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Engineering Properties of Prime Coats Applied to a Granular Base

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ABSTRACT: Prime coats have been widely used to protect sub-base layers during pavement construction. The engineering properties of a prime-coated base course play an important role in the overall stability of a pavement system. In this study, prime coats MC-30, AEP, EC-30, CSS-1H, SS-1H, and terra prime (TP) were used for testing. Strength and permeability of the specimens were measured. Crushed limestone was used as the base course. The prime coats were either sprayed on or mixed with the base course to evaluate the effect of the application method. In addition, penetration of the prime coats into reference sand was evaluated. For the conditions of this study, according to a developed ranking system, the best performing prime coats were TP and MC-30, with slightly better performance from TP. The results provided here can be used as a guideline for selecting the proper prime coat for field applications.

KEYWORDS: pavement, prime coat, base course, emulsion, cutback

Introduction

Prime coats are described as the low-viscosity binders that are applied on the base course of a pavement before constructing the subsequent layers. Prime coats are usually preferred if the base course is exposed to weather for at least seven days, or if the road is going to carry light traffic before hot mix asphalt (HMA) application [1]. Prime coats provide an interface between the base and the surface layer that promotes adhesion by filling voids. The main purpose of prime coat application is to provide a waterproof base to protect the subsequent layers against wet weather conditions [2].

Another function of prime coats is to bind the surface fines together; thus, the binder material used in the prime coat should be strong and durable [3]. Several researchers have emphasized that a good bond between pavement layers is required to achieve higher strength and longer pavement life [4–8]. It should be noted that prime coats are not used to bind loose dust on the base course [9]. Dust on the compacted base should be removed before prime coat application. In addition, penetration of the binder material is required to have good bonding. Usually 5 to 10 mm of penetration into the base course is considered adequate [10].

Prime coat materials can be classified under two main groups: cutback asphalt and emulsified asphalt. Cutback asphalt is a mixture of asphalt cement and petroleum solvent. Emulsified asphalt is a suspension of asphalt cement in water. Cutback asphalts are commonly used in practice and provide satisfactory penetration depths. In contrast, emulsified asphalt consists of relatively larger particles (2 μm to 8 μm), thus, can not penetrate into the hard surface of the prepared base. When sprayed, emulsified particles can collect on the top of the base grade and form a sticky, black "skin" [11]. Therefore, spraying emulsified asphalt-based prime coat material may not be an effective method for field implementation.

There are mainly four types of prime coat application methods: spray prime, worked-in prime, covered prime, and mixed-in prime [3]. Research presented here focuses on spray prime and mixed-in prime application methods. For the spray prime method, the prime coat is applied on to the compacted base course using an asphalt distributor. The application rate of spraying should be slow enough that the base course will absorb the prime material uniformly and leave behind a thin and quick drying film on the surface without any puddles. Usually 0.9 to 2.3 l of prime coat is sprayed per m^2 of the surface [12]. For the mixed-in prime method of application, the uppermost 5 to 8 cm of the base course is mixed with diluted emulsion and the mixture is compacted to the required density. The surface is usually sprayed with diluted emulsion for a better bond with the subsequent layers. For mixed-in prime coats, typically 0.2 to 0.5 l of prime is used per m^2 per 1 cm depth in the base course layer.

Although prime coats have been used in practice for decades, there are a limited number of studies published investigating their performance. Chellgren [13] stated that prime coat could not be considered as a glue between the base and the pavement, but its purpose is to protect the base from rain and light traffic, when paving is delayed. However, several other researchers indicated that

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bonding between the pavement and base material coated with prime coat was important in reducing the risk of failure [12]. Mantilla and Button [14] performed direct shear and torsional shear tests on primed bases to determine their performance under two different normal stresses, i.e., 50 kPa and 100 kPa. MC-30 and AEP type prime coats were used in the study. The results showed that the strength of specimens with prime coat was higher, as compared to unprimed specimens. It was also observed that conventional emulsified asphalt materials did not penetrate into the base grade effectively. Mixing the emulsified asphalt material with the top 25 mm to 50 mm of the base course was considered the best alternative application method.

There are several environmental concerns with using cutback asphalt in prime coats. One of the concerns is that cutback asphalt has a relatively low flashing point. According to a manufacturer, MC-30 has a flashing point between 120° and 140°F. This low flashing point poses a potential fire hazard during manufacturing and construction in the field. In addition, the loss of volatile organic compounds (VOCs) into the atmosphere is a major environmental concern. Usually, after application of the prime coat, the base course is not covered so that the asphalt material can cure for several days. During the curing period, evaporation of petroleum in cutback asphalt causes the emission of volatile organic compounds into the atmosphere which creates air-quality problems. Ishai and Livneh [15] reported that only 40 to 60 % of the VOCs evaporated from MC-30 and MC-70 after 7 days. During the construction process, inhalation of these vapors may cause headache, dizziness, and nausea among workers. In addition, physical exposure to kerosene in cutback asphalt may cause dermatitis [16].

Engineering properties of the prime-coated base course layer play an important role in the overall performance of a pavement system. In this study, engineering properties of one cutback asphalt and several emulsified asphalt prime-coated base coarse specimens were investigated. The prime coat materials were either sprayed on or mixed with the base grade. Strength and permeability tests were performed on the cured specimens. Penetration depths of primes into a reference sand were also measured. Finally, a ranking system was developed to compare the performance of tested prime coat materials.

Materials

The base course material for all specimens was a combination of crushed limestone passing through #10 sieve (opening size = 2 mm) and retained on #40 sieve (opening size = 0.42 mm), and passing through #40 sieve in equal weights. The optimum water content and the maximum dry density of the crushed limestone were measured to be 6.7 % and 21.7 kN/m^3, respectively.

Table 1 gives the properties and suppliers of the six prime coats used in this study. MC-30 is a type of cutback asphalt which is a mixture of high viscosity asphalt cement with a petroleum solvent. 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. Terra Prime is an environmentally safe polymer-based prime coat which is applied after dilution with water. Except for MC-30 and AEP, all the other prime coat materials are water-based prime coats.

Specimen Preparation

Specimens were prepared for strength, permeability, and sand penetration tests. For the strength and permeability tests, all specimens were placed in sample cans with dimensions of 10.2 cm in diameter and 6.1 cm in height. The prime coats were applied to the base course either by spraying or mixing in. For the spray-prime specimens, 300 g of crushed limestone was placed into the sample can in three lifts. Each lift was compacted by ramming 25 times. The specimens were compacted using a wooden rammer. After compaction, the prime coat material was sprayed evenly on the top of the soil. 0.91 per square meter of prime coat was used per square yard of the cross section. For the given dimensions and amounts, the required volume of prime coat was calculated as 7.3 ml. The weight of the sample can was measured before and after the prime coat application. TP prime coat had to first be diluted with water before application. 50 ml of water was mixed with approximately 7.3 ml of TP. The entire diluted mixture was applied in two sessions; first, 45 ml of the diluted TP was applied to the base course and, as in the field, after 2 days the remaining portion was applied.

For the mixed in prime specimens, 300 g of crushed limestone was used as the base course. Initially, 200 g of crushed limestone was placed into the can in two layers. Each layer was compacted by ramming 25 times. The last 100 g of the soil was mixed thoroughly with 7.3 ml of prime coat. This mixture was placed in the can as the top most layer and was compacted using 25 blows.

For the penetration tests, a type of reference sand was used as the base course. The gradation of the reference sand is given in Table 2. For the base course, 62.5 g of sand was mixed with 1 g of water. The sand was filled into a sample can with 10.2 cm

TABLE 1—*Prime coats used for performance evaluation.*

Prime Coat	Name	Type	Suppliers
MC-30	Medium curing	Cutback	Valero
EC-30	EcoCure	Emulsion-non-bituminous	PrimeEco
CSS-1H	Cationic slow setting hard base	Asphalt emulsion	Ergon
SS-1H	Slow setting hard base	Asphalt emulsion	Ergon
AEP	Asphalt emulsion prime	Asphalt emulsion-cutback mixture	Waco
TP	Terra Prime	Polymer-based emulsion	Terra Pave International

TABLE 2—*Gradation of the reference sand.*

Sieve	Percentage Passing by Weight or Volume
#80	98–100
#100	94–100
#140	45–55
#200	0–4

diameter and 6.1 cm height up to a height of 4.5 cm. The sand was compressed by applying 689 kPa pressure using a loading frame.

Test Procedures

Strength Tests

Strength tests were performed to determine how well the prime-coated base course would resist ongoing traffic loading. Figure 1 shows a schematic of a pavement section under such traffic loading. As seen, a concentrated load from passing traffic is transferred to the base course through the aggregate particles. As previously stated, a seal coat is a surface treatment placed on a granular base (unlike a chip seal which is placed on an existing paved surface). The materials and construction quality of the base course greatly affect the performance of the surface treatment, but the integrity of the base itself relies heavily on prime coats. In many applications, traffic loads are carried mainly by the base layer. Because of the role of the base layer, increase in the strength of this layer from the prime coat will help support the traffic loads. Base layers are unbound structures and prime coats are able to bind the particles in the upper part of the base layer, which improves the load carrying capacity. In this study, the strength test gave an idea about the effect of different types of prime coat materials on the load bearing capacity of the base layer.

The most common failure associated with a prime coat application is delamination of the surface treatment from the base when potholes and small breaks develop in poorly bonded areas. Strong bonding of granular materials in the base layer helps to prevent these problems. The compressive strength of the specimens was measured using a pocket penetrometer, because this equipment applied a point load which was similar to the field condition where the load was transferred through the aggregate particles. Figure 2 shows the pocket penetrometer used for this study. As of the date of submission of this manuscript, there was no ASTM standard for the use of a pocket penetrometer. The penetrometer reading was verified by pressing it on a precision scale and comparing the read-outs. Because of the small cross-sectional area of the specimens, the diameter of the tip of the penetrometer was modified from 6.4 mm to 1.0 mm. For each specimen, strength was measured at five points. The average of these five measurements was reported.

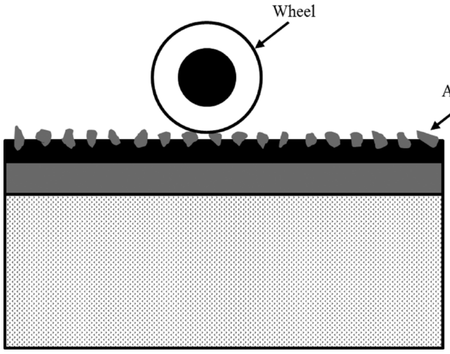

FIG. 1—*Typical pavement section after application of prime-coat and seal coat.*

FIG. 2—*Pocket penetrometer.*

Permeability Tests

To measure the permeability of the specimens, an approach similar to the ASTM D5856 test method for permeability was used [17]. In this approach, first, the initial weight of each specimen in the can was measured after curing. 100 ml water was poured on to the surface of each specimen and allowed to stand for 10 min. After 10 min, 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. Assuming a constant hydraulic gradient, the change in the volume of water was determined to calculate the coefficient of permeability using Darcy's equation,

$$k = \frac{V}{A \cdot t}$$

where k is the coefficient of permeability, V is the volume of water penetrated into the soil, A is the cross-sectional area of the specimen, and t is the time interval the test was performed, which was 10 min for all permeability tests.

Penetration Test

Sand penetration tests were performed to determine how much prime coat would penetrate into the reference sand placed as the base course. Five grams of the prime coat was poured onto the

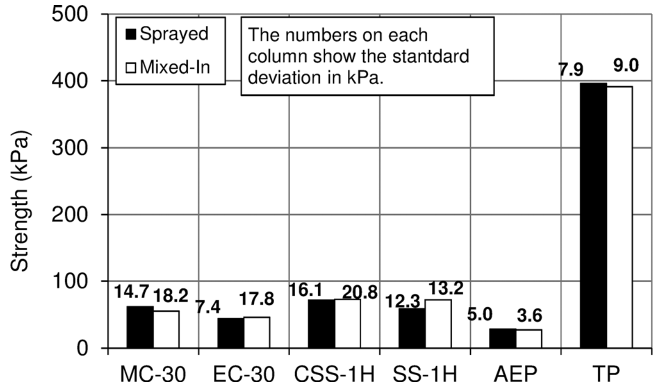

FIG. 3—*Strength and standard deviation of dry sprayed and mixed-in specimens.*

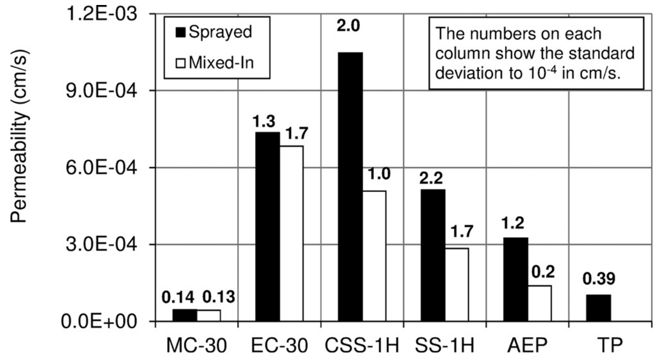

FIG. 5—*Permeability and standard deviation values of sprayed and mixed-in prime coat materials.*

sand surface at a constant speed from a height of approximately 11 cm. The specimen was allowed to stand for 24 h. Then, the specimen was cut in the vertical direction and the penetration depth of the prime coat into the sand was measured using a vernier caliper.

Results

Strength Tests

For each application method, a total of 10 samples were tested for each type of prime coat. Strength tests were performed on both dry and wet cured specimens. After measuring the dry strength, a permeability test was performed on the specimen. After the permeability test, the strength was measured again on the wet specimen in a second location. Figures 3 and 4 show the average strength values for dry and wet specimens, respectively. The numbers on each data column show the standard deviation of the results in kPa for each prime coat and application method. For the dry specimens, the standard deviation of the strength tests varied between 3.6 and 20.8 kPa. The results showed that for dry specimens, the application method generally did not have a significant effect on strength. The mixed-in SS-1H specimen had 23 % larger strength than the sprayed specimen. For all other prime coats, the difference in strength for the different application method was equal to or less than 12 %. The lowest strength was measured for the specimen with AEP. The strength of the specimen with TP was more than five times larger than the specimens with other prime coats. The strengths of all wet specimens, except the ones with TP, were less than or equal to the detectable limit of the pocket penetrometer (24.5 kPa). In Fig. 4, if the measured strength value was lower than the detectable limit, its strength value was conservatively assumed as 9.8 kPa. The strength of all specimens were lower when they were wet. The wet strength of the specimen with TP was the largest and approximately 395 kPa.

Permeability tests were performed on 10 specimens for each prime coat and each application method. The values which were greater than or less than two times the standard deviation were considered as outliers and were excluded from the average permeability calculations. This discrepancy was observed only for two tests. In addition, mixed-in TP specimens had cracks around the sides of the sample cans; therefore, coefficient of permeability values for these specimens could not be measured.

Figure 5 shows the average coefficient of permeability values for sprayed and mixed-in specimens. The numbers at the top of each data column indicate the standard deviation of the results for that particular type of prime coat and application method. The results show that mixed-in specimens had consistently lower permeability values than the sprayed specimens. The permeability values of the mixed-in specimens were 4 % (MC-30) to 57 % (AEP) smaller than the sprayed specimens. This difference shows that mixing the prime coat with the base layer increased the efficiency of the application. It can be also observed that the

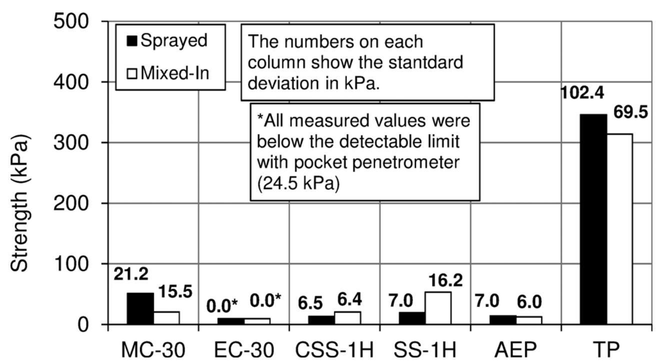

FIG. 4—*Strength and standard deviation of wet sprayed and mixed-in specimens.*

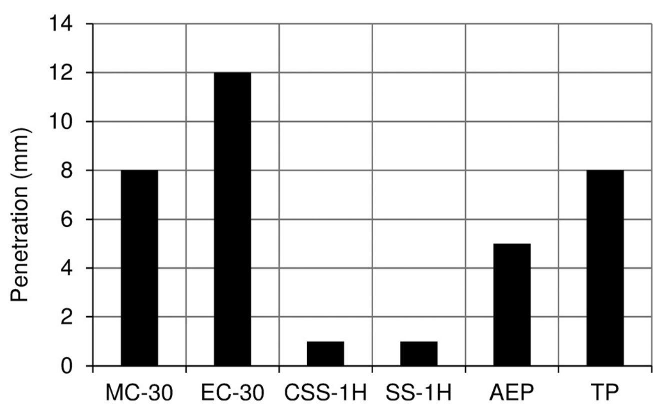

FIG. 6—*Penetration values measured for different prime coats.*

TABLE 3—*Performance ranking of prime coat materials.*

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

Note: *Indicates tied ranking.

specimens with MC-30 and TP had relatively smaller permeability values when compared to the other prime coats.

Sand penetration tests were performed on six specimens with different prime coats. Figure 6 shows the penetration depths of prime coats into the reference sand after 24 h. The results show that maximum penetration was measured for EC-30. After EC-30, maximum penetration depths were measured for MC-30 and TP. Penetration depths of emulsions such as CSS-1H and SS-1H were significantly lower when compared to other prime coats. It was observed that these two primes did not penetrate into the base material but formed a sticky coat on the surface of the reference sand.

Discussion

To compare the performance, the results of the tests for each prime coat and application method were ranked taking into account the desired behavior which was maximum strength, lowest permeability and maximum penetration. Each prime coat was given a score for each test between 1 and 5, with 1 being the best and 5 being the poorest in performance. If the results were similar for several prime coats, the same score was assigned to them.

Table 3 shows the performance rankings for all primes. TP was ranked number one in three tests and number two in one test. MC-30 ranked number one in one test and number two in three tests. According to the developed ranking system, the best performing prime coat was TP and the second best was MC-30. Some of the materials have been given the same ranking because the values obtained for the respective properties had negligible difference.

Conclusions

In this study, strength, permeability, and sand penetration tests were performed on specimens prepared in the laboratory using six different prime coats. For strength and permeability tests, the prime coat was applied either by spraying on the surface or mixing with the top layer of the base course. For the given conditions and specimens, this study revealed the following results:

- The dry strength of the specimens with TP was approximately five times greater than the dry strength of the specimens with other prime coats. The strength of the wet TP specimen was almost the same as the dry one. Other specimens had significantly lower strengths when they were wet than when they were dry.
- Mixing the prime coat with the base course instead of spraying it decreased the permeability of water. The lowest permeability values were measured for the specimens with MC-30 and TP.
- In sand penetration tests, the maximum penetration was observed for EC-30. After EC-30, maximum penetration depths were measured for MC-30 and TP. CSS-1H and SS-1H had significantly smaller penetrations and formed a sticky coat on the surface.
- Using the developed ranking system, the best overall performance was exhibited by TP. The second best performance was observed for MC-30.
- The results indicated here provide a guideline for selecting the prime coat for an actual pavement design.

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