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16. Abstract

A prime coat is the application of a suitable bituminous binder applied to a non-bituminous granular base as a preliminary treatment before the application of a bituminous surfacing. The purpose of this research is to establish practical applications of successful prime coats to replace cutback asphalt. An investigation was conducted in order to (1) examine the importance of the bond between the base and various types of surface courses, (2) explore materials and construction techniques to improve prime coat performance, (3) evaluate alternative prime materials in the laboratory, and (4) develop specialized test procedures for prime coats.

Laboratory tests were developed to (1) measure the penetration of prime materials in a granular base, (2) measure the shear strength of the different alternatives and evaluate the importance of the prime coat in strengthening the interface between the asphalt layer and the granular base layer, and (3) evaluate the benefits of specific construction methods in providing additional stability to the pavement system.

Field evaluations of the different alternatives were performed. End-to-end test pavements were constructed using different prime coat products and construction techniques. Construction and early performance of the different alternatives were monitored.

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PRIME COAT METHODS AND MATERIALS TO REPLACE CUTBACK ASPHALT

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Research Study Title: Improved Prime Coat Methods

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IMPLEMENTATION STATEMENT

This study characterizes prime coat materials and processes and ascertains their benefits and limitations in an attempt to help TxDOT transition from the use of cutback asphalts for priming to the use of materials containing little or no volatiles. This study identified a process routinely utilized in the Austin District where standard emulsified asphalt is successfully applied as a prime. Actually, two alternative priming procedures were identified: one involves mixing the emulsion into the upper stratum of the base during the normal construction process, whereas the other involves compaction of the base followed by scarification, mixing in the emulsion, and recompacting. The "Guidelines for Application of Emulsified Prime Materials" (Appendix D) describe in detail the alternative processes. This guideline is ready for immediate implementation.

This study evaluates several emulsified products which contain little or no asphalt. These are essentially emulsified naphthenic and/or aromatic oils which may contain from zero to about 12 percent asphalt. These emulsified products typically do not penetrate as deeply as cutback asphalts nor do they have the binding power of cutback asphalts. As a result, they do not provide prolonged protection of the base from rainfall and traffic as well as cutback asphalts. However, these products should be considered as viable prime alternatives in certain situations. When the planned construction sequence is such that the compacted base must carry light traffic for no more than two weeks, these products may provide a non-polluting alternative to cutbacks. Actual performance depends on the particular prime product, level of traffic, intensity and duration of rainfall, and the type of base material. The guideline (Appendix D) lists several of these materials which have been effectively used to prime compacted bases.

A simple laboratory test method was developed for measuring penetration depth and penetration rate of prime materials in a sample of the base material to be used on the roadway. This test appears promising but needs more work. The ability of this prime penetration test to help determine the suitability of a prime material for a specific compacted base material should be evaluated. Laboratory penetration results need to be recorded and compared with resulting field performance (actual penetration depth and rate, resistance to traffic and weather, etc.) of various primes over a period of a few years to validate the laboratory procedure and establish criteria for specifications.

DISCLAIMER

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The authors wish to acknowledge the guidance and assistance of the Technical Panel. Mr. Joe Higgins, P.E., served as Project Director. Members of the panel were Mr. Will J. Parks, P.E., and Mr. Clifton E. Coward. They provided assistance in designing the laboratory and field experiments, assisted in preparation of the construction guidelines, and provided guidance in the overall prosecution of this research study.

Mr. Jim Hanks, P.E. of the Bryan District and Mr. Joe Higgins, P.E. of the Abilene District contributed pavement construction projects to accommodate the field trials and provided assistance in setting up and performing the evaluations.

Mr. Danny L. Smith, P.E. of the Austin District assisted the researchers in collecting video on construction projects in which a special priming procedure was used. He also reviewed the construction guidelines prepared as part of this work and made suggestions to improve their utility.

Final typing of the manuscript was performed by Ms. Lupe M. Fattorini.

The work was sponsored and funded by the Texas Department of Transportation in cooperation with the Federal Highway Administration.

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SUMMARY

Historically, a prime coat has been applied using a distributor truck to spray a thin coating of cutback asphalt onto the surface of a fully compacted lime or cement stabilized or unstabilized base. Cutback asphalt is a solution of asphalt cement and petroleum distillate. The prime coat cures by evaporation of the distillate into the atmosphere. To reduce the obvious pollution problem associated with this process, some agencies have attempted to replace cutback asphalt with emulsified asphalt. Since emulsions are not pure solutions, but rather colloidal suspensions, penetration of the asphalt into the compacted base has typically been unsatisfactory. Furthermore, some emulsified prime materials that have proven successful in penetrating a compacted base are nothing more than emulsified cutback asphalt and, as such, do not provide a solution to the pollution problem associated with cutbacks.

Laboratory and field tests were performed to examine the important functions of prime coats and establish practical applications for successful prime coat materials to replace cutback asphalts. Specific objectives were:

- To examine the importance of the bond between the base and various types of surface courses,
- To explore materials and construction techniques to improve prime coat performance,
- To evaluate alternative prime materials in the laboratory, and
- To develop specialized test procedure for evaluation prime coats.

Since there are neither standard methods for prime coat sample preparation nor standard tests to evaluate primed laboratory specimens, this study had to develop these procedures. Sample preparation procedures attempted to simulate as closely as possible the field application process. Tests developed and used in this study to evaluate various prime materials and prime application techniques included:

1. Torsional shear at the primed interface,
2. Direct shear at the primed interface,
3. Penetration depth and penetration rate, and
4. Cohesion of a fully cured primed layer.

These procedures were used to characterize prime coats, to evaluate different materials and application processes, and to examine the importance of the bond between the primed base and the subsequent pavement layer.

End-to-end field tests were constructed near Snyder and Bryan to evaluate different prime materials including asphalt and non-asphalt products. Researchers visited construction sites in the Austin District on several occasions to familiarize themselves with a successful prime application process which involved mechanically mixing emulsified asphalt into the top 25 to 50 millimeters (1 to 2 inches) of a base during construction. The "mixing in" priming processes used in the Austin District have been used in a few other districts but are not being used routinely. Since these processes appear to be viable solutions to priming relatively high traffic facilities without the use of cutbacks, the construction guidelines in Appendix D describe these processes. In addition, an instructional video was developed.

The researchers submitted several conclusions and recommendations based on laboratory and field experiments.

CHAPTER 1

INTRODUCTION

A prime coat is the application of a suitable bituminous binder applied to a non-bituminous granular base as a preliminary treatment before the application of a bituminous surfacing. The prime coat is designed to perform several functions including (1):

- To promote adhesion between a granular base and a subsequently applied bituminous surface by precoating the surface of the base and by penetrating the voids near the surface,
- To help seal the surface pores in the base, thus reducing the migration of moisture and preventing the absorption of the first spray of surface binder,
- To waterproof the base,
- To help strengthen the base near its surface by binding the finer particles of aggregate, and
- To provide the base with temporary protection against the detrimental effects of weather and light traffic until the surfacing can be constructed.

A prime coat must be capable of wetting and penetrating the dust film covering a compacted granular base and coating the aggregate particles with a strongly adhering film of bituminous binder. It must also be capable of penetrating the surface of the base, normally to a depth between 5 mm and 10 mm on dense graded bases (1).

Using existing construction specifications and technology and available material, the most effective means of priming a flexible base layer is to use a cutback asphalt. However, the use of cutback asphalts is under scrutiny. Their use is currently limited and may be disallowed by future regulations.

It is necessary to identify asphalt emulsion modifiers, non-asphalt materials and/or construction techniques that can be used to apply prime coats without using cutbacks. The most common alternative to cutback asphalt for the construction of prime coats is emulsified asphalt.

Because emulsified asphalt consists of discrete particles of asphalt ranging from about 2 to 8 microns in size, they will not normally penetrate well compacted bases with dense, tight surfaces. If the spaces between soil particles are small, the soil acts as a filter, screening out the emulsified particles. The emulsified asphalt particles collect on the surface, forming a sticky, black "skin." There are, however, emulsified products that will penetrate fine soils. These emulsions contain non-volatile oils and resins with viscosities lower than that of asphalt and may contain little or no asphalt (2).

BACKGROUND

In years past, most paving engineers specified some type of cutback asphalt (MC-30, MC-70, etc.) for successful prime coats. Due to a greater awareness of air pollution associated with the use of cutback asphalt in pavement construction, the use of slow setting and sometimes medium setting emulsified asphalt for prime coats has become more prevalent.

Emulsified asphalt is a liquid product in which a substantial amount of finely divided bitumen is suspended in water by means of one or more emulsifying and stabilizing agents. The nature and quantity of the emulsifying and stabilizing agents control the type, stability, and setting rate of an emulsion. There are two types of bitumen emulsion, namely, anionic and cationic (3).

Anionic emulsion contains emulsifying and stabilizing agents of an alkaline nature. The bitumen content is variable depending upon its final application. Anionic emulsions are classified according to their setting (or breaking) times into rapid setting (RS), medium setting (MS) and slow setting (SS). Rapid-setting emulsion is one that is characterized by rapid breakdown on application. RS emulsion may be diluted with water at a concentration that normally does not exceed a ratio of 1 to 1 by volume. Medium-setting emulsions have sufficient stability to permit mixing with aggregate before break occurs. They may be diluted with water at a concentration that generally does not exceed 2 to 1 by volume. Slow-setting emulsions have sufficient mechanical and chemical stability for all purposes including mixing with densely graded aggregates, soils, or finely divided materials of small maximum size. They may be used for soil stabilization and for light applications where a high dilution rate with water (1 or more by volume) is required. (3)

Cationic emulsions contain emulsifying and stabilizing agents of an acidic nature. Cationic emulsions may provide better bonding than anionic emulsions with acidic types of aggregate, such as siliceous materials, and in damp conditions (3). Cationic emulsions are classified according to their setting (or breaking times) into rapid setting (CRS), medium setting (CMS) and slow setting (CSS). Rapid setting emulsions are characterized by rapid break on application. Slow setting emulsions are suitable for soil stabilization.

An inverted emulsion is one in which cutback asphalt is the continuous phase and water is the colloidal phase. Inverted emulsions have been used as primes to provide improved penetration, but these products typically contain only about 20 percent less solvent than cutback asphalt (4). Inverted emulsions can not be diluted with water.

Emulsified asphalts have been used successfully in many applications once dominated by cutback asphalts, such as stockpiled patching mixtures, tack coats, cold-mix base and subbase, and mixed-in-place construction. Prime coats require a binder that penetrates soil or untreated aggregate.

Most of the research conducted on prime coats has concentrated on the penetration of emulsified asphalts. The Arizona Highway Department sponsored a research project to evaluate the penetration of SS-1h and CSS-1h among other objectives. Wetting agents were used to improve penetration of these emulsions. A traditional spray method of application for prime coats was simulated in the laboratory. They reported unsuccessful penetration of these emulsions (5).

The need for a prime has been the subject of heated debate in engineering circles for years. Are they really functional? Primes appear to be most useful on untreated bases to protect the surface from erosion by wind, rain, and traffic during pavement construction. With full-depth asphalt construction or when using asphalt stabilized bases, a prime coat is not needed (2).

The Federal Highway Administration, South Carolina Division, sponsored a research program (6) for improving the design and construction specifications of surface treatments for secondary roads in South Carolina. Field trial sections were constructed to evaluate surface treatment design as well as several variations in materials and construction procedures. The construction variables were selected to determine the effect of prime coats. The investigators concluded that a prime should be applied prior to all surface treatments to avoid delamination.

Penetration should not be the only criteria when selecting a specific prime coat product. A comprehensive evaluation of the properties of a specific product should be performed to determine its suitability to perform all functions that a prime coat needs to provide.

PURPOSE AND SCOPE

The overall objective of this research is to establish practical applications of successful prime coat materials and/or techniques to replace cutback asphalt. Specific objectives of this research include the following:

1. To examine the importance of the bond between the base and various types of surface courses,
2. To explore materials and construction techniques to improve prime coat performance,
3. To evaluate alternative prime materials in the laboratory and field,
4. To develop specialized test procedures to evaluate prime coats, and
5. To develop construction guidelines for priming a compacted base.

CHAPTER 2

SUPPORT FOR THEORIES USED IN TESTING AND ANALYSIS

There are frequent examples where, even at the completely exposed and unsupported edge of a bituminous pavement, no indications of instability have developed after years of traffic. These unsupported pavement edges are stable under traffic, either because of the high compressive strength of the paving mixture or because bituminous materials can develop additional resistance to lateral flow, quite apart from the lateral support normally provided by adjacent pavement material, or both. (7)

Figure 1 illustrates the resistances developed when a horizontal force, *L*, is applied to an isolated section of bituminous pavement held between two rough flat surfaces carrying a vertical load. It is apparent that the horizontal pressure, *L*, applied as shown, will develop frictional resistance, *s*, between the pavement and each of the two rough surfaces. That is, frictional resistance can be developed between the pavement and the two rough surfaces equivalent to a horizontal pressure, *L*. In Figure 2, the section of bituminous pavement is subjected to sufficient vertical load, *V*, to cause it to flow laterally. Figure 2 demonstrates that, as the vertical load attempts to squeeze out the paving mixture, its lateral movement is opposed by the frictional resistance, *s*, developed between the pavement and tire and between pavement and base. It is apparent from both Figures 1 and 2 that this frictional resistance between the pavement and tire and pavement and base is equivalent to a lateral support, *L* . (7)

The shearing stress in material that is squeezed between two rough parallel plates is at a minimum on the plane parallel to and midway between the two plates. The maximum shearing stress occurs at the boundaries between the plates and the material. In the case of a bituminous pavement squeezed between a tire and the base course, it seems reasonable to assume, therefore, that the maximum shearing stress is developed at the interfaces between pavement and base. (7)

The maximum frictional resistance that can be mobilized between the pavement and base can be expressed as a function of a coefficient of friction, *g*, and the uniformly applied load , *V*, as follows: (7)

$$s = Vg.$$

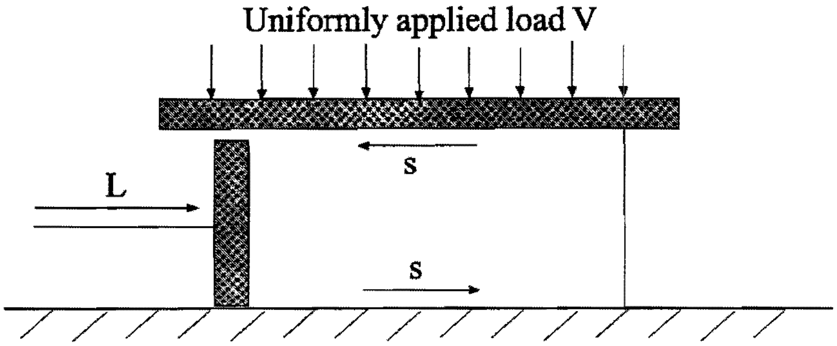


Figure 1. Diagram of an Isolated Section of Bituminous Pavement Held between Two Rough Flat Surfaces Carrying a Vertical Load (After Ref. 7).

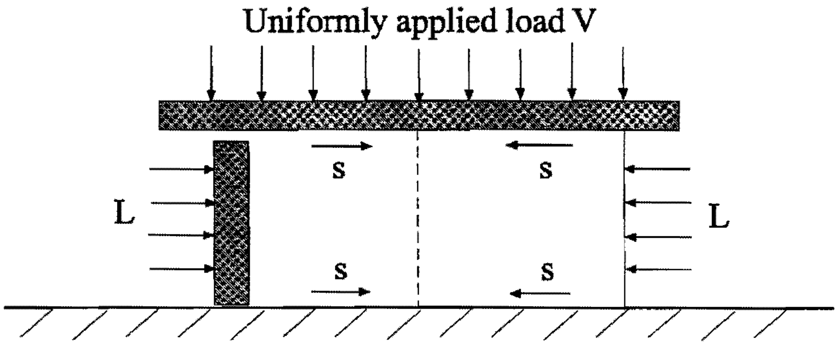


Figure 2. Diagram Showing the Frictional Resistance Developed between Pavement and Base, between Pavement and Tire, and Lateral Support L (After Ref. 7).

Moyer (8) and Giles and Lee (9) routinely measure values of the coefficient of friction between pavements and tires. However, no data are available in the literature concerning actual values for the coefficient of friction between the pavement and the base.

The bonding condition between the base and the finishing layer plays an important role in the pavement's performance. Some computer models such as Bisar contain equations which account for different bonding conditions. This interface has been analyzed in terms of friction, slip factor, and slippage factor. It seems more appropriate to analyze it in terms of strength. Friction occurs when there is an internal or external force trying to displace an element from its original location. There is also an internal force that keeps the elements together, namely, cohesion. The Mohr model suggests that the total shear strength is a function of cohesion of the material and angle of internal friction (7). The resistance to displacement of the asphalt layer over the base is a function of both the bond (cohesion) between the two layers, and the angle of internal friction developed at the interface. Analyzing the interface in terms of cohesion and angle of internal friction permits one to determine what materials and construction methods improve the strength of the interface.

The theories of shear stresses in a solid mass, shear strength of soils, and some standard test procedures used to measure the shear strength of soils and other materials are presented below. The concepts and limitations of selected test procedures performed in this investigation are described. Concepts of the vane and torvane shear test are presented because they were the bases used to develop a test procedure to measure the cohesion of a primed granular base.

SHEARING STRESS

Shearing stresses act parallel to a plane as distinguished from tensile and compressive stresses which act normal to a plane. Loadings that produce shear conditions of principal interest in materials testing are (10):

1. The resultants of parallel but opposed forces act through the centroids of sections that are spaced "infinitesimal" distances apart. It is conceivable that the shearing stresses over the sections should be uniform and a state of pure direct shear would exist.

2. The applied opposed forces are parallel, act normal to a longitudinal axis of a body, and are spaced finite distances apart. Then, in addition to the shearing stresses produced, bending stresses are developed.
3. The applied forces are parallel and opposite but do not lie in a plane containing the longitudinal axis of the body. A couple is set up which produces a twist about a longitudinal axis. This twisting action of one section of the body with respect to a contiguous section is termed torsion. Torsional shearing stresses on circular cross sections vary from zero at the axis of twist to a maximum at the extreme fibers. If no bending is present, "pure shear" exists.

At any point in a stressed body, the shearing stresses in any two mutually perpendicular directions are equal in magnitude (10). If at a point on some pair of planes, only shear stresses act, the material at that point is said to be in "pure shear." These shear stresses are greater than those on any other plane through the point. Figure 3, which represents an elementary block on which the stresses are uniformly distributed, illustrates the pure shear condition.

On all planes inclined to the plane of maximum shear, normal tensile or compressive stresses act, and on mutually perpendicular planes at 45° with the planes of maximum shear, the tensile and compressive stresses are a maximum and the shear stress is zero (10). The maximum normal stresses are equal in magnitude to the maximum shearing stresses. Conversely, equal and normal stresses induce pure shear, as shown in Figure 4. Figure 5 shows the Mohr circle representation of the state of stress induced by pure shear.

In the common theory of torsion, it is assumed that plane sections remain plane after twisting. The circular section is the only one that conforms to this condition; hence, the simple theory of torsion does not apply to sections other than those of circular form. Various stress and strain relations for cylindrical elements in torsion are stated below in terms of the following symbols: (10)

T = torque or torsional moment,

J = polar moment of inertia = $\pi r^4 / 2$,

ϕ = shearing strain,

r = outside radius of a cylindrical element, and

L = distance between collars of strainometer (gage length).

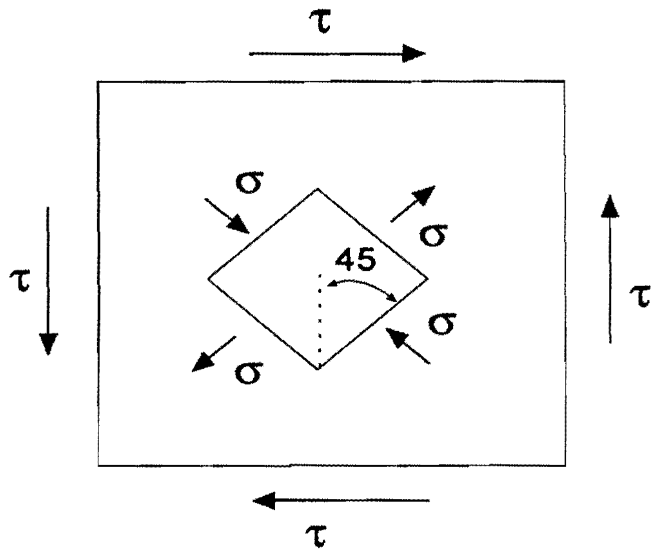


Figure 3. Pure Shear Condition, σ = τ (After Ref. 10).

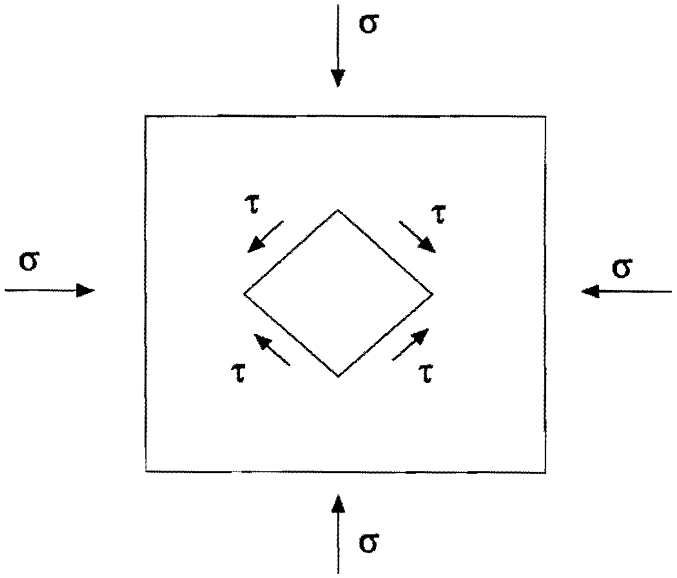


Figure 4. Pure Shear Induced by Primary Normal Stresses, σ = τ (After Ref. 10).

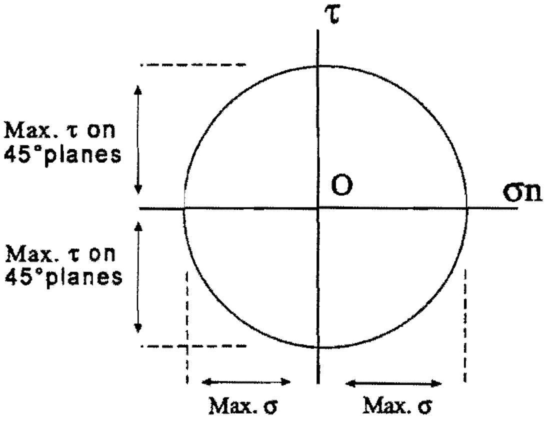


Figure 5. Mohr Circle Representation of State of Stress Known as Pure Shear (After Ref. 10).

By summing up the stresses over a cross section, the relation between shearing stress on extreme fiber and the applied torque may be found:

$$\tau = \frac{Tr}{J} = \frac{2T}{\pi r^3}$$

In a solid cylindrical bar in torsion, the exterior fibers are more highly stressed than the interior fibers (see Figures 6 and 7). Consequently, when the exterior fibers reach the proportional limit or yield point, they are, in a sense, supported by the interior fibers. Thus, the effect of yielding of the exterior fibers during the early stage of plastic action is masked by the resistance of the remaining section. It is not until considerable yielding has occurred that any noticeable effect is apparent with instruments ordinarily used to measure angle of twist (10). In some materials, particularly materials composed of granular elements, as concrete and soil, the resistance to rupture by shear is a function not only of the shear strength of the material but also of frictional resistance to sliding on the surface of rupture. For such materials, it is necessary then to evaluate both of these factors. (10)

A relation between such materials and total shearing resistance (Coulomb's Law) is (10)

$$\tau = c + \sigma \tan \phi$$

where σ = normal stress on plane of failure,

τ = shear resistance,

c = shear strength of the material under no normal load, often referred to as cohesion, and

ϕ = angle of internal friction.

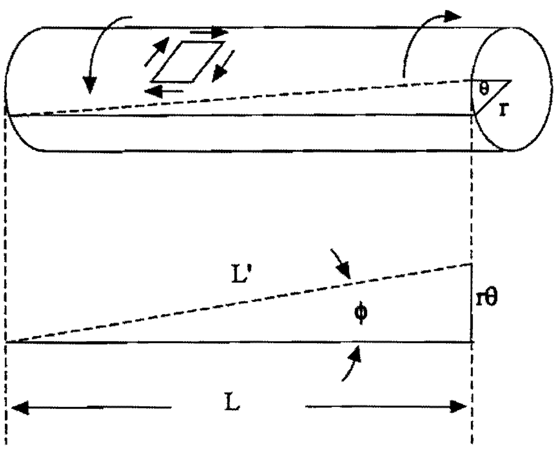


Figure 6. Torsional Strain in a Twisted Solid Cylinder (After Ref. 10).

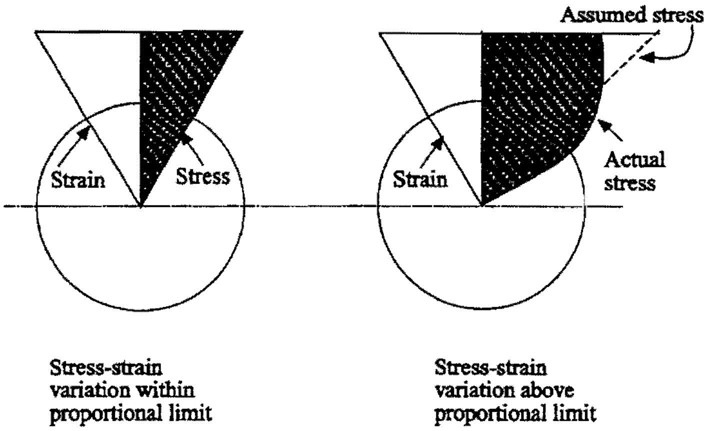


Figure 7. Stress-Strain Variation in a Twisted Cylinder (After Ref. 10).

SHEARING RESISTANCE

Shear strength of a soil is its maximum resistance to shearing stresses. When this resistance to shearing is exceeded, failure occurs, usually taking the form of surfaces of slip. Shear strength is usually assumed to be made up of: a) internal friction, or the resistance due to interlocking of the particles; and b) cohesion, or the resistance due to the forces tending to hold the particles together in a solid mass. Generally speaking, coarse-grained soils such as sands derive their shear strength almost entirely from intergranular friction, but with other soils the strength is a combination of both forms of resistance (11).

A law governing the shear failure of soils was first introduced by Coulomb in the form $\tau = c + \sigma \tan\phi$. Figure 8 shows the relationship schematically; shear strength, s, is plotted against normal stress, σ. The previous relationship presented by Mohr held that a material fails through a critical combination of normal stress and shearing stress and not through either maximum normal or shear stress alone. The failure envelope plotted in Figure 8 is an approximation of the actual envelope which is a curved line. For most soil mechanics problems, this approximation is sufficient (12).

The significance of the failure envelope can be explained as follows. If the normal stress and shear stress on a plane in a soil mass are such that they plot as point A in Figure 8, shear failure will not occur along that plane. If the normal stress and shear stress on a plane plot as point C (which falls on the failure envelope), shear failure will occur along that plane. A state of stress on a plane represented by point B cannot exist, since it plots above the failure envelope, and shear failure in a soil would have occurred already (12).

The Mohr-Coulomb model has three obvious defects as a method of describing real soil behavior: a) the model makes no statement about strains and cannot be used to predict displacements; b) the model implies that the volume changes do not affect the shear strength, which is certainly untrue; and c) the model implies that the intermediate principal stress does not affect the shear strength (13).

Mohr-Coulomb theory has the advantage that it is so widely used and well understood by soil engineers. Moreover, it gives the plane on which failure occurs and the angle such plane makes with the principal directions. There is fairly good evidence that simple theories of the form of Mohr's theory apply reasonably well in describing the conditions of failure of soil (14).

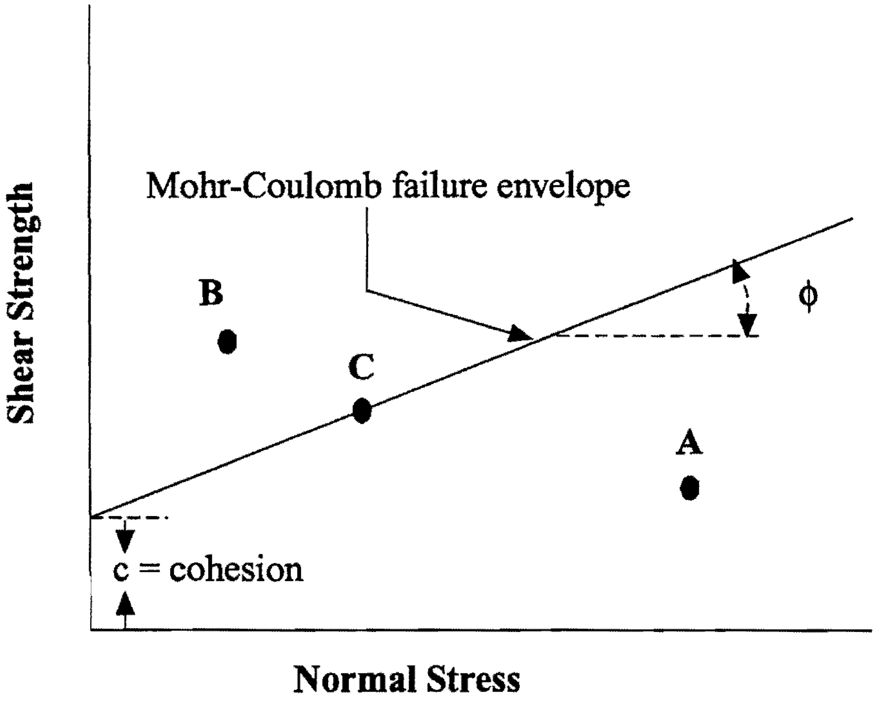


Figure 8. Relationship between Shear Strength and Normal Stress (Mohr-Coulomb Law).

Because of the complex nature of the shearing resistance of soils, many methods of testing have been tried with various degress of success. The principal shear tests in use today are direct, ring or double direct, and triaxial.

Direct Shear Test

One of the earliest methods for testing soil strength, used extensively today, is direct shear (12). Figure 9 shows a diagram of the direct shear apparatus. The test equipment consists of a metal shear box in which the soil sample is placed (Figure 10). The soil samples may be square or circular in plan. The sizes of the samples generally used is about 1,935 or 2,580 mm^2 (3 or 4 $in.^2$) across and about 25.4 mm (1 in.) high. The box is split horizontally into two halves. Normal force on the sample is applied from the top of the shear box by dead weights. Shear force is applied to the side of the top half of the box to cause failure in the soil sample.

Depending on the equipment, the shear test can be either stress-controlled or strain-controlled. In stress controlled tests, the shear force is applied by dead weights in equal increments until the sample fails. Failure takes place along the plane of split of the shear box. After the application of each incremental load, shear displacement of the top half of the box is measured by a horizontal dial gauge. The change in the height of the sample (or the volume change of the sample during the test) can be obtained from the readings of a dial gauge that measures the vertical movement of the upper loading plate (12).

In strain-controlled tests, a constant rate of shear displacement is applied to the top half of the box by a motor acting through gears. The constant rate of shear displacement is observed by a horizontal dial gauge. The resisting shear force of the soil corresponding to any shear displacement can be measured by a horizontal proving ring. In new models, the horizontal resisting force is measured by means of an electronic load cell which transmits a voltage signal to either a computer or a electronic display system. The advantage of strain-controlled tests is that, in case of dense sand, peak shear resistance as well as lesser shear resistance can be observed and plotted. In stress-controlled tests, only the peak shear resistance can be observed and plotted (12).

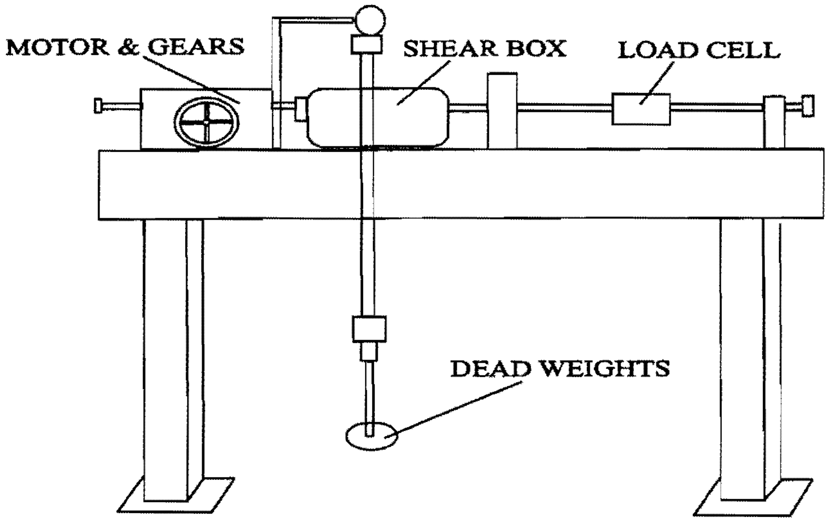


Figure 9. Diagram of Direct Shear Test Apparatus.

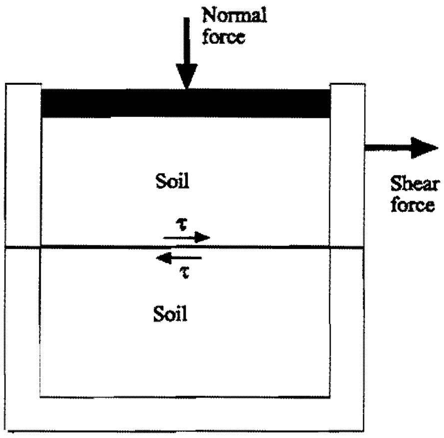


Figure 10. Direct Shear Test to Determine the Cohesion and Internal Friction Angle of Soils.

Note that the peak shear resistance measured in stress-controlled tests is only approximate. This is because failure occurs at a stress level somewhere between the prefailure load increment and the failure load increments. Nevertheless, stress-controlled tests probably model real field situations better than strain-controlled tests (12).

For a given test, the normal stress can be calculated as

$$\sigma = \textit{normal stress} = \frac{\textit{normal force}}{\textit{area of cross-section of the sample}} .$$

The resisting shear stress for any shear displacement can be calculated as

$$\tau = \textit{shear stress} = \frac{\textit{resisting shear force}}{\textit{area of cross-section of the sample}} .$$

Direct shear tests are repeated on similar samples at various normal stresses. The shear strength parameters (C and σ) are determined by plotting the normal stresses and their corresponding ultimate shear resistance.

The direct shear test is rather simple to perform, but it has some inherent shortcomings when used to determine shear strength characteristics of soils (12). The reliability of the results may be questioned. This is due to the fact that, in this test, the soil is not allowed to fail along the weakest plane but is forced to fail along the plane of split of the shear box (12). This was not a shortcoming for the purposes of this research because the objective of using this test was to analyze the shear strength characteristics of the interface between a granular base material and the asphalt mix layer. Therefore, failure was required to occur at this interface which was the plane of split of the shear box. Another shortcoming of this test is that the shear stress distribution over the sheared surface of the sample is not uniform due to the deformation within the material (12).

In many foundation design problems, it will be necessary to determine the angle of internal friction between the soil and the material in which the foundation is constructed. The foundation material may be concrete, steel, or wood. The shear strength along the surface of contact of the soil and the foundation material can be given as (12)

$$\tau_f = c + \sigma \tan \delta$$

where c = cohesion,

δ = angle of friction between the soil and the foundation material, and

τ_f= shear strength of the interface between the soil and the foundation.

The same principle was used in this investigation. The shear strength parameters between a soil and an asphalt mix were conveniently determined by a direct shear test. The granular base material was placed at the bottom part of the shear box, and the asphalt mix was placed above it (that is, in the top portion of the shear box), as shown in Figure 11. This was done to force the shear plane to occur at the upper surface of the compacted base.

Vane Shear Test

Fairly reliable results of undrained cohesion, c_u, (Φ=0 concept), of very plastic cohesive soils may be obtained directly from vane shear tests. Vane shear tests can be conducted in the laboratory and in the field during soil exploration. The shear vane usually consists of four thin, equal-sized steel plates welded to a steel torque rod (Figure 12). First, the vane is pushed into the soil. Then torque is applied at the top of the torque rod to rotate the vane at a uniform speed. A cylinder of soil of height and diameter equal to the vanes will resist the torque until the soil fails. Some researchers (15) have reported sensitivity of the vane shear test to the angular rotation of the vane. The undrained cohesion of the soil can be calculated as follows.

If T is the maximum torque applied at the head of the torque rod to cause failure, it should be equal to the sum of the resisting moment of the shear force along the side surface of the soil cylinder (M_s) and the resisting moment of the shear force at each end (M_e) (Figure 13).

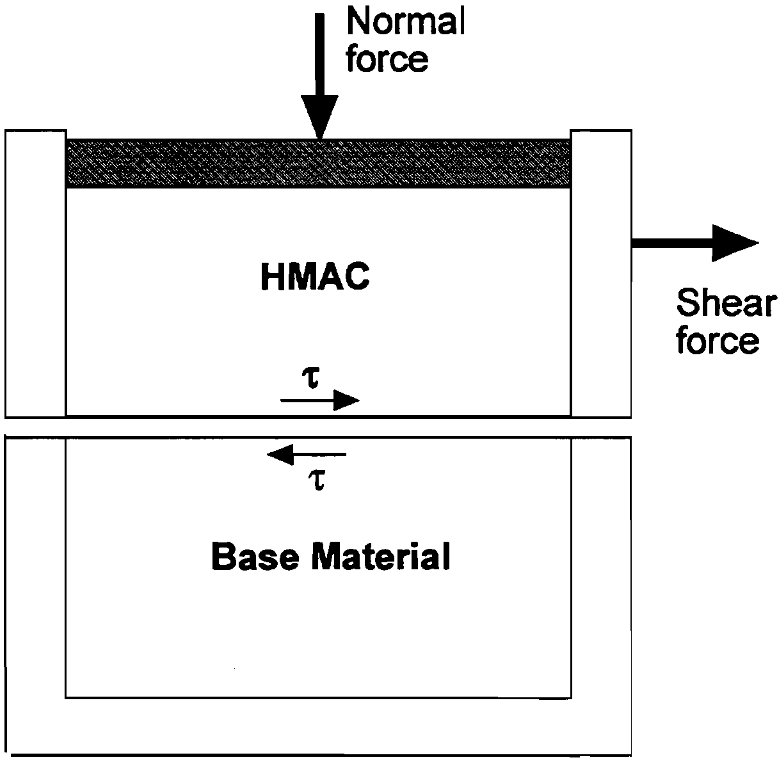


Figure 11. Direct Shear Test Arrangement to Determine the Cohesion and Friction Angle of the Interface between a Granular Base and a Bituminous Layer.

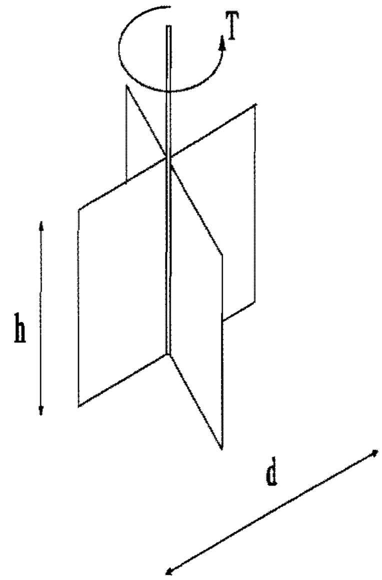


Figure 12. Diagram of Vane Shear Equipment.

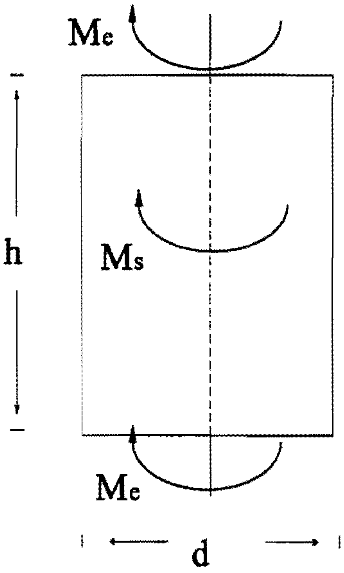


Figure 13. Resisting Moment of Shear Force Applied to a Vane.

$$T = M_s + 2M_e$$

The resisting moment, M_s , can be given as:

$$M_s = (\pi dh) * c_u * (d/2)$$

where d = diameter of the shear vane,

h = height of the shear vane, and

c_u = undrained cohesion of a soil.

For calculation of M_e, investigators have assumed several types of distribution of shear strength mobilization at the ends of the soil cylinder (Figure 14).

a) Triangular: Shear strength mobilization is c_u at the periphery of the soil cylinder and decreases linearly to zero at the center.

b) Uniform: Shear strength mobilization is constant from the periphery to the center of the soil cylinder.

c) Parabolic: Shear strength mobilization decreases parabolically from the periphery to zero at the center.

A modified form of the vane shear test apparatus is a torvane, which is a hand-held device with a calibrated spring. This can be used for determination of c_u for tube samples collected from the field during soil exploration, and it can also be used in the field. The torvane is pushed into the soil and then rotated until the soil fails. Shear strength can be read off the calibrated dial (12).

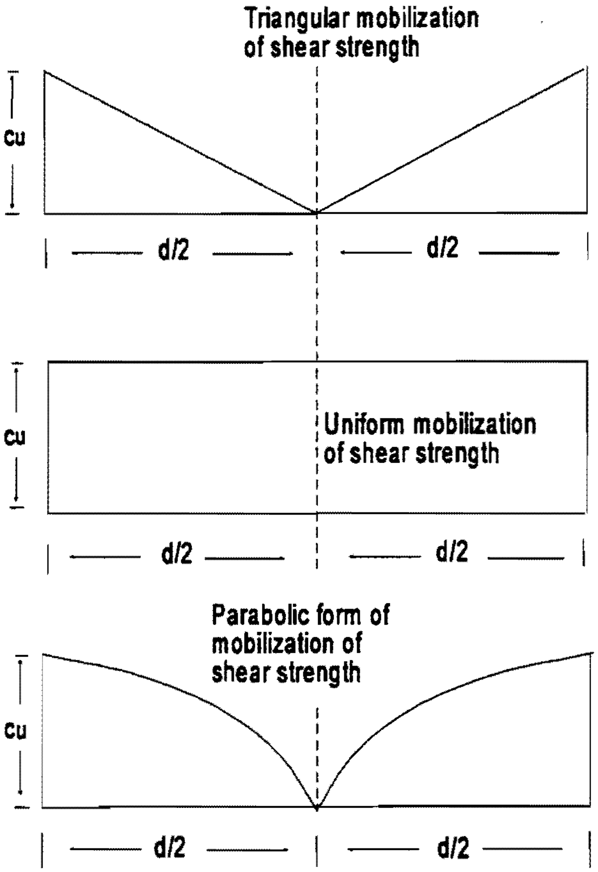


Figure 14. Types of Distribution of Shear Strength Mobilization (After Ref. 12).

Torsional Shear Test

The torsion test has been used extensively for testing structural and machine members which are often subjected to shear and bending stresses. It is not used as a standard test for determining shear strength of soils. Therefore, the shortcomings of this test for testing anisotropic materials have not been reported.

In the usual torsion test, a specimen of solid circular cross section is subjected to a twisting moment, M_t , by a torsion test machine. At selected increments of load, the angle of twist (θ) is measured by a twistmeter for a given gage length, *L*, of the specimen. From the torque and angle-of-twist readings, torque-twist diagrams are plotted as illustrated in Figure 15. From these diagrams, the stress-strain or mechanical properties in pure shear can be evaluated.

Elastic shear strength: The elastic shear strength is measured by the maximum stress in the torsion specimen, corresponding to a torque load representing the transition from elastic to the plastic range (16). This yield torque load is usually defined as Johnson's apparent elastic limit load (point A in Figure 15). If M_{tp} is the value of this torque, then one measure of the elastic shear strength is the maximum shear stress corresponding to this torque load, or

$$S_{sp} = \frac{M_{tp} r}{J}$$

where r = the radius of the cross section and

$J = \pi r^4 / 2$ = the polar moment of inertia of the cross section.

The elastic strength in torsion is sometimes measured by using an offset angle of twist to determine the yield torque, as represented by point B in Figure 15. If the yield torque corresponding to point B is designated by M_{ty}, an approximate value of the elastic shear strength (16) is

$$E_s = \frac{M_{ty} r}{J}$$

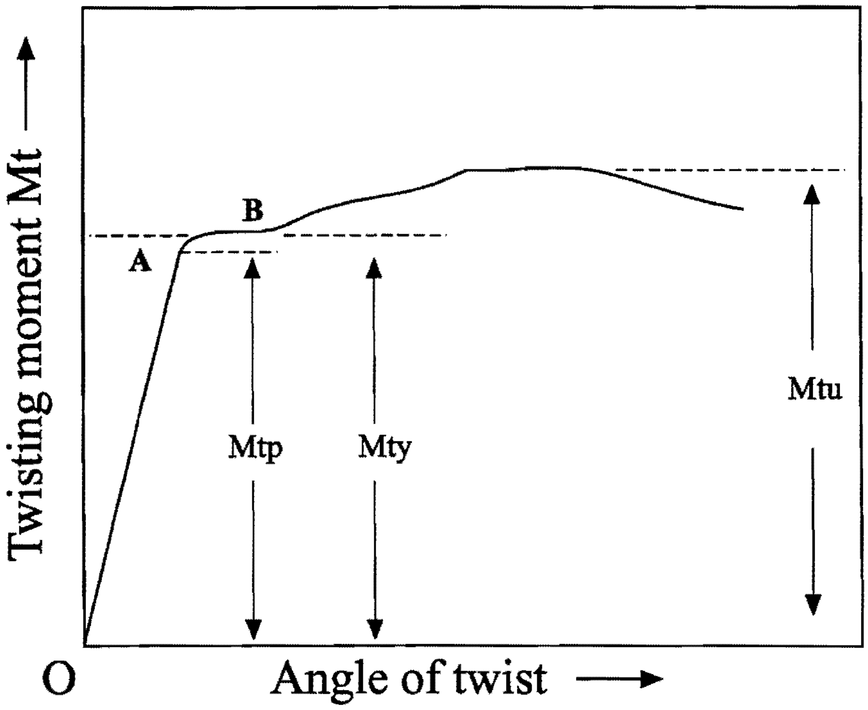


Figure 15. Torque-Twist Diagram for Both the Elastic and Plastic Range for the Torsional Shear Test (After Ref. 16).

The previous equation represents the approximate strength since the equation, $S_s = M_t r/J$, assumes a linear relation between stress and strain. In the plastic range, the shear stress distribution is no longer linear but becomes nonlinear as shown previously in Figure 7.

Stiffness: The torsional resistance to deformation in the elastic range, or stiffness in torsion, is measured by the modulus of elasticity in shear, E_s, sometimes called the modulus of rigidity. The value of the modulus can be determined from the relation (16)

$$E_s = \frac{M_t L}{\theta J}$$

where L = gage length,

J = polar moment of inertia of the cross section,

M_t = torque for some point on the linear part of the twist-torque diagram, and

θ = angle of twist in radians corresponding to the torque M_t .

Plastic Shear Strength: The plastic shear strength in torsion is usually determined by the apparent maximum strength in torsion and is called the modulus of rupture. The modulus of rupture is the maximum stress in the outer fiber corresponding to the maximum torque (Figure 15). In determining the value of this stress, it is assumed that the relation, $S_s = M_t r / J$, applies in the plastic range (16). That is, the modulus of rupture in shear, S_{su}, is

$$S_{su} = \frac{M_{tu}\, r}{J}$$

where M_{tu} = the torque-to-failure (Figure 15),

r = the radius of the cylinder, and

J = the polar moment of inertia of the cross section.

Although the shear strength defined in the previous equation is considerably in error, since the relation, $S_s = M_t r / J$, is not valid for the plastic range (16), this approximation is useful for comparative purposes and for selecting suitable materials.

CHAPTER 3

LABORATORY STUDY

The purpose of this laboratory study was to develop some test procedures to examine the importance of the bond between the base and various types of surface courses and evaluate alternative prime materials to cutback asphalts.

Four tests were developed in this investigation:

1. A test to measure the penetration capabilities of prime materials,
2. A test to investigate the benefits of using prime coats for bonding the surface particles of a base material, and
3. Two tests to compare the shear strength of the interface between a surface course and a granular base with and without a prime coat.

PRIME PENETRATION TEST

This effort was undertaken to develop a test procedure for predicting the penetration capabilities of certain emulsified primes into a compacted base. The work was based on a test procedure used by the Indiana Department of Transportation that specifies the requirements of minimum penetration depth and maximum penetration time for Penetrating Emulsion Prime (PEP) to penetrate a standard Ottawa sand. The goal was to develop a test procedure to predict the penetration of prime materials on local base materials. It was important to develop a handy, easy and reliable test to select a satisfactory prime material to assure proper penetration in a specific granular base. The results obtained from this test were compared with field measurements to evaluate the reliability of the test.

Materials Tested

Six emulsified primes, three specially prepared blends of two emulsified products, and two cutback asphalts were tested.

EPR-1, Blacklidge,
PEP, Elf Materials,

AE-P, Elf Materials,
AE-P, Reed & Graham,
LVOC-1, Prime Materials, and
SS-1, Prime Materials.

Combinations of LVOC-1 and SS-1 were tested in the following mixing proportions:

95% LVOC-1 + 5% SS-1 (Mix A in the figures),
90% LVOC-1 + 10% SS-1 (Mix B in the figures), and
70% LVOC-1 + 30% SS-1 (Mix C in the figures).

MC-30 from Fina and Exxon were tested to compare their penetration properties to that of the emulsified products.

Crushed limestone passing the No.4 sieve was used to test the penetration properties of the prime materials mentioned above.

Description of Test

The parameters considered to assure proper prime penetration were: time required for maximum penetration of the product into a particular granular base, penetration depth into the base, and moisture conditions to optimize penetration. Initially, minus No.10 sieve material was used to prepare the specimens for penetration testing. Due to the unrealistically low permeability of this size fraction, the material passing the No.4 sieve was used. Small samples were desirable in order to develop a simple and economical test with no requirement for a specialized compaction device.

The first step in the preparation of the samples was to collect granular base material passing the No.4 sieve. Optimum moisture (for compaction) was added to the granular base and mixed until completely blended. The moist aggregate was placed into 170 grams (6 oz.) tins and statically compacted using a plunger with a diameter slightly smaller than the tin. Prime materials were applied on the surface of the samples. The time that the prime materials required to penetrate into the aggregate samples (liquid no longer visible at the surface) was recorded. Penetration depth was acquired by slicing the sample transversely using a knife and measuring penetration depth with a ruler. Penetration depths achieved by the prime materials into the base samples at different times after the application were recorded.

The first objective was to simulate some of the field base conditions at the moment of prime application. The base conditions that can be controlled in the field which were simulated in the laboratory were:

a) Base density: The density achieved in the field was simulated in the laboratory by determining the optimum moisture content and the uniaxial load required to compact the samples to the density obtained in the field, which was near the maximum. The optimum moisture content and appropriate uniaxial load for sample preparation were determined by compacting samples at different moisture contents and loads and comparing with known field values. After several trials, a uniaxial compressive load of 1,380 kPa (200 psi) was found suitable to compact the samples. This permitted realistic optimum moisture content and dry density, as can be seen in Figure 16.

b) Moisture content prior to application of the prime coat: In road construction, a base surface is usually allowed to dry to some extent before the application of the prime material. This construction step was initially simulated by placing the compacted sample in an oven at 40°C (104 °F) for one hour before priming. Due to the different specific heat between the tin and the base material, the tin heated up faster than the base material. The heat transmitted by the tin to the base material at the edges evaporated the moisture faster than that in the middle of the sample. This situation was undesirable since the measure of penetration depth in the middle was different from the measure at the edges of the sample. For this reason, the oven was no longer used to simulate the drying effect produced by the sun and wind energy on the surface of the base. Therefore, the samples were cured by forced air at room temperature for 24 hours before application of the prime.

Penetration of the emulsions and cutback asphalts at different base moisture contents was analyzed. Moisture contents of 5%, 7%, and 9% were selected for testing.

c) Penetration time: An important parameter is the time required for a prime material to penetrate before measuring the depth of penetration. Several samples were prepared and penetration depth was measured two minutes, one hour, and 24 hours after priming.

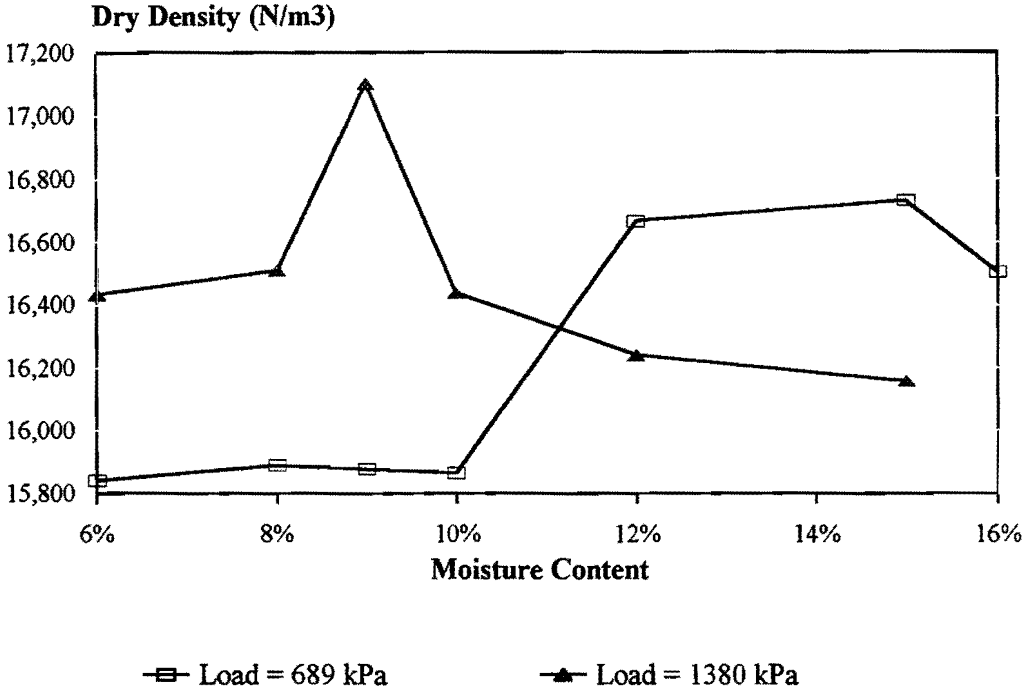


Figure 16. Compaction Curves for a Limestone Base (Fraction Passing the No.4 Sieve) Prepared at Two Different Stress Levels.

Test Results

The optimum moisture content for compacting the fine crushed limestone samples to achieve the maximum density was nine percent at 1380 kPa (200 psi). However, since the samples were made using a relatively small fraction of the total base material, the samples compacted to the maximum density were unrealistically impermeable and thus inhibited penetration of the primes. For this reason, the granular base samples were compacted at a lower moisture content, i.e., 7%, in order to achieve a lower density and thus more closely simulate field conditions. Figure 17 infers that the penetration depth of the MC-30s is not dependent upon the moisture content of the base. AE-P (R&G) penetration showed a lower penetration at all moisture contents tested.

Assume a satisfactory penetration depth for a prime coat should be at least 5 millimeters (0.2 in.). Therefore, if AE-P from Reed and Graham is to be applied on this specific crushed limestone base, the moisture content of the base should be above seven percent to break the surface tension, and thus promote penetration. Figure 17 shows the other products which will achieve the minimum required penetration at any moisture content between 5% and 9%.

Figure 18 shows that all the blends of LVOC-1 and SS-1 achieved the minimum penetration required at any base moisture content within 2 minutes after application. SS-1 penetrated the crushed limestone base adequately at moisture contents greater than 7%.

Figures 19 and 20 show that, for all the prime materials but SS-1, the time required for penetration into this crushed limestone base material was less than one hour. This suggests that the penetration depth of the samples should be measured one hour after application of prime.

Figures 21 and 22 infer that, for AE-P Elf, PEP Elf, and all three blends of LVOC-1 and SS-1, the time required to fully penetrate the base remained the same at any moisture content tested. SS-1 did not penetrate satisfactorily at base moisture contents lower than 7%. LVOC-1 and AE-P (R&G) penetrated faster at the higher moisture contents. The two MC-30s took longer to penetrate the base at high moisture content. It is important to comment that a large percentage of the SS-1 remained on the surface of the base, which shows it is unacceptable as a prime (unless dusted with crusher screenings or sand).

Comparison of the Test Results with Field Measurements

In June 1994, prime test pavements were placed on FM 46 south of Franklin, Texas, in Robertson County. The job included major rehabilitation and widening of a two-lane farm road.

Four different prime materials were applied on the test sections in both lanes of the two-lane road. The penetration depths achieved for the different prime materials were recorded. Using the same materials as used in the field and the penetration procedure discussed above, laboratory specimens were prepared and penetration depths were measured. Four replicate tests were performed on each sample. Laboratory penetration depths were compared with the field measurements. Table 1 shows the average penetration for the laboratory samples to be 1 mm less than the field measurements in each case.

Table 1 infers that the prime penetration test procedure predicts reasonably well the penetration depth achieved by a prime material into a specific granular base.

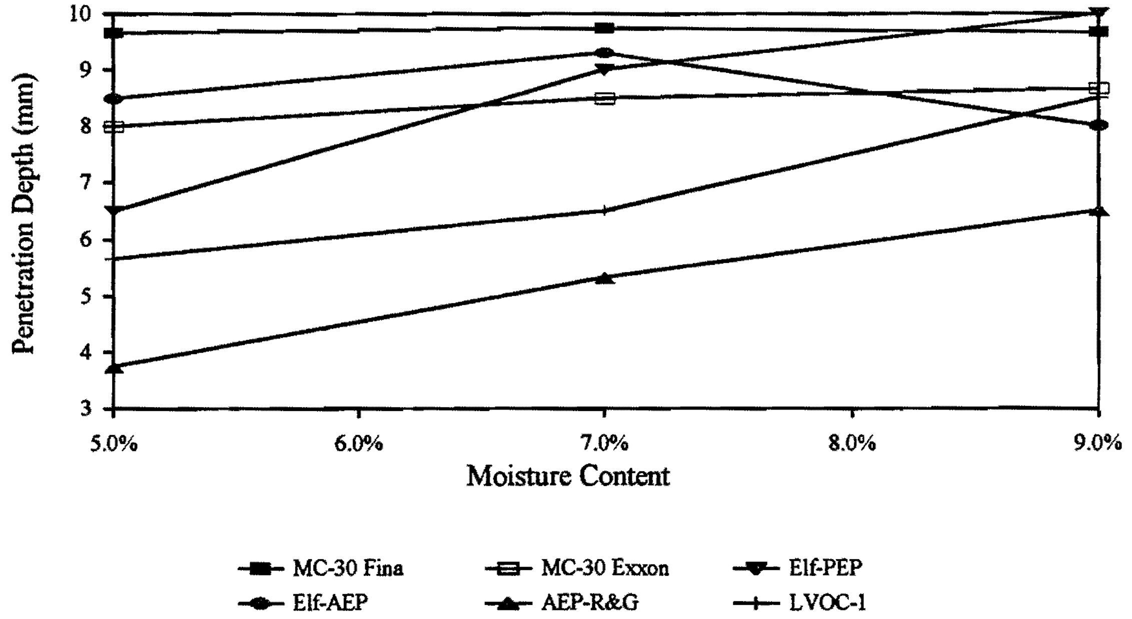


Figure 17. Penetration Depth Achieved by Various Primes Two Minutes After Application.

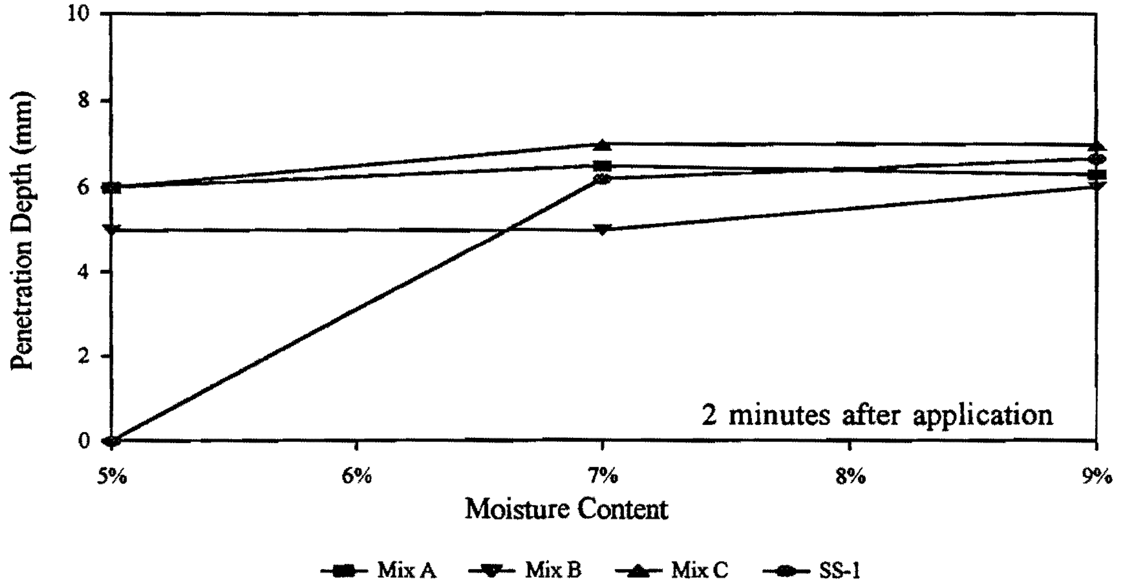


Figure 18. Penetration Depth Achieved by SS-1 and Three Blends of SS-1 and LVOC-1 (0.05/0.95, 0.1/0.9, 0.3/0.7) at Different Moisture Contents of the Base.

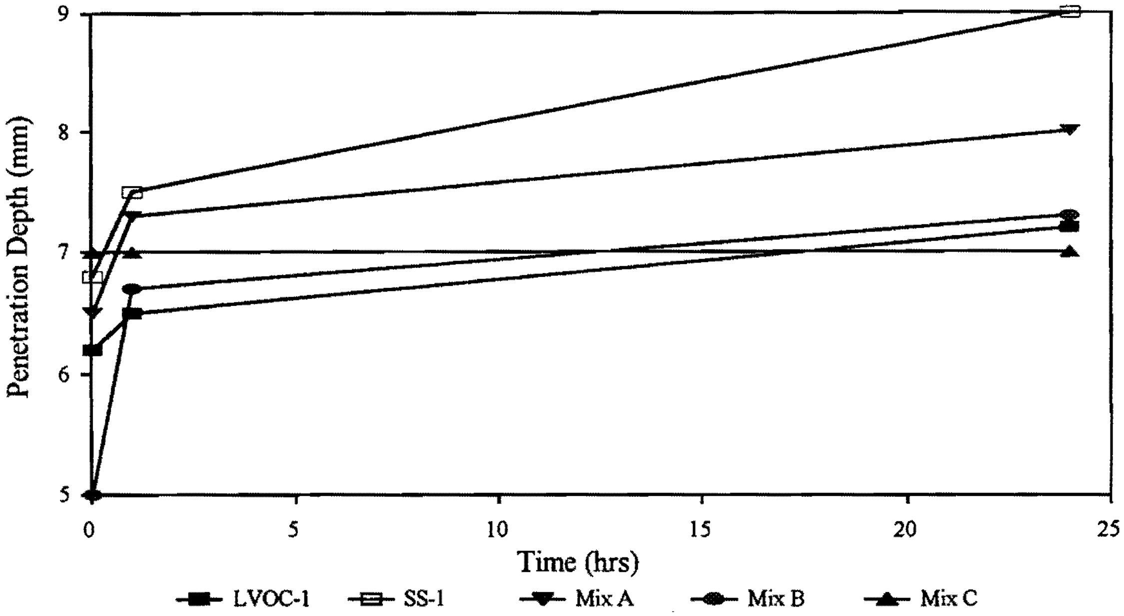


Figure 19. Penetration Depth Achieved by SS-1, LVOC-1, and Three Blends (0.05/0.95, 0.1/0.9, 0.3/0.7) at Different Times After Application.

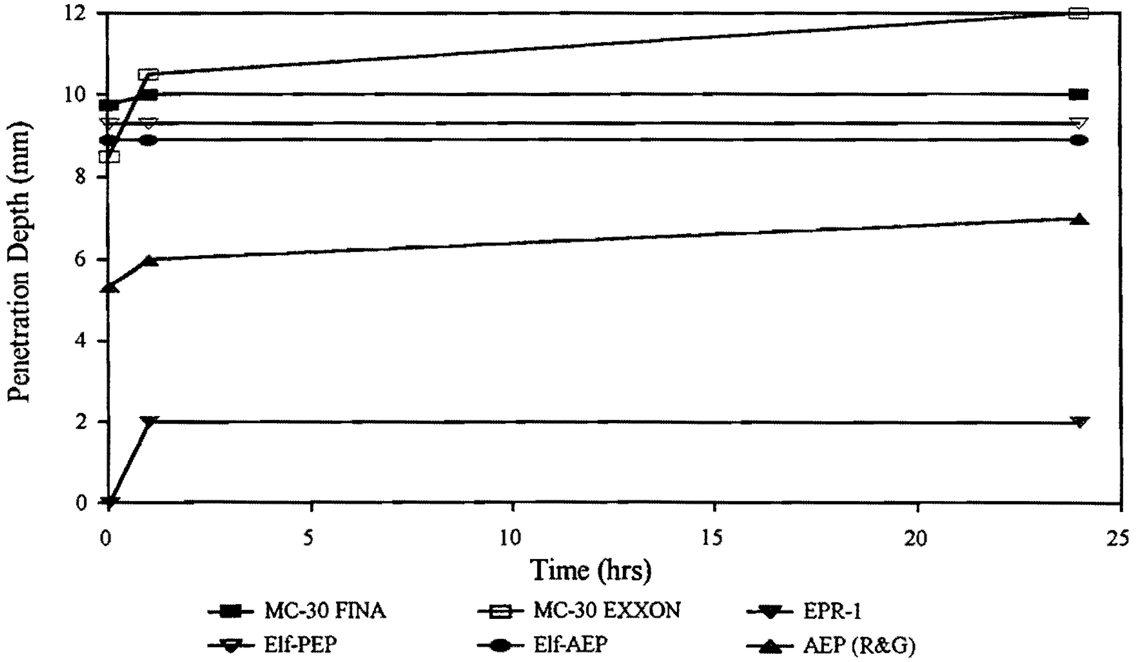


Figure 20. Penetration Depth Achieved by Various Primes at Different Times After Application.

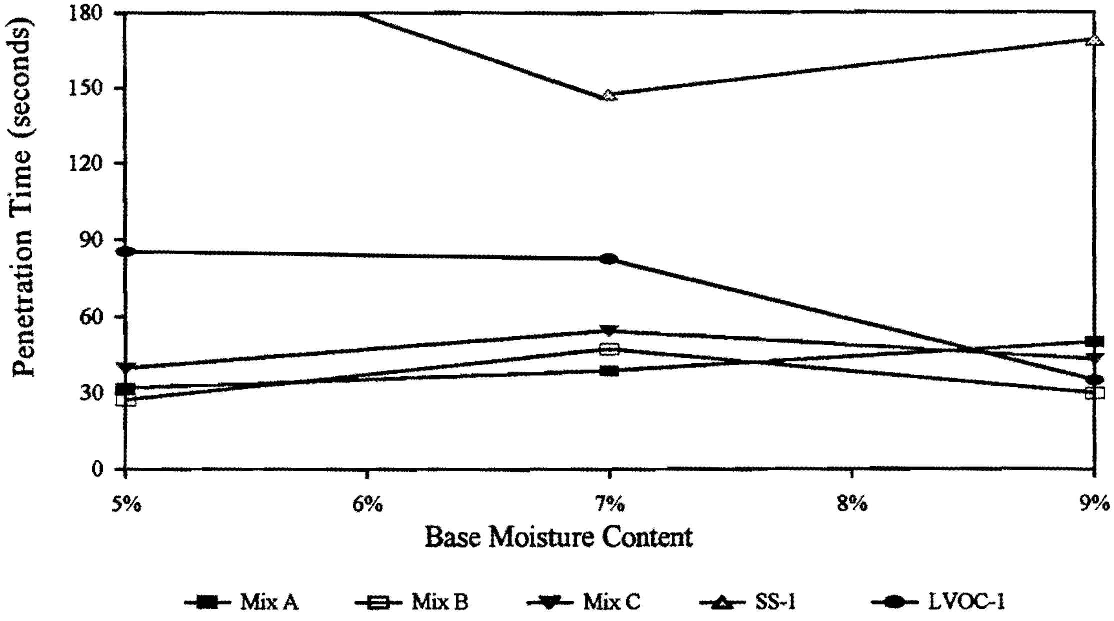


Figure 21. Penetration Time Required for LVOC-1, SS-1, and Three Different Blends of SS-1 and LVOC-1 (0.05/0.95, 0.1/0.9, 0.3/0.7) to Penetrate the Base at Different Moisture Contents.

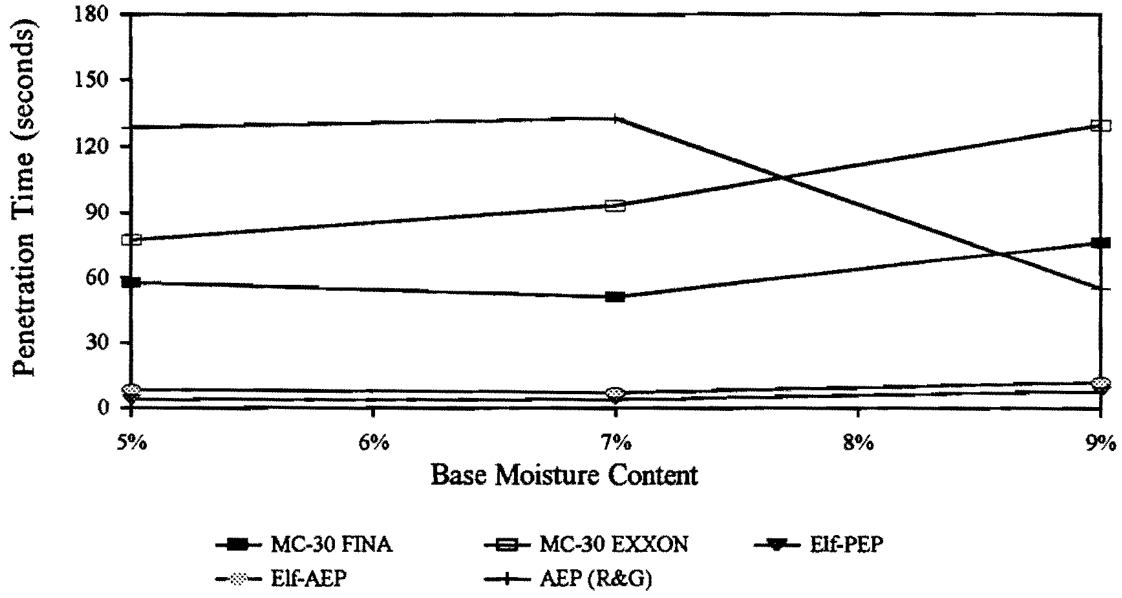


Figure 22. Penetration Time Required for Selected Primes to Fully Penetrate the Compacted Base Specimen at Different Moisture Contents.

Table 1. Penetration Depth in Millimeters (1 mm = 0.039 in.) Achieved by the Different Prime Materials in FM 46 and in Laboratory Samples.

Prime Material	Average Penetration in Laboratory, mm	Average Penetration at Jobsite, mm
LVOC-1	2	3
EPR-1	2	3
AE-P	3	4
TP-1	1	2

COHESION TEST

One of the purposes of applying a prime coat is to provide adequate protection for the compacted base from rainfall, temporary traffic, and construction equipment. The objective of this test was to investigate the benefits of using prime coats for bonding the surface particles of a base material. MC-30 and unprimed samples were tested as control specimens.

Materials Tested

Seven emulsified asphalts and two MC-30s from different producers were tested.

EPR-1, Chalet Emulsions,
PEP, Koch,
AE-P, Koch,
LVOC-1, Prime Materials,
SS-1, Koch,
Coherex HD, Witco,
MC-30, Fina, and
MC-30, Exxon.

Crushed sandstone base material passing the No.4 sieve was used to test the bonding properties of these prime materials.

Description of Test and Findings

A cohesion tester was used to determine the influence on cohesion due to the application of a prime coat product. ASTM D 3919-80 describes a machine similar to this one, which has been used to classify micro-surfacing mixtures. A modification was made to the equipment that consisted in exchanging the rubber foot for a vane-type attachment as shown in Figure 23.

The samples were prepared using the same procedure as described for the prime penetration test. After compaction, the samples were cured for 24 hours at ambient temperature. Then they were primed and allowed to cure (one set for 3 days and other set for 8 days) in the oven at 40°C (104°F). The reason for testing samples at different curing time was to examine the effect of curing times for each of the prime products tested. Field priming processes were simulated as closely as possible.

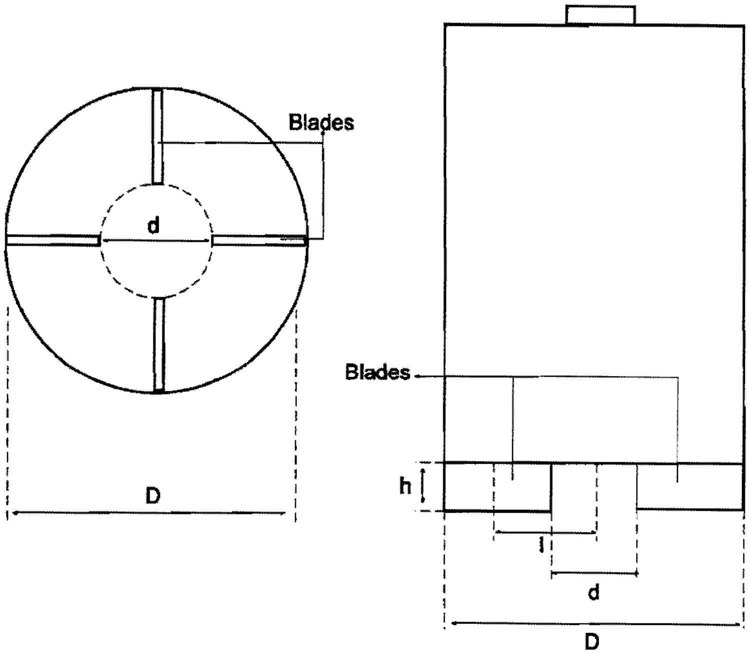


Figure 23. Vane-Type Foot Attached to the Cohesion Tester Used to Measure the Cohesion Provided by the Different Prime Coat Materials.

SS-1 samples were prepared by mechanically mixing the emulsion into the base as follows: Moist granular material was compacted the same way it was for the penetration test samples. The top ½ inch of base material was scraped off using a small spatula. The removed material was blended with five grams of SS-1 and compacted back in the tin. After curing, the samples were placed in the cohesion tester and torqued to failure. Torque at failure for each specimen was recorded and used for computing the cohesion. The equation to compute cohesion of the samples was developed using the vane and torvane principle as explained below.

If T is the maximum torque applied to the sample to cause failure, it should be equal to the sum of the resisting moment of the shear force along the outside surface of the soil cylinder (M_{ext}), the shear force along the inside surface of the soil cylinder (M_{int}), and the resisting moment of the shear force at the end (M_{end}).

$$T = M_{ex} + M_{ine} + M_{end}$$

$$T = \pi \cdot s \cdot h \cdot \frac{d^2}{2} + \pi \cdot s \cdot h \cdot \frac{D^2}{2} + \frac{\pi}{4} \cdot (D^2 - d^2) s \cdot \frac{(D+d)}{4}$$

where s = cohesion of the surface,

h = height of the vane's blades (Figure 23),

d = separation of the blades along the diameter, and

D = diameter of the foot.

$$s = \frac{16\,T}{\pi \cdot 8h \cdot (D^2 + d^2) + (D^2 - d^2)(D+d)}$$

For the vane-type foot (Figure 23):

h = 0.45 cm,
d = 1.54 cm, and
D = 3.10 cm.

If p is the depth in centimeters that the vane's blades penetrate the sample, and T is the torque at failure in newtons, the equation for calculating the cohesion, s, in kPa becomes:

$$s = \frac{5x10^2\ T}{9.59p + 3.36}$$

Some limitations on the conclusions can be drawn from the results of this test. The maximum torque obtained with the vane shear test depends on the rate of rotation. This has been investigated for the standard vane shear test and correction factors have been developed (15) to account for it. Since this correction factor is only applicable to the standard vane test for soils, it is not applicable in this investigation. Sessions of operator training to accomplish a constant rate of rotation using the cohesion tester were performed. An almost constant rate of rotation was achieved for individual test series; however, this rate was probably not the same for all sessions of testing. In order to develop this test into a reliable standard procedure for measuring the cohesive properties of different prime coat materials, it will be necessary to use a motorized cohesion tester with a constant rate of rotation.

Results such as those shown in Figure 24 would be very useful in determining the degree to which a specific prime alters the cohesion at the surface of a base. Figure 24 shows the averages of four test values of cohesion with different prime coats. Due to possible errors in rotation speed, these results are not considered reliable. Therefore, they are presented only to illustrate the potential value of such a procedure. More work is needed to fully develop this test protocol and criteria.

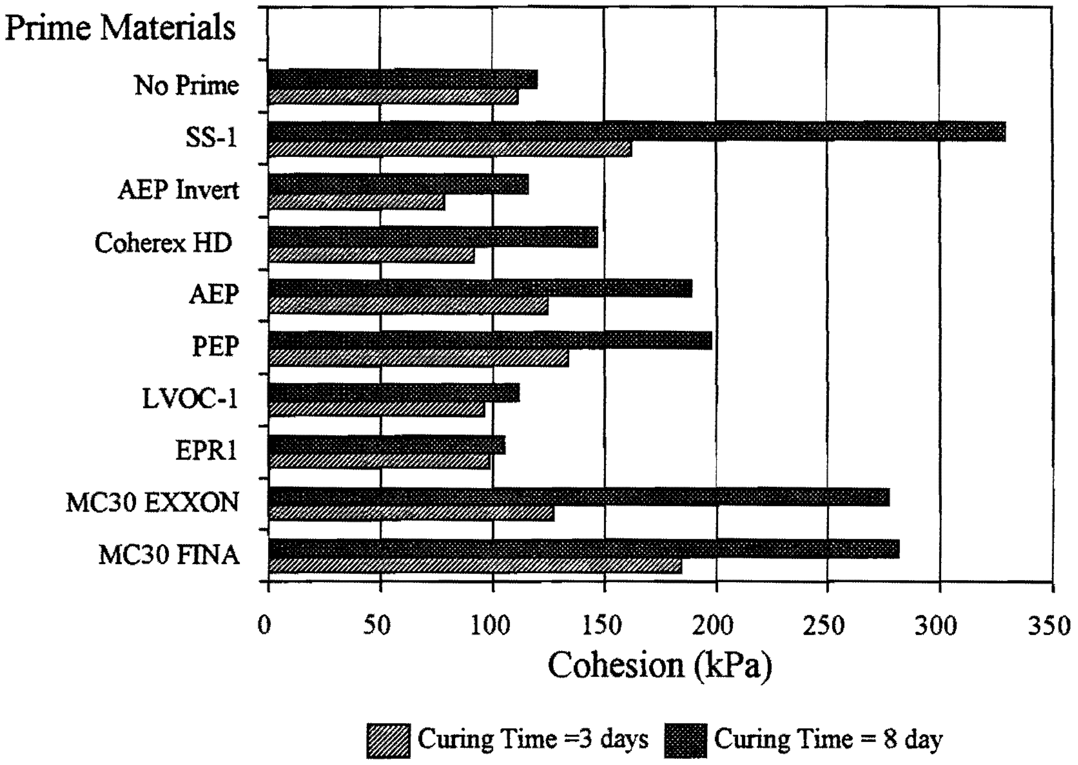


Figure 24. Cohesion Test Results for Different Prime Materials Cured for 3 and 8 Days.

TORSIONAL SHEAR TEST

The primary objective of this test was to measure the shear properties of the interface between a base and a hot mix asphalt layer with different prime coat products. Specimens with no prime at the interface and with MC-30 were control samples. Does a prime coat enhance the shear strength of the interface between the granular base and bituminous layer? This investigation attempted to answer this question.

The products listed below are either prime materials currently used for priming granular bases or promising alternatives to cutback asphalts. Some of these materials have been used satisfactorily for wind erosion control and as dust palliatives.

Materials Tested

The following prime materials were tested in this laboratory investigation:

MC-30, Fina,
MC-30, Exxon,
EPR-1, Chalet Emulsions (3 percent asphalt),
AE-PL, Koch,
AE-P, Koch,
LVOC-1, Prime Materials (no asphalt),
SS-1H, Koch,
SS-1 from Prime Materials, from now on SS-1P,
SS-1 from Koch Materials, from now on SS-1K, and
SP-6, Koch.

The following blends of SS-1 and LVOC-1 were tested:

5% SS-1 + 95% LVOC-1,
10% SS-1 + 90% LVOC-1, and
30% SS-1 + 70% LVOC-1.

Description of Test

Cylindrical samples were molded in 6-inch diameter molds. The molds were fabricated in two sections to accommodate shear testing at the primed interface between the base and the pavement layer (Figure 25). An MTS torsional shear machine was used to test the samples. The torque-twist plots of each test were recorded for further analysis.

Optimum moisture (7%) was added to the granular base material and completely blended using a mechanical mixer. Then the moist base material was placed in the lower half of the mold and compacted using a Cox kneading compactor. The compacted base samples were cured in an oven at a temperature of 40°C (104°F) for 24 hours. The samples were withdrawn from the oven and allowed to cool by forced air for 2 hours at ambient temperature. Then the compacted base was primed using one of the prime materials previously listed. After that, they were put back in the oven at 40°C (104°F) to cure for 24 hours. They were then cooled to ambient temperature by the same means and a seal coat was applied. CRS-1 was applied at a rate of 1.1 liter per square meter (0.24 gal/yd^2), on top of the samples. Grade 4 aggregate was immediately distributed on top of the seal coat to simulate an under seal.

The specimens were again allowed to cure for 24 hours. The upper half of the mold was attached to the lower half with the base material. Spacers were placed between the two halves to create a 2 mm space at the point of shear. This was designed to apply a shear force at the primed interface between the base and the asphalt layer. After curing and cooling, hot mix asphalt was compacted in the top portion of the mold and allowed to cure for 24 hours at ambient temperature. Finally, a uniform torsional deformation rate of 2.9E-04 radian per second was applied to the top of the sample while holding the bottom portion stationary until failure occurred. Specimens were tested at 25°C (77°F).

A normal load of 414 kPa (60 psi) was used for the samples with the limestone base material. Tests with normal loads of 414 kPa and 110 kPa (60 and 16 psi) were performed on the samples with pit run gravel base. Using the results from these tests, Mohr-Coulomb failure envelopes for the different prime materials were produced.

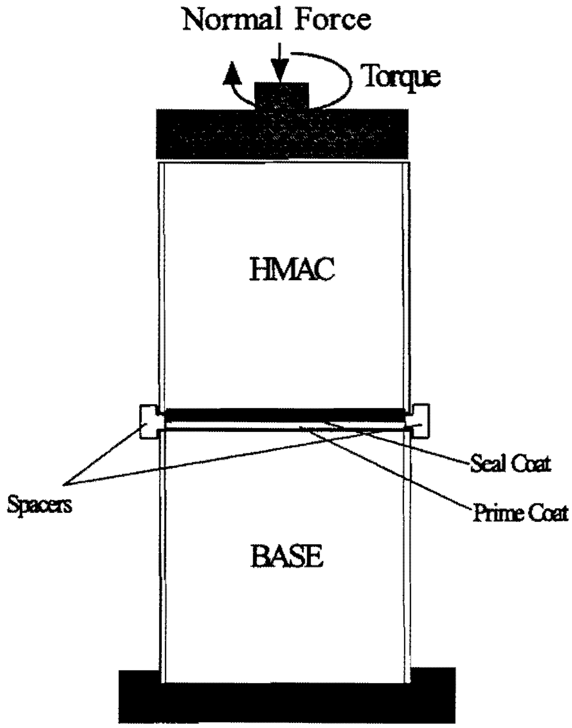


Figure 25. Diagram of Cylindrical Molds Fabricated to Accommodate Torsional Shear Testing at the Primed Interface between the Asphalt Layer and the Granular Base.

Test Results

Linear regression analysis was performed on the data contained in Table A1, Appendix A, to determine the Mohr-Coulomb envelope coefficients for the different prime materials. The least-squares estimation method was used in the regression analysis (see Appendix E). Shear strength was the dependent variable and normal stress the independent variable. The intercept of the best-fit line for each prime material corresponds to the cohesion. The slope of the best-fit line corresponds to the tangent of the angle of internal friction tan ϕ.

Tables A1 and A2, Appendix A, contain the results of all the samples prepared with pit run gravel base material. Table 2 contains a summary of these test results. Table 3 contains the best-fit estimates for cohesion and tan ϕ for the different prime materials tested and the statistical indicators of the best-fit regression line for the different prime materials tested. A statistical analysis (T-test with $\alpha = 0.05$) was used to compare the mean values for the different populations (each prime material vs no prime) at the two different levels of normal stress. Even though the statistical analysis suggests no significant differences among the means, the following comments appear appropriate.

Table 2. Summary of Results from Torsional Shear Test for Pit Run Gravel Base Material.

Prime Material	Shear Strength, kPa (psi)			
	Normal Stress = 110 kPa (16 psi)		Normal Stress = 414 kPa (60 psi)	
	No. replicates	Mean	No. replicates	Mean
No prime	4	70 (10.2)	3	263 (38.1)
MC-30	4	111 (16.1)	3	244 (35.8)
LVOC-1	4	92 (13.3)	3	240 (34.8)
EPR-1	3	113 (16.4)	3	250 (36.3)
AE-P Invert	3	112 (16.2)	3	225 (32.6)
PEP	4	87 (12.6)	3	242 (35.1)
SS-1 mixed-in	3	98 (14.2)	3	244 (35.4)

Table 3. Best-Fit Mohr-Coulomb Envelope Coefficient Estimates Using the Least-Squares Estimation Method for Pit Run Gravel Base Material Samples.

Prime Material	Mohr-Coulomb Envelope Coefficients		Statistical Indicators	
	Cohesion, kPa (psi)	tan ϕ	C.V.	R^2
MC-30	62 (9.0)	0.44	26	0.75
LVOC-1	38 (5.5)	0.49	18	0.91
EPR-1	64 (9.3)	0.45	29	0.72
AE-P invert	72 (10.4)	0.37	14	0.89
PEP	31 (4.5)	0.51	19	0.91
SS-1 mixed-in	44 (6.4)	0.48	4	0.99
No prime	0 (0)	0.64	24	0.90

Figures 26 through 32 show the best-fit regression lines for the different prime materials. Figure 33 shows each of the Mohr-Coulomb envelopes for the different prime materials tested, including unprimed samples as a control. Figure 34 shows the cohesion achieved at the interface between the base and the bituminous layer for the different prime materials.

Figure 33 shows that, at high levels of normal static stresses, there is not much difference in the shear strength among the samples with different prime materials (including unprimed samples). However, for low levels of normal static stresses the shear strength of the interface varies significantly; the unprimed samples yielded the lowest value, and MC-30, AEP, and EPR-1 yielded the highest values.

From the results, it is inferred that the failure envelopes that correspond to the different materials converge at a high level of normal stress. Therefore, at high levels of normal stress, the shear strength is not dependent on the type or presence of the prime material. The level of stresses at which they converge for this specific base material is about 300 kPa (44 psi). It is difficult to define the exact normal stress value at which the Mohr-Coulomb envelopes come

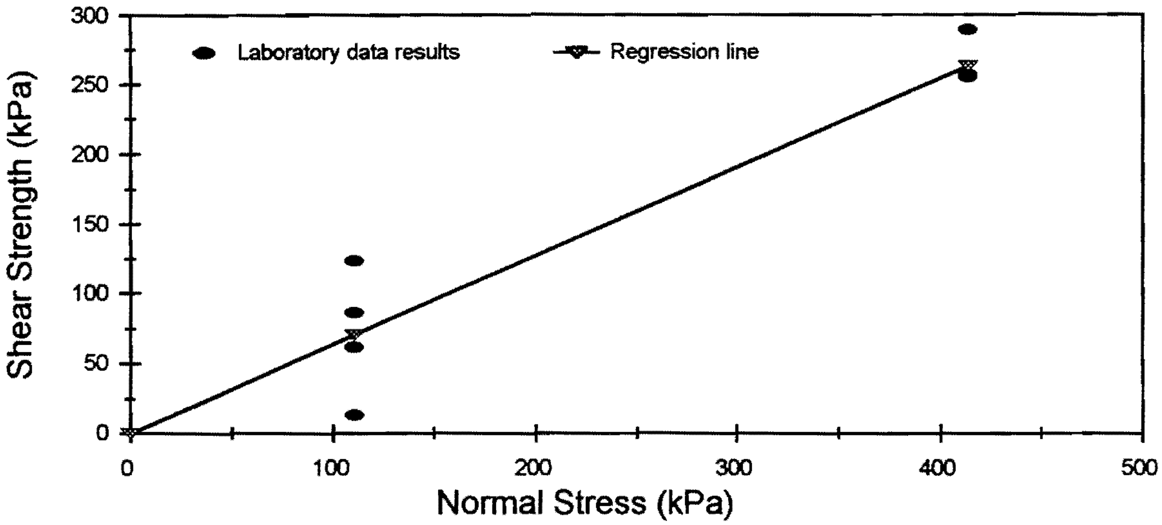


Figure 26. Mohr-Coulomb Envelope for Samples with no Prime and Pit Run Gravel Base Material.

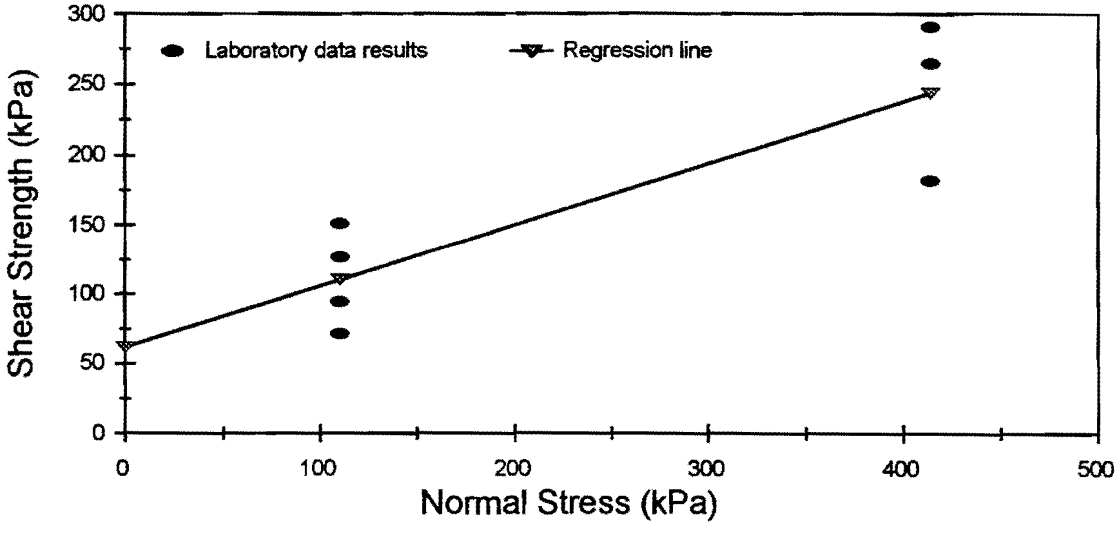


Figure 27. Mohr-Coulomb Envelope for Samples Primed with MC-30 and Pit Run Gravel Base Material.

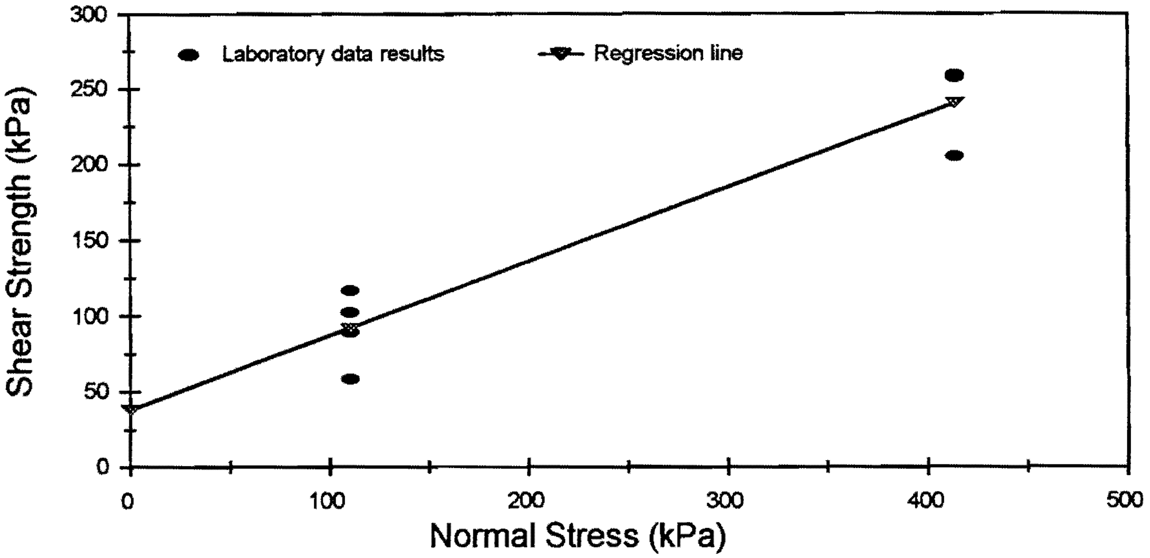


Figure 28. Mohr-Coulomb Envelope for Samples Primed with LVOC-1 and Pit Run Gravel Base Material.

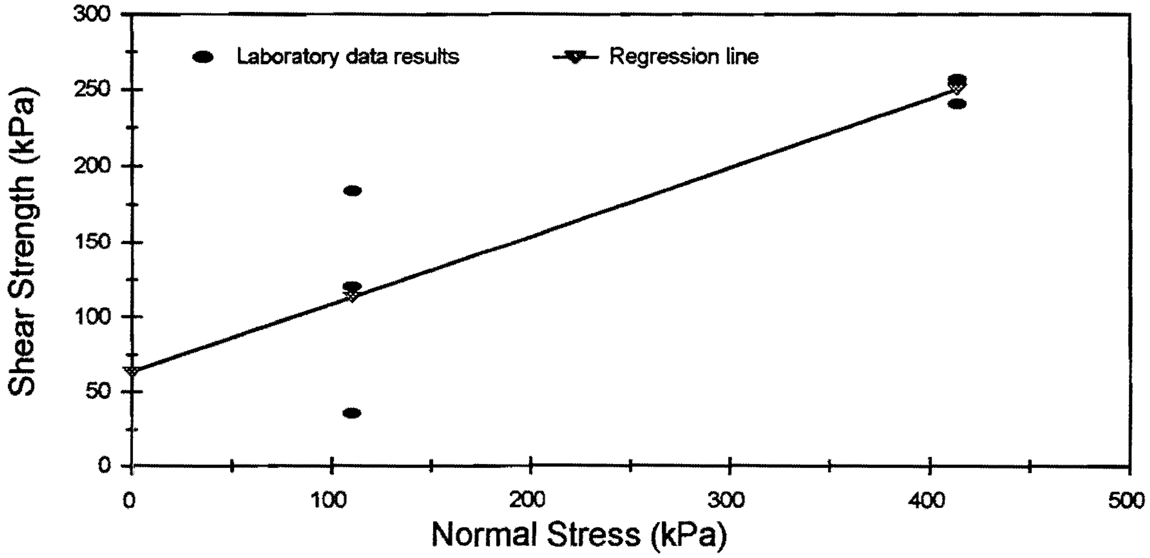


Figure 29. Mohr-Coulomb Envelope for Samples Primed with EPR-1 and Pit Run Gravel Base Material.

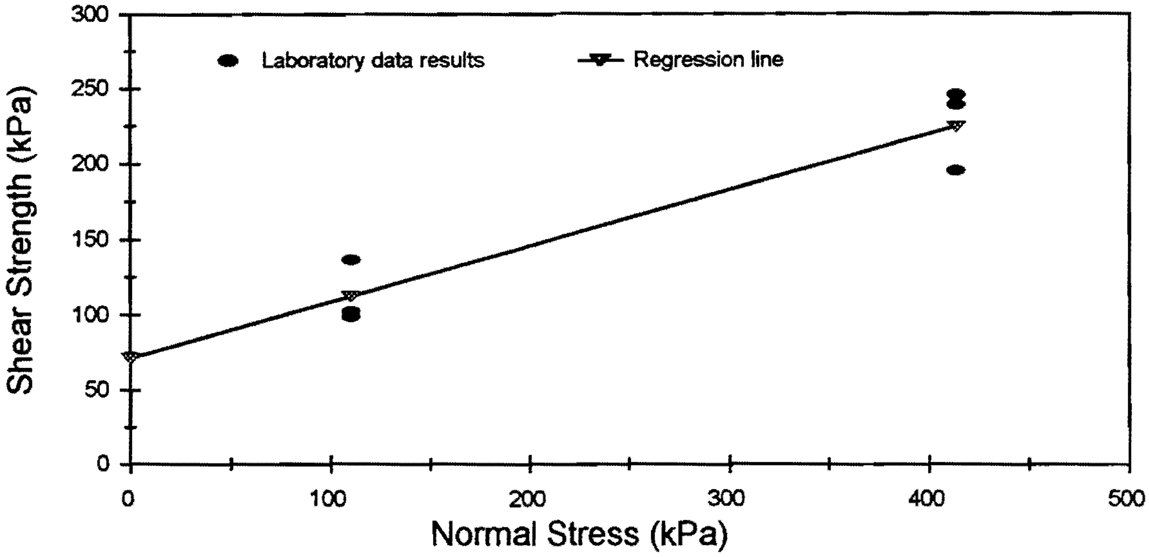


Figure 30. Mohr-Coulomb Envelope for Samples Primed with AEP-Invert and Pit Run Gravel Base Material.

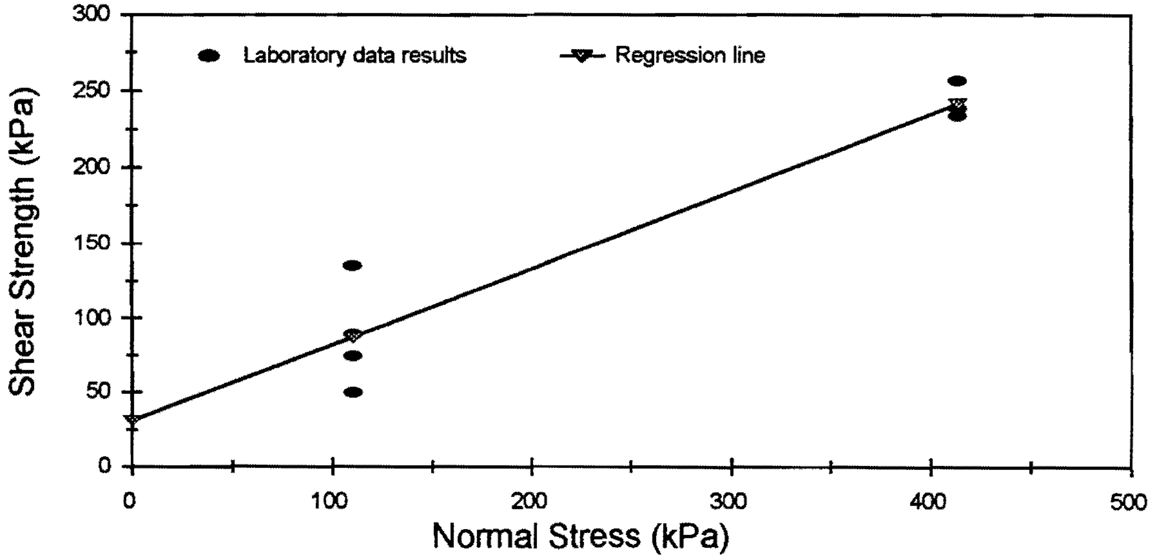


Figure 31. Mohr-Coulomb Envelope for Samples Primed with PEP and Pit Run Gravel Base Material.

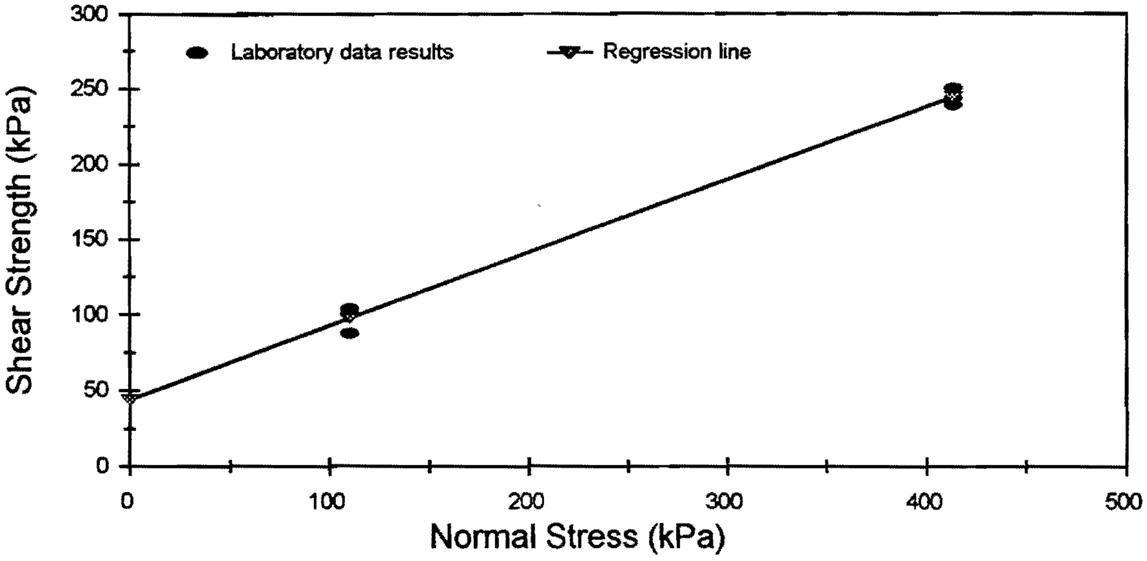


Figure 32. Mohr-Coulomb Envelope for Samples Primed by Scarification and Mixing-in with SS-1 and Pit Run Gravel Base Material.

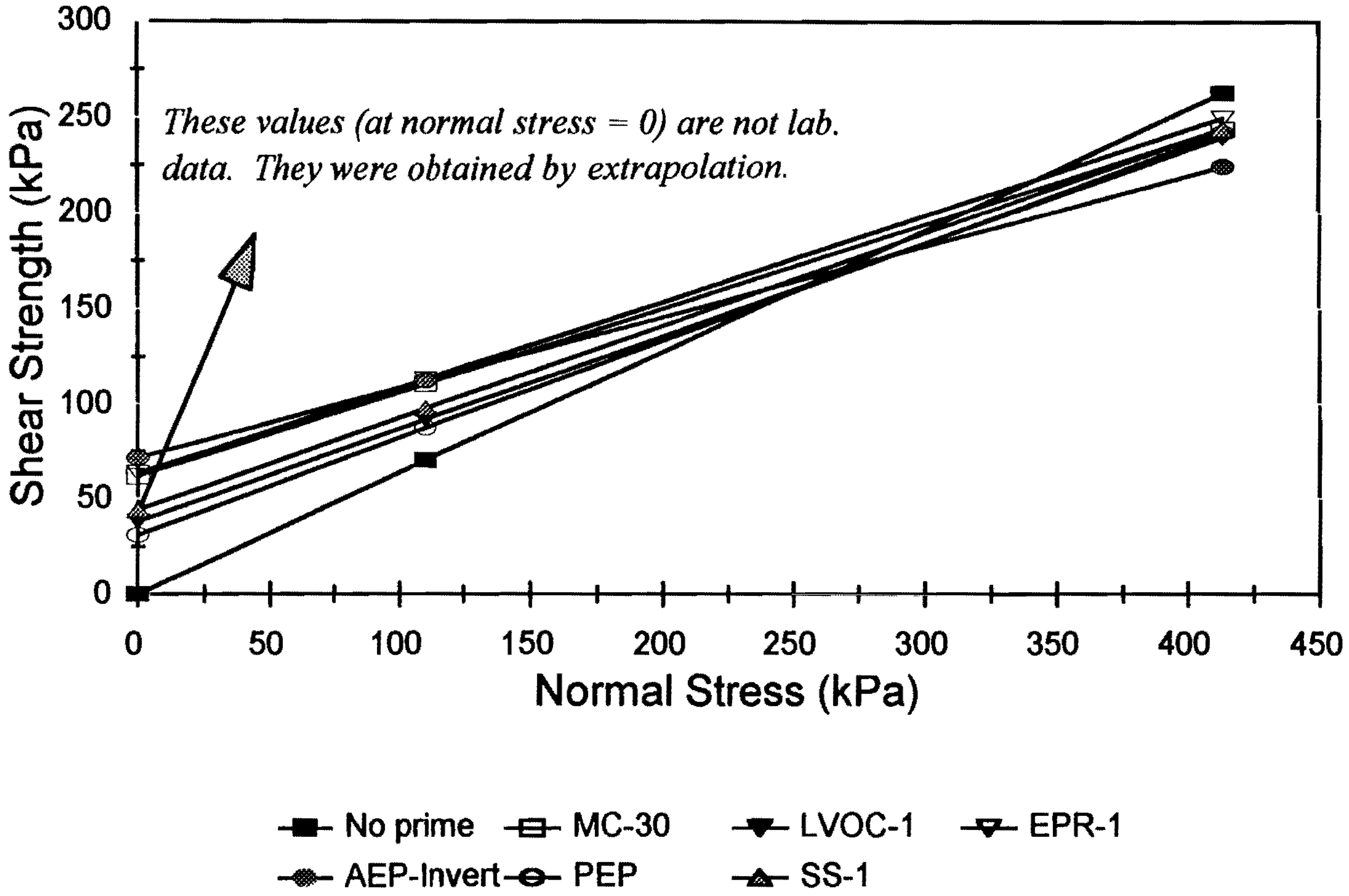


Figure 33. Mohr-Coulomb Failure Envelopes for the Interface between a Pit Run Gravel Base and the HMAC for Different Prime Materials Tested in Torsional Shear (1 psi = 6.894 kPa).

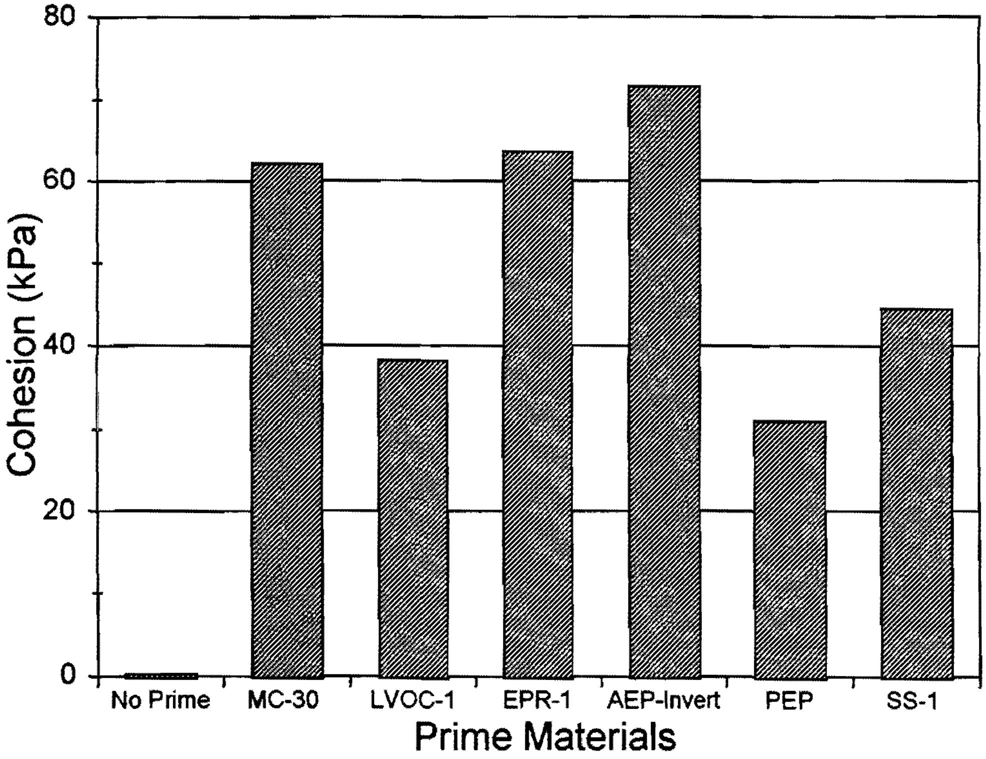


Figure 34. Cohesion Values from the Torsional Shear Test for Different Prime Materials and Pit Run Gravel Base Material (6.89 kPa = 1 psi).

together due to the variability of the laboratory results. The most influential factor in this variability is the anisotropic nature of these composite materials (soil-aggregate and asphalt-aggregate mixtures).

It is important to note that the normal stresses at the interface between a bituminous layer and the base are somewhat less than the vehicle tire pressure. Stress at the interface depends on the resilient modulus of the bituminous layer, Poisson's ratio, and the thicknesses of the layers that comprise the pavement structure. Figure 35 shows the normal stresses produced by different standard vehicle tire pressures for different pavement configurations. Resilient modulus of the different layers of the pavement selected for the calculations are common to the weather conditions and soils in Texas. A linear elastic computer model, CHEVPC, developed by the Chevron Research Company (17), was used for the analysis. Even though linear elastic models cannot be used for accurate calculations of pavement stresses and strains, their results are accurate enough in cases when a good approximation is sufficient. They are also very convenient because of the limited number of input variables required for the calculations. Therefore, reasonable *comparative* estimates can be predicted from the models. Other software packages that model the pavement more realistically require much information that is often not available.

In Figure 35, the most critical pavement configuration consists of a bituminous layer of 7.5 cm (3 in.) and 5E+06 kPa (72.5E+04 psi), a granular base of 15 cm (6 in.) and 1E+05 kPa (14.5E+03 psi), and a subgrade with a resilient modulus of 4E+04 kPa (5.8E+03 psi). For this configuration, which corresponds to the minimum design characteristics for that subgrade, the normal stresses caused by a truck tire are below 130 kPa (18 psi). Since this design configuration would not be built for a road with heavy truck traffic, the higher stresses shown (Figure 35) are not likely to occur. If they do, the number of load applications would be very low. It is more probable that this pavement configuration would be built for vehicles that cause stresses at the interface below 110 kPa (16 psi). Nevertheless, Figure 33 shows that, even at this lower level of a static stress, the additional cohesion provided by the prime coat plays an important role in the shear strength of the interface.

There are other non-load related stresses that generate shear stresses at the interface between the pavement and the base. Among these non-load related stresses are the stresses due to temperature changes. Yoder and Witczak (18) showed that the bond between layers is a

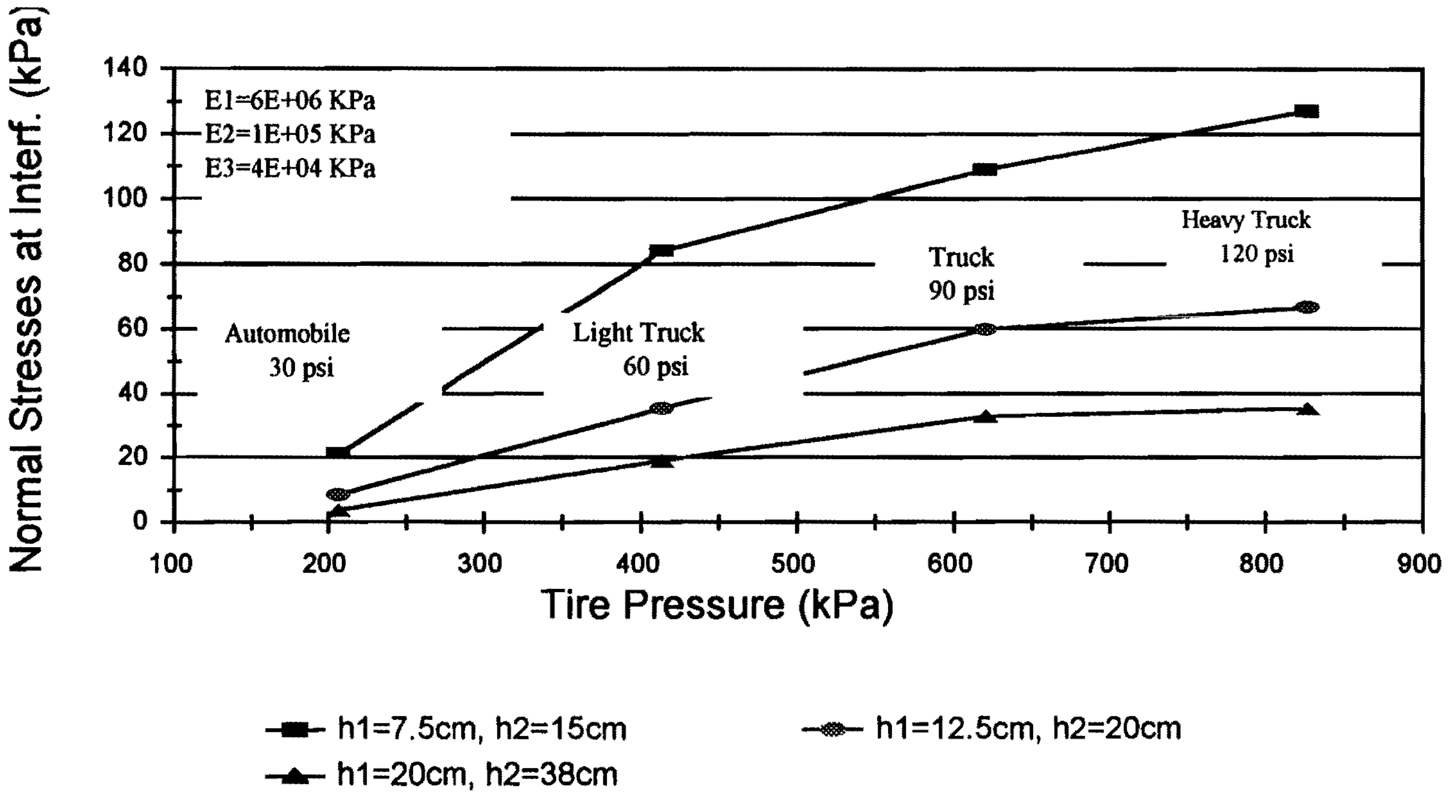


Figure 35. Normal Stresses Computed by CHEVPC due to Standard Tire Pressures for a Flexible Pavement (1 psi = 6.894 kPa).

factor that affects the susceptibility to low-temperature cracking of flexible pavements. Stresses due to temperature changes may be present at low levels of normal stress which makes the cohesion between the two upper layers an important and relevant factor. That is, a stronger bond at the primed interface should reduce thermal cracking, particularly in thin asphalt concrete pavements and surface treatments.

One cause of slippage cracking is, of course, a poor bond between the surface and the next layer of the pavement structure (19). A suitable prime will help reduce slippage cracking.

Mc Leod's approximate solution (7) for evaluating the bearing capacity of asphalt concrete mixtures shows benefits form increased frictional resistance between the pavement layers.

From Figure 34, some comments can be made. First, all prime coat products tested in this investigation seem to enhance the cohesion of the interface. For this function, AEP and EPR-1 performed as well as MC-30. It is important to mention that the plane of failure in most of the specimens tested, at a level of normal stress of 410 kPa (60 psi), was just *below* the penetrated depth of the prime which indicates some strengthening of the layer penetrated by the prime.

Figure 36 shows the shear strength of the interface for the different prime materials tested with crushed limestone base material at a normal stress of 410 kPa. Table A3, Appendix A, contains the test data. Due to time and funding constraints, it was not possible to test limestone base samples at a lower normal stress to facilitate computation of the Mohr-Coulomb coefficients.

DIRECT SHEAR TEST

The objective of this test was to measure the shear properties of the interface between a base and a hot mix asphalt layer with different prime coat materials. This part of the investigation was performed in order to reduce variability in the data from that obtained during the torsional shear tests. The torsional shear test was by comparison much more time, effort, and material intensive.

A second part of this effort was to investigate the effect of prime coats for different base conditions. When the surface of the base is covered with dust, the cohesion between the two upper layers is reduced. The importance of a prime coat for a dusty base was investigated. Dust is a very important factor to control in the road construction process. The process of sweeping

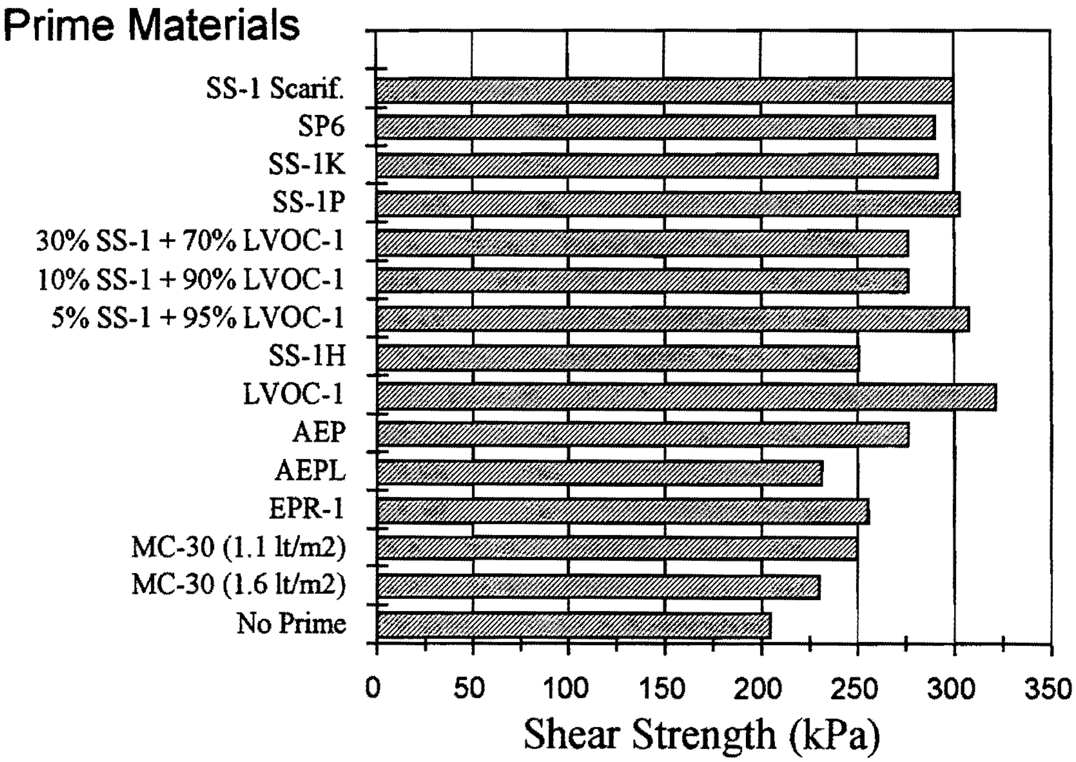


Figure 36. Torsional Shear Strength of the Interface between the Base and the Bituminous Layer at a Normal Stress of 410 kPa (60 psi) for Different Prime Materials on Limestone Base.

the dust off the road is not 100 percent effective and on occasion may result in a worse condition. For this reason, this part of the investigation appeared relevant.

Materials Tested

The following prime materials were tested in this portion of laboratory study:

MC-30, Fina,
LVOC-1, Prime Materials,
EPR-1, Chalet Emulsions,
AE-P, Koch,
PEP, Koch,
SS-1, Koch, and
TP-1, Prime Materials.

Description of Test

A strain-controlled direct shear device, typically used in soils testing, was used to examine shear properties of primed pavement interfaces. Two normal stresses were used in this experiment to define the Mohr-Coulomb failure envelope for the different prime coat materials (Figure 37). Samples were prepared as follows: optimum moisture content (7 percent) was added to a sample of base material. The moist aggregate was compacted in the lower half of the mold using a plunger with a diameter slightly smaller than that of the shear box.

A prime material was applied on top of the compacted base at a rate of 1.1 liters per square meter (0.24 gallons per square yard). They were allowed to cure for 24 hours at a temperature of 40°C (104°F). A seal coat of CRS-2 was applied on top of the primed base at the rate of 1.1 l/m^2. Grade 4 aggregate was sprinkled on top of the emulsion to simulate conventional underseal construction. The seal coat was allowed to cure at ambient temperature for 24 hours. Hot mix asphalt was compacted on top of the primed and sealed base, and then it was allowed to cure for 24 hours.

To fail the specimen in direct shear, a constant rate of deformation of 1.4 millimeters per second was applied to the top portion (Figure 37). Shear force as a function of time was recorded for each specimen. For the samples which were set up for analyzing dusty conditions,

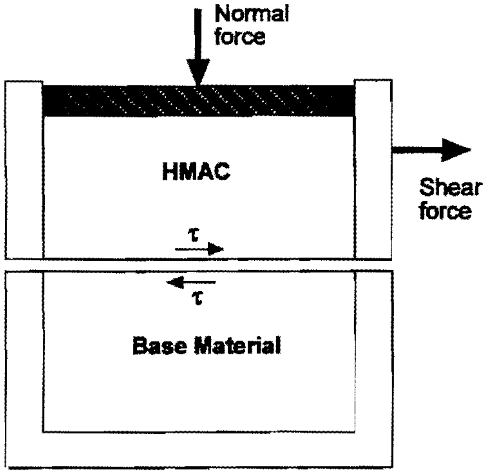


Figure 37. Arrangement to Study the Interface Between the HMAC and the Base Using the Direct Shear Equipment.

5 grams of dry dust from the same base material (fraction of material passing the No. 40 sieve) was spread on top of the base (this produced a layer of about 3 millimeters of dust) before priming. The dusted surface was sprayed with water (1.6 liters per square meter, 0.28 gal/yd^2) to promote distribution of the prime coat on the surface. The samples were primed with the different prime coat materials, and then their preparation followed the same procedure as the dust-free samples.

After testing the initial samples, prime coat material was observed to have leaked between the two horizontal facing edges of the shear box. When this material set, the two edges stuck together generating an additional and undesirable shear resistance. Therefore, silicone grease was applied between the two edges to discourage intrusion of the prime material and minimize the friction.

The internal vertical surfaces of the upper half of the box (the one that received the HMAC) was also lightly greased before compacting the HMAC into the upper half. This was done to minimize the friction between the HMAC and the box due to the normal load. However, there was still significant friction between the HMAC and the shear box. Consideration of this force was very important because the normal stress applied at the top of the HMAC was not totally transmitted to the horizontal interface between the base and the HMAC. Therefore, in order to generate a realistic Mohr-Coulomb envelope it was necessary to measure this friction. A special arrangement (Figure 38) was devised to measure the stress transmitted to the bottom of the asphalt layer. Only the upper part of the shear box was filled with HMAC and compacted. A load cell was placed at the bottom of the asphalt layer and different normal loads were applied at the top of the HMAC. The loads transmitted were read from a display connected to the load cell. Figure 39 plots the results of this experiment.

A linear regression analysis was performed on the data recorded from this test to determine the applied normal stresses needed to produce normal stresses of 50 and 100 kPa at the interface. The best-fit linear relation between the applied stress and the stress (in Newton) at the interface was as follows:

$$\sigma_{interface} = 1.03\ \sigma_{applied} - 14.69$$

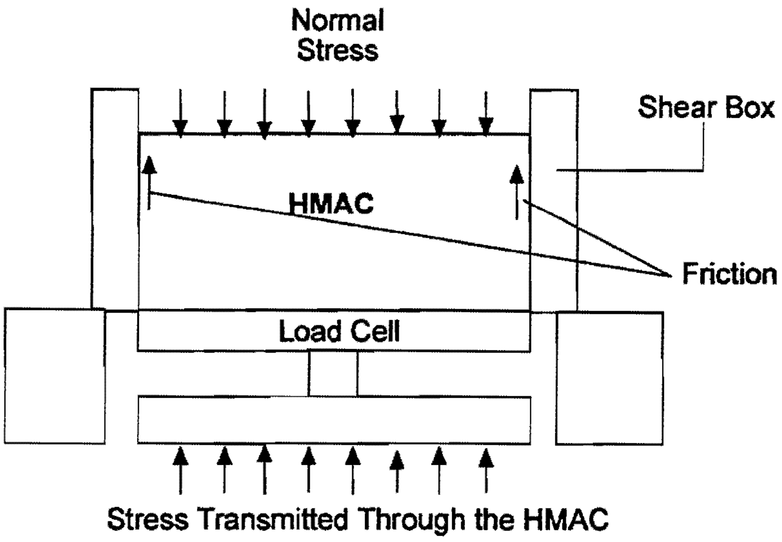


Figure 38. Setup for Determining the Friction between the HMAC and the Shear Box.

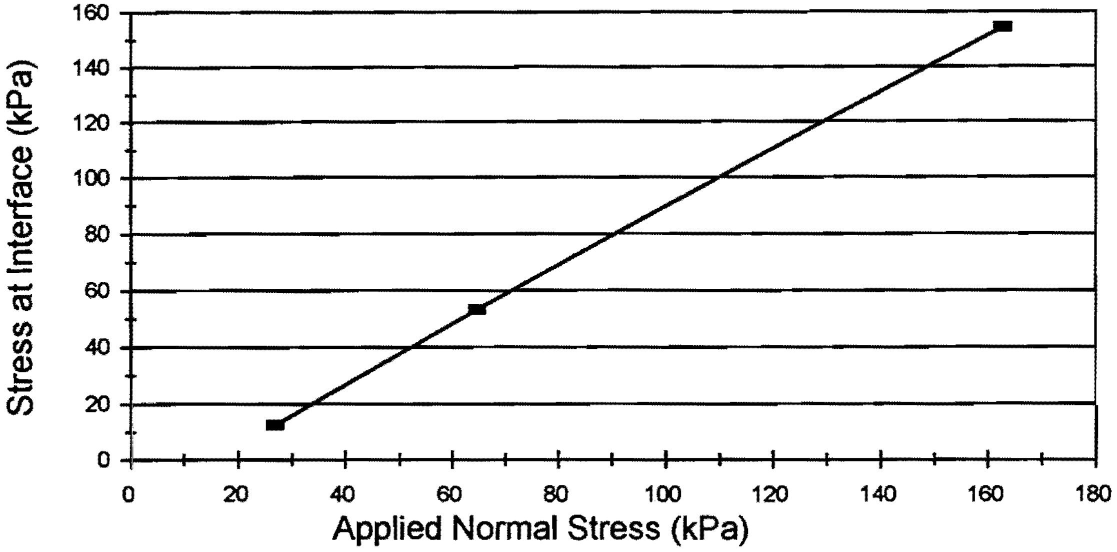


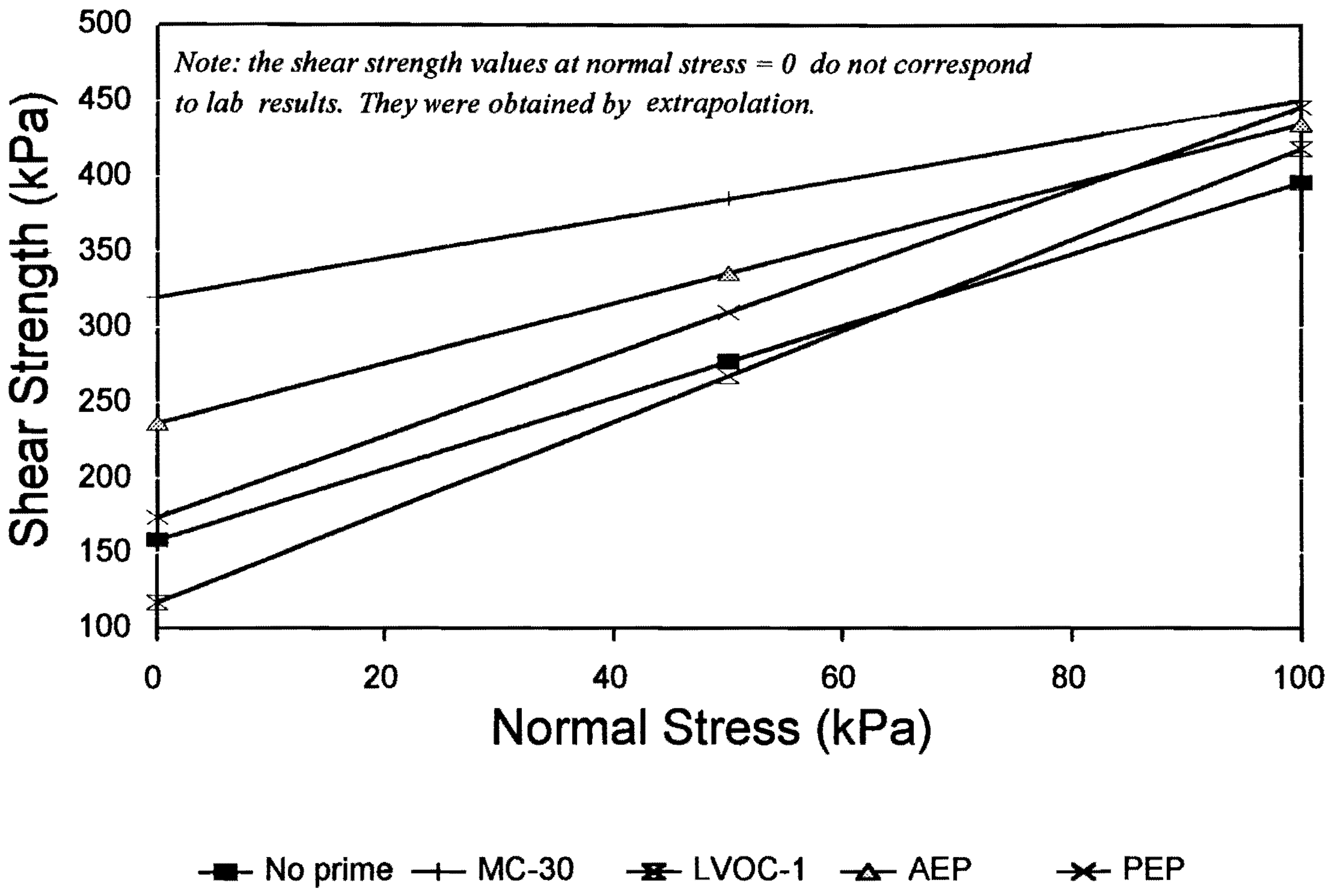
Figure 39. Normal Stresses at the Bottom of the HMAC Produced by Dead Weights and Transmitted through the HMAC in a Direct Shear Box.

Test Results

Results of the direct shear test for the dust-free samples are plotted in Figure 40. From that figure, we can see that, in the overall range of normal stresses, MC-30 and AEP samples performed better than unprimed samples. PEP and LVOC-1 performed similar to the unprimed samples.

Figure 41 shows the cohesion values obtained from a linear regression analysis. AEP and MC-30 samples exhibited the highest cohesion values. PEP and LVOC-1 exhibited cohesion values about the same as the unprimed samples.

The results shown in Figure 42 and 43 correspond to the samples to which dust was applied at the interface. The data do not show a consistent or logical pattern. It is believed that the samples were not allowed enough time to properly cure before testing. It is important to emphasize the fact that the samples were wetted after the application of the dust to permit uniform distribution of the primes. Without wetting, the prime materials would not spread evenly over the surface but would combine with the dry dust to form rich and lean areas. Some of the



Note: the shear strength values at normal stress = 0 do not correspond to lab results. They were obtained by extrapolation.

Figure 40. Mohr-Coulomb Failure Envelopes for Various Primes with a Dust-Free Interface between the HMAC and the Base Tested in Direct Shear.

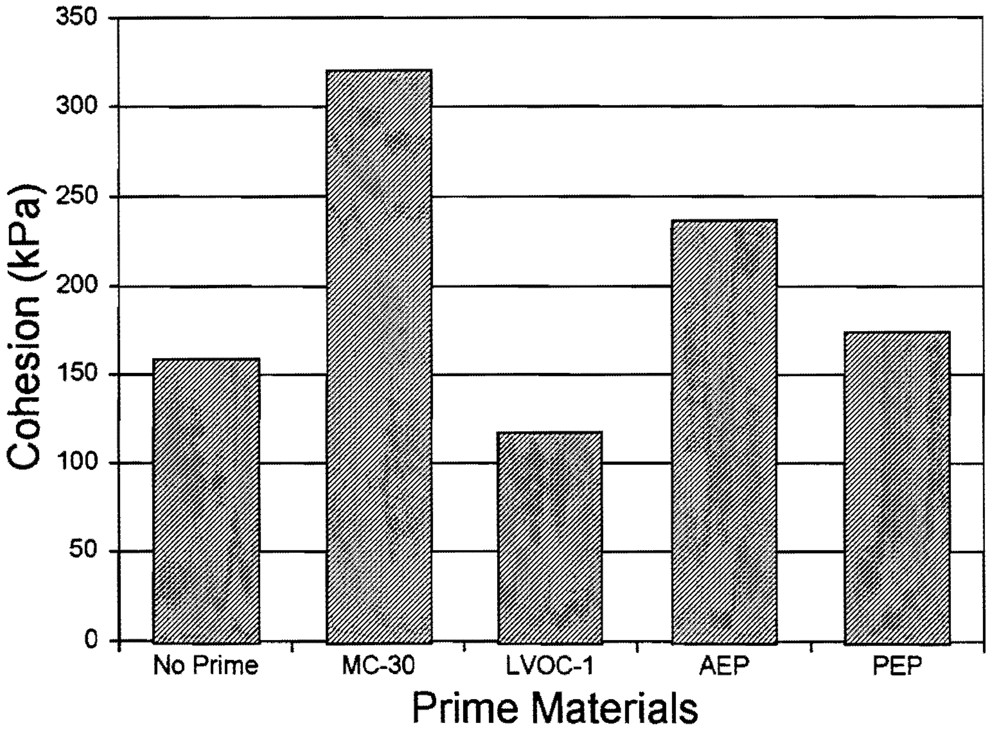


Figure 41. Cohesion Values for Various Primes with a Dust-Free Interface between the HMAC and the Base (1 psi = 6.894 kPa).

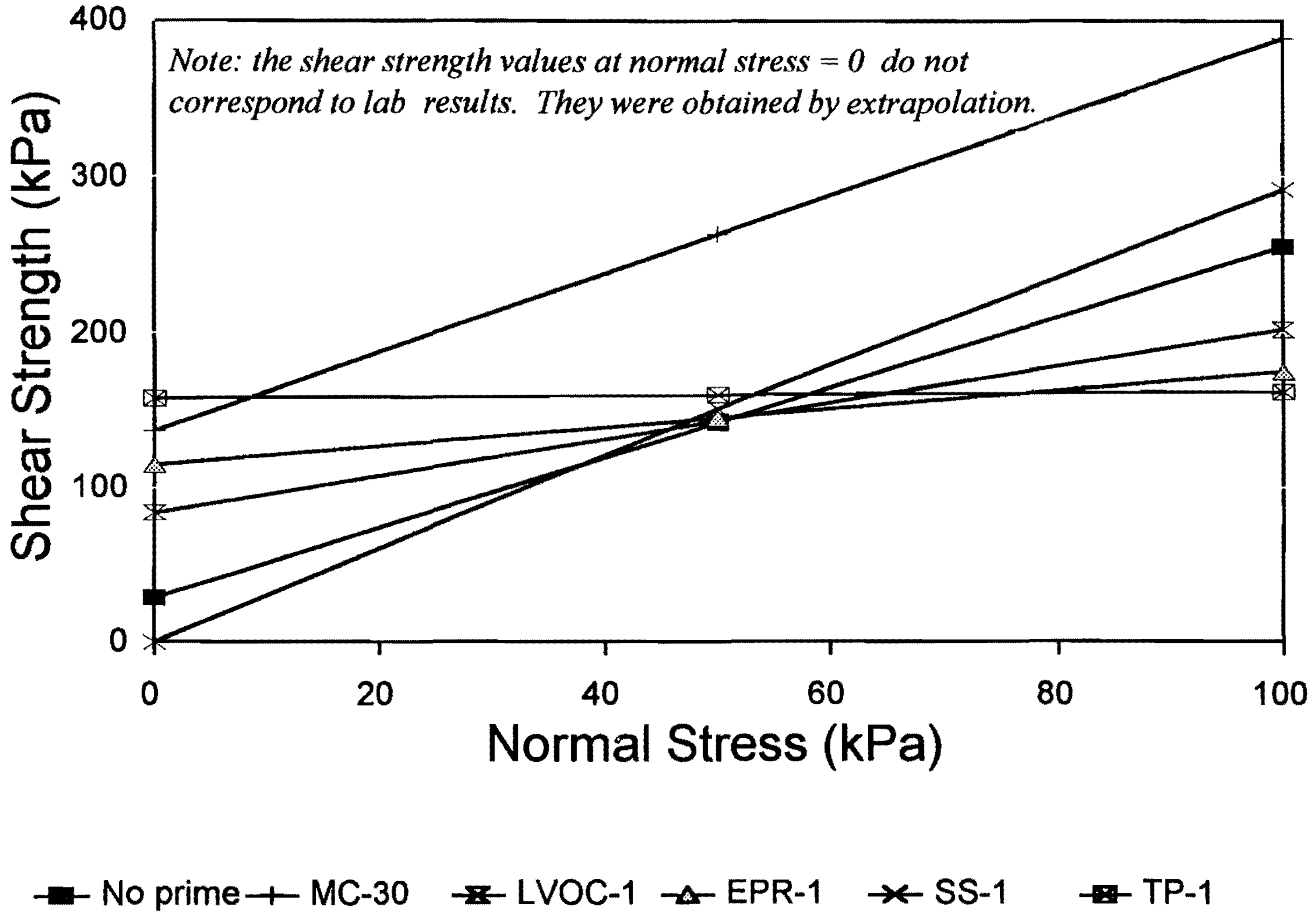


Figure 42. Mohr-Coulomb Failure Envelopes for Various Primes with a Dusty Interface between the HMAC and the Base Tested in Direct Shear.

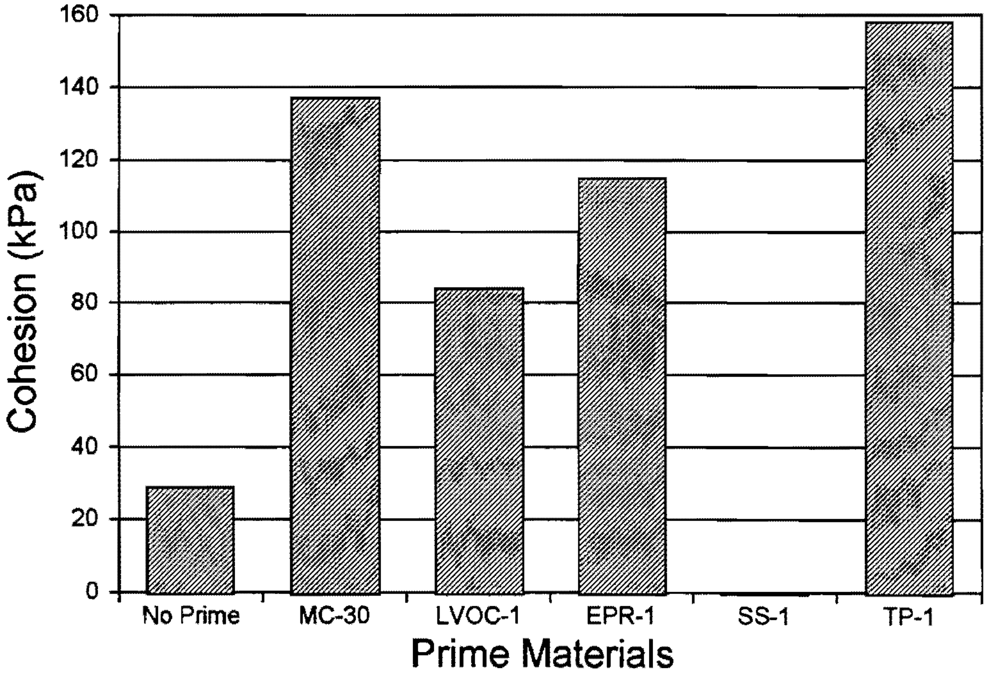


Figure 43. Cohesion Values for Various Primes with Dust in the Interface between the HMAC and the Base (1 psi = 6.894 kPa).

applied water was trapped between the base and the prime coat and not allowed to completely evaporate. This was actually observed when inspecting the samples after testing. This phenomenon resulted in lower shear strength of the interface for some of the samples. The unprimed samples were not affected because the water could evaporate uninhibited by any vapor barrier.

From Figures 44 through 46, the difference in shear strength of the samples with and without dust at the interface is observed. This suggests another justification for priming a base: minimizing the negative effect of dust on interfacial shear strength.

Unfortunately, there was no time to repeat testing of the prime materials that required longer to cure (all except MC-30 and unprimed samples) in order to more completely investigate the impact of all the prime materials on the shear strength of the interface for dusty bases. However, this part of the investigation demonstrated the importance of minimizing the dust to assure adequate strength of the interface between the HMAC and the base.

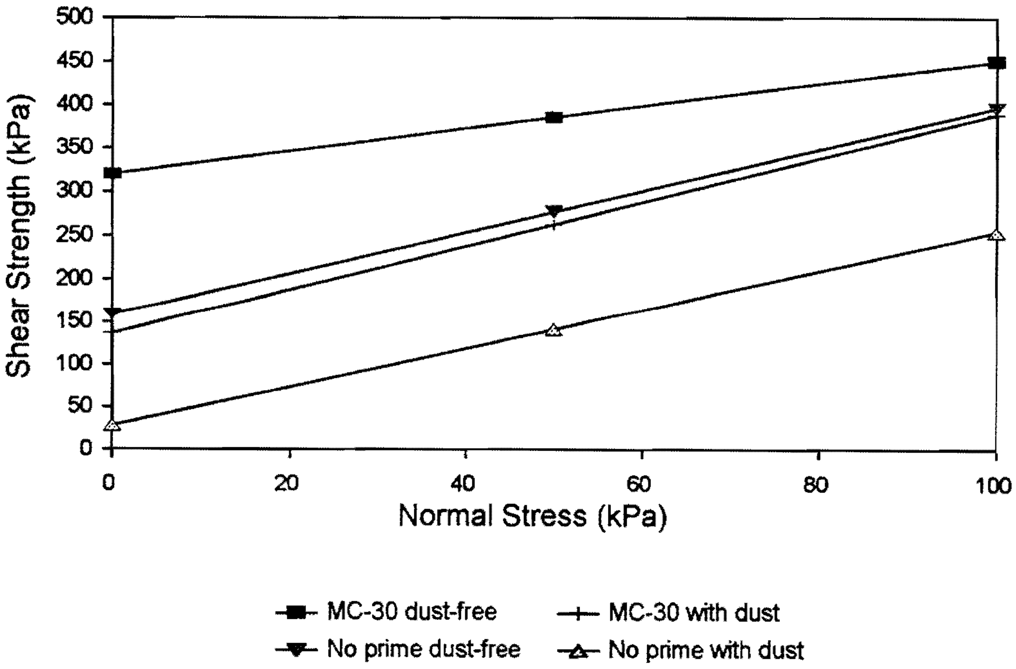


Figure 44. Mohr-Coulomb Failure Envelopes for MC-30 and Unprimed Samples with and without Dust at the Interface (from Direct Shear Tests).

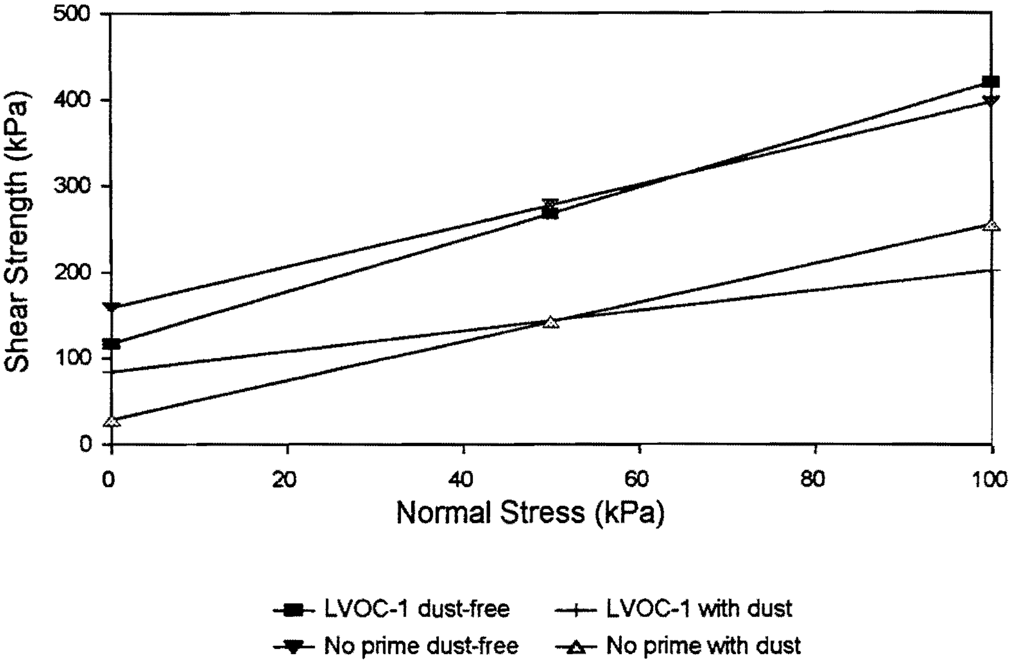


Figure 45. Mohr-Coulomb Failure Envelopes for LVOC-1 and Unprimed Samples with and without Dust at the Interface (from Direct Shear Tests).

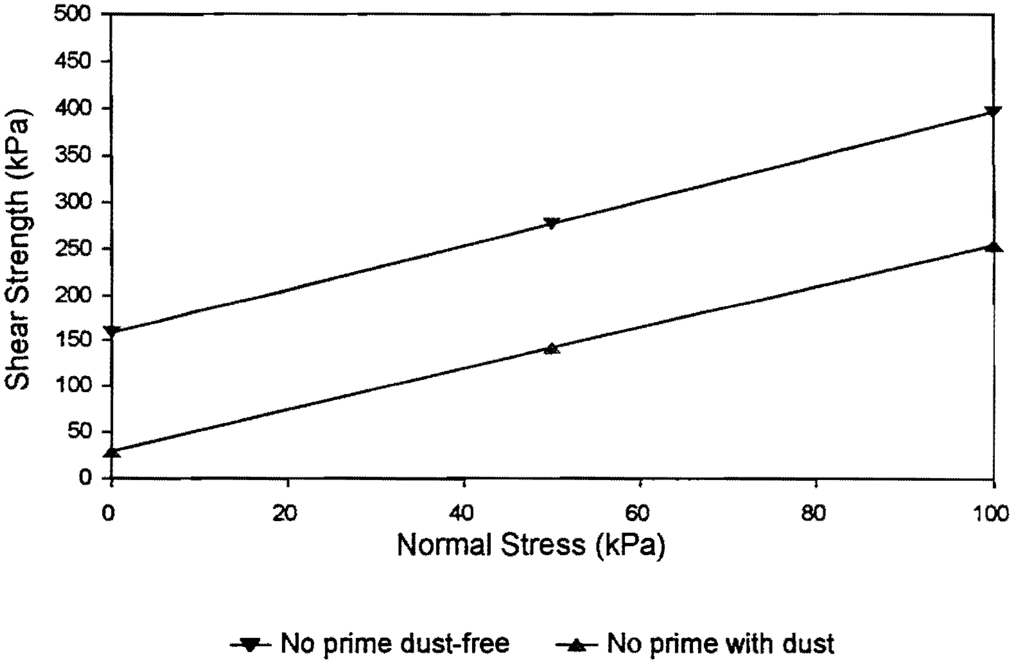


Figure 46. Mohr-Coulomb Envelopes for Unprimed Samples with and without Dust at the Interface (from Direct Shear Tests).

CHAPTER 4

FIELD INVESTIGATIONS

End-to-end field tests in the Abilene district and the Bryan district provided valuable experience with several prime materials and construction techniques. Both locations used crushed limestone base material which is typical for much of Texas. These operations provided an opportunity to evaluate relative penetration of several emulsified prime materials and their resistance to traffic and wet conditions.

Materials specifications for certain new prime materials were obtained from manufacturers/suppliers and sent to the Area Engineer in charge of the construction project. Appendix F provides these specifications.

Observations of priming operations in the Austin District demonstrated the simplicity and even advantages of using conventional emulsified asphalt for prime when proper construction techniques are employed. Videotape obtained at in the Austin District was used to produce an instructional video for contractor and TxDOT personnel to demonstrate the application of conventional emulsified asphalt for prime .

ABILENE DISTRICT

Construction

In June 1993, field trials were placed on FM 1673 near Snyder in Scurry County. The project included reconstruction and widening of a 2-lane rural road. The old base was pulverized and compacted, new base material was added, compacted, and primed, and, finally, a two-course surface treatment was applied.

Seven different prime materials (Table 4) were applied on approximately 300 meter (1000-foot) test sections in both lanes of the 2-lane road. Figure 47 illustrates the layout of the test pavements.

MC-30 was used as the Control, since it has been widely used for many years throughout the state and may be considered the standard prime. MC-30 was used on all of the project except the test pavements. Two different products called Asphalt Emulsion Prime (AE-P) were used. One was an inverted emulsion (oil phase is the continuous phase) which, of course, cannot be

Table 4. Test Results for Prime Coat Field Trials in the Abilene District

Prime Material	**Dilution Ratio,** emul/ water	**Shot Rate,** liter/m^2 (gal/yd^2)	**Initial Quality of Seal**	**Resistance to Rainfall**
MC-30	NA[1]	0.81 (0.18)	excellent	excellent
AE-P (inverted emulsion)[3] Koch Materials, Lubbock, Tx.	NA[1]	0.81 (0.18)	good	fair
PEP[3], Koch Materials, Lubbock, Tx.	2/1[1]	0.91 (0.20)	fair	poor
EPR-1[3] (3% asphalt), Blacklidge Internat'l Houston, Tx.	1/3[1]	0.68 (0.15)	good	poor
AE-P (regular emulsion),[3] Koch Materials, Lubbock, Tx.	1/0[1]	1.04 (0.23) sb-lane	good	fair
	3/1[1]	0.91 (0.20) nb-lane	fair	poor
MS-2, Koch Materials, Lubbock, Tx.	1/5[2]	1.04 (0.23)	good	good
	1/15[1]	0.91 (0.20)	fair	–
LVOC-1[3] (no asphalt), Prime Materials, Houston, Tx.	1/3[1]	0.91 (0.20)	fair	poor

[1] Applied prime directly to surface of compacted base and allowed to cure.

[2] Applied prime and used blade of motor grader to blend prime with the uppermost .5 in (1.27 m) (or less) of compacted base. Spread and compacted primed material.

[3] Specifications are in Appendix D.

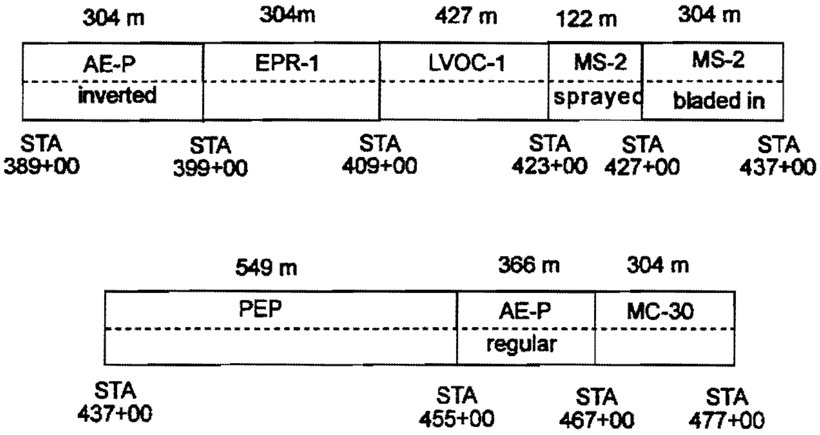


Figure 47. Layout of Prime Coat Test Sections at Snyder, Texas (Not to Scale).

diluted with water. The other AE-P was a conventional emulsion with water as the continuous phase. The AE-P primes contained about 15 percent oil distillate by weight of asphalt. TxDOT specification allows 25 to 40 percent oil distillate in AE-P. Penetrating Emulsion Prime (PEP) typically contains 12 to 14 percent light cycle oil (partly petroleum distillate). The distillates are added to promote penetration of the asphalt cement into a compacted base. The Emulsified Petroleum Resin (EPR-1) used at Snyder was a slow setting cationic emulsion of petroleum resin containing about 3 percent asphalt by weight of emulsion. The Low Volatile Organic Compound (LVOC-1) used was a slow setting anionic emulsion of naphthenic oil containing no asphalt. All of the above materials were applied using a distributor truck. Dilute MS-2 was applied in two passes using a water truck, and a motor grader was used after each pass to blade the emulsion into the top 3 to 9 mm (1/8 to 3/8 inch) of base. In one section about 122 meters (400 feet) long, very diluted MS-2 (diluted about 15/1 with water) was applied to the surface of the compacted base and allowed to cure without any mixing.

During construction, the weather was hot and dry with a daily maximum temperature near 38°C (100°F). This fostered rapid curing of the prime materials. The traffic level during construction was very low, consisting of construction vehicles plus about 20 to 30 passenger cars per day.

Performance

Only limited performance data was obtained on this project because the evening the last section was placed, a flash flood destroyed most of the test sections. At a nearby weather station, 108 mm (4.25 inches) of rain was recorded in a period of less than two hours. For the sake of expediency, the base was reshaped and primed with MC-30 prior to placement of the 2-course surface treatment. However, some useful information was obtained (Table 4).

The EPR-1 and AE-P (inverted) cured very quickly and could have carried traffic within 1 hour after application. LVOC-1 could have carried traffic within less than 2 hours. Penetration of the PEP was relatively slow; it could not have carried traffic in less than 3 hours without dusting with aggregate fines. MS-2 blade mixed with base could have carried traffic immediately upon completion of compaction. MC-30 required 3 to 4 hours before it could carry traffic.

PEP did not penetrate the base; it formed a sticky layer of asphalt on the surface. The PEP foamed so much when transferred to the distributor truck that the tank could not be strapped. It foamed considerably when applied to the surface of the base, but the foam dissipated rather quickly. Surface tension and/or foaming of the PEP caused small holes about the size of a dime to form in the surface of the prime within a few seconds after application. The dry, dusty surface probably contributed to this problem. A light application of water about 30 to 60 minutes before application of the prime may have prevented this phenomenon.

Diluted MS-2 was easily mixed into the top 6.4 mm (1/4 inch) of base but did not appear to provide a well sealed surface that would be resistant to traffic and rainfall. Ideally, this mixing process should have been done as a part of a preplanned construction sequence. In other words, more emulsion (0.5 liter/m^2 or 0.1 gal/yd^2 of residual asphalt) should have been mixed more deeply (25 mm or one inch) into the base during final preparation for compaction.

MC-30 clearly provided the best seal and most traffic resistant primed surface when compared to the other products and techniques tested at this location. LVOC-1, which contained no asphalt at that time, initially provided a waterproof surface but did not provide the cohesion necessary to maintain a good seal under the abrasive action of traffic.

After the flash flood, the primed surfaces were visually evaluated. The MC-30 exhibited no appreciable damage. The AE-P (invert) had been about 20 to 50% eroded. EPR-1 and LVOC -1 were about 77% eroded. Although the PEP did not exhibit erosion, it allowed water to penetrate into the base and then the asphalt film held it there for a prolonged period thus creating an undesirable situation. The southbound lane, where the undiluted AE-P (regular emulsion) was sprayed, was in fair condition with some water penetration. The northbound lane, where the diluted AE-P was applied, was in poor condition. The section where MS-2 was bladed in was in fair condition and performed better than all other materials except MC-30.

BRYAN DISTRICT

Construction

In June 1994, prime test pavements were placed on FM 46 south of Franklin, Texas, in Robertson County [Project STP-92(110)R]. The job included major rehabilitation and widening of a 2-lane farm road. The existing asphalt surface treated pavement was in fair to very bad condition. The shoulders of the existing pavement were widened using crushed limestone, then approximately 150 mm (6 inches) of the crushed limestone base material were spread over the existing pavement and compacted. A 2-course asphalt surface treatment was applied as the final paved surface.

Five different prime materials (Table 5) were applied on the test sections in both lanes of the 2-lane road (Figure 48). AE-P (inverted emulsion) and MC-30 were used as controls. One or the other of these products were used on the bulk of the job. The LVOC-1 used on FM 46 contained about 3 percent asphalt and was supplied to the job site already diluted with water to expedite construction. TP-1 is an emulsified wood pitch which is insoluble in water. It contains no asphalt or petroleum products. This was the first field application of TP-1. The EPR-1 used on this job contained about 11 percent asphalt. All prime materials were applied using a distributor truck. LVOC-1, TP-1, and EPR-1 were applied at ambient temperature. AE-P and MC-30 were applied at about 66°C (150°F).

The primes were applied as the construction sequence permitted over a period of about five weeks. When the LVOC-1 and TP-1 were applied, the weather was hot but cloudy and rain was threatening. EPR-1 was applied during hot, dry weather. The traffic level during construction was low, consisting of construction vehicles plus about 150 to 200 passenger cars per day.

Performance

Table 5 records relative performance evaluations and depth of penetration of the different primes.

During the cloudy, humid weather, the LVOC-1 cured fairly slowly. The surface remained sticky for about 3 hours and traffic was held off for about 4 hours. One week after application, many bare spots from 25 to 100 mm (1 to 4 inches) in diameter were observed on the LVOC-1 primed surface. This indicated that the LVOC-1 prime was capable of carrying light traffic for only a few days on this particular base. About 2 weeks after the first application of LVOC-1, it was reapplied just before application of the surface treatment.

Application of TP-1 using a conventional distributor truck presented no unusual circumstances. It was applied on a superelevated segment in a curve. TP-1 cured quite rapidly. In fact, less than 1 hour after application, a light rain shower caused water run off from the

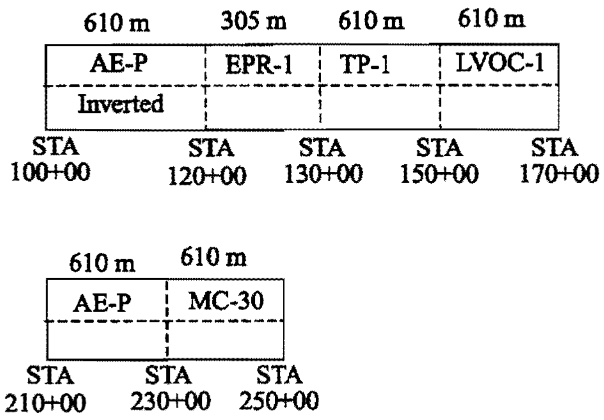


Figure 48. Layout of Prime Coat Test Sections at Bryan, Texas (Not to Scale).

Table 5. Test Results for Prime Coat Field Trials in the Bryan District

Prime Material	**Dilution Ratio,** emulsion/ water	**Application Rate,** liter/m^2 (gal/yd^2)	**Pene Depth,** mm	**Traffic-ability**	**Time to Traffic,** hours	**Resistance to Rainfall**
MC-30, Gulf States, Houston, Tx.	NA	0.81 (0.18)	7	good	4-5	good
AE-P (inverted emulsion) Koch Materials, Austin, Tx.	NA	1.36 (0.30)	4	good	4-5	good
LVOC-1, (with 3% asphalt), Prime Materials, Houston, Tx.	1/3	1.04 (0.23)	3	poor	3-4	good
TP-1, (wood pitch) Prime Materials, Houston, Tx.	1/3	1.36 (0.30)	2	fair	3-4	fair
EPR-1 (with 11% asphalt), Blacklidge Internat'l Houston, Tx.	1/3	1.00 (0.22)	3	good	2-3	good

section; however, none of the TP-1 was lost. This moisture and the humid weather (apparently) caused the TP-1 to remain sticky for 3 to 4 hours so that traffic had to be held off. After about 1 week of exposure to traffic and intermittent rainfall, the TP-1 had several small bare spots but looked fairly good.

EPR-1 was applied on a clear day and cured very quickly. In fact, within 30 minutes, one could walk on it without it sticking to the bottom of one's shoe soles. It probably could have carried traffic within 1 hour after application. It was trafficked for only 4 days and suffered a little more damage from traffic than the AE-P.

AUSTIN DISTRICT

The researchers travelled to the Bastrop vicinity on several occasions to observe and/or video the "cutting in" of conventional asphalt emulsion (MS-2) into the top 25 to 50 mm (1 to 2 inches) of base which provides a "primed" surface ready to receive the asphalt surface course. The process may be performed while the base is being prepared for compaction or the base may be fully compacted then the top 25 mm (1 inch) or so may be scarified, mixed with emulsion, and then recompacted.

In either case, the process involves diluting the emulsified asphalt with 10 to 15 parts water and applying it with a water truck until the loose base material is at the optimum fluids content for compaction. The mixture is periodically blade-mixed in the usual manner until completely blended. It is then spread using the motor grader and compacted in the usual fashion. If the surface appears a little lean, a light application of the dilute emulsion can be applied (skeeted) onto the compacted surface to control dust, provide resistance to abrasion by traffic and erosion by rainfall, and promote bonding to the subsequent pavement layer. If it is necessary for the base to carry traffic for an extended period, the base can be periodically skeeted with diluted emulsion to keep the surface tough and water resistant.

A detailed description of this construction process is provided in the "Guidelines for Application of Emulsified Prime Materials." An instructional video to demonstrate this procedure has been prepared to assist implementation of these important project findings.

CHAPTER 5

METHODS FOR APPLYING EMULSIFIED ASPHALT PRIME

Emulsions of aromatic and/or naphthenic oils often lack sufficient asphaltenes to provide the binding power, and thus resistance to damage, by traffic and rainfall provided by asphalt. Emulsified asphalts often do not adequately penetrate a compacted base. As a result, several so-called emulsified asphalt products, termed asphalt emulsion prime (AEP) or penetrating emulsion prime (PEP), have been developed. These products contain various quantities of cutter stock (petroleum solvents) to promote penetration. Therefore, these products cannot provide complete solutions to the long-term pollution problem that this study considers. When using emulsified asphalt (without solvents) for prime, it is usually necessary to mechanically mix the prime with the uppermost 25 mm to 50 mm (1 to 2 inches) of base to achieve desirable "penetration" depth. The "Guidelines for Application of Emulsified Prime Materials" (Appendix D) describe two alternative methods for mechanically mixing the emulsified prime materials with the base.

BENEFITS OF THE MIXED-IN PRIMING METHOD

Benefits of the mixed-in priming method include:

- it can be performed in weather conditions when the conventional priming method is not advisable,
- the resulting surface provides good protection against inclement weather,
- the base may be trafficked for several weeks before paving,
- the time required for curing before trafficking is less than for spray application, and
- the treated layer provides significant additional strength to the pavement structure.

RESULTS OF LABORATORY TESTS

Tests have shown that the treated layer provides significant structural benefits to the pavement system. As part of this investigation, resilient modulus tests were performed on samples prepared in the laboratory simulating the mixed-in priming method. Granular base material was mixed with SS-1 or MC-30. The prime materials were added to obtain a residual asphalt content of 3 percent by weight. The samples were compacted using the gyratory compactor and cured at a temperature of 40°C (104°F) for 180 days to allow adequate time for evaporation of solvents and water. After curing, the samples were cooled to 25°C (77°F) and resilient modulus was measured. Three specimens of each prime material were prepared and tested. The average resilient modulus of the samples were:

- SS-1 treated samples - $1.7\text{x}10^6$ kPa (245,000 psi),
- MC-30 treated samples - $1.5\text{x}10^6$ kPa (218,000 psi), and
- Untreated samples - 10,000 kPa (14,500 psi).

Figure 49 shows a pavement configuration that consists of 15 centimeters (6 in) of HMAC with a resilient modulus of $6\text{x}10^6$ kPa (870,000 psi), 5 centimeters of a mixed-in primed layer with a resilient modulus of $1.7\text{x}10^6$ kPa (245,000 psi) (laboratory test average result for SS-1 samples), 25 centimeters of granular base with a modulus of $1.0\text{x}10^5$ kPa (14,500 psi), and a subgrade with a modulus of $4\text{x}10^4$ kPa (5,800 psi). A dual tire load configuration with 653 kPa (4500 psi) per tire (124,110 kPa [18 kips] axle load) was assumed to be acting in that pavement. The same loading condition on a similar pavement configuration without the primed layer (e.g., 30 centimeters [12 in] of untreated granular base) was analyzed for comparison purposes.

The tensile strain at the bottom of the asphalt layer and the compressive strain at the top of the subgrade were calculated using the CHEVPC computer program. They were analyzed to determine the number of applications of the above described load for each pavement configuration (primed and unprimed) that is required to fail the pavements by fatigue cracking and to produce a specified permanent deformation. A criterion for fatigue cracking is expressed as

$$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$$

in which

N_f is the allowable number of load repetitions without fatigue cracking,

ε_t is the tensile strain at the bottom of the asphalt layer,

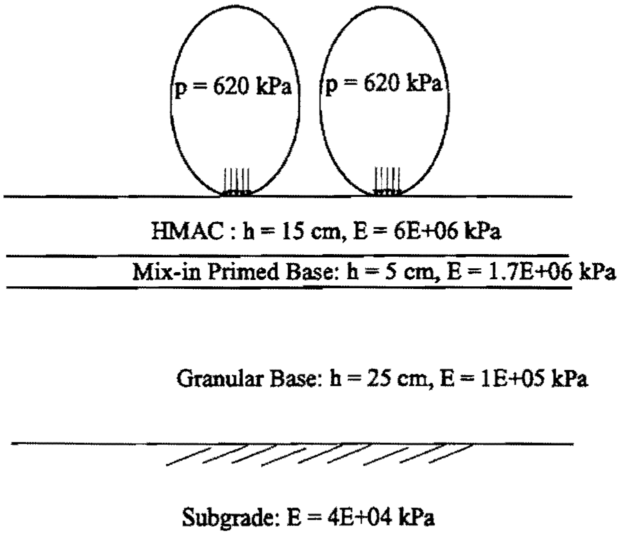


Figure 49. Example of Pavement Configuration with a Mixed-in Primed Layer.

E_1 is the resilient modulus of the asphalt layer, and

f_1, f_2, and f_3 are constants determined from laboratory fatigue tests.

The Asphalt Institute (21) used 0.0796, 3.291, and 0.854 for f_1, f_2, and f_3, respectively, in their analytically based design procedure. The corresponding values used by Shell are 0.0685, 5.671, and 2.363 (20).

The criterion for permanent deformation is expressed as

$$N_d = f_4(\varepsilon_c)^{-f_5}$$

in which

N_d is the allowable number of load repetitions to produce a permanent deformation of 13 mm (1/2 in),

ε_c is the compressive strain on top of subgrade, and

f_4 and, f_5 are constants determined from field performance of actual road tests.

Values of f_4 and f_5 suggested by the Asphalt Institute (21) are $1.365\text{x}10^{-9}$ and 4.477, respectively. Values suggested by Shell (22) are $6.15\text{x}10^{-7}$ and 4.0, respectively.

Using the results obtained from CHEVPC and the failure equations previously defined, the load applications to failure due to fatigue cracking and permanent deformation were calculated. The results are shown in Table 6. These data represent only one base material and are not presented as exhaustive. However, from Table 6, we can infer that the benefits of the mixed-in primed layer are significant with regard to fatigue cracking and permanent deformation.

Although mixing in prime appears to be an expensive process, specifying this method of priming has historically had negligible effects on the total bid price (23) for road construction. Depending on the application, construction sequence, timing, and level of traffic, it may be more cost effective to treat the top 25 to 50 mm (1 to 2 inches) than to just spray prime the surface. Proof of this hypothesis must come from field experience.

Table 6. Number of Load Applications to Failure Using the Fatigue Cracking and Permanent Deformation Criteria from the Asphalt Institute and Shell Oil Company.

Pavement Configuration	Number of Load Applications to Failure			
	Fatigue Cracking		Permanent Deformation	
	A.I. Constants	Shell Constants	A.I. Constants	Shell Constants
With mixed-in primed layer	$7x10^6$	$16x10^6$	$3.7x10^6$	$38x10^6$
Without mixed-in primed layer	$1.8x10^6$	$1.7x10^6$	$1.7x10^6$	$20x10^6$

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A study of prime coating materials for compacted highway bases and their application techniques was conducted to provide the TxDOT with information needed to transition from cutback asphalts to materials containing lower quantities of volatile pollutants. The researchers submit the following conclusions and recommendations, based on laboratory and field experiments.

1. Bond strength at the interface between a compacted base and an asphalt concrete layer was examined in the laboratory using direct shear and torsional shear. All prime materials tested in this investigation consistently yielded higher bond strengths over that of no prime as determined by shear strength or cohesion at the lower normal stresses; however, the differences were not always statistically significant.
2. At the higher static normal stresses, shear strength at the interface is not appreciably affected by the type or even the presence of a prime coat. That is, the confining pressure produced by a heavy vertical static load causes the shear strength at the base-pavement interface to increase to a point that the prime has little or no effect.
3. The plane of failure in the vast majority of the torsional shear tests was just below the penetrated depth of the prime. This indicates that the stratum of base penetrated by the prime was stronger than the untreated base material.
4. According to theory, a stronger bond at the primed interface should reduce damage due to vertical and horizontal traffic loads and reduce thermal cracking, particularly under thin asphalt concrete pavements and surface treatments.
5. Conventional emulsified asphalts do not adequately penetrate most compacted bases when applied as a prime. Dilution of the emulsion with water helps but still does not usually provide acceptable penetration.

6. Mechanical mixing of very dilute emulsified asphalt into the top 25 to 50 mm (1 to 2 inches) of a granular base appears to be the most promising alternative to priming with cutback asphalt. The stabilized layer resulting from this priming process can contribute significantly to the structural strength of the pavement. The Guidelines in Appendix D describe this process.
7. Although mechanical mixing of emulsified asphalt into a granular base requires more labor than spray-on applications of cutback asphalt prime, when considered in the total bid price for highway construction, the cost difference is insignificant.
8. Emulsified oils containing little or no asphalt can be used as successful primes. However, they typically do not protect the base from damage by traffic or rainfall as well as MC-30 or other cutback asphalt primes. Actual performance depends on the particular prime product, level of traffic, intensity and duration of any rainfall, and the type of base material. Appendix D provides a list of these products.
9. Dust at the interface between the base and the pavement is detrimental to shear strength. A prime material containing a binder that provides cohesion, such as asphalt, can strengthen the bond when dust is present but not to the extent of a dust-free interface. Wetting a dusty surface before priming will aid in uniform distribution of the prime.
10. Some emulsified asphalt primes (AEPs) are essentially cutback asphalts that have been emulsified. Because they contain significant quantities of volatile hydrocarbons, they are no less polluting than MC-30.

RECOMMENDATIONS

1. Use emulsified asphalt as prime by mechanically mixing with the top 25 to 50 mm (1-2 inches) of base material as described in the "Guidelines for Application of Emulsified Prime Materials" contained in Appendix D.
2. When traffic is relatively light and the primed base will not be exposed to traffic for more than one or two weeks, prime with non-asphalt or low asphalt content primes that are commercially available. All such products currently known to the researchers are listed in the "Guidelines."

3. Use the prime penetration test developed in this study to help determine the suitability of a prime material for a specific base material. Record resulting field performance (actual penetration, resistance to traffic and weather) of the prime over a period of a few years to validate the laboratory procedure and establish criteria for specifications.
4. A cohesion tester was modified with vanes affixed to a metal foot to measure vane shear within the penetrated depth of a laboratory prepared specimen of primed base. Limited experiments using this device to evaluate cohesion and shear resistance within the penetrated depth appeared promising. Sample preparation and testing is quick, simple, and inexpensive. This work should be continued and correlated with field performance of primes to develop a specification test with criteria.

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APPENDIX A

TORSIONAL SHEAR TEST DATA

Table A1. Shear Strength Values from the Torsional Shear Test for a Normal Stress of 110 kPa and Pit Run Gravel Base Material.

Sample #	Prime Material	Shear Strength, kPa (psi)
1	Non-primed	13 (1.89)
2	Non-primed	62 (8.99)
3	Non-primed	86 (12.5)
4	Non-primed	124 (18.0)
5	MC-30	72 (10.4)
6	MC-30	127 (18.4)
7	MC-30	94 (13.6)
8	MC-30	151 (21.9)
9	LVOC-1	117 (17.0)
10	LVOC-1	89 (12.9)
11	LVOC-1	102 (14.8)
12	LVOC-1	59 (8.56)
13	EPR-1	120 (17.4)
14	EPR-1	184 (26.7)
15	EPR-1	36 (5.22)
16	AE-P Invert	102 (14.8)
16	AE-P Invert	99 (14.4)
17	AE-P Invert	137 (19.9)
18	PEP	135 (19.6)
19	PEP	75 (10.9)
20	PEP	89 (12.9)
21	PEP	50 (7.25)
22	SS-1 Scarified base	88 (12.8)
23	SS-1 Scarified base	101 (14.7)
24	SS-1 Scarified base	104 (15.1)

Table A2. Shear Strength Values from the Torsional Shear Test for a Normal Stress of 410 kPa and Pit Run Gravel Base Material.

Sample #	Prime Material	Shear Strength, kPa (psi)
25	Non-primed	257 (37.3)
26	Non-primed	255 (37.0)
27	Non-primed	289 (41.9)
28	MC-30	182 (26.4)
29	MC-30	265 (38.4)
30	MC-30	291 (42.2)
31	LVOC-1	257 (37.3)
32	LVOC-1	205 (29.7)
33	LVOC-1	258 (37.4)
34	EPR-1	241 (35.0)
35	EPR-1	257 (37.3)
36	EPR-1	254 (36.8)
37	AE-P Invert	239 (34.7)
38	AE-P Invert	195 (28.3)
39	AE-P Invert	245 (35.5)
40	PEP	239 (34.7)
41	PEP	257 (37.3)
42	PEP	234 (33.9)
43	SS-1 Scarified base	239 (34.7)
44	SS-1 Scarified base	250 (36.3)
45	SS-1 Scarified base	244 (35.4)

Table A3. Shear Strength Values from the Torsional Shear Test for a Normal Stress of 410 kPa and Limestone Base Material.

Sample #	Prime Material	Shear Strength, kPa (psi)
46	Non-primed	203 (29.4)
47	Non-primed	210 (30.5)
48	Non-primed	197 (28.6)
49	MC-30 (1.6 lt/m2)	265 (38.4)
50	MC-30 (1.6 lt/m2)	236 (34.2)
51	MC-30 (1.6 lt/m2)	187 (27.1)
52	MC-30 (1.1 lt/m2)	221 (32.1)
53	MC-30 (1.1 lt/m2)	189 (27.4)
54	MC-30 (1.1 lt/m2)	229 (33.2)
55	MC-30 (1.1 lt/m2)	317 (46.0)
56	MC-30 (1.1 lt/m2)	189 (27.4)
57	MC-30 (1.1 lt/m2)	327 (47.4)
58	MC-30 (1.1 lt/m2)	301 (43.7)
59	MC-30 (1.1 lt/m2)	245 (35.5)
60	MC-30 (1.1 lt/m2)	219 (31.8)
61	EPR-1	219 (31.8)
62	EPR-1	228 (33.1)
63	EPR-1	314 (45.5)
64	AE-PL	205 (29.7)
65	AE-PL	229 (33.2)
66	AE-PL	255 (37.0)
67	AE-P	384 (55.7)
68	AE-P	206 (29.9)

Table A3. Continued.

Sample #	Prime Material	Shear Strength, kPa (psi)
69	AE-P	234 (33.9)
70	LVOC-1	182 (26.4)
71	LVOC-1	258 (37.4)
72	LVOC-1	232 (33.7)
73	LVOC-1	359 (52.1)
74	LVOC-1	447 (64.8)
75	LVOC-1	439 (63.7)
76	SS-1H	291 (42.2)
77	SS-1H	304 (44.1)
78	SS-1H	299 (43.4)
79	SS-1H	189 (27.4)
80	SS-1H	215 (31.2)
81	SS-1H	198 (28.7)
82	5% LVOC-1 + 95% SS-1	268 (38.9)
83	5% LVOC-1 + 95% SS-1	325 (47.1)
84	5% LVOC-1 + 95% SS-1	324 (47.0)
85	10% LVOC-1 + 90% SS-1	294 (42.6)
86	10% LVOC-1 + 90% SS-1	270 (39.2)
87	10% LVOC-1 + 90% SS-1	260 (37.7)
88	30% LVOC-1 + 70% SS-1	281 (40.8)
89	30% LVOC-1 + 70% SS-1	276 (40.0)
90	30% LVOC-1 + 70% SS-1	267 (38.7)
91	SS-1 Prime Materials	335 (48.6)

Table A3. Continued.

Sample #	Prime Material	Shear Strength, kPa (psi)
92	SS-1 Prime Materials	302 (43.8)
93	SS-1 Prime Materials	268 (38.9)
94	SS-1 Koch	289 (41.9)
95	SS-1 Koch	307 (44.5)
96	SS-1 Koch	276 (40.0)
97	SP6	299 (43.4)
98	SP6	286 (41.5)
99	SP6	283 (41.1)
100	SS-1 Scarified Base	298 (43.2)
101	SS-1 Scarified Base	285 (41.3)
102	SS-1 Scarified Base	288 (41.8)
103	SS-1 Scarified Base	254 (36.8)
104	SS-1 Scarified Base	335 (48.6)
105	SS-1 Scarified Base	333 (48.3)

APPENDIX B

DIRECT SHEAR TEST DATA

Table B1. Shear Strength Values from the Direct Shear Test for a Normal Stress of 50 kPa and Pit Run Gravel Base Material. Samples without Dust at the Interface.

Sample #	Prime Material	Shear Strength, kPa (psi)
1	No prime	261 (37.9)
2	No prime	267 (38.7)
3	No prime	305 (44.2)
4	MC-30	387 (56.1)
5	MC-30	413 (59.9)
6	MC-30	357 (51.8)
7	LVOC-1	244 (35.4)
8	LVOC-1	257 (37.3)
9	LVOC-1	302 (43.8)
10	AE-P	270 (39.2)
11	AE-P	402 (58.3)
12	PEP	270 (39.2)
13	PEP	269 (39.0)
14	PEP	391 (56.7)

Table B2. Shear Strength Values from the Direct Shear Test for a Normal Stress of 100 kPa and Pit Run Gravel Base Material. Samples without Dust at the Interface.

Sample #	Prime Material	Shear Strength, kPa (psi)
15	No prime	457 (66.3)
16	No prime	419 (60.8)
17	No prime	313 (45.4)
18	MC-30	465 (67.4)
19	MC-30	430 (62.4)
20	MC-30	457 (66.3)
21	LVOC-1	554 (80.4)
22	LVOC-1	398 (57.7)
23	LVOC-1	305 (44.2)
24	AE-P	579 (84.0)
25	AE-P	491 (71.2)
26	AE-P	236 (34.2)
27	PEP	553 (80.2)
28	PEP	450 (65.3)
29	PEP	336 (48.7)

Table B3. Shear Strength Values from the Direct Shear Test for a Normal Stress of 50 kPa and Pit Run Gravel Base Material. Samples with Dust at the Interface.

Sample #	Prime Material	Shear Strength, kPa (psi)
30	No prime	108 (15.7)
31	No prime	177 (25.7)
32	MC-30	311 (45.1)
33	MC-30	214 (31.0)
34	LVOC-1	140 (20.3)
35	LVOC-1	146 (21.2)
36	EPR-1	136 (19.7)
37	EPR-1	154 (22.3)
38	SS-1	153 (22.2)
39	SS-1	149 (21.6)
40	TP-1	166 (24.1)
41	TP-1	154 (22.3)

Table B4. Shear Strength Values from the Direct Shear Test for a Normal Stress of 100 kPa and Pit Run Gravel Base Material. Samples with Dust at the Interface.

Sample #	Prime Material	Shear Strength, kPa (psi)
42	No prime	317 (46.0)
43	No prime	193 (28.0)
44	MC-30	361 (52.4)
45	MC-30	416 (60.3)
46	LVOC-1	211 (30.6)
47	LVOC-1	193 (28.0)
48	EPR-1	173 (25.1)
49	EPR-1	177 (25.7)
50	SS-1	357 (51.8)
51	SS-1	226 (32.8)
52	TP-1	169 (24.5)
53	TP-1	154 (22.3)

APPENDIX C

COHESION TEST DATA

Table C1. Cohesion Test Results for Sandstone Base Material Samples Primed with Different Prime Materials and Cured for 3 Days.

Sample #	Prime Materials	Torque, N-m (lbf-in)	Blades Penetration, mm (in)
1	Unprimed	1.2 (10.6)	4.5 (0.177)
2	Unprimed	1.8 (15.9)	
3	Unprimed	2.0 (17.7)	
4	MC-30 Fina	2.9 (25.7)	
5	MC-30 Fina	1.9 (16.8)	
6	MC-30 Fina	3.5 (31.0)	
7	MC-30 Exxon	1.5 (13.3)	
8	MC-30 Exxon	2.5 (22.1)	
9	MC-30 Exxon	1.7 (15.0)	
10	LVOC-1	2.0 (17.7)	
11	LVOC-1	1.0 (8.85)	
12	LVOC-1	1.3 (11.5)	
13	EPR-1	1.9 (25.7)	
14	EPR-1	1.0 (8.85)	
15	EPR-1	1.5 (13.3)	
16	AE-P Invert	1.0 (8.85)	
17	AE-P Invert	1.5 (13.3)	
18	AE-P Invert	1.0 (8.85)	
19	PEP	2.0 (17.7)	
20	PEP	2.2 (19.5)	
21	PEP	1.8 (15.9)	

Table C1. Continued.

Sample #	Prime Materials	Torque, N-m (lbf-in)	Blades Penetration, mm (in)
22	AE-P	1.6 (14.2)	4.5 (0.177)
23	AE-P	1.7 (15.0)	
24	AE-P	2.3 (20.4)	
25	Coherex HD	1.0 (8.85)	
26	Coherex HD	1.6 (14.2)	
27	Coherex HD	1.5 (13.3)	
28	SS-1	2.8 (24.8)	3.5 (0.138)
29	SS-1	1.5 (13.3)	
30	SS-1	2.1 (18.6)	

Table C2. Cohesion Test Results for Sandstone Base Material Samples Primed with Different Prime Materials and Cured for 8 Days.

Sample #	Prime Materials	Torque, N-m (lbf-in)	Blades Penetration, mm (in)
1	Unprimed	1.5 (13.3)	4.5 (0.177)
2	Unprimed	2.0 (17.7)	
3	Unprimed	1.9 (16.8)	
4	MC-30 Fina	5.0 (44.2)	
5	MC-30 Fina	3.7(32.7)	
6	MC-30 Fina	4.0 (35.4)	
7	MC-30 Exxon	4.0 (35.4)	
8	MC-30 Exxon	5.0 (44.2)	
9	MC-30 Exxon	3.5 (31.0)	
10	LVOC-1	1.8 (15.9)	
11	LVOC-1	1.2 (10.6)	
12	LVOC-1	2.0 (17.7)	
13	EPR-1	1.0 (8.85)	
14	EPR-1	1.9 (16.8)	
15	EPR-1	1.8 (15.9)	
16	AE-P Invert	2.5 (22.1)	
17	AE-P Invert	1.5 (13.3)	
18	AE-P Invert	1.2 (10.6)	
19	PEP	3.8 (33.6)	
20	PEP	2.7 (23.9)	
21	PEP	2.4 (21.2)	

Table C2. Continued.

Sample #	Prime Materials	Torque, N-m (lbf-in)	Blades Penetration, mm (in)
22	AE-P	2.8 (24.8)	4.5 (0.177)
23	AE-P	2.2 (19.5)	
24	AE-P	3.5 (31.0)	
25	Coherex HD	2.2 (19.5)	
26	Coherex HD	2.4 (21.2)	
27	Coherex HD	2.0 (17.7)	
28	SS-1	2.9 (25.7)	3.5 (0.138)
29	SS-1	3.8 (33.6)	
30	SS-1	3.5 (31.0)	

APPENDIX D

GUIDELINES FOR APPLICATION OF EMULSIFIED PRIME MATERIALS

GUIDELINES FOR APPLICATION OF EMULSIFIED PRIME MATERIALS

INTRODUCTION

Because of the volatile hydrocarbons in cutback asphalts, their use is currently limited and may be disallowed by future regulations. In addition, one of TxDOT's strategic goals is to remain environmentally vigilant. This guideline has been prepared to aid in further reduction of the use of cutback asphalt products. By using alternatives to cutbacks for prime coats, the Department can reduce the amount of potentially hazardous material released into the atmosphere. Some emulsified prime materials such as asphalt emulsion prime (AEP) contain large quantities of volatile solvents much like cutback asphalts. These types of products will not provide a solution to the long-term environmental pollution problem.

Some pavements have performed satisfactorily without a prime coat while others have failed apparently due to omission of a prime coat. Improperly applied prime coats can be a source of perpetual problems. This guideline is designed to aid the Engineer in determining when a prime coat for an untreated base is necessary, what emulsified prime products are likely to perform satisfactorily, and how they may be successfully applied.

In this guideline, a prime coat is defined as the application of a low viscosity, *emulsified* product to the surface of a non-bituminous compacted granular base course. The primer penetrates the top 5 mm to 10 mm (0.2 to 0.4 inch) or is mixed with the uppermost 25 mm to 50 mm (1 to 2 inches) of the base. An emulsified prime product may contain other materials such as naphthenic or aromatic oils but should contain little or no volatile products.

This guideline is not designed to replace specification Items 310, 312, and 314. It supplements these items by providing many more practical details particularly with regard to application of emulsified prime materials.

FUNCTIONS OF A PRIME COAT

A prime coat:

- Promotes adhesion between a granular base and a subsequently applied bituminous surfacing by precoating the surface of the base and penetrating the voids near the surface;

- Seals the surface pores in the base, thus reducing the migration of moisture, and reduces absorption of the first application of surfacing binder;
- Strengthens or toughens the surface of the base by binding the finer particles of aggregate; and
- Temporarily protects the base against the detrimental effects of weather and light traffic until the surfacing is constructed.

TYPES OF EMULSIFIED PRIMES

1. Emulsified asphalts (mixing grades)
    a. Medium Setting: MS-1, MS-2
    b. Slow Setting: SS-1, SS-1h CSS-1, CSS-1h
2. Emulsified oils with little or no asphalt available in Texas (suitable as sprayed-on penetrating prime in some cases)
    a. Blacklidge International EPR-1 (naphthenic oil with ≈10 % asphalt)
    b. Prime Materials LVOC-1 (naphthenic oil with ≈3 % asphalt)
    c. Witco Coherex (aromatic oil - no asphalt)
    d. Koch PEP (Penetrating Emulsion Prime, may contain 10 % kerosene)
3. Emulsified non-asphalt primes
    a. Prime Materials TP-1 (wood pitch, paper industry by-product)
    b. Prime Materials LVOC-1 (with no asphalt)

SELECTING PRIME COAT MATERIAL

The contractor should select any emulsified prime material from an approved list unless the plans or special provisions require the use of a specific material or technique. Types and grades of prime materials other than those normally specified should be allowed if it can be shown that the alternative material will properly perform the function of a prime coat for the required time period without evaporation of significant solvent to the atmosphere.

The main factors governing selection of prime and rate of application are the type of base on which it is used, the absorptive characteristics of the base, the weather conditions, and traffic volume. A high asphalt content material normally provides a superior prime, but desired application rates may not readily penetrate the base. High asphalt content prime materials will usually need to be mechanically mixed into the surface of the base material. In some instances, a curing membrane type material with low asphalt content may perform satisfactorily as a prime coat in a spray application. Ideally, the viscosity and rate of application should be chosen so that the surface will absorb all the applied prime and leave only a thin, non-tacky layer on the surface which dries quickly. When considering what type of prime to use in a given case, one must take into account not only its viscosity but also its composition.

For priming a very dense crushed stone base, a prime with a relatively low asphalt content (e.g., curing membrane type material) may suffice. However, for a natural gravel base with comparatively high permeable voids and low cohesive strength at the surface, the binding power of a higher asphalt content prime may be required.

If the primed base must carry traffic for an extended period (more than one week), particularly during rainy weather, then a high asphalt content material (e.g., emulsified asphalt) may be required to provide adequate protection for the base. For very dense bases, it may be necessary to manually mix this type of prime into the uppermost 25 mm to 50 mm (1 to 2 inches) of the base. Procedures for accomplishing this are given in the subsection titled "Methods of Priming with Conventional Emulsified Asphalt." If an emulsified material with a low asphalt content is used to prime a base exposed to traffic for more than one week, then periodic hand spraying of bare areas or periodic respraying may be required.

WHEN IS A PRIME NECESSARY?

A compacted granular base should always be primed before application of a bituminous surface treatment or an asphalt pavement less than 76 mm (3 inches) thick. When the subsequent pavement layer is to be an asphalt stabilized base or any asphalt pavement thicker than 100 mm (4 inches), a prime coat may not be necessary. If application of the subsequent pavement layer is to be delayed such that the compacted base may be damaged by weather and/or traffic, a prime should be applied. The need for a prime will be dependent on the characteristics of the granular base, that is, its susceptibility to damage by weather and traffic.

A typical crushed limestone base has a tightly bonded, dense surface. For this type of base, a prime coat may be omitted or the quantity may be greatly reduced particularly if an underseal is to precede the asphalt concrete layer. If the prime coat is to be omitted, construction of the surface course must proceed without delay to avoid damage to the compacted base by weather and traffic. The binder for the underseal should be increased by approximately 0.15 l/m^2 (0.03 gal/yd^2) more than that typically used for a primed base to allow for absorption by the dry surface. If, however, a prime coat is used, a prime of relatively low viscosity sprayed at a low rate of application should be used to avoid an excess of unabsorbed prime on the surface.

Natural gravel bases and some poorly graded crushed stone bases may have relatively high permeable voids and thus relatively high absorptive properties. These types of bases are more likely to need a prime to prevent surface damage between construction sequences and to provide an interfacial bond.

THE PRIMING PROCESS

Preparation of the Base

The surface of the fully-compacted base should be broomed until all loose or caked fines and foreign materials have been removed and some stone particles are exposed. The cleaned width should be at least 0.6 m (2 feet) wider than the width to be primed.

Moistening the surface by light sprinkling and possibly rolling with a light pneumatic roller immediately before priming reduces surface tension and helps an emulsified prime uniformly cover the surface. Excess water should not be applied, since voids filled with water cannot be filled with prime. Wetting of the surface may be performed using water containing an emulsifying agent or other surfactants to further reduce surface tension and aid in penetration of emulsified asphalts. Standard emulsified asphalts normally do not penetrate satisfactorily into a compacted base and must be manually mixed with the base material and/or dilution with water or non-asphaltic oils. It is advisable to test a small section to establish an effective priming method and adequate application rate.

Timing for Priming

Priming with sprayed-on emulsion should be performed as soon as possible after final compaction of the granular base to protect it from weather and traffic. The surface of the base should be moist but not saturated with water. Moisture content should not exceed 90 percent of the optimum for compaction.

A primed base can be preserved by periodically spraying (skeeting) with a light application (0.47 to 0.94 l/m^2 or 0.10 to 0.20 gal/yd^2) of diluted emulsified asphalt (diluted with 10 to 20 parts water). If the primed base is left open to traffic and/or exposed to weather for an extended period, a tack coat may be required before placing the next pavement layer. Long delays in the construction sequence may necessitate reprocessing or reshaping of the base to provide a smooth, compacted surface.

Rate of Application

For sprayed-on application of emulsified prime, the application rate depends on the characteristics of the surface to be primed, the prime material used, and the dilution ratio of the emulsion in water. The rate should be sufficient to coat the surface thoroughly and uniformly with no puddles and no tackiness that would cause vehicle tires to dislodge the primed surface. As a general guide, the rate of prime application for a dense crushed stone base is 0.23 l/m^2 to 0.45 l/m^2 (0.05 to 0.10 gal/yd^2) of emulsion (before dilution) and for a less dense natural aggregate (pit run gravel) is 0.45 l/m^2 to 0.91 l/m^2 (0.10 to 0.20 gal/yd^2) of emulsion (before dilution). Most of the spray-on type emulsions are diluted with three or four parts water prior to application; manufacturers' recommendations should be followed. The initial rate of application should be near the lower end of the recommended range. If necessary, the rate of application can be adjusted as the job proceeds.

If the prime is mechanically mixed with the uppermost 25 mm to 50 mm (1 to 2 inches) of the base material, then an application rate of approximately 1.36 l/m^2 (0.30 gal/yd^2) of emulsified asphalt (before dilution) is required.

If puddles or a tacky surface is evident after the prime has been left to cure for as long as possible, cover such areas with a light application of small aggregate (icing stone) or preferably precoated stone (Grade 5). Sand and crusher dust used for this purpose may diminish the bonding ability of the prime and create a shear susceptible interface. However, if these materials are used, no more than 4 to 6 pounds per square yard should be applied. Other successful methods to alleviate excess prime include brooming to spread the prime or watering the primed surface followed by pneumatic-tire rolling to spread and incorporate the excess prime into the base. Bleeding may occur if an asphalt surfacing is placed over a base with excessive primer. When access to traffic must be provided during construction, a freshly primed surface should be covered with a layer of icing stone or precoated stone (Grade 5) as soon as it is necessary to open the road to traffic.

Skipped, deficient, or damaged areas of prime must be corrected prior to placement of the subsequent pavement layer.

Heating the Prime

The maximum temperature for spraying or mixing applications of all emulsified asphalts is 82°C (180°F). Usually, no heating is necessary for spray applications of diluted emulsified primes containing little or no asphalt.

Initial heating should be done slowly to avoid local overheating which could result in foaming over the sides of the distributor truck. Prime should be stirred or circulated during heating. In some cases, it may be advisable to turn off the heaters for short periods.

For blade mixing of prime, very dilute asphalt emulsion (10 to 20 parts water) is usually applied using a water truck and, of course, no heating is necessary.

Applying the Prime

Sprayed-on prime should be applied using a pressure distributor calibrated to give an accurate rate of application and tested for satisfactory transverse distribution in accordance with Test Method Tex-922-K, Part I.

Emulsified asphalts should not normally be considered for sprayed-on applications since they do not penetrate the base sufficiently. When diluted asphalt emulsion is blade mixed into the base, application can be adequately achieved using a water truck. Emulsified asphalt must be diluted with 13 to 100 parts water (1 to 8% in water) before application to aid in distribution. The diluted prime should be placed in multiple applications with sequential blade-mixing performed between applications to assist in incorporating the prime uniformly into the uppermost portion of the base (25 mm to 50 mm or 1 to 2 inches). The final compacted base should contain a total of about 1.36 l/m^2 (0.30 gal/yd^2) of undiluted emulsion.

A small amount of surfactant or the same emulsifying agent used for the preparation of the emulsion could be added to the water used to dilute the emulsion to avoid breaking the emulsion. When an emulsion is diluted, the final product must be a homogeneous mixture. The water should always be slowly added to the emulsion, not the emulsion to the water. Adding very cold water may cause an emulsion to break. If in doubt, a dilution test should be performed in a bucket to be certain that the water to be used is compatible with the emulsion. A diluted emulsion should not be stored for more than a few days. Dilution should be performed in accordance with the emulsion manufacturer's recommendations.

Weather Conditions. Priming with sprayed-on emulsions should not be performed:

- when the road surface temperature is lower than 10°C (50°F) ,
- when the air temperature is lower than 10°C (50°F) and falling,
- when spraying performance of distributor will be adversely affected by wind, or
- when rain is probable within 2 hours after spraying.

When priming by blade mixing of emulsion into the base, weather conditions are a less significant problem. However, freezing of the compacted primed base within 48 hours should be avoided.

Curing the Prime

After an emulsified prime is applied, it cures by loss of water and volatile diluents, if present. Drying time depends on a number of factors such as type of prime, rate of application, base permeability, and weather conditions (temperature, solar radiation, humidity, and wind velocity). A prime is considered to be fully cured when it is no longer tacky and will permit light traffic without excessive pick-up of the primed surface. The subsequent pavement layer can usually be applied within a few hours. One advantage of emulsions over cutbacks is that they cure faster and may be trafficked sooner since evaporation of large quantities of solvent is not necessary.

Typical minimum curing times are given below.

Type of Prime	Allowing Traffic	Subsequent Paving
Mixing application	Immediately	Immediately
Spray application (penetrating prime)	1 - 4 hours	3 - 6 hours

Traffic must be kept off the primed surface until it has dried or until it is no longer picked up by tires of vehicles. Where it is necessary to allow traffic to use the road before the prime has dried, the primed surface must be covered with a layer of small stone. Before proceeding with pavement construction, loose stones must by removed from the surface. The stone layer should not be applied unless required.

Methods of Priming with Conventional Emulsified Asphalts

When using emulsified asphalt for prime, it is usually desirable to mechanically mix the prime with the uppermost 25 mm to 50 mm (1 to 2 inches) of base to achieve desirable "penetration" depth. The most desirable of 2 alternative methods for applying emulsified asphalt prime coats is described as follows:

1. Prepare and compact the granular base and blade to grade minus the depth of material to be treated with prime. One should not create a smooth surface at this point which could result in a weak interface between this lift and the next.
2. Windrow the material to be primed onto the compacted base.
3. Spray the windrow with the predetermined quantity of dilute emulsified asphalt and blade mix.
4. Add more dilute emulsion and mix until the mixture reaches optimum fluids content for compaction. Total undiluted asphalt emulsion in the treated approximately 38 mm (1.5 inch) of base should be approximately 1.36 l/m^2 (0.30 gal/yd^2). About 0.23 l/m^2 (0.05 gal/yd^2) should be held back and applied to the surface of the base as it is being finished.
5. Blade mix until thoroughly blended.

6. Spread treated material and compact to grade.
7. It may be necessary to periodically spray (skeet) the compacted surface with a light coat of diluted emulsion to minimize damage by traffic and/or just prior to placement of the next pavement layer to provide a clean, tacky surface.

This method minimizes effort and thus maximizes efficiency and should be used for priming whenever possible.

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

1. Complete compaction of the flexible base to grade, set blue tops, and insure that proper density has been achieved.
2. Before the base dries and hardens, scarify or blade off the top 38 mm (1½ inch), more or less; normally the blade of a motor grader is used for this step.
3. Windrow the loose material, and apply a predetermined quantity of dilute asphalt emulsion and blade mix.
4. Add more diluted emulsion and mix until the mixture reaches optimum fluids content for compaction. Total undiluted asphalt emulsion in the treated approximately 38 mm (1.5 inch) of base should be approximately 1.36 l/m^2 (0.30 gal/yd^2). About 0.23 l/m^2 (0.05 gal/yd^2) should be held back and applied to the surface of the base as it is being finished.
5. Blade mix until thoroughly blended.
6. Spread the blended mixture and compact to grade while quite wet. Use a vibratory steel wheel roller to push the larger stones down and pump fines and some emulsion to the surface.
7. Once the roadway has dried somewhat (usually 1-2 days) so that it is (1) hard enough that no further compaction can occur and (2) soft enough that it can be shaved using a blade without excessive damage to the underlying material, it is ready to be finished.

8. Apply a light shot of less concentrated solution of emulsion in water. Then use the blade to cut the surface to a depth approximately as deep as any depressions that may exist. This will create a rather small, dry roll of fines. This roll is not ever sprayed.
9. Spray the roadway with another light application of dilute emulsion and, immediately, drift the dry roll across the surface depositing the fines in any depressions. Repeat this operation until the desired surface texture is obtained.
10. Then skeet the roadway periodically with dilute emulsion to obtain the proper amount of oil to form a "membrane" on the surface to promote bonding to the subsequent pavement layer.

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

Blading off the top portion of the fully compacted base and subsequent reworking and compacting breaks up many of the larger aggregate. This creates a weakened layer right where strength is needed most -- at the top of the base layer. It is recommended, therefore, that the emulsion be added during the building of the base whenever possible.

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

- Carries traffic longer (several weeks),
- Provides better protection against rainfall,
- Is less dependent on weather conditions,
- Requires less time required for curing (before placement of next lift), and
- Adds significant strength to the pavement structure.

Although this appears to be an expensive process, requirement of this method of priming has historically had negligible effects on the total bid price. Depending on the application, construction sequence, and timing, it may be more cost effective to mix emulsion into the upper stratum of the base than to just spray prime the surface.

A third method of using a conventional emulsified asphalt for prime involves a process similar to application of a surface treatment; it is sometimes referred to as "inverted prime." Undiluted emulsified asphalt is sprayed onto the compacted base using a distributor truck; then uniformly graded stone is immediately spread to provide a driving surface for temporary traffic and construction vehicles. Typically, undiluted HFRS-2 emulsion is applied at a rate of 1.4 l/m^2 to 1.9 l/m^2 (0.30 to 0.40 gal/yd^2), depending on the time of year (less in the spring if traffic must be carried during hot weather to avoid flushing). Grade 5 stone is spread at a rate of about 1 $m^3/109\ m^2$ (1 $yd^3/100\ yd^2$). After about 1 hour, a pneumatic roller is used to seat the stone. This surface can be opened to traffic in about 4 hours. It can carry passenger vehicle traffic for a few months, but heavy truck traffic may damage the surface. The use of emulsified asphalt for this process instead of cutback asphalt reduces the probability of flushing during hot weather due to evaporation of cutter stock up through the overlying pavement surface.

Alternative Priming Method Using Emulsified Spray-On Products

As an alternative to the methods described above, spray-on type penetrating primes can be used. These primes typically contain naphthenic or aromatic oils along with 0 to 10 percent asphalt. They are simply sprayed onto the compacted base like cutback asphalt prime and allowed to cure. Curing normally requires less time than cutback primes (e.g., MC-30) since water is the only volatile product they contain. Therefore, the subsequent pavement layer may be placed in a shorter time period after priming.

Appropriate quantities of prime and dilution ratios differ for the different products. Manufacturer's guidelines should be followed until the appropriate quantity is established for a given site.

These types of primes will not carry traffic as well as the priming methods described in the previous subsection. If light traffic is carried for more than 1 week, some hand spraying to repair damaged areas of prime may be necessary.

PRECAUTIONS

No subsequent pavement course should be placed on a primed surface until the prime material has dried and cured so that it does not stick to vehicle tires. Construction traffic should generate no significant damage on the primed surface.

Emulsified primes can be harmful to growing plants, since it seals pores and interferes with intake of carbon dioxide. Reasonable care should be taken to prevent overspray on crops, ornamentals, and other foliage.

Reasonable care should be exercised to prevent spraying of prime on buildings, fences, curbs/gutters, and other areas where dark stains are undesirable.

APPENDIX E

PRIME PENETRATION TEST PROTOCOL

PRIME PENETRATION TEST PROTOCOL

1. Scope

1.1. This method is intended to serve as a rapid field-correlation test. The purpose of this test method is to evaluate the ability of an emulsified prime to penetrate into a compacted granular base. The penetration depth that a prime material can achieve as well as the time required for it to fully penetrate the granular base can be estimated.

2. Referenced Documents

2.1. AASHTO Standards

T2 Sampling Aggregates

T27 Sieve Analysis of Fine and Coarse Aggregates

T248 Reducing Field Samples of Aggregate to Testing Size

M92 Wire Cloth Sieves for Testing Purposes

M231 Weighing Devices used in the Testing of Materials

3. Summary of Method

3.1. Aggregate in the granular base is separate using a No. 4 sieve. The fraction of material passing the No. 4 sieve is collected. Seven percent water is added to this fraction of material and mixed until completely blended. The moist aggregate is placed in to a 170 grams (6 oz.) tin and statically compacted using a plunger with a diameter slightly smaller than the tin. Prime material is applied to the surface of the sample. The time required for the prime to fully penetrate the base is recorded. The prime is allowed to penetrate for 1 hour. Finally, the sample is sliced transversely and the vertical penetration depth of the prime is measured.

4. Significance and use

4.1. This is a handy, easy, and reliable test that can be used to select a satisfactory prime material to assure adequate penetration in a specific granular base.

4.2. The time required for a prime to fully penetrate the sample is a good indicator of the relative time required before traffic can be allowed on the primed base.

5. Apparatus

5.1. Balance - A Class G2 (AASHTO M231) balance capable of reading to 0.1 grams.

5.2. Compaction device - A device capable of applying a static load of (1200 lb).

5.3. Miscellaneous equipment:

  5.3.1. A plunger to apply a uniform load to the surface of the sample.
  5.3.2. A 170 gram (6 oz.) ointment tin.
  5.3.3. Squeeze-bottle for applying prime.
  5.3.4. Knife or small spatula.
  5.3.5. Ruler, caliper, or other measuring device.
  5.3.6. Stopwatch.
  5.3.7. Bowl and spatula to blend aggregate and moisture.

6. Materials

6.1. Minus No.4 sieve aggregate from the base to be primed.

6.2. Prime material as used in construction. If diluted in field, it should be diluted similarly in the laboratory.

7. Procedure

7.1. Add 14 grams of water to 200 grams of minus No. 4 aggregate and mix until completely blended.

7.2. Place the moist aggregate into the 170 gm (6 oz.) tin.

7.3. Place sufficient prime material into the squeeze-bottle.

7.4. Using the plunger, compact the moist aggregate by applying a static stress of 200 psi for 10 seconds.

7.5. Remove the plunger from the sample. Be careful to avoid disturbance of the compacted aggregate surface.

7.6. Set the sample on the balance, zero it, and quickly squirt 5 grams of prime material onto the sample using the squeeze-bottle. The prime material should be squirted in a circular motion to obtain a uniform application.

7.7. Record the time required for the prime material to fully penetrate in the aggregate. Start measuring the time when all of the prime has been added. Stop measuring time when the grainy surface of the sample is completely visible and no longer changing.

7.8. Allow the prime to penetrate for 1 hour. Then slice the sample and measure the penetration depth of the section in at least 3 locations and obtain the average penetration depth.

8. Criteria (Interim)

8.1. Time for penetration should be equal to or less than that of MC-30.

8.2. Depth of penetration should be 2 mm or greater. Actual penetration in the field will be at least one millimeter greater than that measured in the laboratory due to the higher concentration of fines in the laboratory sample and more efficient compaction.

APPENDIX F

SPECIFICATIONS FOR EMULSIFIED PRIME MATERIALS TESTED

SPECIFICATION FOR PEP (PENETRATING EMULSION PRIME)

PEP is a medium-slow breaking, low viscosity, low-asphalt content type emulsion intended for use as a penetrating prime.

TESTS ON EMULSION:

	MIN.	MAX.
Viscosity, Saybolt Furol, 25°C (77°F), sec	-	75
Sieve Test, %	-	0.1
Residue from Distillation, % by weight	38	-
Oil Portion from Residue from Distillation test, ml oil per 100g., emulsion, %	0	4
Sieve Test, %	-	0.10

TESTS ON RESIDUE FROM DISTILLATION:

	MIN.	MAX.
Solubility in Trichloroethylene, %	97.5	

PERFORMANCE TESTS ON EMULSION:

	MIN.	MAX.
Penetrating ability of emulsion	PASS	

THE USE OF PENETRATING EMULSION PRIME (PEP)

PEP is a solventless asphalt emulsion developed for a non-polluting, low cost priming material. It was designed to penetrate compacted granular base materials. The material will bond aggregate particles to form a resilient, waterproof material and make a desirable surface for future bituminous treatments, such as, seal coat or bituminous overlays.

PEP may be diluted with water for very light applications when used as a dust control procedure. Dilution is also desirable when a dusty surface is to be primed.

PEP may settle on storage. The settlement requires a very minimal amount of agitation to re-mix. PEP is stored at ambient temperature.

PEP is applied through conventional distributors. Application temperatures do not aid in penetrating ability and may be detrimental to the emulsion quality. Application rates vary from 1.3 to 2.3 l/m^2 (0.3 to 0.5 gallon/sq. yd). For rates over 1.58 l/m^2 (0.35 gsy), usually two passes of a lighter application are better than a single heavy dosage. Test application results have been obtained using a bar height of 254 mm-305 mm (10-12 inches) as compared with usual emulsion application bar heights of 127 mm to 152 mm (5-6 inches). Also, lower bar pressures are advantageous. PEP is applied at a pressure of 113 kPa/m (5 psi/ft) of bar as compared to other emulsions at 226 kPa/m (10 psi/ft) of bar.

PEP was designed for optimum performance on new, well-compacted gravel bases. It penetrates within a few minutes to a depth of 6.4 mm to 13 mm (¼ to ½ in). Traffic can be resumed in 2 to 4 hours. Tightly compacted stone, excessive surface dust, high-clay content aggregates, and surface dirt will decrease penetratation depth and increase the time to penetrate. If the aforementioned conditions exist, precautions such as lower application rates and more dilute emulsion may be helpful.

Several distinct advantages of PEP have become apparent:

1. The cost is much less than solvent bearing primes.
2. There are no light oils to evaporate to create air pollution or heavy metals to contaminate the ground water.
3 There is no explosion or fire hazard present.
4. Application is possible while the base is still damp.
5. Penetration is rapid. Traffic may be resumed quickly.
6. Handling and application occurs at ambient temperatures.

SPECIFICATION FOR EPR-1
(EMULSIFIED PETROLEUM RESIN)

A. EPR-1 Prime: Slow curing emulsion of petroleum resin and asphalt cement conforming to the following requirements.

PROPERTIES	MIN	MAX
Fural Viscosity at 25°C (77°F), sec	14	40
Residue by Evaporation, % by weight	60	-
Sieve Test, %	-	0.1
Particle Charge Test	Positive	
Tests on the Distillation Residue:		
Flash Point, COC, °C (°F)	204 (400)	-
Kinematic Viscosity @ 60°C (140°F) cSt	190	350

B. For use, EPR-1 may be diluted with water up to a maximum of 3 parts water to 1 part EPR-1 in order to achieve the desired concentration of residual resin/asphalt and facilitate application.

SPECIFICATIONS FOR AE-P

TESTS ON EMULSION:

	MIN	MAX
Viscosity @ 50°C (122°F), SF, sec.	15	150
Sieve Test, %		0.1
Demulsibility, 50 mL 0.1 N $CaCl_2$, %		70
Storage Stability, 24 hr., %		1.0
TESTS ON RESIDUE FROM CUTBACK DISTILLATION TO 360°C (680°F) USING RESIDUE FROM 260°C (500°F) DISTILLATION, %	40	
Total Oils[1] from Distillation, %	20	35
Float @ 50°C (122°F) on Residue from Cutback Distillation	50	200
Solubility in Trichlorethylene, %	97.5	

[1] Cumulative total from 260°C (500°F) distillation of emulsion and distillation of residue by cutback distillation to 360°C (680°F).

ASPHALT EMULSION PRIME

(AE-P)

AE-P is an *inverted* asphalt emulsion that is used as priming material. AE-P is composed primarily of asphalt, light oils, water and a small amount of emulsifier to stabilize the emulsion system. The advantages of an inverted emulsion prime over a cutback asphalt are related to the ability to penetrate a compacted granular base and the resultant higher viscosity of the AE-P as compared to solvents used in cutback asphalts. This generally would mean that with equivalent curing times, the AE-P would have a higher residue viscosity than cutback asphalt resulting in tighter, higher stability asphalt stabilized granular bases.

AE-P and cutback asphalt are applied at the same rate, generally, 1.36 l/m^2 (0.3 $gallon/yd^2$). The actual resultant residue percentage of the 2 products are very similar; however, the AE-P, for equal curing time, will yield a higher viscosity residue yielding greater stability.

MIXTURE RATES
FOR
CONCENTRATED EPR-1 PRIME

<u>CURING SEAL</u> - is 1 part EPR-1 prime to 3 parts water

Note: Spread factor for curing seal varies due to the type of base used.

"Non-Porous" bases such as clay requires an application rate of 0.68 l/m^2 (0.15 gal/yd^2).

"Porous" bases such as "sand & gravel" may require a slightly heavier application rate of 0.91 to 1.13 l/m^2 (0.20 to 0.25 gal/yd^2).

<u>Soil Erosion</u> - is 1 part EPR-1 prime to 7 parts water

Note: Mixture could vary due to soil conditions and slope of terrain.

Spread factor of 1.13 l/m^2 (.25 gal/ yd^2)

<u>Dust Control</u> - is 1 part EPR-1 prime to 10 parts water

Note: EPR-1 prime is a maintenance program for dust control that "accumulates" with each application. Water is the carrier, for deeper penetration. The surface should be graded to shed rain before applying. EPR-1 prime bonds the dust particals together making them to heavy too float in the air. The accumulated EPR-1 prime will also resist water penetration that causes potholes and mud.

Recommended Application:

1st Spray, shot at 12 parts water to 1 part EPR-1 prime

2nd Spray, 4 hours later or next day, shot at 8 parts water to 1 part EPR-1 prime

3rd Spray, approximately 3 weeks or as fresh dust particle surface. (Depends on traffic) shot at 10 parts water to 1 part EPR-1 prime

4th Spray, approximately 6 weeks (depending on traffic) shot at 10 parts water to 1 part EPR-1 prime

ITEM 300

PCE

(LVOC-1)

ASPHALTS, OILS AND EMULSIONS

For this project, Item 300, "Asphalts, Oils and Emulsions," of the Standard Specifications, is hereby amended with respect to the clauses cited below and no other clauses or requirements of this item are waived or changed hereby.

Article 300.2 Materials, Subarticle (6) Emulsions is supplemented by the following:

Type	Slow Setting
Grade	PCE

Description, PCE shall be a slow curing anionic or cationic emulsion of a petroleum based material in water. The supplier must clearly state whether the material supplied is cationic or anionic. PCE may be used as a curing seal for stabilized base materials. PCE may be diluted with water to achieve the desired concentration of residual. The following maximum rates may be used as guidelines.

USE	Recommended Dilution Ratio
Curing Seal	1 part PCE to 3 parts water

Properties	Minimum	Maximum
Viscosity, Saybolt Furol at 25°C (77°F), sec.	10	100
Sieve Test, %	-	0.1
Miscibility*	Passing	
Residue, % by wt.**	60	-
Test on Residue from Evaporation Test:		
Flash Point, C.O.C., °C, (°F)	200 (392)	-
Kinematic viscosity at 60°C (140°F), cSt	100	350

* Miscibility shall be determined in accordance with ASTM D224, except the dilution shall use 350 ml of distilled or deionized water and a 1000 ml beaker.

** Residue by evaporation shall be determined according to ASTM D244, except that the sample shall remain in the oven until foaming ceases, then cooled and weighed.

LVOC-1

(PCE)

ASPHALT, OILS AND EMULSIONS

Description: LVOC-1, "Low Volatile Organic Compound" emulsion, is a slow setting non-hazardous anionic emulsion. This emulsion can be used as a curing seal for cement stabilized base materials, as a dust palliative, priming, and erosion control. The material can be diluted with water to achieve the desired effect. The recommended dilution rates are as follows:

Intended Use	**Recommended Dilution Ratio**
Curing Seal	1 part LVOC-1 to 3 parts water
Dust Palliative	1 part LVOC-1 to 3 to 10 parts water
Priming of Base Materials	1 part LVOC-1 to 3 - 4 parts water
Erosion Control	1 part LVOC-1 to 5 - 8 parts water