS-1H and SS-1H. Out of this group, MC-30 is a cutback, AEP is an emulsified cutback, EC-30 is an environmentally friendly alternative to a prime coat and, CSS-1H and SS-1H are emulsions. Different prime coat types can be found from Figure 3 to Figure 5:

Figure 3- Spray Prime (MC-30, AE-P)

Figure 4- Worked-in (Cut-in) Prime

Figure 5- Covered (Inverted) Prime

The use of a prime coat can be omitted if the surface is not going to be exposed to wet weather and the base can be covered within seven days. Also, use of prime coats are not advised in the winter season when prime coats have difficulty curing, as placing the HMA layer on an uncured base is riskier than placing it on an unprimed base. The reason is that the excess prime on the surface can cause slippage of the pavement surface.

To ensure the functioning of a prime coat, it needs to be cured completely. Curing time is the time required for the evaporation of most of the carrier from the prime coat. Application of subsequent layers or allowing traffic to travel on the coated layer is only done after the prime coat is completely cured. The curing time of prime coats depends on a number of factors; namely, type of prime material, application method and rate, weather conditions, dilution rate, properties of the base material and other factors (Freeman, Button and Estakhri, 2010). Systematic investigation on prime coat properties is also crucial to make informed decisions.

A research study sponsored by TPPC was conducted at TxDOT to investigate the properties of prime coat most commonly used in Texas.

Considering the lack of data on the time required for curing of different prime coats and the extent to which each of these factors cited above affect the curing time, the primary objectives of this research are the following:

1. Determination of the curing times of prime coats most commonly used in Texas and how the application method and weather conditions affect the curing time, and

2. Compare the strength, permeability and penetration of the prime coats tested and also study the effect of application method on these properties.

Literature review

Upon reviewing the literature, it was found that extensive information has not yet been published in this field, despite the fact that prime coats have been in use for decades. Very little information has been published on prime coat application techniques, test methods to evaluate prime coats in the field and in the laboratory, relative performance of prime coats, selection of prime coats and also the appropriate curing times for prime coats under different conditions (Freeman, Button and Estakhri, 2010). In this part, a summary of all publications related to prime coats covering most of the aspects related to prime coat application are presented.

According to Mantilla and Button (1994), a prime coat should always be applied to a compacted granular base before the application of a bituminous surface treatment or an asphaltic pavement with a thickness less than 3 inches. A prime coat is also necessary in the case where there is a delay in the application of subsequent courses and the base may be damaged due to weather or traffic.

Design of prime coat materials

Senadheera and Vignarajah (2007) concluded that the design of any prime coat consists of three basic components:

- Selection of suitable priming method- Suitable priming methods can include mixing the prime coat into the top layers of the base or spraying of prime coat onto the base.
- Selection of prime coat material- Prime coat materials can be broadly divided into two categories, namely, cutback asphalt and emulsions or emulsified asphalt.
- Selection of an appropriate application rate- There are mainly four different ways in which prime coats can be applied to the prepared base. Senadheera and Vignarajah (2007) described these four methods as follows: 1. Spray Prime 2. Worked-in or Cut-in Prime 3. Inverted Prime or Covered Prime 4. Mixed-in Prime

Before the application of a prime coat, it should be established that the surface of the base is structurally strong, reasonably smooth and porous, and free from any dust.

Penetration of prime coats

One of the main purposes of the prime coat is to provide a good bond between surface treatment and base. The binders used in surface treatment courses do not have a viscosity low enough to penetrate the base layer. A prime coat, which is a low viscosity binder, when applied will act as an intermediary between the base and the surface coat so as to ensure a good bond between both. Thus, it is clear that adequate penetration is necessary for a prime coat to serve its purpose.

Figure 6 shows the penetration observed in emulsions and cutbacks. In this figure, the top left picture shows an emulsion (CSS-1H) which was applied on the surface and the top right picture shows that the emulsion did not penetrate at all into the sand after 24 hours and it peels off from the surface. Bottom left is the picture of MC-30 prime coat (cutback) application and bottom right shows the penetration obtained by MC-30 after 24 hours. It can be seen that the penetration obtained by cutbacks is more than that of emulsions.

Figure 6- Penetration observed in emulsions (top) and cutbacks (bottom)

Functional and structural role of prime coats

Prime coats do not provide any significant amount of structural benefit. The unbound layer of material is stabilized by the addition of a prime coat but it does not increase the load bearing capacity of a pavement significantly (Cross, Voth and Shrestha, 2005).

Environmental issues

Environmental issues can be broadly classified into air and water quality issues.

Air quality issues

Cutback asphalts are a major source of volatile organic compounds (VOCs) and VOCs are the primary pollutant of concern from asphalt paving operations. With the awareness of the detrimental effects of VOCs to the ozone layer increasing, there has been a reduction in the use of cutback asphalt as prime material.

Water quality issues

Hazardous chemicals may be present in prime coat materials in very small quantities (in concentrations less than the reportable quantity (RQ)). Generally, in a normal paving operation, these RQ values are never reached. The Resource Conservation and Recovery Act (RCRA) determines what the reportable quantities are, but it may be different (lower) in case of state/local jurisdictions and the suppliers or local agencies should be contacted in case of a spill (Cross, Voth and Shrestha, 2005).

Experimental Design and Testing Procedures

Material used:

Limestone base soil which is commonly found in Texas was used as the base material throughout the testing program. However, for this study, equal weights of rushed limestone passing through sieve #10 and retained on sieve #40, and passing through sieve #40 were mixed and used to prepare the specimens.

This study looks into cutbacks, emulsions, emulsified asphalt and polymer based prime coat materials. The most commonly used prime coat in Texas is MC-30. CSS-1H and SS-1H are the emulsions that have been included in this study. EC-30 is a completely organic prime coat material which is harmless to the environment. EC-30 will not clog spray machines, has little or no odor and can even be applied using a pressurized hand garden sprayer. Top Seal Black is an environmentally safe polymer based prime coat which is applied after dilution with water. Prime coats which were included in this study and the suppliers of these prime coats to TxDOT are listed below in Table *1*.

Table 1 Prime coat materials used in this study

Prime Coat	Type	Suppliers
MC-30 (Medium Curing)	Cutback	Valero, TX
AEP (Asphalt Emulsion Prime)	Emulsified Cutback	Ergon, Waco, TX
EC-30 (Eco Cure)	Emulsion-Non bituminous	PrimeEco, TX
CSS-1H (Cationic Slow Setting Hard Base)	Emulsion	Ergon, Waco, TX
SS-1H (Slow-Setting Hard Base)	Emulsion	Ergon,Mt.Pleasant, TX
TP - (Terra Prime)	Polymer based Emulsion	Terra Pave International, TX

Specimen preparation procedure:

The method of specimen preparation can have a significant effect on the properties (curing time, strength and permeability) and thus is important while interpreting the results later on. Only two application methods, spray prime and mixed in prime, were included in this study. For this study an application rate of 0.20 gallons per square yard was used. Taking into consideration the size of the container and by making the necessary calculations, the amount of prime coat material required per specimen was determined to be 7.3 milliliters per square millimeter. The specimen preparation procedure is shown below in Figure 7.

3. Compact the soil.

4. Spray or mixed-in prime coat.

5. Expose the specimen to weather to cure.

6. Run analysis.

Figure 7 Specimen preparation procedures

Testing procedure

Tests were performed to determine the curing time, strength, permeability and penetration of the specimens prepared using different prime coats.

Soil specimen were tested in three different weather conditions, namely Test Season 1, Test Season 2, Test Season 3, to reflect the weather condition in Texas, as shown in Table 2.

Table 2 Testing Seasons

Testing Season	Testing Period	Temperature (°F)		
		Maximum	Minimum	Average
1	October	87.6	47.5	69.6
2	November-December	81.4	30.2	58.1
3	February-March	88	20.5	55.4

Tests to Determine Curing Time

For each testing season, at least five different prime coats were tested. For each prime coat, samples were prepared using two application methods: spray and mixed-in.

Weather information was collected using weather station in TxDOT. Air temperature, solar radiation, humidity and wind speed are expected to have significant impact on curing time.

The curing time of all the prime coats was mainly affected by temperature and temperature had a negative correlation with curing time. MC-30 took the longest time to cure in all three different weather conditions and EC-30 cured the fastest in all three different weather conditions. Curing times of the various prime coats increased in the order EC-30<SS-1H<AEP<CSS-1H<MC-30. Terra Prime (TP) has not been included in the comparison for curing times as it was tested in a weather condition different from the other prime coats.

The average curing time for each specimen is shown below:

MC-30 sprayed specimens

Testing Season	Curing time (days)	Average Daily Temperature/ 12- Hour Daytime Temperature (°F)
1	8	69.6/75.6
2	11	58.1/66.9
3	12	55.4/61.6

MC-30 mixed-in specimens

Weather Condition	Curing time (days)	Average Daily Temperature (°F)
1	11	69.6/75.6
2	12	58.1/66.9
3	13	55.4/61.6

EC-30 sprayed specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1	1	65.9/71.6
2	7	57.8/66.7
3	8	57.2/63.3

EC-30 mixed-in specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1	3	65.9/71.6
2	8	57.8/66.7
3	9	57.2/63.3

CSS-1H sprayed specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1	7	70.4/77.4
2	9	57.8/65.0
3	10	57.2/63.9

CSS-1H mixed-in specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1	8	70.4/77.4
2	10	57.8/65.0
3	11	57.2/63.9

TP sprayed specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1st Set	7	71.9/91.0
2nd Set	6	72.7/92.3

TP mixed-in specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
3	9	57.2/65.7

AEP sprayed specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1	7	71.7/78.0
2	7	57.7/67.3
3	9	57.2/65.7

AEP mixed-in specimens

Testing Season	Curing time (days)	Average Daily Temperature/12-Hour Daytime Temperature (°F)
1	7	71.7/78.0
2	8	57.7/67.3
3	9	57.2/65.7

Strength Test

Strength tests were done to understand how well prime coats would resist oncoming traffic loading and how they would behave under such loading conditions. This process can be explained in detail with the Figure 8. When a wheel moves on top of the aggregates, it applies a pressure to the aggregates which in turn applies a pressure on the prime coat. So it is important to compare the strengths of different prime coats to see how effective they will be in the field. The strength of the cured samples was determined using a pocket penetrometer.

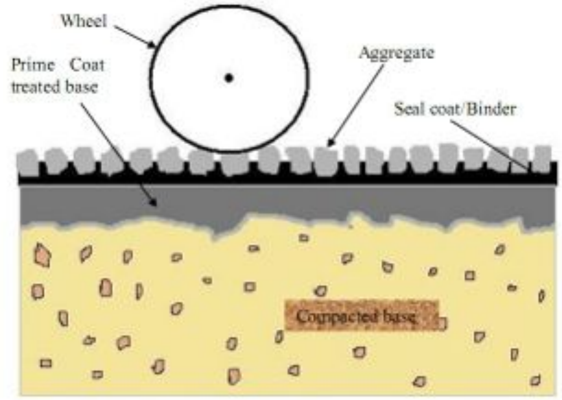

Figure 8 Pavement section showing penetration of prime coat

The values obtained from strength tests for both sprayed prime and mixed-in prime are presented together in Figure 9. The strength obtained was higher for mixed-in prime application than in sprayed application for emulsions CSS-1H (only slight increase in strength) and SS-1H (almost a 23% increase in strength). Thus, mixing emulsions into the top layer of the soil not only ensures sufficient penetration but also increases the strength. For EC-30, the strength of mixed-in specimens was slightly more than that of sprayed application. But in the field, EC-30 is always applied by spraying the prime coat on the surface because this method ensures maximum penetration. The strengths slightly decreased in case of MC-30, AEP and TP when the application method used was mixed-in prime.

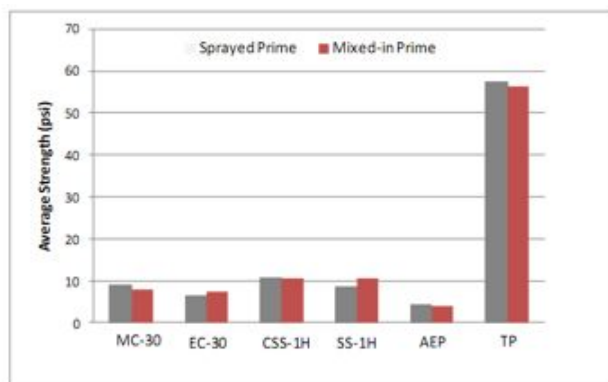

Figure 9 Comparison of strength for sprayed prime coats and mixed-in prime coats

Permeability Test

This study looks into how effectively each prime coat prevents the penetration of water into the base material. The effectiveness of a prime coat in reducing the permeability will depend on the size and distribution of pores and how well the prime coat moves into these pores.

The application rate, application method and depth of penetration will also influence the permeability.

The cured samples were taken and weighed. After weighing, 100 ml of water was poured onto the surface of each sample and was allowed to stand on the surface for 10 minutes. After 10 minutes, the amount of water still standing on the surface of the sample was decanted and weighed. This quantity when subtracted from 100 ml will give the amount of water that actually penetrated into the surface (V ml). From the amount of water absorbed, the coefficient of permeability was calculated in the following way:

Volume of water absorbed = V ml = V cm3

Time taken to absorb V cm3 of water = t seconds

= 600 seconds

Area of the surface on which water is in contact = A cm2

= 81.03 cm2

Assuming the hydraulic gradient to be constant,
Coefficient of permeability (cm/s), k, = V/At

These values were calculated for each sample and an average value was found for each prime coat. From these set of values, a comparison was made between the permeability characteristics of the prime coats tested. A comparison was also made to see how the application method affects the permeability rate.

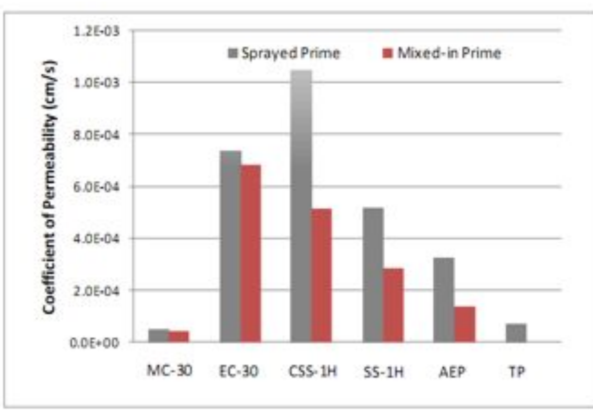

Figure 10 Comparison of permeability for sprayed prime and mixed-in application types

A comparison between the coefficients of permeability for the two different application types is presented in Figure 10. The coefficient of permeability is always lower for mixed-in prime coat when compared to the sprayed application. Since in the mixed-in prime application, the top layer is mixed with the prime coat, it covers the pores present on the base more effectively than in the sprayed application, thus reducing the permeability. But for TP mixed-in specimens, a large number of cracks were seen along the sides of the container and therefore, the permeability for TP mixed-in specimens could not be calculated. It can also be concluded from the above chart that emulsions such as CSS-1H, have a higher permeability when compared to cutbacks such as MC-30.

Penetration Test

Penetration achieved by a prime coat will determine how efficiently and effectively it can serve its purpose. Penetration achieved by prime coat must be adequate enough to ensure a good bond between the surface treatment and base. To study the penetration performance of the different prime coats that were tested, a sand penetration test was conducted. The testing procedure described below is commonly used by TxDOT to determine penetration depths of prime coats.

Initially, 62.5 grams of sand was taken and mixed with 1 gram of water. 3 oz. metal ointment tin containers were filled with this sand to a depth of 45 millimeters. Six such containers were made to test the six different prime coats used in this study. The sand in the container was then compressed to a compaction pressure of 100 psi using a load frame. 5 grams of the prime coat was measured and applied to the surface at a constant speed. The prime coat should be applied from a height of 40 to 50 inches from the top of the container. The specimen is allowed to stand for 24 hours. After 24 hours a vertical cross section of the sand and the visible penetration depth (in microns) is measured using vernier calipers. Figure 11 shows the process of cutting through the specimen to determine penetration depths of prime coats. A comparison was made between the penetrations achieved by the different prime coat materials.

Figure 11 Penetration test for prime coat

A comparison is shown in Figure 12. The penetration obtained was the maximum for EC-30 and minimum for CSS-1H and SS-1H. Emulsions have very little penetration when compared to cutbacks or polymer based prime coats. It just covers the surface without penetrating into the base. The penetration values decrease in the following order: EC-30>MC-30=TP>AEP>CSS-1H=SS-1H.

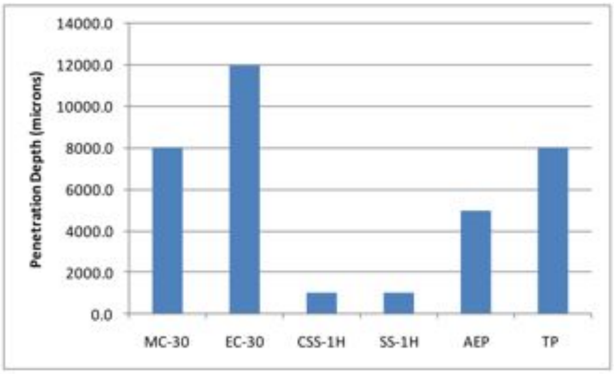

Figure 12 Comparison of penetration for various prime coat materials

Summary and Ranking

The time required for curing of different prime coats were determined under three different testing seasons. Based on the curing times, strength tests, permeability and penetration tests, a ranking in terms of performance in each of the intended functions is presented in Table 3. All prime coats are ranked from 1 to 5, with 1 being the best and 5 being the worst. The prime coat with the least curing time will be ranked 1, and the prime coat which takes the most number of days to cure will be given a ranking of 5. In the same way the prime coat with the maximum strength, least permeability and most penetration will be ranked 1 in their respective categories. Curing times, strength and permeability values are averages for both mixed-in and sprayed specimens. TP was not included in the comparison for curing time as the testing for TP was done when the weather conditions were different from the weather conditions existing for testing season 1, 2 or 3. Some of the materials have been given the same ranking because the values obtained for the respective properties have negligible difference.

Table 3 Ranking of prime coats in terms of performance in intended functions

Prime coat	Curing Time	Dry Strength	Wet Strength	Permeability	Penetration
MC-30	3	2*	2*	1*	2*
EC-30	1	4*	3*	4	1
CSS-1H	2*	2*	3*	5	4*
SS-1H	2*	2*	2*	3	4*
AEP	2*	4*	3*	2	3
TP	-	1	1	1*	2*

- 1 being the best for the intended purpose and 5 being the worst
- * indicates a tied ranking

Recommendations and future studies

The range of temperatures for which this study was conducted is small. The average daily temperature range was from 55°F to 75 °F. It would be beneficial to extend the temperature range to higher and lower temperatures to determine the effect of these temperatures on curing times. If more data was collected for curing times under a wider range of weather conditions, mathematical expressions could be derived that show the dependence of curing time on different weather parameters. Correlation analysis could be performed to determine which of the weather parameters have the more significant effect on curing time. And, using these correlations, multivariable regression analysis could be carried out to determine mathematical expressions for each prime coat.

Only six different prime coats were tested to determine the curing times in this study. Curing time also depends on the type of base material used, but throughout this study only one type of base material was used. The same study could be extended to a larger number of prime coats and base materials, and the effect of weather factors on the curing time could be evaluated for each one of them separately. Since, curing time for all the specimens depends on temperature, it would be interesting to know the exact effect of temperature on curing time. If an experiment were conducted in a controlled environment, the exact effect of the various weather parameters could be analyzed.

The application rate used throughout this study was a constant. Therefore, the effect of change in application rate on the curing time could not be evaluated. By using different application rates, the application rate gives the minimum curing time with the maximum strength and penetration could be determined for each prime coat.