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16. Abstract

Micro-surfacing is a complex mixture of polymer modified emulsified asphalt cement, crushed mineral aggregate, mineral filler, water, and other additives. When designed and constructed properly, micro-surfacing can be used in thin layers as preventive maintenance and in thick layers to fill ruts as corrective maintenance treatments. Several Districts are using micro-surfacing to repair pavement in the Texas Department of Transportation. The contractor provides the mixture design, and the Department accepts the mixture. The mixture designs submitted by the contractors are based on tests that the Department has not previously used and that have questionable validity.

This project developed specifications, mixture design procedures, mixture design verification procedures, usage guidelines, and quality assurance requirements for micro-surfacing treatments applied to highway pavements. The mixture design procedure tests were evaluated in the laboratory and modified as needed. Detailed protocols were developed for each test. Micro-surfacing mixture designs and quality assurance procedures were tested in the field. Quality assurance checklists were developed for use by field personnel. This report presents a method for evaluating cost-effectiveness along with preliminary results. An approach for completing forensic analysis of early failures was also prepared.

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USE OF MICRO-SURFACING IN HIGHWAY PAVEMENTS

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IMPLEMENTATION STATEMENT

This project developed specifications, mixture design procedures, mixture design verification procedures, usage guidelines, and quality assurance requirements for micro-surfacing treatments to be applied to highway pavements. The mixture design procedure tests were evaluated in the laboratory and modified as needed. Detailed protocols were developed for each test. Micro-surfacing mixture designs and quality assurance procedures were tested in the field. Quality assurance checklists were developed for use by field personnel. A method for evaluating cost-effectiveness along with preliminary results are presented. An approach for completing forensic analysis of early failures was also prepared.

The following items developed in this micro-surfacing research study and presented in this report should be adopted for immediate implementation by the Department:

- methods and materials specification;
- usage guidelines;
- mixture design procedure;
- test protocols; and
- quality assurance guidelines and checklist.

The end-result specification with warranty should be refined into an implementable form and evaluated by the Department. A true quality assurance program for micro-surfacing should be formulated based on the findings and recommendations of this study and be implemented.

These documents are presented in the report as appendices. This will allow them to be extracted for easy distribution to the appropriate groups within the Department for review and adoption. They are available on diskette and can be printed as separate documents in standard TxDOT formats for distribution and adoption.

Use of these procedures by Texas Department of Transportation personnel should provide those responsible for selecting treatments guidelines for selecting micro-surfacing to ensure that micro-surfacing is selected to treat the roads best suited for repair with micro-surfacing. The mixture design verification procedure will provide the Department with a method to evaluate the mixture designs submitted by contractors. The specification should provide the requirements for a high quality micro-surfacing that can be enforced. The quality assurance guidelines should provide inspectors with the guidance they need to ensure that the contractor meets the requirements of the contract. Adoption of these should result in improved performance of micro-surfacing resulting in more cost-effective repair of pavements maintained by the Department.

DISCLAIMERS

The contents of this report reflects the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENT

Many Texas DOT and industry personnel helped with this project. Mr. Maghsoud Tahmoressi provided valuable guidance as the Technical Coordinator. Engineers, laboratory supervisors, and inspectors in several districts assisted in providing information, assisting in taking samples, completing tests, trying draft procedures, and providing responses to question. Their time, effort, assistance, and guidance was a vital part of the effort needed to complete this project.

The International Slurry Seal Association provided assistance and guidance in several ways including providing copies of their test procedures and reviewing draft mixture design procedures, usage guidelines, and specifications. They provided considerable assistance with test procedures and evaluation of results. Materials suppliers provided access to their laboratories and personnel completing tests to help the project staff understand the test procedures and learn intricacies of material combinations. Contractors helped take samples in the field, provided information on how the equipment operates, how adjustments are made to the mixture in the field, factors that affect performance from their perspective, and changed mixes to help in the project. Alpha labs provided assistance with test procedures and equipment including providing a field cohesion meter on loan.

No acknowledgment on micro-surfacing would be complete without mentioning Mr. C. Robert "Ben" Benedict, the acknowledged "father" of mixture design testing for micro-surfacing. Even though he was terminally ill at the time, he provided training to the project staff and gave advice and direction up to the time of his death. His experience and insight will be sadly missed by those who work with slurry systems.

The work on the gel permeation chromatography was completed by Moon-Sun Lin and Kevin M. Lunsford of the TTI Chemical Engineering Program.

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SUMMARY

Micro-surfacing is a very complex mixture. Unlike hot mix asphaltic concrete, it is a "wet system" that relies on chemical processes for strength development. It is composed of a polymer modified emulsified asphalt cement, crushed mineral aggregate, mineral filler, water, and other additives. When designed and constructed properly, micro-surfacing can be used in thin layers as preventive maintenance and in thick layers to fill ruts as corrective maintenance treatments.

Several Districts are using micro-surfacing to repair pavement in the Texas Department of Transportation. The contractor provides the mixture design, and the Department accepts the mixture. The mixture designs submitted by the contractors are based on tests that the Department has not previously used and have questionable validity. Although micro-surfacing can be used for different purposes, guidelines for appropriate use are needed.

This project developed specifications, mixture design procedures, mixture verification procedures, usage guidelines, and quality assurance requirements for micro-surfacing treatments to be applied to highway pavements.

The recommended specifications are methods and material specifications, but end result with warranty specifications are recommended for evaluation. The specifications address basic material properties, mixture requirements, equipment requirement, and final workmanship requirements.

The mixture design procedure is based on volumetric determination of asphalt need followed by testing to determine if that level of asphalt is expected to provide the desired service. New and modified test procedures are required to complete this design procedure. A mixture design verification procedure to evaluate a mixture submitted by a contractor uses a sub-set of these test procedures. The mixture design procedure tests were evaluated in the laboratory and modified as needed. Step-by-step protocols were developed for each test recommended for use.

Usage guidelines were developed to provide guidance on how to select roads that are in an appropriate condition to be treated with micro-surfacing. An approach to evaluation is provided. A method for forensic analysis of early failure was also developed.

Quality assurance guidelines that can be currently used by Department personnel were developed. They address materials acceptance, monitoring materials during construction, and monitoring the finished surface. A checklist was prepared to help in the evaluation of the surface condition. A discussion of problems, possible corrections, and approaches to dealing with the contractor when the problems develop was also included.

Mixture designs, different mixtures, and quality assurance procedures were evaluated in field trials. Projects in Brownwood, Bryan, Corpus Christi, Dallas, Houston, Lubbock,

San Antonio, Tyler, and Waco Districts were visited and evaluated. Quality assurance checklists were used and evaluated by TxDOT personnel in Brownwood, Dallas, Tyler, and Waco Districts.

A method of cost-effectiveness evaluation with preliminary results is presented.

The following conclusions were reached.

Micro-surfacing can be used effectively in both preventive and corrective maintenance, primarily for restoring skid resistance, filling ruts to restore transverse surface profile, and to repair weathering and raveling. The micro-surfacing mixtures applied in the State of Texas generally provide 5 to 7 years life if they are applied to pavements in the appropriate condition. Micro-surfacing should not be selected as the treatment if the primary problem is cracking, because the cracking will reflect through relatively quickly.

A few districts have applied micro-surfacing as a part of a Cape-seal. In this treatment, a chip seal is placed first, and then the chip seal is covered with micro-surfacing. It is possible that this treatment would give better crack protection, but that needs to be evaluated over time.

The contractor supplied mixture designs were prepared by the emulsion suppliers for all of the projects evaluated in this project. These mixtures have generally provided the desired service. The most common mixture problems are related to the aggregate having too many fines or too many plastic fines based on a low sand equivalency value. Other major problems are generally related to the construction and the skill of the crews operating the equipment.

The skill of these crews is critical to getting the desired final product. It does not seem possible to force a contractor to have a good crew with a methods and materials type specification.

Several of the laboratory tests used in the ISSA mixture design procedure are of questionable value and are quite variable. The micro-surfacing industry does not agree on a common mixture design approach. They appear to depend on experience in the field, and they try to identify materials and mixtures that can cause problems based on a series of tests. However, their tests do not set asphalt content based on a test that is independent of water content and other factors that would be expected in most asphalt applications.

The mixture design procedure developed by the project staff is a rational approach to determining the minimum amount of residual asphalt cement for a micro-surfacing mixture for the aggregates evaluated. The mixture design should be evaluated over several years to ensure that it works with any other aggregates used for micro-surfacing in Texas.

Adopting end result specifications with a warranty clause could reduce the need for the Department to spend as much time and effort testing materials and completing mixture design tests with specialized equipment not currently available in the Districts. The contract testing in the Tyler District will provide a reasonable estimate of the cost of inspection testing that the contractor would have to bear in such an approach. Some of the new equipment provides a constant record of the mixture proportions based on the equipment settings which should be investigated for use in mixture acceptance. This would make calibration more critical than it is now, and it is extremely important now.

It is currently impossible to distill a polymer modified emulsion without changing the properties of the residual asphalt cement and polymer. An end result specification with warranty would remove the need for so much testing by defining an end product and requiring it to retain desired properties for a given period of time.

It will be easier to implement an end result specification with warranty for micro-surfacing than for hot mixed asphalt concrete. If micro-surfacing lasts through construction and the first severe environmental cycle, it generally gives the desired service for 5 to 7 years. By limiting the warranty to two years, many of the problems associated with the structural capacity of the pavement will be eliminated.

For an end result with warranty specification to work, a partnering with industry will have to be developed. The industry and Department will have to agree jointly which projects can be warranted. The Department may want to use micro-surfacing as a "stop-gap" maintenance treatment on an inappropriate road surface to get two or three years life, but that type of application should not be warranted.

Visiting several field sites provided the staff considerable knowledge to help develop usage and quality assurance guidelines. Continued evaluation of the performance of several of the test sections developed during this project would provide important information on the performance on micro-surfacing in general and the impact of specific factors such as residual asphalt content, amount of mineral filler, specific conditions such as the presence of cracking, use of rut filling versus scratch course, traffic levels, and different surface condition, and the presence of fibers.

Field inspectors liked the concept of the quality assurance guidelines with problems and possible solutions. They liked having simple checklists to use to determine the acceptability of the finished surface.

The project staff was not able to quantify the quality of hand worked areas.

The gel permeation chromatography can be used to determine the presence and quantity of natural rubber in a polymer modified emulsion.

CHAPTER 1
INTRODUCTION

GENERAL

Micro-surfacing materials and application procedures have been developed over the last several years, generally by contractors in the slurry seal industry. Several districts in Texas have used them, some extensively. The first micro-surfacing products were developed in Europe and were proprietary, and most of them remain proprietary products.

Mixture design for micro-surfacing materials is extremely important, and the actual materials proposed for use on the project must be used in the mix design tests. Different aggregates with exactly the same gradation can perform differently with the same emulsified modified binder, and two different binders can perform differently with the same aggregate. When portland cement is used as a mineral filler, it not only acts as a mineral filler, but also acts to control break time of the emulsified asphalt and may have other effects.

Since micro-surfacing is a cold mixed material prepared in a special traveling plant that also applies it to the road surface, the mixture design procedures used by the Texas DOT for hot mixed asphalt concrete or seal coats are not applicable. Most mixture designs are prepared for the contractors by micro-surfacing emulsion suppliers, but there are no universally accepted mixture design methods available. The most commonly used procedures were developed by members of the International Slurry Surfacing Association (ISSA), but few of their members use them as prescribed. There are several questions concerning the meaning and importance of the tests used in the ISSA mixture design procedures for micro-surfacing materials.

Density and Hveem stability values are used by the Department to determine the optimum asphalt content for hot mix asphalt concrete. Stability may be important in thick micro-surfacings which are used to fill ruts or which are placed in multiple layers. However, the relationship between density of micro-surfacings and performance has not been well established. Although the material is a surface layer, the level of acceptable voids may be much different than that for hot mix asphalt concrete. In addition, the manner in which the density is determined does not replicate the construction procedure in the field, and the relationship between the two is not presently known.

The ISSA specifications set limits on the residual asphalt content, mineral filler, and minimum polymer content. Water content is selected based on visual observations of mixture consistency during mixing and construction. The water content can change as the road surface and environmental conditions change.

Specifications have been developed by ISSA in their "Recommended Performance Guidelines for Micro-Surfacing." The Department also prepared a "Special Specification Item, Micro-surfacing (Polymer Modified)." Neither has been fully tested to ensure that it provides the desired quality for a reasonable cost. There are concerns about the limits established which were based on experience with hot mixed asphalt concrete and the tests which are used to define some of the properties.

Since the contractor is responsible for developing the mixture design, a possible approach would be for the Department to use an end-result type specification, possibly with a warranty clause. Both the Department and ISSA specifications describe the equipment which should be used and provide some guidance on how the micro-surfacing materials are to be placed. However, there are no quality control or quality assurance guidelines. It would appear that if the contractor is responsible for materials selection and mix design, he should also be responsible for quality control. The Department should be responsible for quality assurance. Quality assurance sampling and testing procedures need to be developed.

Micro-surfacing is relatively new to the paving industry, and no well developed guidelines for use of the product exist. It has the same basic components as a hot mix asphalt concrete (HMAC) overlay (graded aggregate, asphalt binder, mineral filler, etc.); however, it is placed at ambient temperature, without compaction and in much thinner layers than HMAC. It should provide essentially the same surface sealing properties that a chip seal will provide, in that it will reduce the aging of the underlying asphalt concrete and the associated weathering and raveling. Since the binder is more liquid at ambient temperatures, it should seal fine cracks, although a chip seal will likely seal larger cracks than micro-surfacing. It provides no better remedy for sealing thermal cracks than a thin HMAC overlay. The high stability of the material created by the crushed aggregate and the modified binder has allowed micro-surfacing material to be successfully used to fill ruts and reestablish transverse profiles. However, guidelines for this purpose need to be developed because it is well known that filling ruts does not correct the basic problem. Ruts are symptoms of problems in the pavement structure. If the ruts have developed over a long period and are due to the overall consolidation of the pavement layers, then filling the ruts with micro-surfacing may provide a considerable life extension. However, if the ruts are due to a basic structural inadequacy of the pavement or due to an instability in the asphalt layer, filling them may not provide significant additional pavement life. There have been some problems reported where micro-surfacing materials did not adhere to some crack sealing materials, especially those which were used in "bandaid" type sealing applications. This type of information needs to be clearly presented in an easy-to-follow set of guidelines for using micro-surfacing.

OBJECTIVES OF STUDY

The objectives of the study are to verify or develop mix design procedures, quality assurance tests, quality assurance guidelines, and treatment application guidelines for micro-surfacing.

Researchers accomplished this by the following approach. A set of draft specifications, mixture design procedures, quality assurance testing plans, and usage guidelines were prepared. These were tested in the laboratory and in field operations. Several sections of micro-surfacing were placed based on designs provided by the project staff. Some of these are experimental sections designed to determine how much impact changes in asphalt content have on performance.

As a part of this effort, the laboratory tests recommended by ISSA and TxDOT for materials evaluations, mixture designs, and quality measurements were evaluated. Based on these evaluations, some tests were discarded from further use, some were accepted, some were modified, and some still need further evaluation. Detailed protocols were developed for all of the tests recommended for use by the Department.

Based on results of the field trials, the mixture design, usage guidelines, quality assurance guidelines and field tests were modified to reflect the experience from the point of view of TxDOT staff and contractors. A mixture design verification procedure was prepared to simplify the effort required by Department staff when the contractor provides the mixture design. Approximate service lives and costs were determined and used in a simple life-cycle cost analysis. Based on experience of the project staff, a method of forensic analysis was prepared for use when early failure of micro-surfacing develops.

Since many of the experimental treatments are still performing well at the end of the project, it is recommended that they continue to be evaluated on a periodic basis until they fail or are removed from service.

CHAPTER 2
BACKGROUND

GENERAL

Micro-surfacing is a mixture of polymer modified emulsified asphalt cement, crushed mineral aggregate, mineral filler, and water. Other additives are sometimes used in the mixture. It is typically used as a maintenance treatment to protect the pavement from environmental effects, repair damaged surfaces, improve skid characteristics, and improve surface drainage problems caused by rutting and cross-slope deficiencies (1). The primary use of micro-surfacing is to fill ruts or as a surface seal. Figure 1 shows a typical application of micro-surfacing used to fill ruts and as a finish course.

Two types of maintenance treatments are usually considered, preventive and corrective. Some treatments can be used for both preventive and corrective maintenance. Rut filling is usually considered corrective maintenance, and surface sealing is generally considered preventive maintenance.

Preventive maintenance treatments should be applied before major surface failure occurs, while the pavement is in relatively good condition (2). The types of treatments used are surface seals, thin asphalt overlays, thin micro-surfacing applications and crack sealing. This type of treatment is not used to enhance the structural capacity of the pavement. It is used to preserve the current structural capacity, extend the useful life and improve the level of service of a pavement (3). Corrective maintenance treatments are used after damage to the pavement has occurred. These treatments are used to delay major rehabilitation that is generally much more expensive. Based on the performance of various projects in Arkansas, Oklahoma, Ohio, Pennsylvania, Texas, and Virginia, it appears reasonable to expect at least four to five years of service life from micro-surfacing treatments applied to pavements in an appropriate condition (4).

Micro-surfacing has been used to repair ruts, restore surface friction and repair cracks. Most successful rut filling projects repaired rut depths of three to nineteen millimeters (one-eighth to three-quarter inches) (4). The material will typically resist rutting for about three years (4). The level of skid resistance is dependent on the quality of aggregate used in the mixture. Most states have reported positive skid resistance changes (4). Success in crack repair has not been as good. Most States report that micro-surfacing is not good for crack repair (4). Most cracks in the existing pavement will reflect through the micro-surfacing material similar to those reflecting through thin hot mix asphaltic concrete layers.

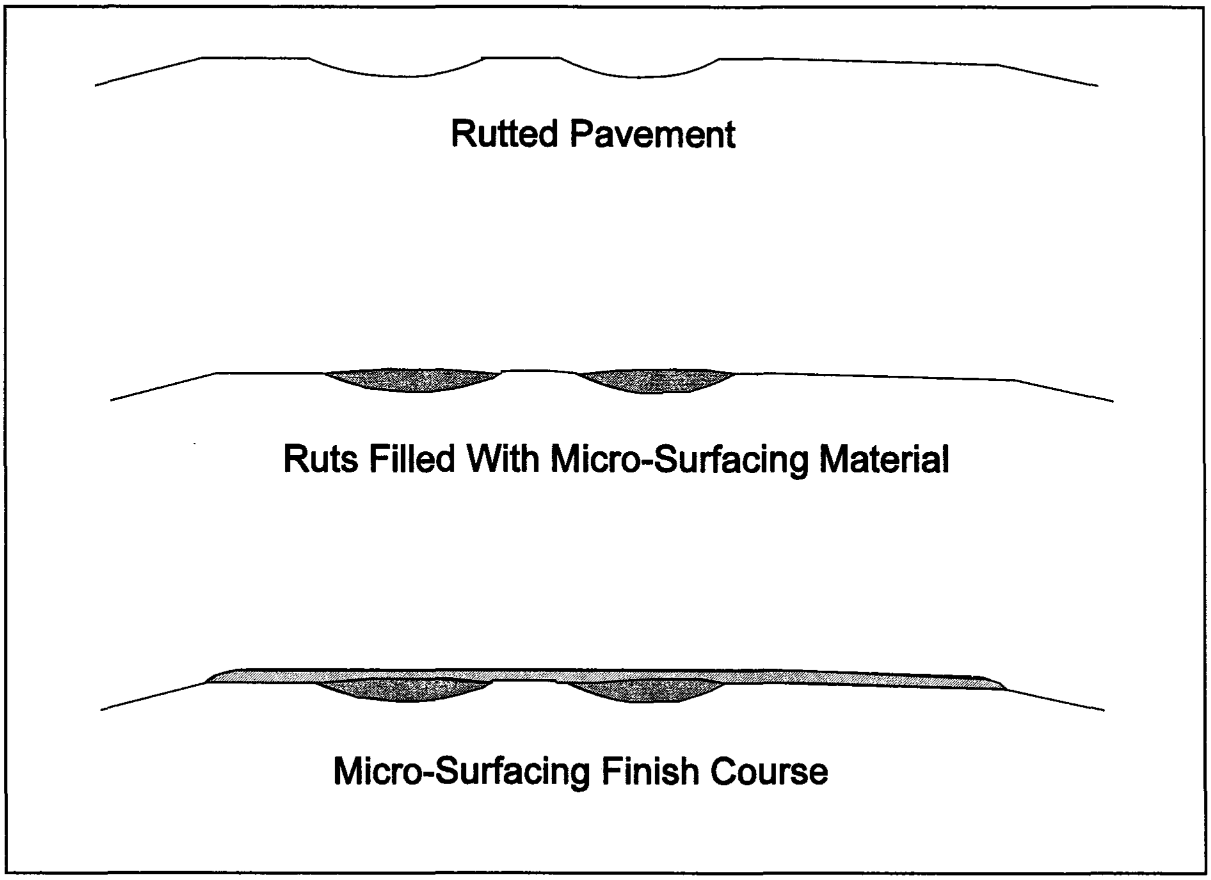

Figure 1. Typical Applications of Micro-Surfacing

Origin of Micro-Surfacing

The original slurry seal was developed in the 1920s and 1930s and applied in very thin layers as a mass crack sealer and surface dressing (4, 5). Since that time, there has been a trend toward using thicker applications. Because conventional slurry seal is inappropriate for thick applications, micro-surfacing was developed. It was used as a surface course to reestablish surface friction, restore cross section profile, and seal the surface without damaging pavement lane markings. It was developed in Europe and introduced in the United States in 1980 (4, 5). Spain, Germany and France are the European leaders in the use of slurries and modified slurries (4).

Construction

Micro-surfacing is applied by a traveling plant that mixes the components in a continuous mixing pug mill. Most equipment used in Texas are continuous mix machines that only carry the full supply of required mineral filler and set retardant additive. The emulsified asphalt, water and aggregate are carried by nurse trucks. Conventional dump trucks or rear feed conveyor trucks are modified by adding tanks to carry polymer modified asphalt emulsion and water. The aggregate is carried in the bed of the truck between the two tanks.

A typical crew on a micro-surfacing job consists of six people. Two people are located at the front of the machine. One person drives the machine and the other hooks up the service trucks. Three people are located at the rear of the machine. One person monitors the mix and adjusts the material amounts if necessary. Two people operate the spreader box by adjusting the thickness and width of the mat. A sixth person typically helps out where needed. This could include hand work or replacing one of the other crew members. Other crew members are used to drive nurse trucks, load the trucks, handle traffic control, and supervise the work.

For rut filling, a rut box is typically used to place the material. Rut boxes are normally 1.5 to 2 m (5 to 6 ft) wide and have been used to fill ruts up to 50 mm (2 in) deep (4). Finish course applications are applied using a spreader box wide enough to cover a lane in a single pass. Spreader box widths of 2.5 to 4.5 m (8 to 14 ft) are typical (4). For ruts up to 12 mm (0.5 in), a full width "scratch" course has been used instead of the rut box to fill ruts (4). Rut boxes allow a small crown to be placed to allow for some compaction in the rutted area. Some equipment manufacturers also provide special spreader boxes with an adjustable cross section. If a project needs rut filling, the ruts are first filled and then a finish course is applied. The finish course gives uniform surface friction and should provide a relatively uniform appearance.

Micro-surfacing that is exposed to direct traffic does not need to be compacted during construction. Areas that are not exposed to traffic may need to be rolled with a pneumatic tire roller (4). This will reduce the void content of the material similar to material subjected to rolling traffic. Micro-surfacing will exhibit some initial compaction due to traffic, especially during warm weather, and then reach a steady state level of density as shown in Figure 2. Rolling may be desirable for airport applications because the micro-surfacing generally will not receive uniform rolling traffic.

Material Characteristics

Micro-surfacing is more complex than conventional hot mix asphaltic concrete due to additional materials including water, emulsifier residues, mineral and chemical fillers and admixtures (6, 7). Hot mix asphaltic concrete (HMAC) is basically a two component system of asphalt and aggregate. HMAC is a thermally controlled material. Heat is applied to fluidize the asphalt cement so it can be mixed with the aggregate and placed. As it cools, it hardens and "sets". Micro-surfacing is a chemically controlled system fluidized by using emulsified asphalt and water. Micro-surfacing hardens and "sets" by the removal of water from the system. The chemistry controlling this phenomenon is complex and difficult to control in some cases.

Micro-surfacing is basically a Type II or Type III standard slurry seal with a polymer modified binder and better aggregates. One of the major differences between micro-surfacings and slurry seals is their response to compaction by traffic (8, 9). Slurry seals can only be placed one-and-a-half times as thick as the largest size aggregate. Micro-surfacing can be placed in thick layers due to the increased stability of the mixture due to the polymer modified binder and use of 100 percent crushed aggregate. This allows ruts, wedges and surface irregularities to be filled to reestablish the transverse profile of a pavement section.

Table 1 shows a comparison of United States and European micro-surfacing systems. European aggregate types and mixes refer to the maximum and minimum nominal stone size in the aggregate gradation (4). The smallest sieve size through which 85 to 100 percent of the aggregate passes is referred to as the nominal maximum size. For example, 0/8 (0 to 8 mm size) means that 8 mm is the nominal maximum aggregate size in the mix and that 85 to 100 percent of the material would pass through an 8 mm sieve.

An ISSA type 3 gradation is compared to the European modified slurry seal systems in Table 1 because it is recommended for rut filling. This type of gradation would be considered a 0/6 gradation, using European standards. This indicates that the Europeans use a larger maximum aggregate size in their mixes. Also, they use a smaller amount of minus 200 material. Hot mix asphaltic concrete mixtures with larger stones are typically more rut resistant than smaller stone mixes (10). The use of larger stone gradations may be one approach that can be used in the United States to develop more rut resistant micro-surfacing mixtures.

Figure 2 shows the compaction characteristics from the International Slurry Seal Association's (ISSA) loaded wheel test (ISSA TB 147). The specific gravity is the weight of aggregate plus the weight of asphalt divided by the volume of aggregate, voids and asphalt. The figure shows that the conventional slurry seal increases in specific gravity due to compaction. Compaction decreases the volume of the voids. The increased stability in the micro-surfacing allows some initial compaction, but then something close to a steady state condition is reached.

Figure 3 shows how the aggregate particles will react to compaction by traffic for both conventional slurry seals and micro-surfacing. The aggregate particles for the conventional slurry seals will move into their most stable position due to the softer asphalt matrix. The asphalt binder will extrude out of the aggregate particles which reduces aggregate exposure and reduces skid resistance (11). The aggregate particles in the micro-surfacing will show some movement but will eventually stop due to the stiff asphalt matrix. This should provide better skid resistance due to the increased aggregate exposure at the pavement surface.

Table 1. Comparison of U.S. and European Modified Slurry Seal Systems (4)

Country		US	GERMANY	DENMARK	ITALY	NETHERLANDS
Type		III *	0/8	0/8	0/9	0/8
Sieve Size				% Passing		
mm	(in.)					
9.50	(3/8)"	100			85-100	95-100
8.00	(5/16)"		90-100			90-100
6.25	(1/4)"			93		67-90
4.75	(No. 4)	70-90	65-85			
4.00	(No. 5)				60-85	55-80
2.36	(No. 8)	45-70				
2.00	(No. 10)		45-65	50	36-55	40-60
1.18	(No. 16)	28-50				
0.60	(No. 30)	19-34				
0.40	(No. 40)				14-28	
0.30	(No. 50)	12-25				
0.25	(No. 60)			17		
0.20	(No. 70)					
0.15	(No. 100)	7-18				
0.075	(No. 200)	5-15	6-12	3	4-8	2-10
Residual Asphalt (% of mix.)		** 5.5-9.5	5-7	5.3	5.5-7.5	*** 5-7
Application Rate kg/m^2 (lb/yd^2)		8.1-16.2 (15-30)	25-30 (46-55)	>16-18 (>29-33)	15-25 (28-46)	

* ISSA type ** % of dry aggregate *** mostly conventional emulsion

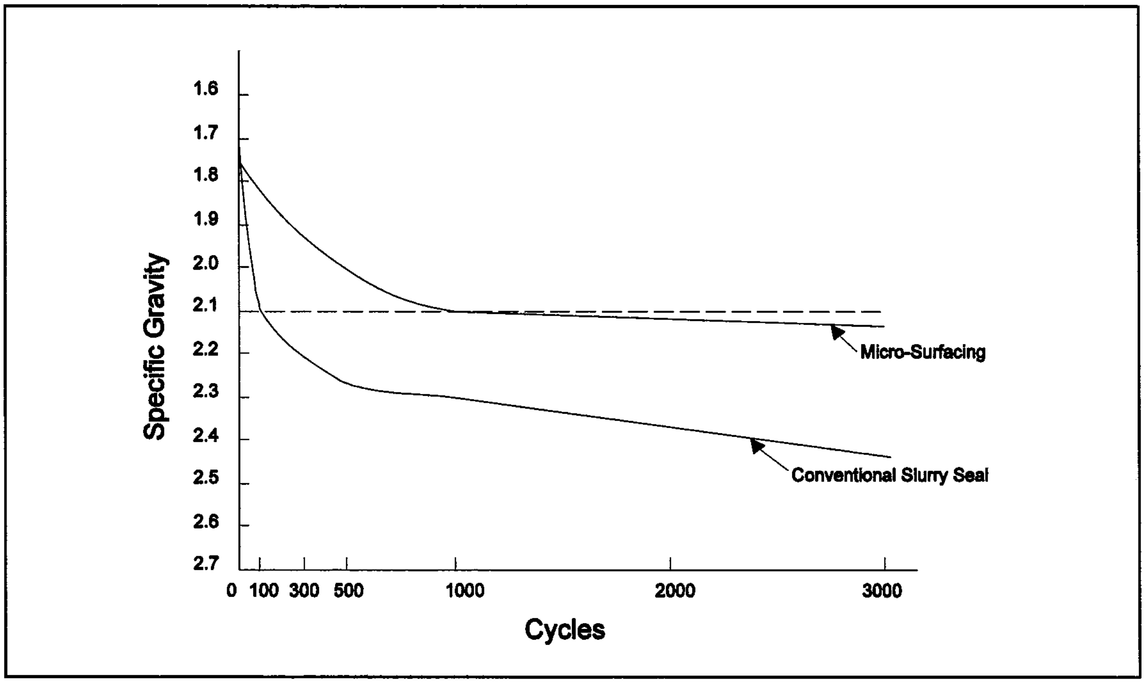

Figure 2. Compaction Characteristics of Conventional Slurry Seals and Micro-Surfacing as Shown by the Loaded Wheel Test (8)

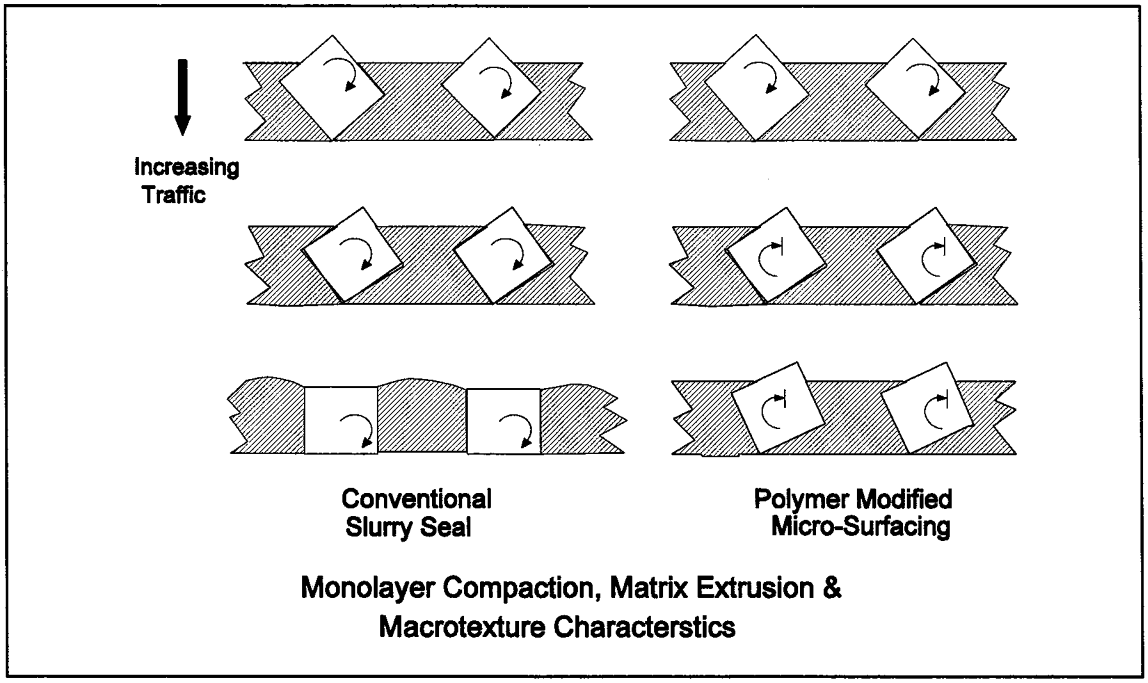

Figure 3. Compaction Characteristics of Conventional Slurry Seal and Micro-Surfacing (11)

Figure 4 shows the effects of layer thickness on the properties of both conventional slurry seals and micro-surfacing. Conventional slurry seals can have low or high voids with a soft matrix. In both cases, skid resistance will be low due to the excess asphalt above the aggregate particles, which reduces aggregate exposure. This demonstrates why conventional slurry seals are not suitable for multi-layer applications. The micro-surfacing with medium voids and a stiff matrix will exhibit increased aggregate exposure as the layer thickness is increased which increases skid resistance (11).

MATERIALS

Micro-surfacing is a four-component system of emulsified asphalt, aggregate, cement and water. Emulsions and water fluidize the system. The system hardens by chemical processes. There is no initial, short-term oxidation of the binder because heat is not used in the construction process (1).

Because the mixture is a chemical system, it can be influenced by many variables. Every aggregate, bitumen, and emulsion is also a chemical system. This is why a theoretical approach to evaluate the system is difficult. An empirical approach by subjecting laboratory samples to field simulated tests is a more realistic approach to evaluate mixture performance (1).

Conventional mono-layer slurry seal design is not applicable to multi-layer design because the bitumen contents required are too high (12). The bitumen contents are high because the purpose of slurry seals are to seal and rejuvenate the existing pavement. Excess asphalt is needed to penetrate and rejuvenate the existing pavement. Slurry seals do not require the stability that is required with micro-surfacing because they are not used to fill surface irregularities.

Material Tests

In general, materials that meet the quality tests contained in micro-surfacing specifications can be used for construction. Quality tests are typically specified for the emulsified asphalt and aggregate by most agencies. Quality tests are not typically specified for the mineral filler, water, or polymer modifier. It should be noted that materials meeting the quality tests may not produce a satisfactory micro-surfacing mixture (7). This is the reason mix performance tests are so important in evaluating micro-surfacing.

The ISSA recommends several tests be performed on the emulsified asphalt (13). These include the distillation (ASTM D 244-89), softening point (ASTM D 36-86), penetration (ASTM D 2397-85) and kinematic viscosity (ASTM D 2170-85). These tests should assure a quality asphalt is being used in the mixture. State agencies may require other tests depending on their policy.

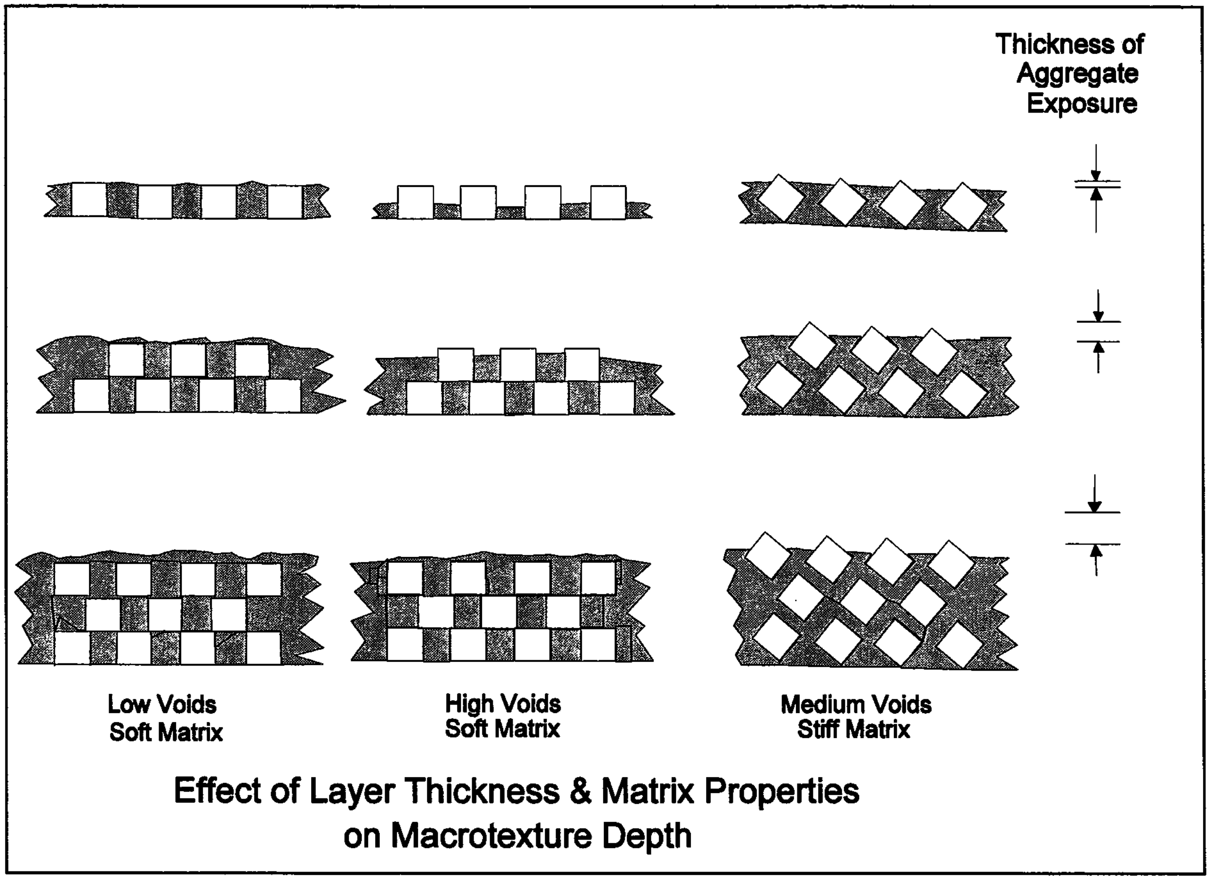

Figure 4. Effects of Layer Thickness for Conventional Slurry Seal and Micro-Surfacing (11)

The purpose of performing laboratory tests on asphalt emulsions are:

- to measure properties related to handling, storage and field use;
- to control the quality and uniformity of the product during manufacturing and use;
- to provide reference procedures for specifications; and
- to predict or control field performance.

It should be noted that tests to examine miscibility of the polymer modifier and the base asphalt are not specified in most specifications. This is generally considered important in the performance of polymer modified asphalts.

The strength of the bond between the bitumen and aggregate are very important in asphalt-aggregate mixtures (10). This property is called compatibility in ISSA documents.

The Schulze-Breuer and Ruck procedures (ISSA TB 144) are recommended by ISSA to measure this property (13). This test was developed by Schulze and Breuer at the University of Munich. It was developed to determine the relative compatibility of a given mineral filler with a given bitumen (14).

The aggregate used is specified to be 100 percent crushed material (13). Figure 5 shows the gradations of the ISSA aggregates used in micro-surfacing. The quality tests recommended are sand equivalent (ASTM D 2419-74), soundness (ASTM C 88-83), and abrasion resistance (ASTM C 131-89). It is also recommended that the aggregate meet state requirements for polish values. The aggregate gradation tests are determined by performing sieve analyses (ASTM C 136-84a and C 117-87). The sampling procedure used for aggregate sampled out of stockpiles is ASTM D 75-87.

The mineral filler can be any recognized brand of non-air entrained portland cement or hydrated lime that is free of lumps. Typically, bagged Type I portland cement is used in the mixture. Lime is not widely used in micro-surfacing mixtures, but when it is used, it can be obtained in bags like portland cement. The chemical composition of the lime will vary according to the material source. It should be noted that when these two mineral fillers are used, moisture will cause the material to lump together. This is a problem when the bags encounter moisture. Lumps will cause bad spots in the micro-surfacing mat when placed in the field.

The only limitation on the water used in micro-surfacing mixtures is that it be free of harmful salts and contaminants. Without understanding the chemistry of micro-surfacing mixtures, it will be difficult to determine what salts and contaminants are harmful. A chemical analysis of the mix water would probably be beneficial if there is evidence that the mix water is responsible for producing a poor mix. This should help in determining why a micro-surfacing mixture is unsatisfactory. Salts and contaminants may not be harmful to all mixtures. Local experience will probably be helpful in determining an acceptable water source. Potable water from an approved source would most likely be the best type of mix water to use. Water used from rivers, ponds or lakes may vary in quality during the course of a project due to rainfall.

At the present time, there are no limitations as to which polymers may be added to the asphalt. Most specifications only require a minimum amount of polymer to be added to the base asphalt. Three percent is typical. Many types of polymers can be added to asphalts. These include elastomers, plastics, and combinations of each. Examples of rubber polymers are styrene-butadiene (SBR), styrene-butadiene-styrene (SBS), and natural rubber. Examples of plastic polymers are polyethylene, polypropylene, ethyl-vinyl-acetate (EVA) and polyvinyl chloride (PVC). Polymers may be added to the base asphalt either at the refinery or at the job site. They can be added to the base asphalt before the asphalt is emulsified or during the emulsification process. Special equipment is needed to blend the polymer and the asphalt. Each blending process will probably have a different effect on the asphalt properties. The addition of a polymer typically stiffens the asphalt, which

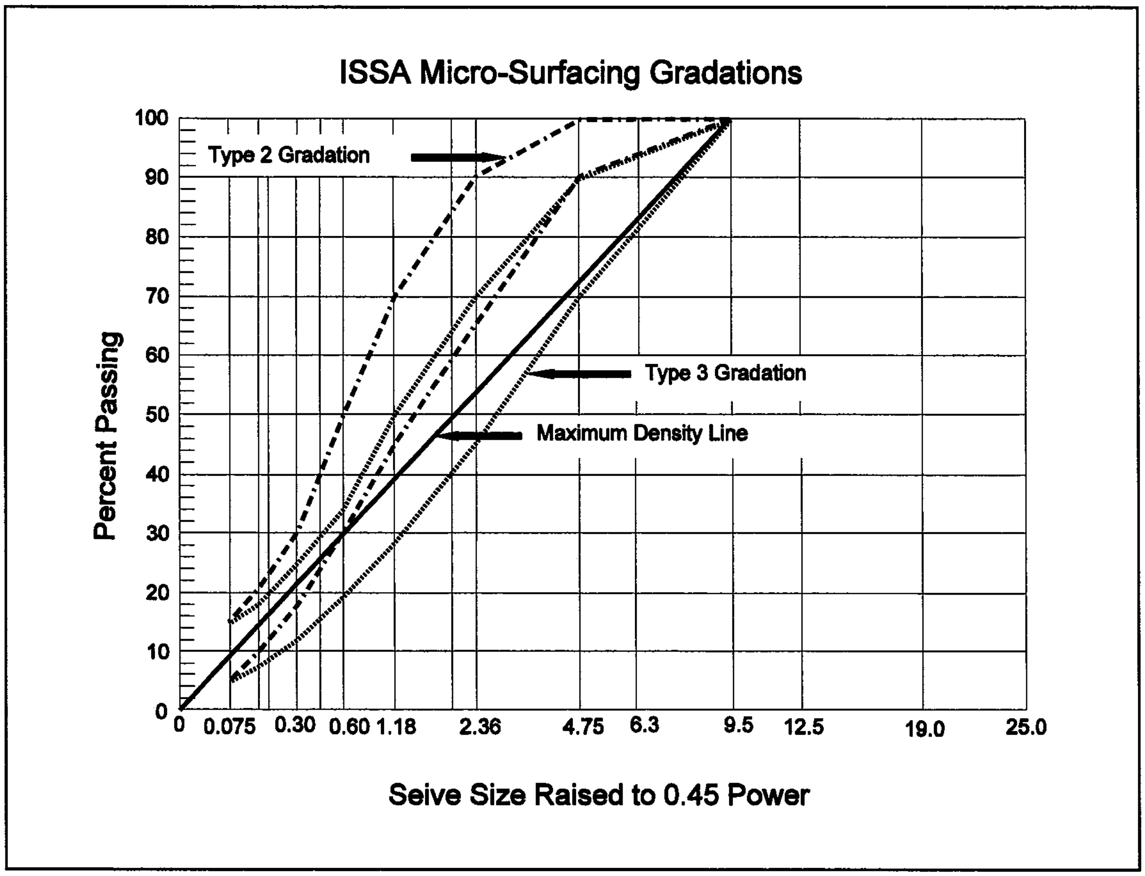

Figure 5. ISSA Type 2 and 3 Gradations for Micro-Surfacing (13)

improves the rutting resistance (10). A change in the asphalt properties will change the performance of the mixture. Some polymers may not be good candidates for micro-surfacing. Further research should be conducted to determine the effects of polymers on the performance of micro-surfacing mixtures. This should include the manufacturing process of polymer modified asphalt emulsions.

The polymer type and amount has a major effect on the compaction characteristics of micro-surfacing mixtures (15). Figure 6 shows the effects of polymer type. The figure shows that all of the polymers are beneficial to the system to various degrees. Figure 7 shows the effects of polymer amounts on micro-surfacing. The material becomes more resistant to compaction as the polymer amount is increased. Notice how the five percent polymer content exhibits a flat compaction curve. Also, notice that the mixture containing three percent polymer is still very sensitive to the amount of asphalt emulsion.

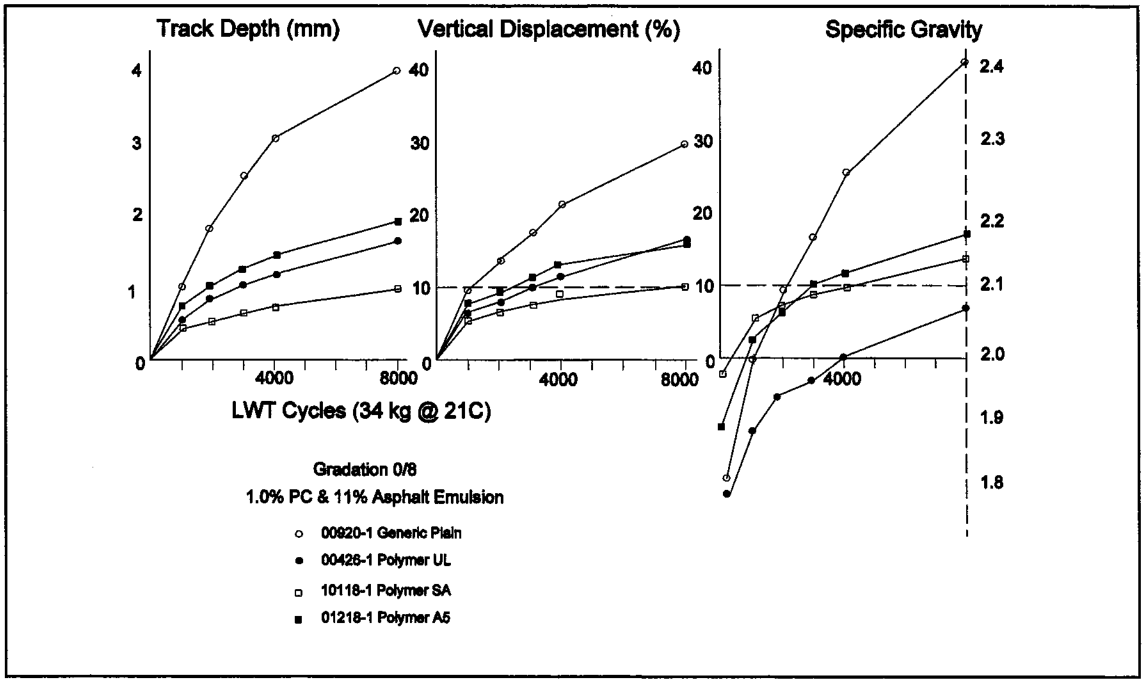

Figure 6. Effects of Polymer Type on the Compaction Characteristics as Shown by the Loaded Wheel Test (15)

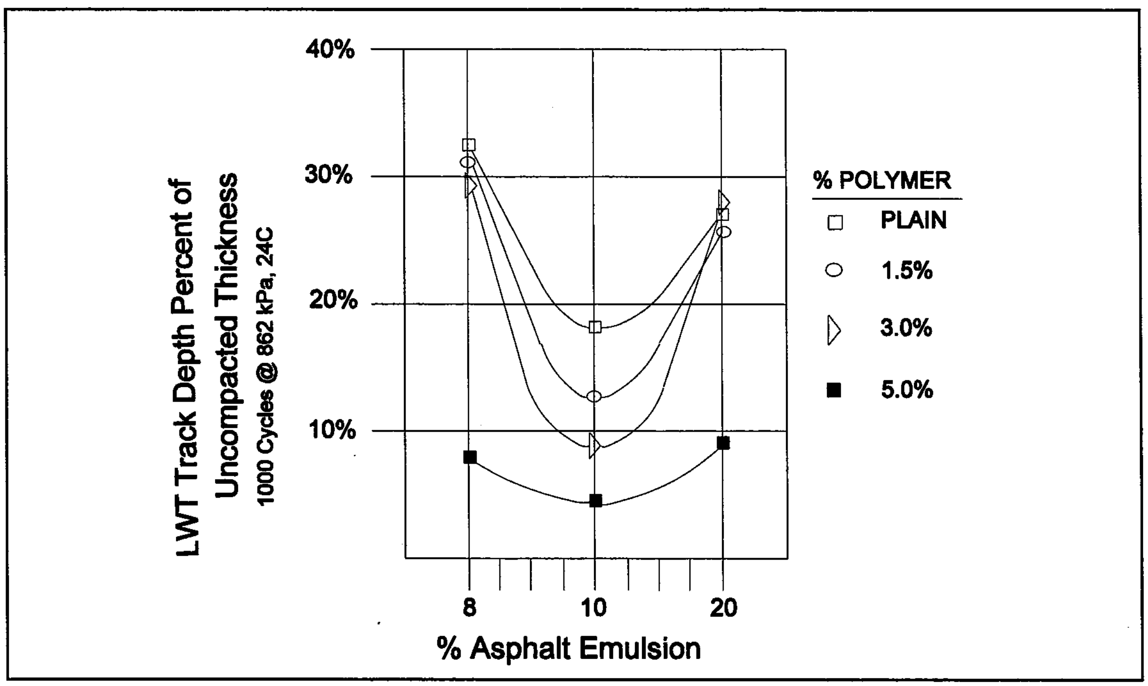

Figure 7. Effects of Polymer Amount on the Compaction Characteristics of Micro-Surfacing as Shown by the Loaded Wheel Test (16)

The only limitation on the types of additives that can be used is compatibility. The additive must be certified as being compatible with the other mixture components. The additive should help control the break time of the mixture and increase the adhesion between the cured asphalt and aggregate. The compatibility of the additive can be shown by the performance of the mixture using laboratory tests. It should not be detrimental to mixture performance.

The emulsifier type and additive type appear to have the most influence on the compaction characteristics of micro-surfacing mixtures (12). A system that shows a flat compaction curve is termed "ISOPAC" (8). These systems typically have high void contents (>8 percent) and low specific gravities (2.00-2.10). An "ISOPAC" system will be more predictable. Field studies have shown that nearly all satisfactory multi-layer applications of micro-surfacing have high void contents (8-12 percent) and low specific gravities (2.10) even after four years of heavy traffic (11). A flat-shaped curve is ideal because it allows a wide variation of bitumen content, which requires less need for precise field proportioning (11).

Figure 8 shows the effects of using different additives on the compaction characteristics as shown by the loaded wheel test (ISSA TB 147). The figure shows how some additives can be beneficial and some detrimental to micro-surfacing mixtures. Mixtures containing additive KZ exhibit more deformation over a wider range of asphalt emulsion contents than those containing no additive. Additive KY is beneficial to the mixture at low asphalt emulsion contents and detrimental to the system at high asphalt contents. Additive KX provides an "ISOPAC" system that is very desirable. This micro-surfacing mixture is not as sensitive to small changes in asphalt emulsion contents as the other micro-surfacing systems.

Asphalt Emulsions

Asphalt emulsions are composed of asphalt, water and emulsifying agent. Other materials are sometimes added. The purpose of an emulsifying asphalt is to disperse the asphalt in water for pumping, storage and mixing (17). The base asphalt is divided into tiny droplets by a high shear mechanical device. A colloid mill is the most common device used. Typical asphalt particle sizes range from 0.001 mm or less to 0.01 mm (17).

Asphalt emulsions are classified as anionic, cationic, and nonionic. Typically, anionic and cationic are the most widely used in the pavement industry. The classification system deals with the basic laws of electrochemistry. Anionic emulsions are negatively charged. Cationic emulsions are positively charged. Nonionic emulsions have no charge and are, therefore, as neutral. Emulsions are further classified according to break time.

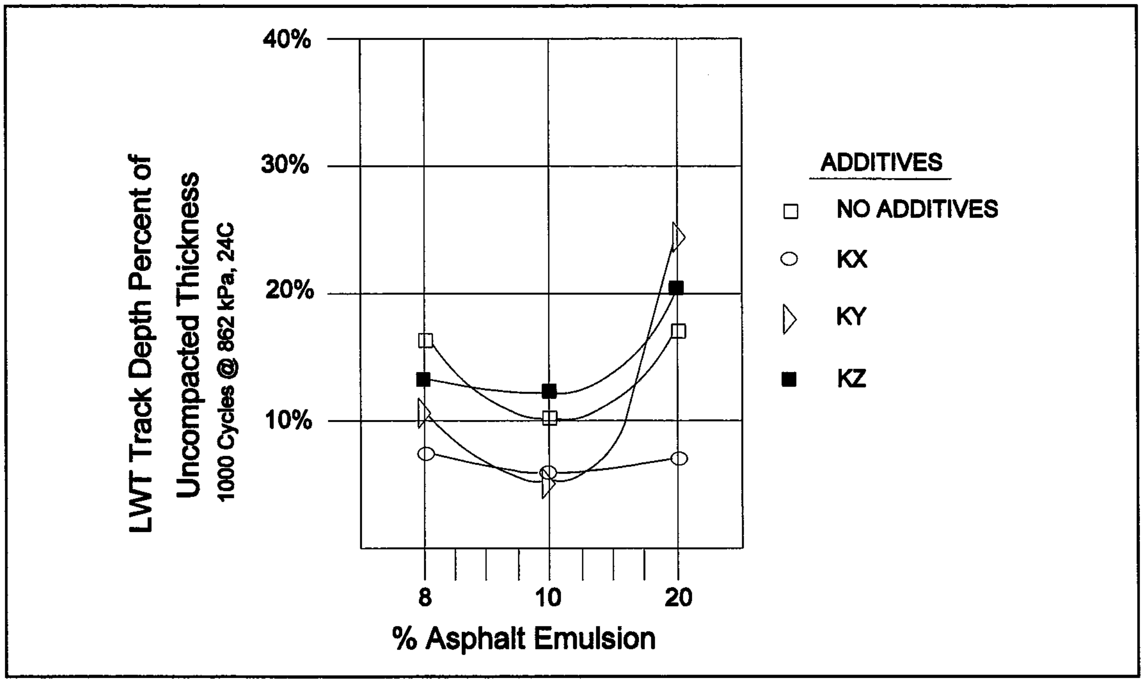

Figure 8. Effects of Additive Types on the Compaction Characteristics of Micro-Surfacing as Shown by the Loaded Wheel Test (16)

Break time is the time needed for most of the asphalt particles to coalesce to form a continuous asphalt phase (17). Rapid-setting (RS), medium-setting (MS) and slow-setting (SS), are the three types of classifications. A "C" preceding the break time designation refers to a cationic emulsion. If a "C" is not present in the designation, it is understood to be an anionic emulsion. If the designation is followed by an "h," it means a harder base asphalt is used (17).

Cationic slow-setting asphalt emulsions are typically used in micro-surfacing mixtures. This allows the break time to be controlled by the mixture components. This is important due to the ever changing environmental conditions that are encountered during a project. Portland cement is typically used for accelerating break times. Additives such as aluminum sulfate are commonly used to retard break times (18).

Many factors affect the properties of asphalt emulsions. Some of these include the following (17):

- chemical properties of the base asphalt,
- hardness and quantity of the base asphalt,
- asphalt particle size,
- type and concentration of the emulsifying agent,

- manufacturing conditions of the asphalt emulsion,
- particle charge of the asphalt emulsion,
- manufacturing equipment used for production, and
- chemical modifiers used.

It is important that these factors are understood. Most of the above factors can be varied to help aid in developing an optimum asphalt emulsion. Each asphalt emulsion may perform differently depending on the aggregate, environment, and other factors.

The size of the asphalt droplets dispersed in the emulsion is important. Stokes' Law states that the smaller the asphalt particle size, the slower the settlement rate (16). Small asphalt particle size will result in a more stable mixture. This will be beneficial while the asphalt emulsion is stored. It will help minimize separation of the mixture. Particle size is a function of bitumen crude source, mill setting, emulsifier type, activity, solubility, pH, and interfacial tension (16).

Some of the factors affecting performance of asphalt-aggregate mixes are cohesive forces within the asphalt, adhesive forces at the asphalt-aggregate interface, and coalescence (18). Premature breaking will occur if the adhesive forces are greater than the cohesive forces. Stripping will occur if the adhesive forces are less than the cohesive forces. Poor mixing characteristics will occur if a high rate of coalescence and large cohesive forces are present in the mixture.

Asphalt Emulsion pH

There is an optimum pH that will support the smallest particle size distribution, which will result in an optimum stability (16). A low pH emulsion has been shown to give the best cohesion test results for set time and traffic time for some systems (16). Lower compaction rates have been obtained at high pH emulsifier and high cement contents for other systems (15). This demonstrates that each micro-surfacing mixture is different. There is apparently an optimum emulsifier solution pH value for each system of emulsion, aggregate, and mineral filler. It has been shown that the emulsifier solution pH is not the same as the finished emulsion pH. The pH has been shown to have an immediate shift to a constant value and in some cases it will keep rising with time (16). The emulsion pH will change when all of the micro-surface components are combined. This will affect the cohesion test results and cause a system to change in classification (16). In all cases, the emulsion pH will rise and affect the mix performance. This shows the complexity of using pH as a parameter to evaluate micro-surfacing mixtures. Each mixture will most likely have a different optimum emulsion pH value.

Figure 9 shows the effects of pH on the performance of a particular micro-surfacing mixture. The mixture was evaluated using the loaded wheel test. The mixture was tested

at two different pH levels and two different portland cement contents. The results show that the higher pH level exhibited less compaction. The figure also shows the effects of the cement content. The lower cement content exhibited less compaction for the high pH levels up until approximately 4000 cycles.
The two cement contents then crossed over with the higher content leveling off and the lower content continuing to rise. The specific gravities of all the systems continued to increase except for the high pH and high cement content, which leveled off. It is evident that a high pH and high cement content would be more desirable due to the flattening of the compaction curves.

Emulsifying Agent

The most important component in a micro-surfacing mixture is the emulsifying agent. The emulsifier or surfactant keeps the asphalt droplets in stable suspension and controls the breaking time (17, 19). The surfactant changes the surface tension at the area of contact between the asphalt droplets and water (17, 19). The surfactant allows the asphalt droplets to remain in a suspended state, due to the droplets having similar charges which cause them to repel each other.

The main action during the preparation of an oil-in-water emulsion is the stabilization of small oil droplets by adsorption of emulsifier at the interface (18, 19). This makes it necessary for the emulsifier to be soluble both in the aqueous stage and in the oil stage. The nature and concentration of the emulsifier in an asphalt emulsion determines the coalescence rate (stability) of the emulsion droplets; it also influences particle size distribution, storage stability, rate of setting, and adhesion of the asphalt to the aggregate when the water is evaporated (18). To assure good adhesion of the asphalt to freshly crushed aggregate, instead of weathered aggregate, usually requires a very high emulsifier concentration (18). This is caused by the adsorption of the emulsifier onto the higher dust fraction caused by the crushing process.

Water

Water is the second largest component of an asphalt emulsion. Water wets, dissolves, adheres to other substances, and moderates chemical reactions (17). The quality of water is very important. Impurities can have detrimental effects on the performance of asphalt emulsions. Until the chemistry of micro-surfacing materials is understood, it will be difficult to determine what impurities are detrimental to a particular mixture. Each system is different. This means that some impurities may or may not be detrimental to some micro-surfacing mixtures.

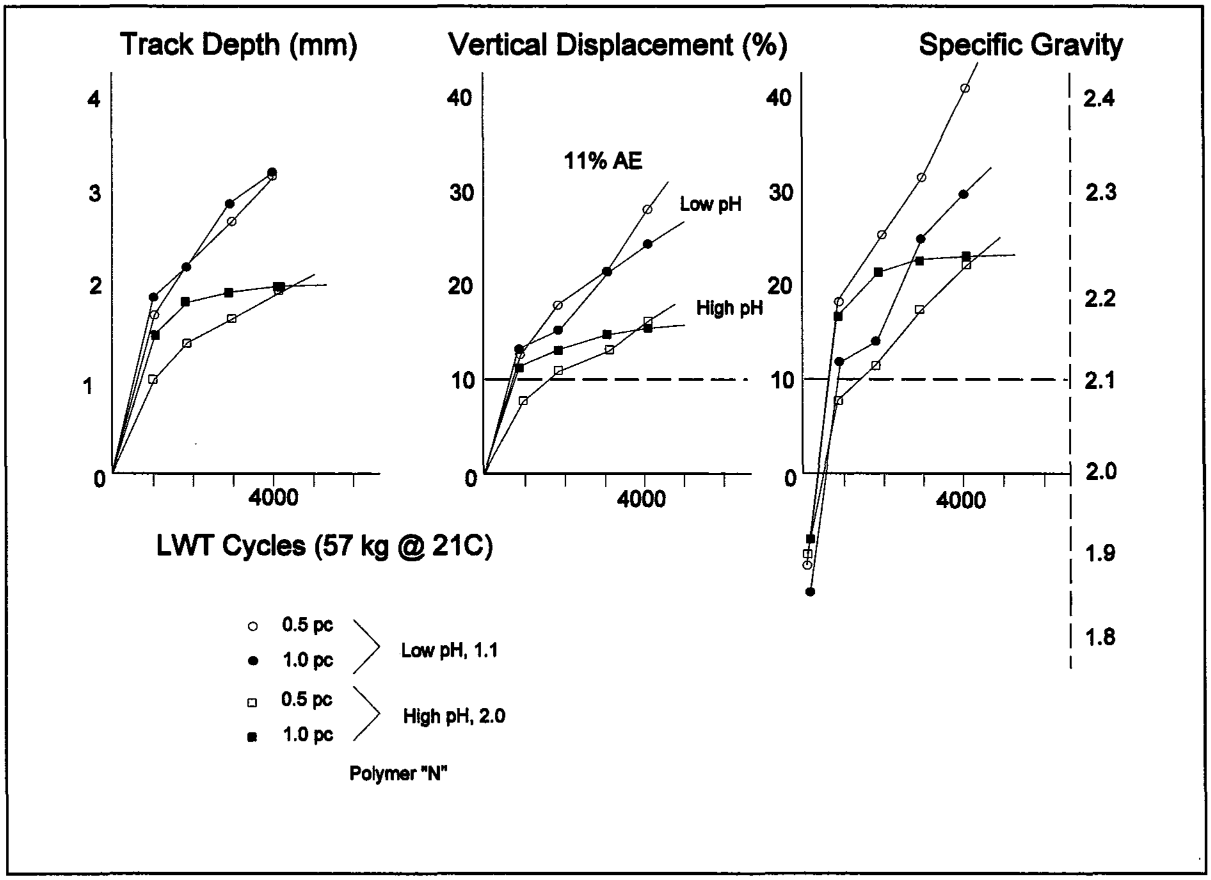

Figure 9. Effects of Emulsifier pH with different cement (pc) contents on the Compaction Characteristics of Micro-Surfacing as Shown by the Loaded Wheel Test (15)

Breaking Process

Two theories have been used to explain the breaking mechanisms of asphalt emulsion mixtures. One theory is that asphalt emulsions break on the surface of mineral aggregates by neutralization of the electrical charges of the emulsion droplets by the charges of the aggregate surface (18). This causes a continuous film of asphalt to form around the aggregate particles due to coalescence of the asphalt droplets. This is why cationic emulsions with highly charged anionic aggregates are generally preferred (18). When a cationic asphalt emulsion is mixed with an aggregate bearing a negatively charged surface, the emulsion droplets are destabilized by proton transfer from the emulsifier to the aggregate surface, which neutralizes its charge and breaks the emulsion (18).

The other asphalt emulsion breaking theory involves the formation of a hydrophobic (water hating) layer around the aggregate. Cationic emulsifiers, which are organic bases, react by an ion-exchange mechanism with the surface of the aggregate (20). The long-chain organic cations are adsorbed onto the surface of the aggregate. This causes the aggregate surface to become hydrophobic and to become wetted by the bitumen (20).

This shows why the formulation of a cationic emulsion is one of the most important factors that influences the breaking.

The adhesion of the bitumen to the aggregate is strongly affected by the breaking mechanism (20). The formation of a olephilic (hydrophobic) layer is required. A strongly absorbed layer by the aggregate permits good wetting of the surface by the bitumen (20). This demonstrates the importance of using an aggregate that can readily adsorb the emulsifiers.

A thick layer of dust on the aggregate particles can cause major problems with emulsifier adsorption. The dust will adsorb the emulsifier, cause the asphalt to be deposited on the dust, and cause the binder not to bond to the aggregate (20). It will not develop the proper strength and will be vulnerable to environmental factors. Prewetting the aggregate may be one solution to this problem because water will help satisfy the liquid demand of the dust particles. The sand equivalent test (ASTM D 2419-74) is used to determine the relative proportions of plastic fines and dust in fine aggregates (10). This is why high sand equivalent values need to be used in micro-surfacing specifications.

The purpose of the breaking process is to coat the aggregate particles in the mixture. Prediction and control of the breaking process are essential for good micro-surfacing applications. The rate of breaking is controlled primarily by the specific type and concentration of the emulsifying agent used, as well as atmospheric conditions (17). The aggregate also affects the rate of breaking. The surface area of the aggregate will be the major factor that influences the break time. The specific surface area is dependent upon the gradation of the aggregate. Denser gradations will have more specific surface area. Higher surface area of the aggregate will exhibit higher absorption of water.

Figure 10 shows the effect of different aggregates on the breaking process. The aggregates used were limestone, porphyry, basalt, and quartzite. The exact chemical composition of the aggregates are not known. Typically, limestone has a silica content below 50 percent and is negatively charged, porphyry has a silica content between 60 to 70 percent and can have a mixed charge to negative charge, basalt has a silica content between 40 to 50 percent and has a positive charge, and quartzite has a very high silica content with a strong negative charge (10). The figure shows the amount of bitumen deposited on the aggregate with time. The limestone had the highest amount of bitumen deposited on it followed by the porphyry, basalt, and quartzite. It is interesting to note that this is not the order of positive to negative charge for the aggregates. This generates questions about the theory of electromagnetic attraction between the aggregate and asphalt.

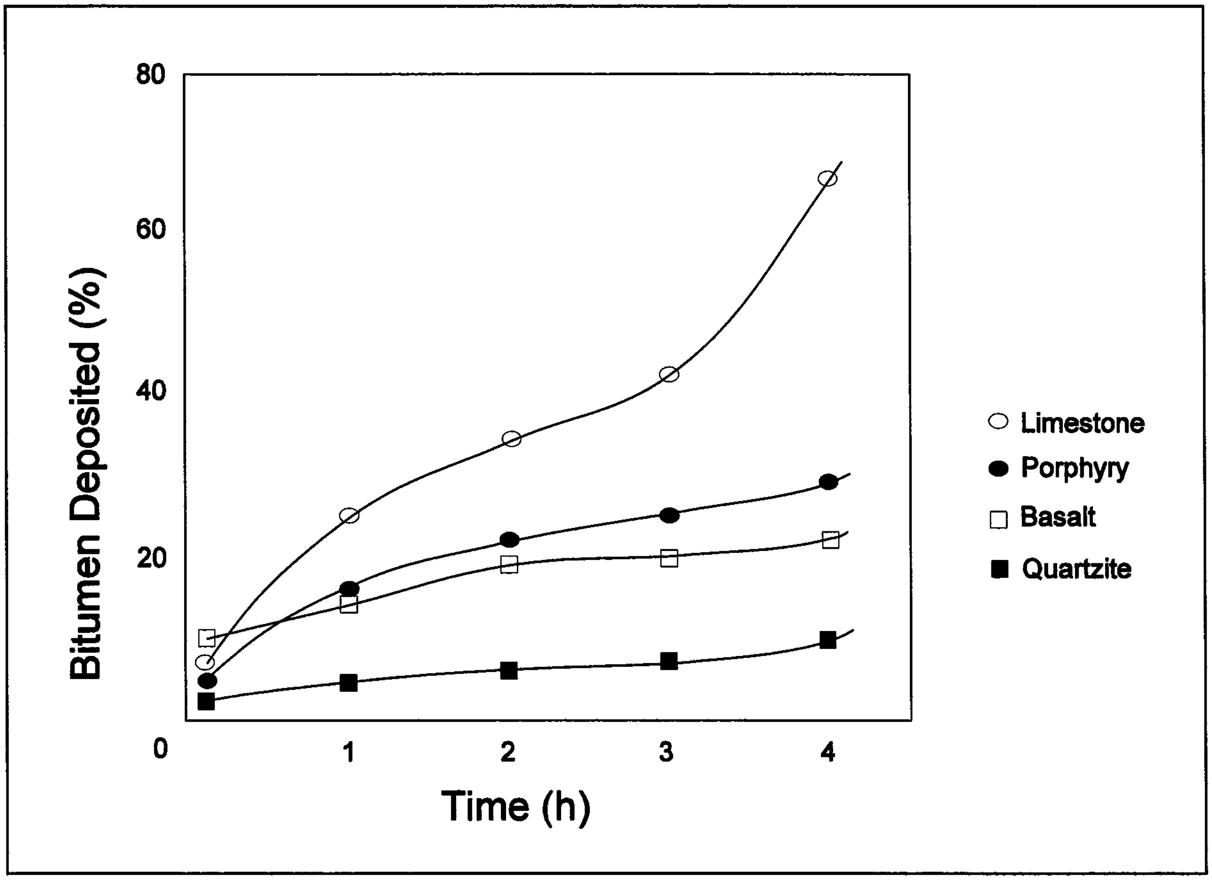

Figure 10. Effects of Aggregate Type on the Breaking Process of Cationic Asphaltic Emulsions (21)

Table 2 shows the surface area measurement as determined by methylene blue dye adsorption and pH values of the water and emulsifier. The surface area measurements do not explain the trends in the data. The porphyry and the basalt have larger specific surface areas than the limestone but did not break as fast. The trend in the data is better explained by pH measurements. The higher the pH (the more basic), the more bitumen that is deposited on the aggregate. This follows the theory that basic rocks have a higher affinity for asphalt (20).

Figure 11 shows the effect of moisture premixed with aggregate on the amount of bitumen deposited on the aggregate after two hours of breaking using 100 gram samples. The amount of bitumen deposited on the gravel increased as the moisture content increased. The amount of bitumen deposited on the quartzite and basalt decreased with increasing moisture content. The figure demonstrates how moisture can be both beneficial and detrimental to a mix depending on the type of aggregate used.

Table 2. The Surface Properties of the Aggregates Used in the Investigation of Cationic Asphaltic Emulsions (21)

Aggregate Type	Surface Area m^2/g	pH of Water Phase[a] In Contact With Aggregate	pH of Emulsifier Solution[b] After Exposure To Aggregate
Limestone	0.14	9.4	8.5
Gravel	0.12	9.3	8.2
Porphyry	0.24	7.6	4.1
Basalt	0.24	8.2	--
Quartzite	0.09	6.3	--

[a] 50 gram aggregate in 250 ml water.

[b] 10 ml emulsifier solution (5×10^{4} M diazine emulsifier acidified to pH 3) mixed for 3 hours with 100 grams of aggregate, then diluted to 250 ml.

Another example of the effect of moisture on the breaking process is shown in Figure 12, which shows the amount of bitumen deposited as a function of time. Emulsion was applied directly to dry gravel and quartzite. The two aggregate samples were then pre-wet before adding the emulsion. In both cases, the amount of bitumen deposited dropped by a substantial amount. The amount of water added to the two aggregates was a substantial amount. In this case, 6.5 grams of water was added to 100 gram samples. This is important to understand because of the variation of moisture content in aggregate stockpiles. There are many instances when aggregate stockpiles are not protected from moisture. This means that the moisture content of the aggregate could become very high, which could affect the performance of micro-surfacing. Some stockpiles may need to be covered in order to minimize the detrimental effects of moisture to the mixture.

The amount of emulsifier can have a great effect on the breaking process. Figure 13 shows the effects of emulsifier concentration on the amount of bitumen deposited on two aggregates. The figure demonstrates how, as the amount of emulsifier is increased, the break time is increased. This is especially true with the gravel. Gravel is a more reactive aggregate based on the high pH in Table 2. The emulsifier suppresses the break time for about three hours before a significant amount of bitumen is deposited on the aggregate. The porphyry shows a greater rate of breaking, but a greater amount of emulsifier does suppress the breaking process. Figures 14 and 15 also show the effects of emulsifier concentration on the break time. Both graphs show that the break time is increased as the amount of emulsifier is increased.

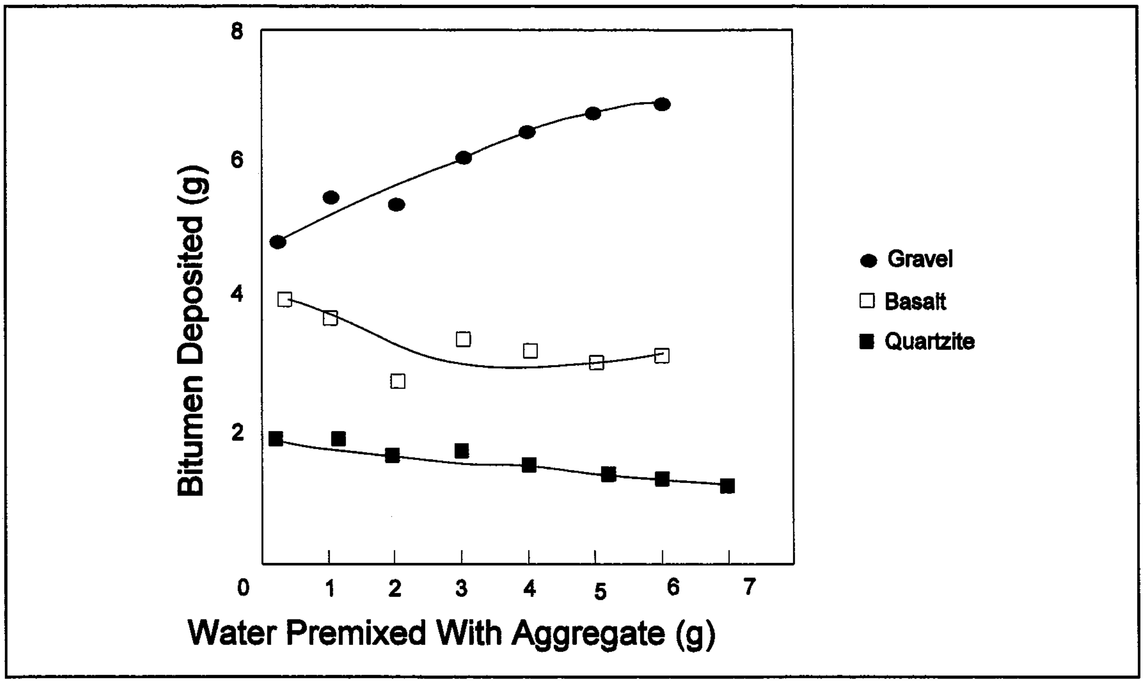

Figure 11. Effects of Aggregate Moisture on the Breaking Process of Cationic Asphaltic Emulsions (21)

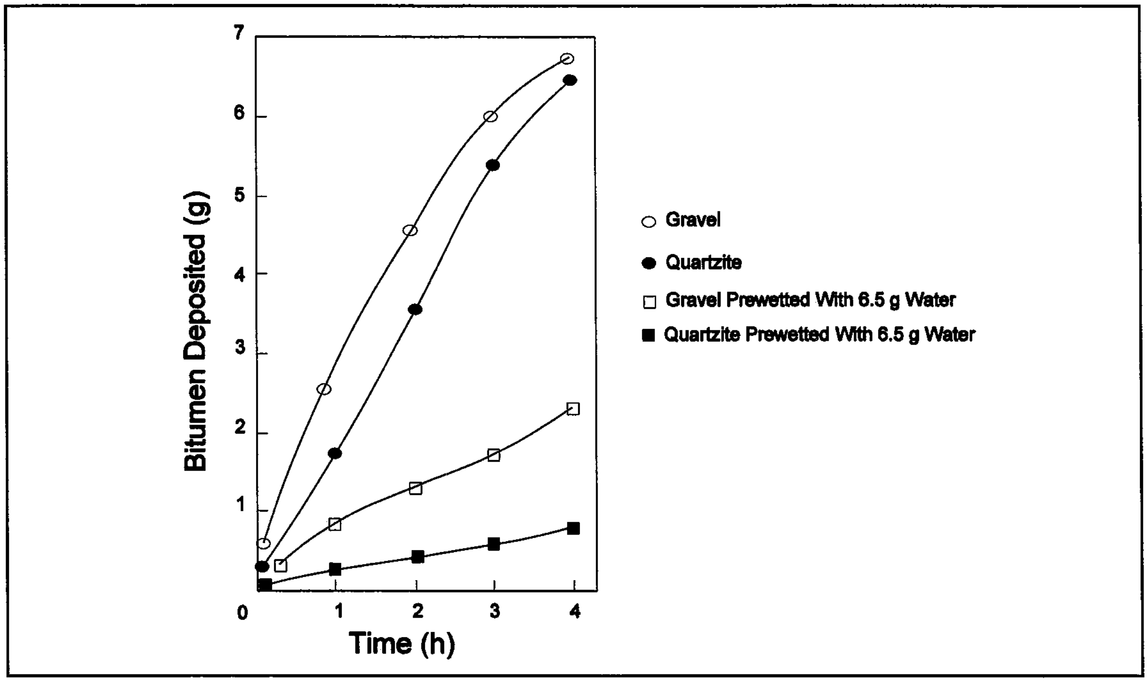

Figure 12. Effects of Prewetted Aggregate on the Breaking Process of Cationic Asphaltic Emulsions (21)

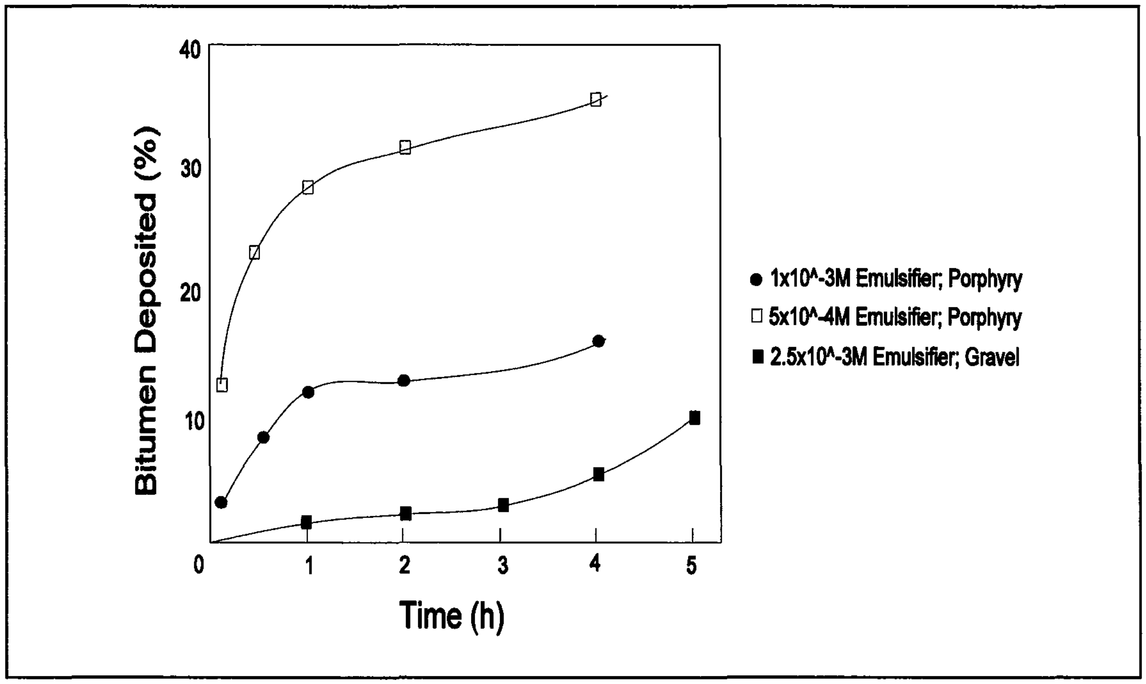

Figure 13. Effects of Emulsifier Content on the Breaking Process of Cationic Asphaltic Emulsions (21)

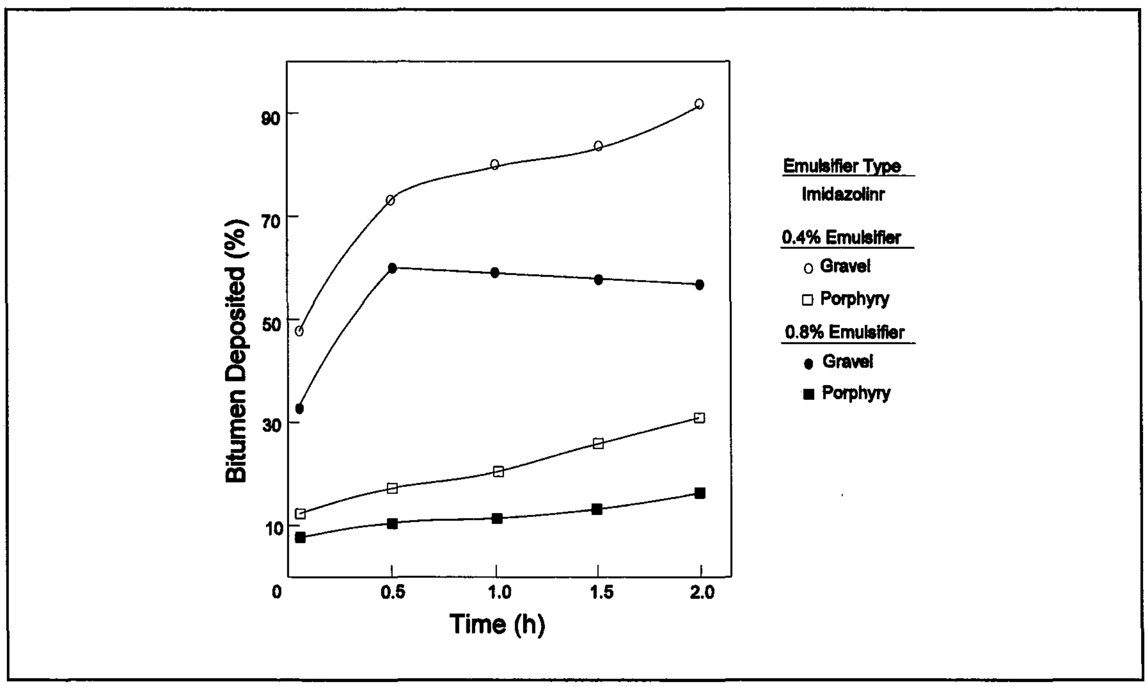

Figure 14. Effects of Emulsifier Concentration on the Breaking Process of Cationic Emulsions Using Gravel and Porphyry Aggregate (21)

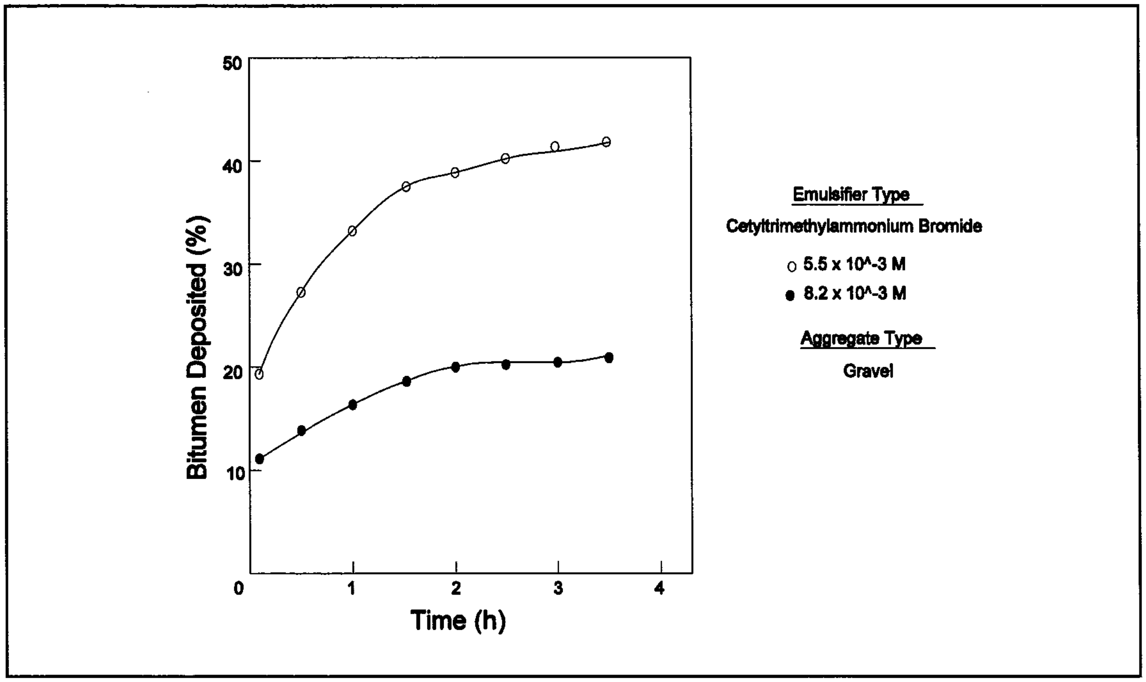

Figure 15. Effects of Emulsifier Concentration on the Breaking Process of Cationic Asphaltic Emulsions Using Gravel (21)

Figures 10 and 13 demonstrate how the breaking process can be divided into three stages. The first stage is an initial interaction between the emulsion and aggregate surface. The second stage is a steady state phase. The third stage is the final stage, when water is removed and the asphalt forms around the aggregate. These three stages occur even in rapid setting emulsions. Determining when these three stages occur in practice would be difficult with fast breaking asphalt emulsions.

In the first stage, emulsifier is adsorbed onto the surface in a fashion dependent upon the nature and concentration of the emulsifier ions, pH, and electrolyte content of the emulsion's aqueous phase, and characteristics of the aggregate (21). The aggregate characteristics include the chemical nature, surface area, and water content. At the same time the emulsifier adsorption is taking place, there is a leaching of ions from the aggregate surface (21). The ions that are leached from the aggregate surface can affect the properties of the emulsifier. The ions can change the adsorption properties of the emulsion on the aggregate (21).

The theory of an attraction between positively charged emulsion droplets and the negatively charged aggregate surface may not be the major mechanism involved in the breaking process. Adsorption of the emulsifier by the aggregate surface may be the major mechanism (21). Research has shown that there are 10^8 more emulsifier ions than bitumen droplets (21). Therefore, the probability of emulsifier adsorption is much greater.

Regardless of the mechanism involved, emulsifier adsorption has been shown to have a great effect on the wettability of aggregate particles (21).

The second stage is a steady state process which shows the stability of the asphalt emulsion. At the beginning of this stage, the aggregate surface may be partially or completely cut off from the remaining emulsion, both by emulsifier adsorption and bitumen deposition (21). This means that the breaking rate will be governed by the amount of emulsion remaining, particle concentration and size distribution, emulsifier concentration, and aqueous composition (21). This shows that there is an initial break in the emulsion; then, a restabilization process takes place which retards the breaking process. This process is probably very short for rapid breaking emulsions.

The third stage is when the remaining portion of the asphalt is deposited on the aggregate surface. This stage begins when evaporation starts to override the other factors involved in the second stage (21). Evaporation of the water brings the asphalt droplets together. This will force the remaining water out of the system. The asphalt will then coalesce, causing an asphalt film to form around the aggregate particles. Of course, different systems will respond differently during this stage.

High humidity and low temperatures will deter proper breaking and curing of asphalt emulsion mixtures. These factors are less critical for cationic emulsions than for anionic emulsions (17). Cationic emulsions will typically give up their water faster than anionic emulsions (17). Cationic emulsions break basically by chemical processes instead of mechanical processes as in anionic emulsions. Of course, mechanical processes are involved in the breaking of cationic emulsions; the contribution is not a major influence on the process. It should be noted that break times are very short for micro-surfacing mixtures. The mechanical breaking processes, such as humidity or temperature, can have a major effect on the mixture if the break times are shortened or lengthened by a matter of minutes.

It has been shown that success or failure of a micro-surface material can occur due to aggregate quality (22). As was shown in Figure 10, the aggregate type does have an influence on the amount of bitumen deposited on the aggregate. Each aggregate exhibited a different breaking curve. This demonstrates why selecting the right aggregate is important in developing an optimum micro-surfacing mixture.

It is important to understand the absorption characteristics of the aggregate because aggregate absorption affects the breaking process. The absorption will be affected by the moisture content of the aggregate. Typically, a light spray of water is applied to the pavement surface before applying micro-surfacing. Also, some aggregates are prewetted before they are used in the asphalt-aggregate mixtures. This may not be advisable for some aggregate types.

The chemical reactions between the aggregate surface and the emulsion droplets determine critical properties of a slurry mix, such as adhesion, cohesion, mix stability, compatibility, set time, and cure time (18). This is why understanding the effect of moisture on the properties of the aggregate is important. Calcareous aggregate has an electropositive charge and siliceous aggregate has an electronegative charge when perfectly dry. The presence of water changes the charge. There is conflicting information regarding this subject. One theory states that both aggregates will become negatively charged in the presence of water (18) while the other states that most siliceous aggregates will become more negatively charged and calcareous aggregates will have a positive charge (10). Some aggregates contain both positive and negative charges due to their chemical composition. Aggregates that contain silica (negatively charged) and calcium (positively charged) can have both positive and negative charges on the aggregate surface (10). This will affect the breaking process if the theory of electrical charge is really the process that takes place. This may not be as important if the theory of adsorption is the actual breaking mechanism. It is obvious that understanding the breaking process is crucial in understanding micro-surfacing. Without understanding the process, optimizing micro-surfacing mixtures will be difficult.

Type I portland cement is typically used as the mineral filler in micro-surfacing. It is a general-purpose cement used in various construction applications. Cement will accelerate the break time of micro-surfacing mixtures. It also affects the strength properties as was shown in Figure 9. Little is known about how the cement affects the chemical processes in micro-surfacing mixtures. It most likely accelerates the breaking process by absorbing the liquids in the mixture, causing the asphalt emulsion to break. Other cement types may have different effects on micro-surfacing mixtures. These should be investigated. Cement will also have a stiffening effect on asphalt residue. It will decrease the penetration and increase the ring and ball softening point (23). This is important in developing a stiff asphalt matrix which will resist rutting in thick applications.

The addition of portland cement has been shown to affect the sand equivalent test (16). It is important that the sand equivalent test be performed on the crushed aggregate without the added cement. It will give a false indication of the amount of detrimental fines in the aggregate due to the small size of the cement particles. The sand equivalent test is typically required only on the aggregate, even though the cement must be included in the aggregate gradation.

Other "additives" that are added to the emulsified asphalt mixture are typically emulsifying agents. These additives are added to retard the break time of the emulsion which retards set of the mixture. Retarders such as aluminum sulfate and emulsifier solution are commonly used (24). Aluminum sulfate neutralizes some of the negative charges of the aggregate and slows down the cohesive strength development (18). Additives are incorporated into micro-surfacing to improve adhesion or cohesion, alter the electric charge of aggregate particles, and increase or decrease the mixing, setting, and curing times (18). Additives also affect the rutting resistance of the material (12, 16). Some additives will flatten out the compaction curves over wide ranges of asphalt emulsions contents. This shows the sensitivity of the system. These additives are used according to environmental conditions. On dry hot days, additives are typically used. On wet cool days, additives are usually not used.

CHAPTER 3
MIXTURE DESIGN

In a micro-surfacing mixture aggregate, emulsified asphalt, polymer modifier, mineral filler, other additives (to control set time or improve adhesion), and water must be combined to allow placement and provide a durable skid resistant surface. It is proposed that the contractor retain primary responsibility for mixture design and that the Department should verify that the mixture provides the properties that indicate that the mixture is expected to provide the desired service.

Micro-surfacing mixtures are usually proprietary in nature; nevertheless, guidelines should be available to aid the contractor and the State in cooperatively selecting the ideal material for the particular application. Independent variables of importance to mixture selection are traffic, climate, pavement surface, and structural condition. Mixture design for micro-surfacing will require some flexibility for the contractor so that adjustments can be made to accommodate hourly changes in temperature and humidity during construction. Setting rate of this material is highly sensitive to humidity and temperature; therefore, periodic adjustments in water and additives are necessary as the day progresses.

Although the contractor will have primary responsibility for mix design, he should furnish to the Department a written report depicting the proportions of aggregate, mineral filler (minimum and maximum), water (minimum and maximum), additive(s), and polymer-modified asphalt emulsion based on dry weight of aggregate. The mixture design must always be performed using materials representative of those to be used on the project. The Department will then evaluate the mix design provided by the contractor and conduct a limited amount of testing on the materials proposed for use by the contractor to check the mix design results provided.

ISSA MIXTURE DESIGN PROCEDURES

The most widely used mixture design procedures are those recommended by the International Slurry Surfacing Association (ISSA). The International Slurry Surfacing Association design technical bulletin (Jan 1991) (13) contains guidelines for the laboratory evaluation of micro-surfacing mixture designs. The tests examined include:

- ISSA No. 139 : Method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics;
- ISSA No.100 : Method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak;
- ISSA No.109 : Method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion; and

- ISSA No.144 : Method for the classification of aggregate filler-bitumen compatibility by Schulze-Breuer and Ruck procedures.

The wet track abrasion test (WTAT) (ISSA TB 100) is used to determine the minimum asphalt content. This test simulates the wet abrasive conditions of a vehicle cornering and braking. A 1-hour and 6-day soak period are recommended. A maximum value of 807 g/m^2 (75 g/ft^2) abrasion loss is recommended by the ISSA after the six-day soak period. This maximum value is the amount of micro-surfacing material lost per unit area during the test. The value is reported to be correlated to field performance (25). There is only a correlation for 6 mm (1/4 in) thicknesses and 0/#4 gradations, ie., gradations that have no material retained on the 4.75 mm sieve.

The loaded wheel test (LWT) (ISSA TB 109) is currently used to determine the maximum asphalt content. The maximum asphalt content is attained when the sand adhesion value is 538 g/m^2 (50 g/ft^2). The sample is preconditioned with 1000 cycles of the 56.82 kg (125 pound) loaded wheel. A measured quantity of hot sand is placed on the sample and 100 cycles of the wheel are applied. The amount of sand that adheres to the sample is measured. A conversion factor is then applied to the weight increase due to adhered sand. The factor converts, the weight of adhered sand to grams per square meter of the sample. The value obtained is termed the sand adhesion. It is thought that when the sand adhesion is below 538 g/m^2 (50 g/ft^2) flushing should not occur (26).

The optimum emulsion content for the mix is chosen by combining graphs from the wet track abrasion test and the loaded wheel test on one graph. The envelope defined is termed as the allowable range. A three percent tolerance for contractor proficiency is subtracted from the maximum emulsion content range defined by the loaded wheel test. The mid-range emulsion content between the envelope defined by the maximum emulsion content as defined by the loaded wheel test (LWT) and the minimum tolerance is termed the optimum emulsion content $\pm$ 1.5 percent. Figure 16 illustrates determination of the optimum emulsion content.

The wet cohesion test (ISSA TB 139) classifies the system into set times and determines the optimum filler content. Micro-surfacing mixtures are classified as slow setting or quick setting, depending on the cohesion torque after some specified time.

The micro-surfacing material required for rehabilitation in Texas is a quick set, quick traffic system that can be opened to traffic within 1 hour. The quick-set system implies that the mixture is required to achieve a cohesion of 12 kg-cm within 30 minutes and 20 kg-cm within 1 hour. A cohesion value of 12 kg-cm indicates that the mixture has set and is not workable. A cohesion value of 20 kg-cm indicates that the surface has developed sufficient cohesion to carry traffic. The optimum mineral filler content can be determined by plotting cohesion torque versus mineral filler at 30 minutes and 60 minutes. The optimum mineral filler content is the value that gives the highest cohesion value consistently.

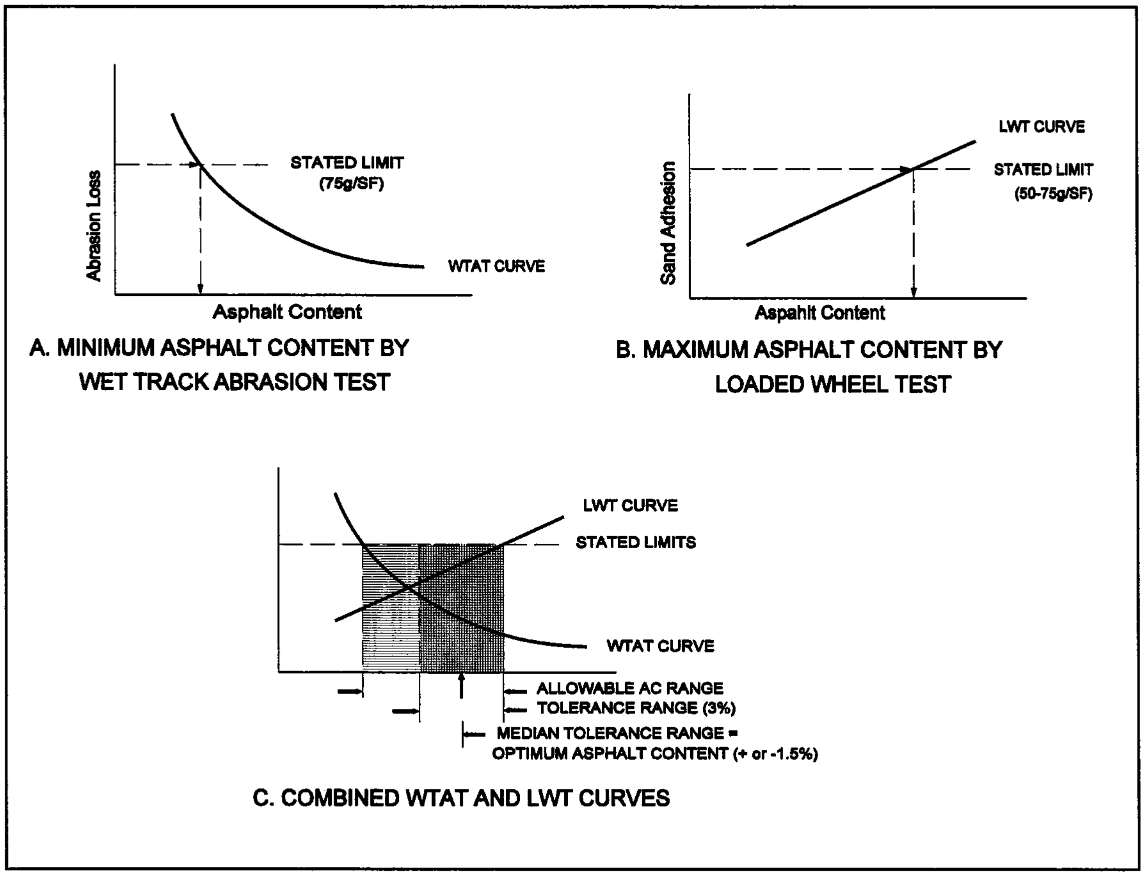

Figure 16. Determination of Optimum Asphalt Content and Allowable Ranges for Micro-Surfacing (13)

An aggregate mineral filler compatibility classification test, the Schulze-Breuer and Ruck procedure, stipulates that a minimum of 11 grade points establishes compatibility. The compatibility is established based on the abrasion, integrity, and adhesion qualities of the sample manifested through weight loss, sample coherence after boiling, and subjective general appearance after drying (13).

EVALUATION OF ISSA MIXTURE DESIGN TESTS

The ISSA micro-surfacing mixture designs tests evaluated include No.s 100, 109, 139, and 144 which were discussed previously. Each of these were evaluated for use in mixture design, quality assurance, and materials acceptance.

Complete descriptions of the test apparatus and procedures used in the Texas Transportation Institute McNew laboratory are given in the Report 1289-1. Generally, apparatus and materials are the same as those described in the ISSA design technical bulletin January 1991 (13), but sample preparation and testing procedures differ slightly.

Evaluation of Repeatability

The ISSA procedures require only a single test for each. Experience with highway materials indicates that tests performed on presumably identical materials under tightly controlled circumstances rarely yield identical results. This can be attributed to unavoidable random errors inherent in every sampling and test procedure (27). Factors that may affect the results of a test cannot be entirely checked. Therefore, in making practical judgements and in interpreting the test data, the inherent variability has to be taken into account. For instance, the difference between a test result and some specified value may be within that which can be expected due to unavoidable random errors, in which case, a real deviation from the specified value has not been demonstrated. Similarly, the difference between two test results from two batches of materials will not indicate a fundamental quality difference if the difference is no more than can be attributed to inherent variability in the test procedure.

There are many contributing factors to the variability observed in the application of a test procedure. These factors may include operator-induced errors, equipment based errors, the method of calibration, and the environment present at the time of testing (27).

Precision when evaluating test methods is expressed in terms of two measurement concepts, repeatability and reproducibility (27). Under repeatability conditions, the factors responsible for variability within test results mentioned hitherto are kept reasonably constant and usually contribute minimally to the variability of test results.

A rigorous statistical analysis was completed to determine if adequately consistent data can be generated from the various ISSA tests. Precision statistics were generated to formulate a precision statement. These are described in Report 1289-1.

Researchers evaluated the following material combinations:

1. Delta aggregate and Koch emulsion

2. Delta aggregate and Ergon emulsion

3. TransPecos aggregate and Koch emulsion

4. TransPecos aggregate and Ergon emulsion

Asphalt emulsion content was the only variable for any specific combination of aggregate and emulsion. Water content and mineral filler amounts were kept constant for all tests. No additives were used.

Observations

The reliability of determining mixture qualities of micro-surfacing through the use of the proposed ISSA mix design tests investigated within the report is questionable. Specific tests such as the modified wet cohesion test, the cured cohesion test, and the 6-day soak wet track abrasion do provide reasonably consistent test results. Consistency in differentiating between the various formulations of all material combinations has been demonstrated for those tests. The loaded wheel test is not a very precise test. It does not distinguish accurately enough between formulations of the same material, nor does it distinguish between mixtures of different materials with the same formulations.

From a graphical display of the consistency statistics for the loaded wheel test, the implication is that the test method is vague and permits a wide range of interpretation (27). The method of shaking loose sand off a compacted sample is very imprecise. While conducting the experiments, it was realized that the amount of water in the mixture had a profound influence on the sand adhered. By changing only the quantity of water in mixtures with the same quantity of emulsion and cement, the sand adhered increased or decreased. It appears that the amount of sand adhered to the sample is not really indicative of the amount of asphalt emulsion or asphalt cement present in the mix. The statistical analysis indicated within material imprecision and lends credence to that fact.

The 1-hour soak wet track abrasion test exhibits substantial within material imprecision for all formulations for two material combinations. This indicates that with certain material combinations, the 1-hour soak test may yield consistently imprecise results.

Statistical analysis of the abrasion part of the Schulze-Breuer and Ruck procedures indicates a precise test response. However, the extremely high and small values of the consistency statistic obtained for the integrity part of the test indicate that there is an insensitive measurement scale. Normally after boiling, the samples disintegrate very badly. Because the sample is not small, the percent of the remaining coherent mass is usually insignificant after 30 minutes of rigorous boiling.

Effects of Water, Additive, and Mineral Filler on Test Responses

The objective of the evaluation was to examine the effects of variations in quantity of portland cement as mineral filler, liquid additive and water on the test results of specific micro-surfacing formulations using four ISSA mixture design test procedures. Additives are usually supplied by the emulsion manufacturer and are normally added to the mixture in the water to control the set time of the mixture in the field. Type I portland cement is normally used as the mineral filler in micro-surfacing; although, hydrated lime has been used in some locations. Portland cement accelerates the break time of the emulsion in micro-surfacing mixtures, and it may also act as a thixotropic and an anti-strip agent in the mixture. The procedures and full evaluation are described in Report 1289-1 (27).

After investigating the trends exhibited by varying the material constituents of micro-surfacing, two major issues are apparent.

1. The amount of mineral filler in the mixture greatly influences the magnitude of the test response for all the tests investigated. However, each mixture formulation behaves in a unique manner. The response of a particular mixture also depends to a large extent on the amount of water used in formulating the mixture. This is particularly evident when the 6-day soak wet track abrasion test is used. Samples which are formulated with high water contents produce a flushed surface and uniform results. It appears that the total liquid content of a sample exerts significant influence on the variability of the test responses obtained with each test. The tests will be more useful if the variability in the tests responses can be limited to an acceptable range. To achieve that, there must be a consistent method to define and correlate with the test responses the liquid contents with which mixtures exhibit uniform characteristics. At that liquid content, the consistency of the mixture can be said to have been defined.

2. Provided adequate curing time is allowed for a sample before testing, the amount of additive used in formulating a sample mixture does not greatly influence the test response. However, it is advisable to use higher quantities of mineral filler (1.5 percent or greater) whenever a high amount of additive is used in formulating the mixture.

An assessment of variability and effects of components indicates that the wet track abrasion test has greater variability when the total fluid content is low, while the loaded wheel test has greater variability when the total fluid content is high. The variability is affected by water content as well as asphalt content. The current ISSA procedures do not define what optimum water content should be. The operator selects the water content to provide the desired consistency of the total mixture based on experience, and even within the project staff there was disagreement concerning the consistency at which samples should be prepared. The mixture designs provided by some contractors used different water contents for the wet track abrasion test and the loaded wheel test.

CHAPTER 4
FIELD AND LABORATORY EVALUATION OF ISSA MIXTURE DESIGN

FIELD PROJECTS DURING 1992

Projects under construction near Hearne, Rockwall, Waco, Brownwood and Brownfield were selected for evaluation and verification of the mixture designs. Samples of paving materials were obtained at the construction sites and conveyed to the TTI laboratory. This goal was to determine how well the mixtures applied in the field matched the mixture design requirements established by the Department in the draft specifications and the ISSA mixture design procedures.

The contractors provided their mixture design for all of the projects. During this evaluation, it was determined that the mixture designs were actually completed by the emulsion suppliers. The mixture designs are generally completed once each season for a selected aggregate and used for all projects that use the same aggregate and emulsion. The emulsion suppliers generally update the mixture design only when a problem occurs or changes in the aggregate are reported. The Ergon mixture designs were submitted with a full set of ISSA mixture design test results. The Koch mixture designs were submitted with a partial set of ISSA mixture design tests accompanied by Marshall-based mixture design tests.

Staff member received training on how to conduct the tests from Mr. C. Robert "Ben" Benedict of Alpha Labs, who developed or modified most of test procedures. The test procedures used in this phase are described in Report 1289-1 (27). TTI did not receive all of the required test equipment until after some of the construction was completed. Therefore, most of the mixture design testing was completed after the projects were completed.

To verify that the mixture designs provided by the contractors could be replicated using the ISSA mixture design procedures, trial mix combinations were made using varying percentages of emulsion, water, and mineral filler with fixed quantities and gradations of aggregate to determine the combination that would satisfy ISSA recommended requirements. Materials used for the tests were collected by the project staff at the construction sites. Sampling of these materials was performed according to ASTM D 140-88. Extensive pretesting to determine which combinations of water, mineral filler, emulsified polymer-modified asphalt cement, and aggregate would yield reasonable values was eliminated by following the material combinations used in the mixture design reports submitted by the contractors. Table 3 identifies the material suppliers and the materials from each test site investigated during the 1992 construction season.

Table 3. Description of Materials from Selected Sites for the 1992 Season

Site	Aggregate	Asphalt Emulsion	Mineral Filler
Hearne and Waco	Capital Aggregates (Delta Materials) Marble Falls, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion, East Waco, TX CSS-1HP	Portland Cement No. 90087-01
Rockwall	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion, East Waco, TX CSS-1HP	Portland Cement No. MF 90081-01
Brownwood	Capitol Aggregates (Delta Materials) Marble Falls, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion, East Waco, TX CSS-1HP	Portland Cement No. MF 90087-07
Brownfield	TransPecos Materials Vehalen, Texas Texas Grade II coarse graded surface aggregate	Koch Material Company Salina, KS CSS-1HP	

In the laboratory, two types of mineral filler were generally investigated: lump free hydrated lime and portland cement. All water used in the study was clean tap water. The effect of set-retarding chemical additives was not investigated in this series of tests.

Materials Tests

The aggregate samples were expected to meet the requirements for TxDOT Grade II aggregate for micro-surfacing specifications. The gradation used in the mixture affects the thickness of the micro-surfacing layer. It is also important in determining the theoretical asphalt content. Aggregate gradation was checked using TxDOT standard test Tex-200-F, sieve analysis of fine and coarse aggregate as presented in the TxDOT Manual of Testing procedures (28). Table 4, shows the grading specifications and the results obtained for all five sites. Figures 17 through 21 depict the actual gradations graphically compared to the specified gradation limits. The tests show that aggregates from Hearne, Waco, and Rockwall, shown in Figures 17 through 19, lie within the specified gradation envelope. The aggregate used in Brownwood had more passing the 4.75 and 2.36 mm (#4 and #8) sieves than that allowed by specifications. The aggregate used in Brownfield had more passing the 0.32, 0.15, and 0.075 mm (#50, #100 and #200) sieves than allowed by specifications. All gradations, however, lie within the stockpile tolerance limit set by the ISSA in the recommended performance guidelines for micro-surfacing revised in January 1990 (13).

Table 4. Gradation of Aggregates Used at Various Test Sites

Sieve Size		TX Grade II Specification, % Retained + Stockpile tolerance limits	Percent Retained				
mm	(in.)		Hearne	Waco	Rockwall	Brownwood	Brownfield
9.50	3/8"	0-1 ± 5%	-	-	-	-	-
8.00	5/16"	- ± 5%	-	-	-	-	-
6.25	1/4"	- ± 5%	-	-	-	-	-
4.75	#4	6-14 ± 5%	9.7	10.2	12.1	16.22	8.13
2.36	#8	35-55 ± 5%	41.12	43.15	43.9	56.14	45.71
1.18	#16	54-75 ± 5%	63.94	65.23	68.32	73.31	73
0.60	#30	65-85 ± 5%	75.51	76.17	80.7	80.64	84.65
0.30	#50	75-90 ± 4%	82.87	83.48	87.12	85.07	91.16
0.15	#100	82-93 ± 3%	87.22	86.24	89.44	88.20	94.31
0.075	#200	85-95 ± 2%	92.32	92.78	94.04	95.18	96.45
Pan	Pan		99.37	99.45	99.5	99.23	99.89

All aggregates were air dried to less than 1 percent moisture content in environmental rooms heated to 40°C (104°F) before being used in sample preparation. This was done to preclude the effect of any moisture apart from that specifically introduced in the sample. As suggested in the relevant procedures for individual tests in the ISSA design technical bulletin 1990 (13), only aggregate passing the 4.75 mm (#4) sieve was used for all tests except the Schulze-Breuer test, for which, only aggregate passing the #10 sieve was used. This was done because larger aggregate particles protrude significantly and are normally the cause of failure of samples during testing.

The sand equivalency test is used to determine the approximate clay content of the aggregates. Aggregates with low sand equivalency values (high clay content) may exhibit mixing and setting difficulties during normal testing. Clayey material in an aggregate will also increase the asphalt emulsion requirement. The tests were conducted in accordance with test procedure Tex 203-F, Sand Equivalent Test (28).

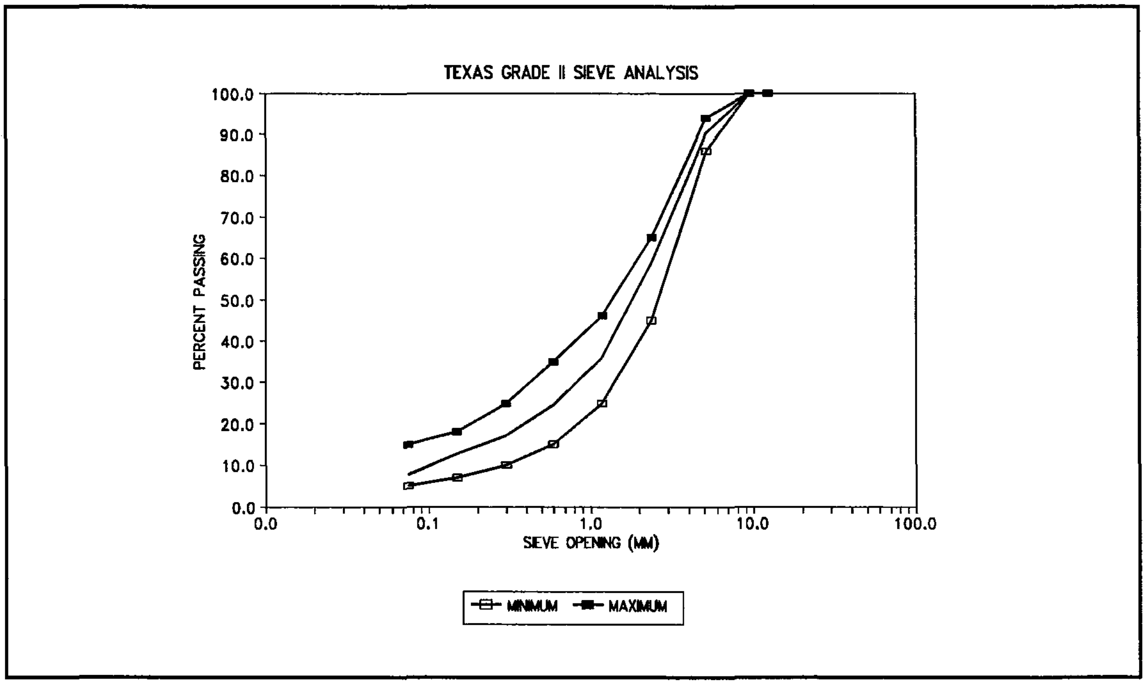

Figure 17. Sieve Analysis for Aggregate from Hearne Project

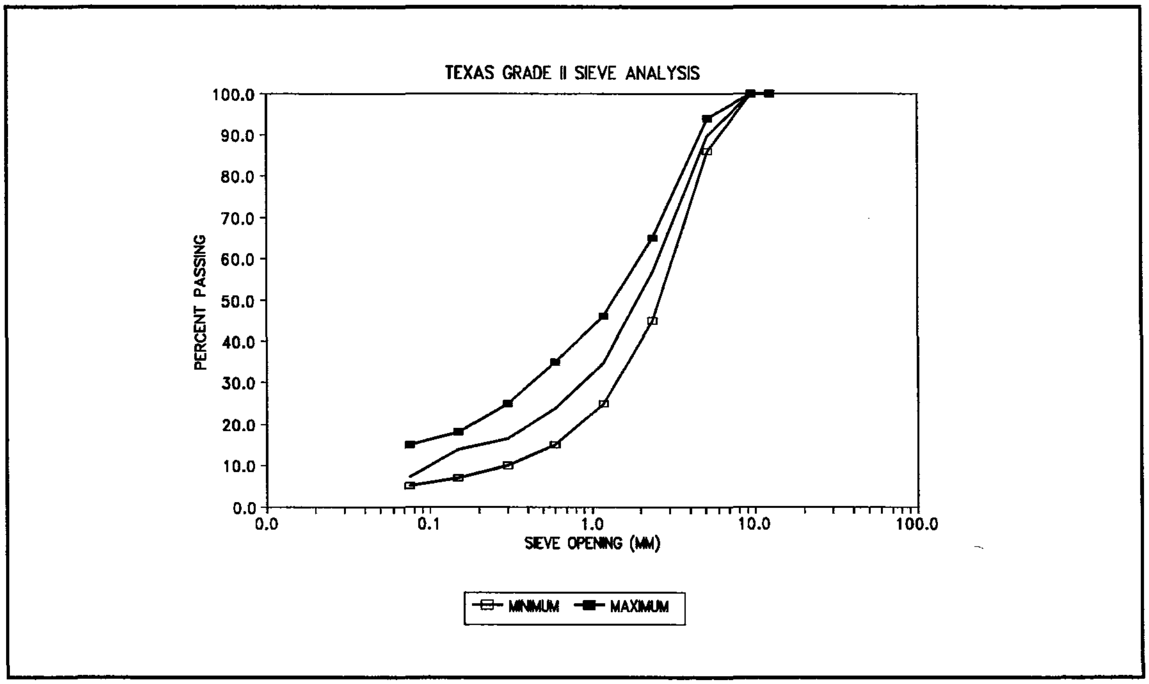

Figure 18. Sieve Aanalysis for Aggregate from Waco Project

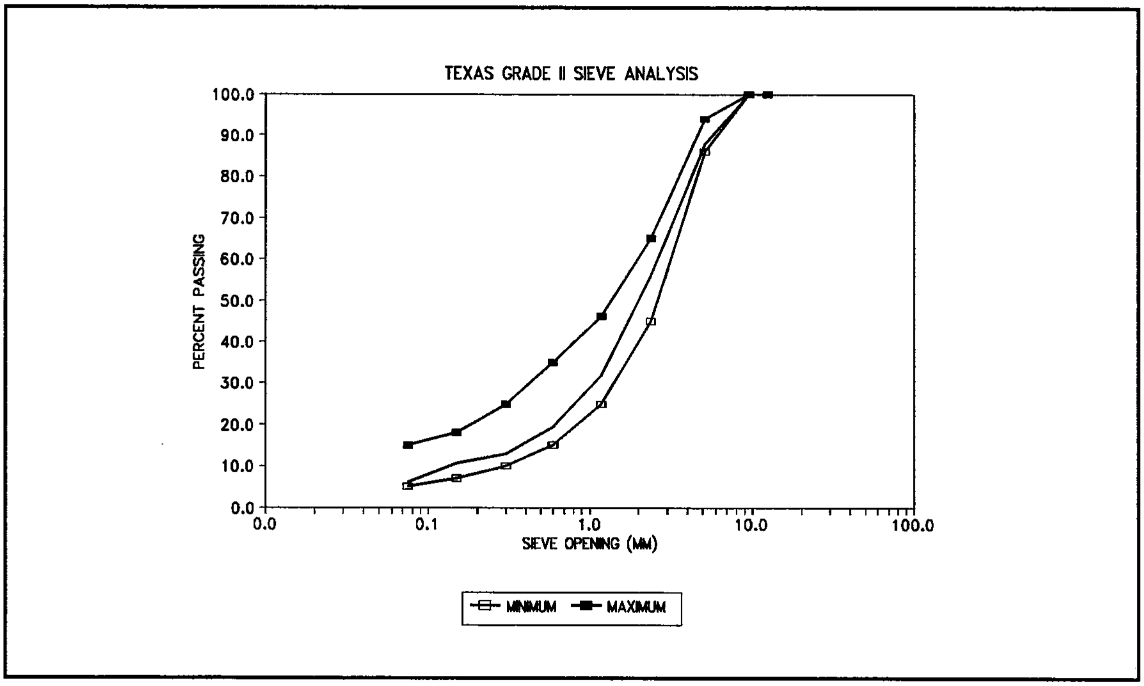

Figure 19. Sieve Analysis for Aggregate from Rockwall Project

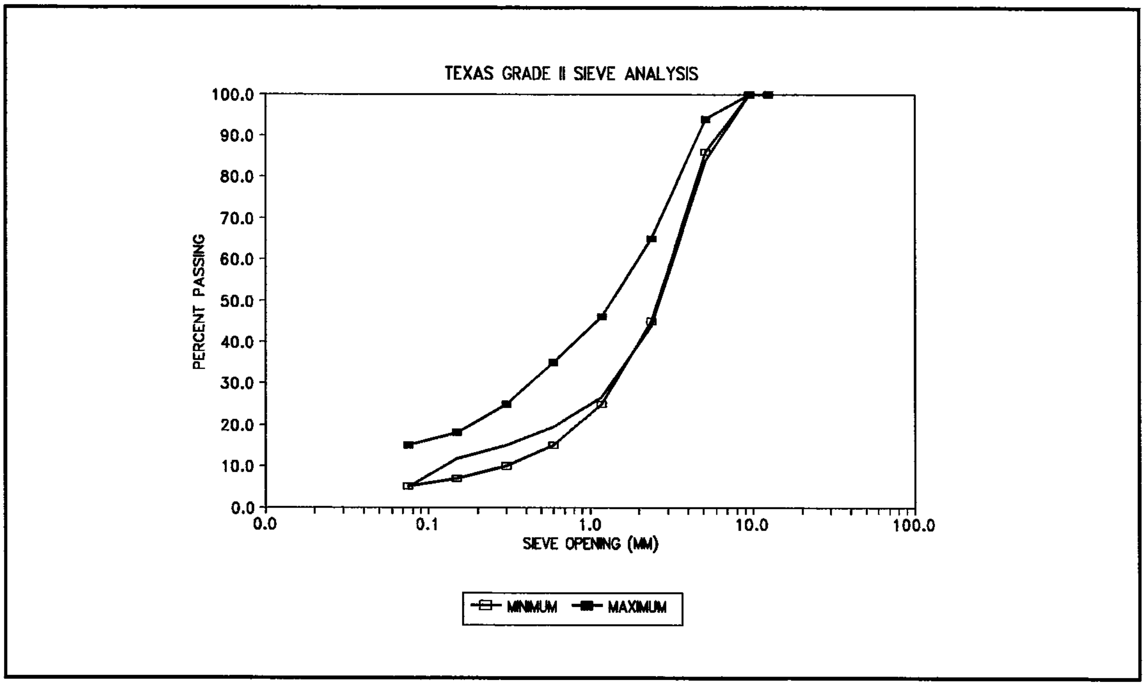

Figure 20. Sieve Analysis of Aggregate from Brownwood Project

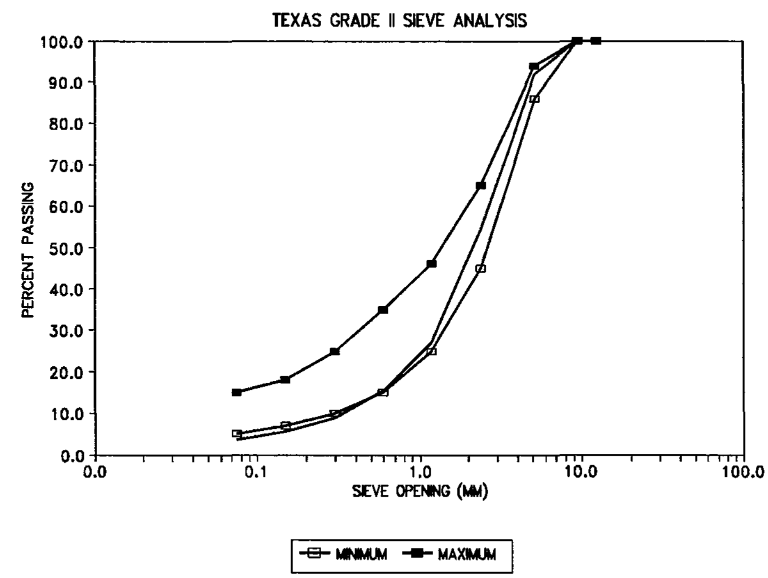

Figure 21. Sieve Analysis of Aggregate from Brownfield Project

Results of the sand equivalency tests are presented in Table 5. The minimum value specified by TxDOT is 60, and all aggregates had values greater than that value.

Table 5. Sand Equivalency Test Results

Hearne	Waco	Rockwall	Brownwood	Brownfield
72	74	75	68	69

ISSA Mixture Design Tests

Each test has a specific set of objectives in the mixture design process. The tests are designed to determine the best combination of aggregate, emulsified polymer- modified asphalt cement and the mineral filler as described in Chapter 3 and Report 1289-1 (27).

The optimum emulsified asphalt cement content is determined by plotting curves of the abrasion loss from the wet track abrasion test and the sand adhesion from the loaded wheel test against the emulsified polymer modified asphalt cement content as shown in Figure 16. A maximum and minimum envelope is thus defined by the specified maximum values set for the two tests. This range is termed the allowable range. Sand adhesion from the loaded wheel test (LWT) is limited to 538 g/m^2 (50 g/ft^2). This defines the maximum asphalt cement content for the mixture. Mixtures with asphalt cement contents greater than this would be expected to flush. An abrasion loss of 807 g/m^2 (75 g/ft^2) by the wet track abrasion test (WTAT) defines the minimum emulsified asphalt cement content of the mixture. Mixtures with emulsified asphalt cement contents less than this would be expected to ravel excessively. Having found this envelope, a 3 percent tolerance range for contractor proficiency is established from the maximum emulsified asphalt cement content. The median between the tolerance range and the maximum emulsified asphalt cement content is defined as the optimum emulsified asphalt cement content of the mixture, with an allowable variation of $\pm$ 1.5 percent. When the allowable range between that found from the LWT and the WTAT is less than 3 percent, the optimum emulsified asphalt cement emulsion is taken as the median of this range.

Table 6 shows basic information on each test. Each test is discussed more thoroughly in the following paragraphs.

The Cohesion Test (ISSA TB 139) determines the quantity of mineral filler needed in the mixture to produce acceptable cohesion torque values at 30 minutes, 60 minutes and after twenty-four hours curing. The results of this test indicate the time required before the mixture can be opened to traffic.

Trial mixes are made using portland cement as mineral filler in varying amounts ranging from 0 percent to 2 percent of dry weight of aggregate and hydrated lime ranging from 0 percent to 0.75 percent. Various water contents were investigated for initial trial mixtures that yielded encouraging values. Initial trial mixes were made with 100 gram aggregate samples and polymer-modified asphalt emulsion contents ranging from 9 percent to 15 percent.

The sample cohesion values at set times were measured with a modified cohesion tester similar to an ASTM D 3910 machine. The pressure indicated by the tester was checked using a load cell before testing began to ensure that the samples were tested at 200 kPa (30 psi). A simple, hand-held torque wrench was used for torque measurements in kg-cm.

The Loaded Wheel Test (ISSA TB-109) establishes the maximum asphalt emulsion content of the mixture. It is used to determine if excess asphalt will be exuded under load. Three hundred grams of aggregate are used in preparing samples with fixed quantities of water and mineral filler. Emulsified polymer-modified asphalt cement contents are varied for each sample. A range of 9 percent through 14 percent was used.

The samples were dried to a constant weight over 12 hours or more. Molds 6.35 mm (1/4 in) in thickness are used. The sample is preconditioned with a 1000 passages of a wheel weighing 56.8 kg (125 pounds) before spreading 200 grams of fine hot sand over the sample. Quantification of the effects of the excess asphalt cement emulsion under wheel loads is made by recording the grams of fine hot sand that adheres to the weighed sample after being subjected to 100 loaded wheel passages.

Table 6. Mixture Design Tests and Specification Values

TEST	DESCRIPTION	SPECIFICATION
ISSA-TB-139	WET COHESION: Defines the set time and early rolling traffic as a function of developed torque and helps establish filler content requirements and water. @ 30 minutes minimum (set) @ 60 minutes minimum (traffic)	12 kg-cm min. 20 kg-cm min.
ISSA-TB-109	LOADED WHEEL TEST (LWT): Traffic simulation of resistance to flushing under heavy loads; determines the maximum amount of binder the mix can withstand. Excess Asphalt by LWT Sand Adhesion	538 g/m^2 (50 g/ft^2) max
ISSA-TB-100	WET TRACK ABRASION: Measurement of resistance to mechanical abrasion kick out, and internal mat adhesion. Fixes the minimum binder content of the mixture, under wet abrasion conditions.	807 g/m^2 (75 g/ft^2) max
ISSA-TB-144	SCHULZE-BREUER AND RUCK PROCEDURES: Determines aggregate filler and bitumen compatibility.Tests were conducted on aggregates which were not regraded and passing the 2.00 mm (#10) sieve.	11 grade points min.

The Wet Track Abrasion Test (ISSA TB-100) determines the minimum emulsified asphalt cement content based on abrasion resistance of the mixture which has been soaked in water for 1 hour or for 6 days. Seven hundred grams of the aggregate are used in making samples, each with a different, emulsified polymer-modified asphalt content. The abrasion loss in grams per square meter for the six-day test is defined as the critical value for complete system classification. Two tests for each test point were run for five minutes and fifteen seconds using a modified Hobart N-50 mixer with a designated rubber hose attached at the mixing end to abrade the sample. It is used to determine if the asphalt content is adequate to prevent excessive ravelling.

The Schulze-Breuer and Ruck Procedures (ISSA TB-144) is used to determine the affinity of the emulsified asphalt cement for the aggregate filler. Only aggregate passing the 2.00 mm (No. 10) sieve is used in the test. The aggregate and the mineral filler are mixed, and the emulsified polymer modified asphalt cement is added. The system is thoroughly mixed until it breaks. The broken mixture is then crumbled and air dried for an hour after which it is then dried for about 20 hours in a 60° C (140°F) forced air oven. The sample is molded after drying by pressing it in a special mold under a load of a 1000 Kg for one minute. The molded samples (pills) are weighed and then soaked in water for 6 days. On the seventh day, they are tested by tumbling at room temperature for 3600 cycles in the Schulze-Breuer abrasion test apparatus. Water absorbed during soaking, abrasion loss, and weight retained after boiling for thirty minutes are determined. A subjective estimate is also made about adhesion of emulsion to the aggregate after the boiling. The abrasion test basically checks for the acceptable adhesion of the emulsified asphalt cement to the finer aggregate particles. The boiling test is a type of stripping test. A four point grading system is used to determine if the results are acceptable. Four points are allotted to the most acceptable values and one point to the least acceptable values.

Results of Tests

The mixture design information provided by the contractors was used to determine limits of water content, emulsified asphalt cement content and mineral filler content. All tests were conducted in accordance with the descriptions presented earlier. A summary of the test results is presented in Table 7. The following paragraphs describe the findings for each test site.

Hearne - The construction site is located in the Bryan District on State Highway 6 just south of Hearne. Work was completed in October 1992. Figures 22 and 23 show the results of the cohesion testing for different percentages of portland cement as a mineral filler. Individual test points have specific water contents that vary from 7 percent through 15 percent. The greatest cohesion values were found at a portland cement filler content of 0.25 percent.

Figure 24 show the impact of hydrated lime as the mineral filler. Figure 25 shows that for samples cured at 60°C (140°F) for 24 hours tested for cohesion, samples with 12 percent and 15 percent emulsified asphalt cement content have values around the specified values of 24 kg-cm when the filler content is 0.25 percent portland cement. Figure 26 shows the results of the loaded wheel test and the wet track abrasion test. The results show that the optimum emulsion content was 11 percent as defined by the minimum emulsion content of 10 percent and a maximum emulsion content of 12 percent. At 64 percent asphalt residue, the optimum asphalt cement residual content is 7.04 percent. A water content of 11 percent was recommended for the mixture based on the results of the cohesion test that yielded the best results. The Schulze-Breuer and Ruck procedure yielded an 11 point average, which meets the specified value of 11 points.

Waco - A section of Interstate 35, south of Waco was treated with micro-surfacing. The contract concluded in August 1992. Cohesion test results for different percentages of portland cement as a mineral filler are shown in Figure 27. A mineral filler content of 0.5 percent portland cement has cohesion values that exceed the minimum specification values

Table 7. Tabulated Results from Mix Designs

Test Name	Test No.	Requirements	Hearne	Waco	Rockwall	Brownwood	Brownfield
Wet Cohesion @ 30 minutes minimum	ISSA TB-139	12 Kg-cm	0.25% @12% AE	0.5% @12% AE	0.5% @ 12% AE	0.75% @ 12% AE	Inconsistent Results
Wet Cohesion @ 60 minutes minimum	ISSA TB-139	20 Kg-cm	0.25% @12% AE	0.5% @12% AE	0.5% @12% AE	0.75% @ 12% AE	Inconsistent Results
Cured cohesion after 24 hours drying		24 Kg-cm	0.25% @12% AE				
Excess Asphalt by LWT Sand Cohesion	ISSA TB-109	< 538 g/m^2 (50 g/ft^2)	12% AE	11% AE	12% AE	Inconsistent results	Inconsistent results
Wet Track Abrasion loss 1 Hour	ISSA TB-100	< 538 g/m^2 (50 g/ft^2)	Okay	Okay	Okay	Okay	Okay
Wet Track Abrasion loss 6 days	ISSA TB-100	< 807 g/m^2 (75 g/ft^2)	10% AE	8.5% AE	9.0% AE	Inconsistent results	Inconsistent results
Compatibility Classification	ISSA TB-140	minimum of 11 grade points	11 points	11 points	11 points		
Optimum Emulsified Asphalt Cement Content	ISSA TB-111		11%	9.75%	10.5%	Inconsistent Results	Inconsistent Results

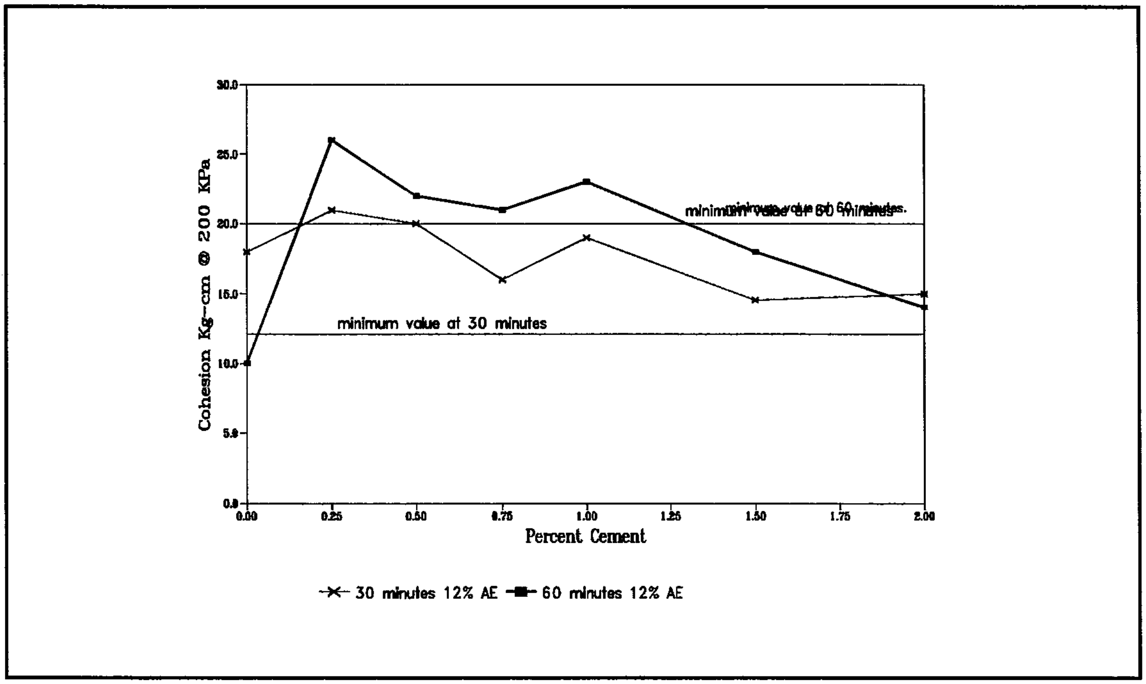

Figure 22. Cohesion Values versus Portland Cement Content for Hearne Project at Water Contents of 7 to 15 %

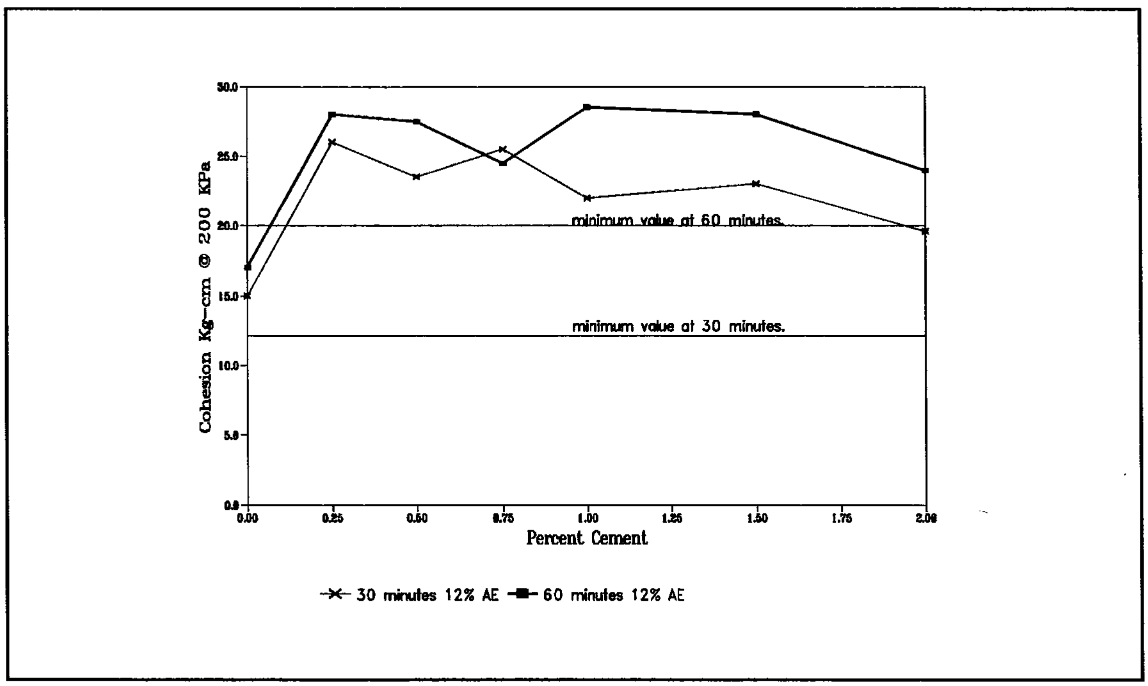

Figure 23. Cohesion Values versus Portland Cement Content for Hearne Project at Water Contents of 7 to 9.5%

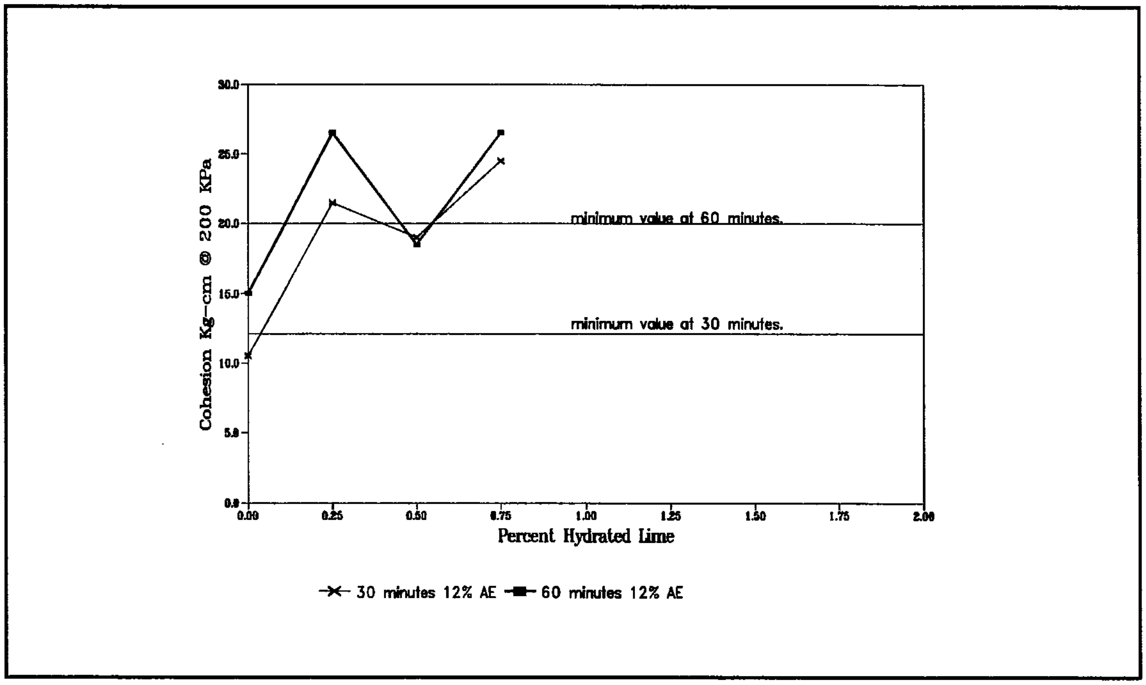

Figure 24. Cohesion Values versus Hydrated Lime Contents for Hearne Project at Water Contents of 8 to 12 %

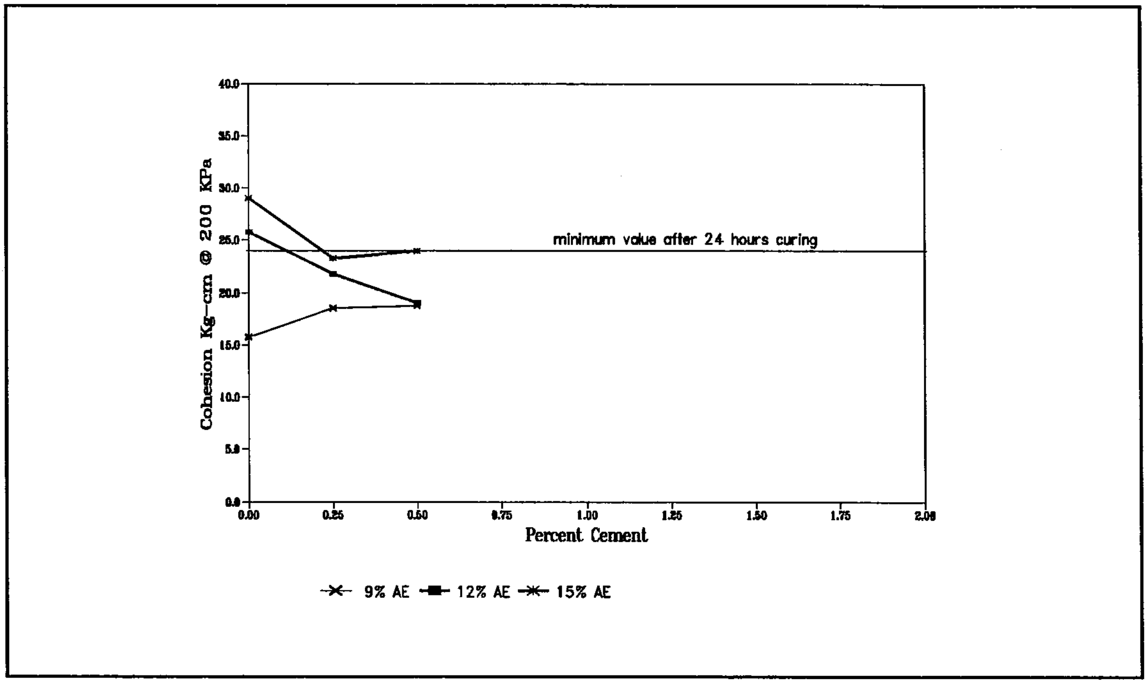

Figure 25. Cured Cohesion Values versus Portland Cement Content for Hearne Project

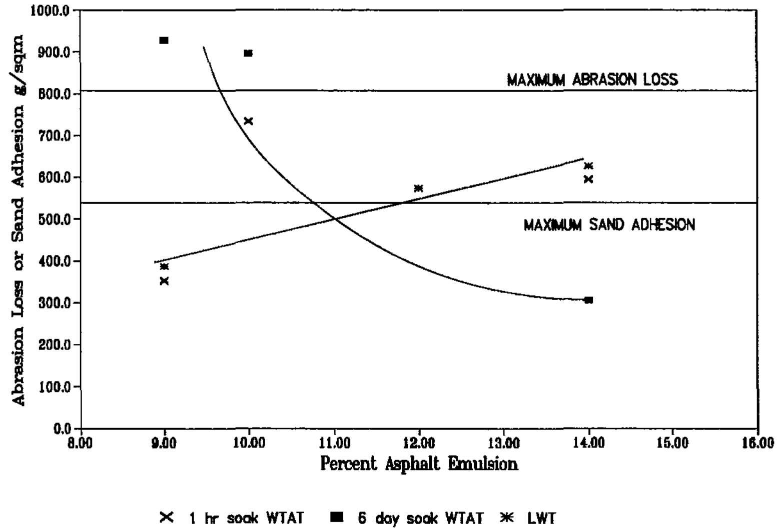

Figure 26. Finding Asphalt Content based on Abrasion Loss from WTAT Sand Adhesion from LWT for Hearne Project

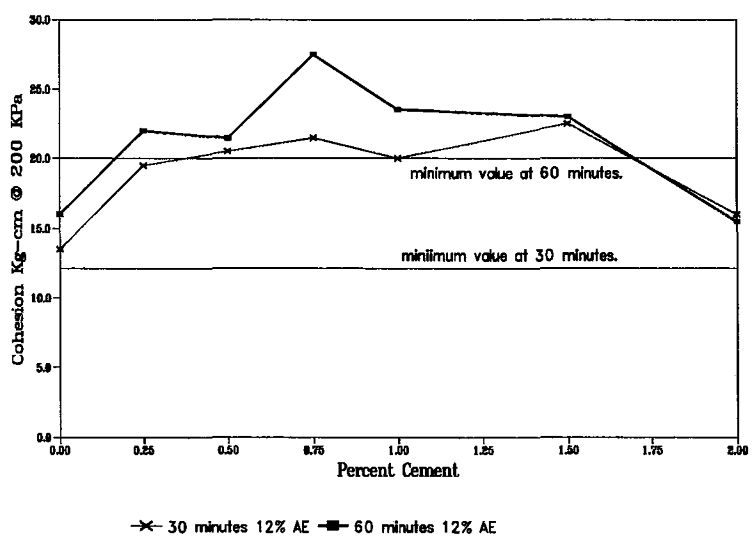

Figure 27. Cohesion Values versus Portland Cement Content at Water Contents of 6 to 15 percent for Waco Project

for both 30 and 60 minute tests. Figure 28 shows that the minimum emulsion content, as defined by the wet track abrasion test was 8.5 percent and the maximum allowable asphalt emulsion content is 11 percent as defined by the loaded wheel test. This gives a 2.5 percent allowable range. The optimum asphalt emulsion content was selected as 9.75 percent. The asphalt cement content was 6.2 percent at 64 percent asphalt residue. From the wet cohesion test data, the water content at which the mixture meets all the specifications is 8 percent. The eleven point average values from the Schulze-Breuer and Ruck was considered acceptable.

Rockwall - The construction site was on State highway 66 in the Dallas district near Rockwall. Figure 29 shows that the mixture at mineral filler contents of 0.25 percent through 1.5 percent has cohesion values at 30 minutes and 60 minutes both exceeding the minimum specified values.

Figure 30 shows that the minimum asphalt cement emulsion content, as defined by the wet track abrasion test, is 9 percent and the maximum allowable asphalt emulsion content is 12 percent as defined by the loaded wheel test. This gives an allowable range of 9 percent to 12 percent. The optimum asphalt emulsion content is selected as 10.5 percent $\pm$ 1.5. At 64 percent asphalt emulsion residue, the asphalt cement content is 6.7 percent. Schulze-Breuer results were acceptable with 11 grade points achieved.

Brownwood - The micro-surfacing work was performed on FM 2126 and US 377 near Brownwood. Results of the wet cohesions in Figure 31 show acceptable cohesion values are obtained for portland cement mineral filler contents of 0.75 percent to 1.5 percent.

Figure 32 shows that the sand adhesion values obtained for the range of asphalt contents tested are rather high. Extrapolating back the maximum asphalt emulsion content would be 5 percent and the minimum asphalt emulsion content is 8.5 percent by definition. Schulze-Breuer and Ruck abrasion loss obtained on this aggregate is unacceptable.

Brownfield - The construction site was located in the Lubbock district on US highway 180. Figures 33 shows that the mixtures for this aggregate did not meet most of the specifications for wet cohesion testing, except for one 30 minute reading at 0.25 percent portland cement. Figure 34 shows that the system classification values are inverted. By definition, the wet track abrasion test yields the minimum asphalt content; however, the asphalt emulsion content where the specified allowable abrasion occurs is larger than the asphalt emulsion content obtained at the specified limit for sand adhesion by the loaded wheel test. One-hour soak results for wet track abrasions is reasonable. The sand adhesion values are high. The Schulze-Breuer and Ruck results were acceptable.

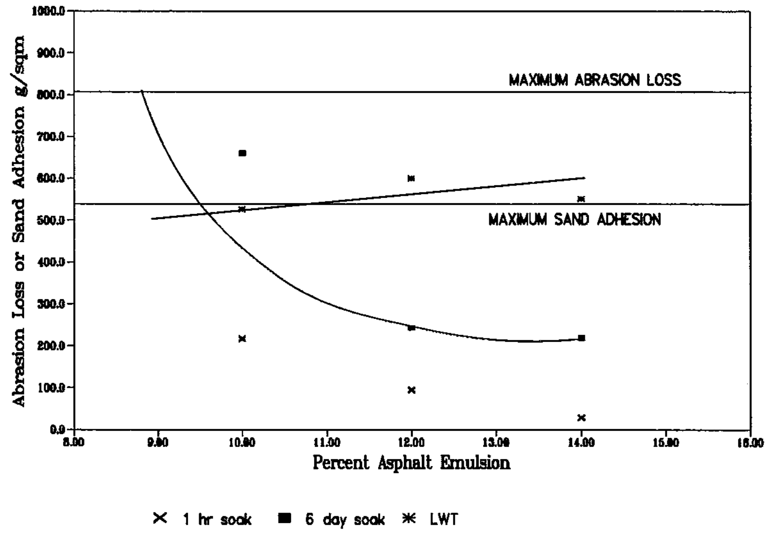

Figure 28. Determining Asphalt Content based on Abrasion Loss from WTAT and Sand Adhesion from LWT for Waco Project

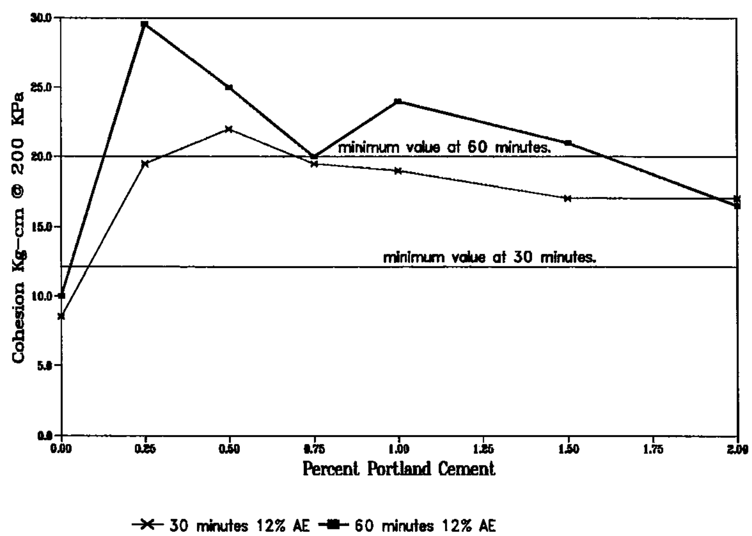

Figure 29. Cohesion Values versus Portland Cement Content for Rockwall Project

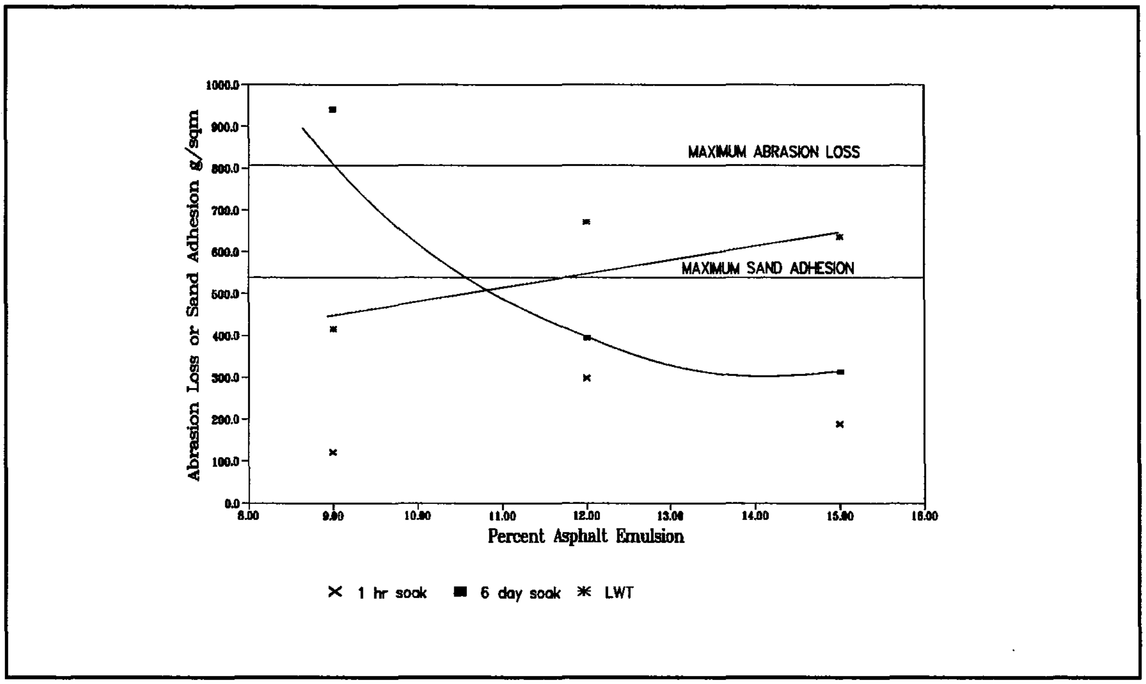

Figure 30. Determining Asphalt Content based on Abrasion Loss from WTAT and Sand Adhesion from LWT for Rockwall Project

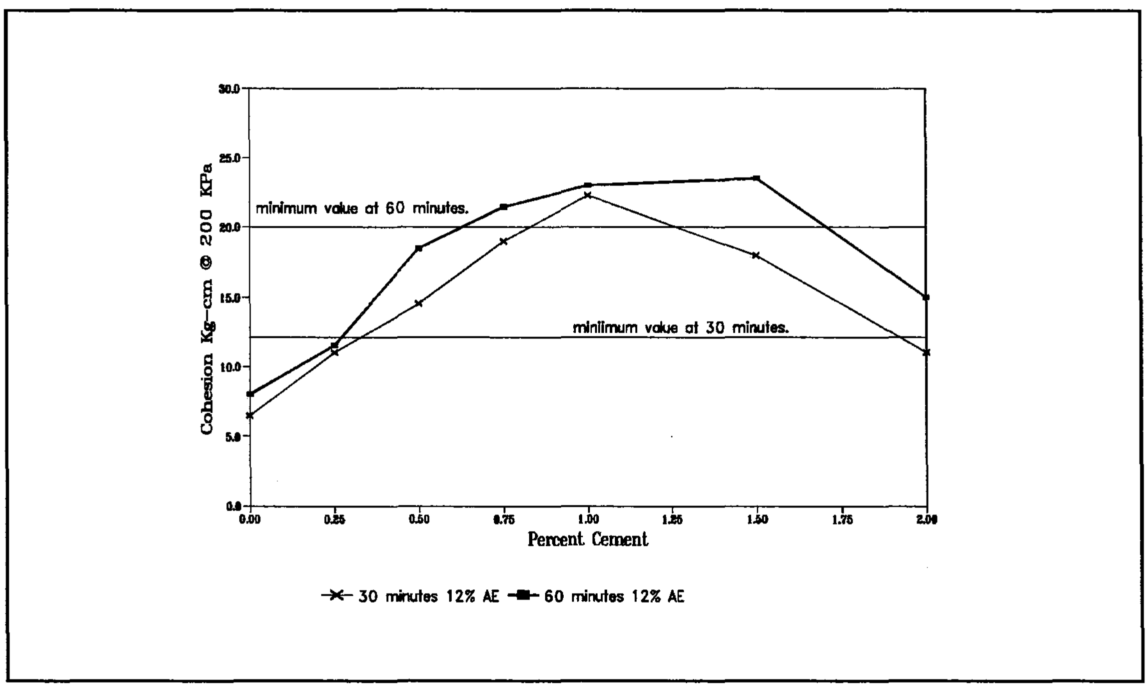

Figure 31. Cohesion Values versus Portland Cement Content at Water Contents at 6 to 15 % for Brownwood Project

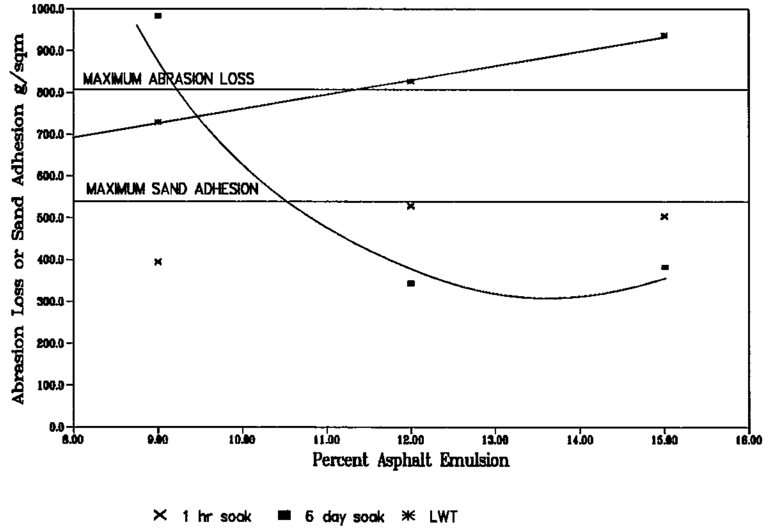

Figure 32. Determining Asphalt Content from Abrasion Loss from WTAT and Sand Adhesion from LWT for Brownwood Project

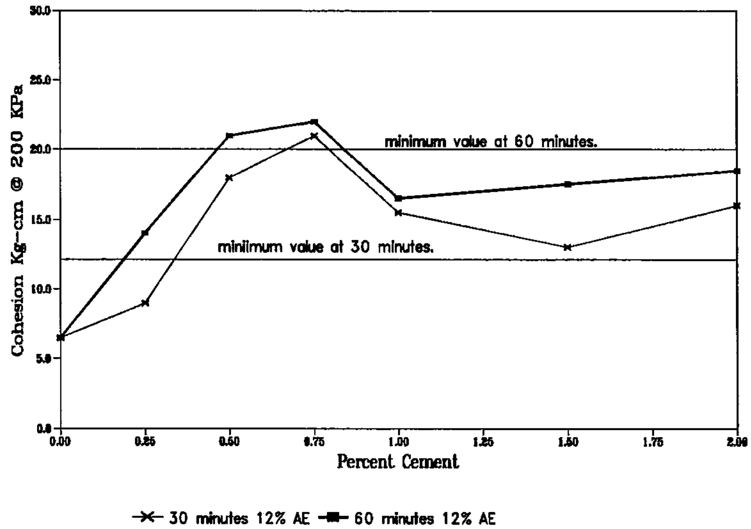

Figure 33. Cohesion Values versus Portland Cement Content at Water Contents of 5 to 9 % for Brownwood Project

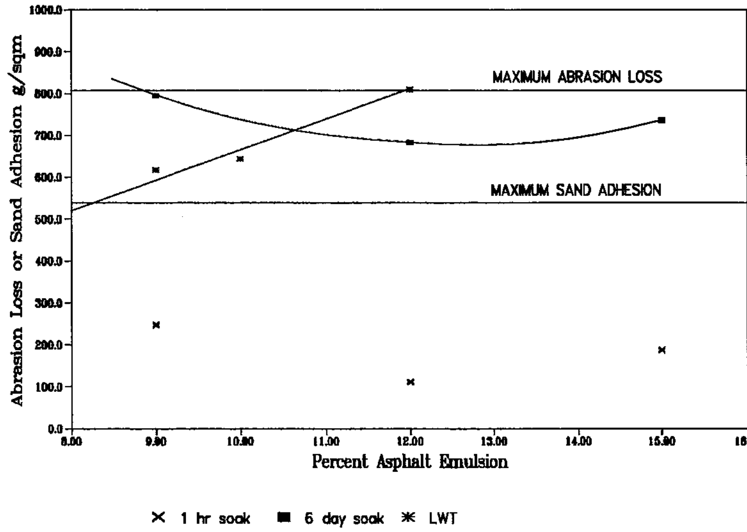

Figure 34. Determining Asphalt Content based on Abrasion Loss from WTAT and Sand Adhesion from LWT for Brownfield Project

Evaluation of Results

A comparison of the results obtained from the TTI mixture design evaluation to the contractor mixture as given in table 8 shows that portland cement content lies within a band of 0.25 to 0.75 percent of aggregate. Tests revealed that modified cohesion meter testing of mixture samples gives the most repeatable results. It appears that, with mineral filler contents of 1 percent or higher, the higher cohesion values are obtained at water contents of 10 percent or more; however, whenever this occurs there is a mineral filler content within the 0.25 to 0.75 percent band, that also yields acceptable values. With a slight reduction in water content, higher mineral filler contents outside the band break down and set rapidly and normally have unacceptable cohesion values.

Lower asphalt emulsion contents were obtained in the TTI laboratory for all the projects. Apart from Waco, the asphalt contents obtained for Rockwall and Hearne are within the contractor's given tolerance of $\pm$ 1.5 percent asphalt emulsion. Generally, a mixture seems to work pretty well with asphalt emulsion contents of 9.75 to 12 percent.

Water contents range from 8 to 11 percent. Water contents greater that 12 percent for mineral filler contents of 0 to 2 percent rarely yield cohesion torque values that are acceptable. At such water contents, it was observed that there was partial settlement of fines in loaded wheel test and wet track abrasion samples, which left the larger particles jutting out at the top of the sample; this leads to rapid abrasion and high sand adhesion.

Table 8. Comparison of TTI and Contractor Mixture Design Constituents by Percent Weight of 100 grams of Aggregate

Location	Tester	Mineral Filler	Asphalt Emulsion	Water
Hearne	Contractor	0.75	12	11
	TTI	0.25	11	11
Waco	Contractor	0.75	12	11
	TTI	0.5	9.75	8
Rockwall	Contractor	0.25	12	10
	TTI	0.5	10.5	9

Results of the tests completed indicate that there are problems with repeatability of the tests. Another set of tests was conducted to define the amount of variability in the test results which was discussed in Chapter 3 and is reported in Report 1289-1. Table 8 shows a comparison of the mixture designs obtained in the TTI laboratory with the mixture designs supplied by the contractors. The ISSA test procedures use multiplying factors without defining their basis nor when to use different factors. For example, depending on whether the mixer used is a Hobart N-50 or modified N-50 with the wet track abrasion tests, different multiplying factors are used. Procedure No. 100 suggests in caption 6.6, note 2 that the multiplying factor (3.06 x 1) for N-50 modified is valid for losses of less than 24.5g. No suggestions are made as to what factor one can use when losses are greater than 24.5g. ISSA technical guideline 1990, procedure No. 109 specifies the dimensions of the mount for the loaded wheel tester. The tester shown in the procedure has a 50.8 mm by 381 mm (2 in by 15) inch mold; therefore, a factor to achieve an adhesion in g/ft^2 should be 144/(2 X 15) = 4.8. Ergon uses 7.049, and no suggestion is given in the guideline.

In determining the optimum emulsified asphalt cement content, the guideline does not explain exactly what is meant by the system classification value. Either the one-hour abrasion soak test or the six-day abrasion soak could be selected. Neither does the procedure explain the 3 percent tolerance range. It is apparently due to equipment constraints during construction.

There may be a large variation due to sample preparation. The possibility of introducing standard sample makers to increase uniformity should be examined. A source of error in the wet track abrasion test is the clamp used to hold the sample down. It often breaks or chips a portion of the sample, creating a weight loss which is not due to abrasion. A rubber pad fitted at the bottom of the clamp might eliminate such cracks. A different style of torque wrench used with the cohesion tester produces more consistent results. A more consistent turning rate and applied pressure could further improve results.

The Schulze-Breuer test does not provide any critical information when used on aggregates that meet existing specification values. It is expected to be helpful in differentiating among good and poor performing aggregates.

The Cone Consistency test is not very helpful because samples of quick setting systems such as micro-surfacing set too fast. There is little guidance on how much water should be used in each set of tests. The mixture designs tests in the ISSA procedures use different water contents for different tests, but there is no guidance on how to establish the water contents for testing micro-surfacing. One emulsion supplier in the Northeastern U.S. avoids that problem by formulating the emulsion so that water does not need to be added. However, water must be added to the emulsions available in the Texas area.

The ISSA tests provide a skeletal framework on a rational basis for developing a polymer modified slurry seal cold mix design. However, the tests are prone to user subjectivity. There is a need to calibrate each individual testing device to achieve greater uniformity and consistency in results.

SPRING 1993 EVALUATION OF ISSA MIXTURE DESIGNS

Due to the work completed on the mixture designs for the 1992 evaluations and the variability studies, the project staff was much more familiar with the ISSA test procedures during the 1993 studies. Further, the staff discussed the testing procedures with several ISSA members. It was apparent that other concepts besides the ISSA procedures should be evaluated. A volumetric approach was selected for trial, but at the start of the season, the ISSA procedure was considered the standard. In addition, mixture design using the Texas gyratory to prepare samples was being evaluated.

Three project sites were selected within Texas to evaluate the ISSA mixture design procedures. The projects were to be completed in the Spring of 1993. The three project sites were located near Commanche in the Brownwood District, near Rockwall in the Dallas District, and near Rusk in the Tyler District.

Three trial emulsion contents were selected for testing. The trial emulsion contents were selected based on the contractor's mixture design or past experience with the materials. The cone consistency test had been used to select the water content. This test gave erratic results in mixture design verification work done in the fall of 1992. Therefore, this procedure was eliminated from the evaluation of the ISSA mixture design procedure. The water content was selected based on the operators judgement of the desired consistency and the results from the wet cohesion test. The desired consistency should be a homogenous, creamy mixture.

The wet cohesion test is used to classify the system and to select the optimum mineral filler content. Texas specifications require that a micro-surfacing system be a quick set, quick traffic system. A minimum cohesion value of 12 kg-cm at 30 minutes is required to be classified as a quick set system, and a minimum value of 20 kg-cm at 60 minutes is required for a quick traffic system. The wet cohesion test was performed at several water contents and portland cement contents. The optimum portland cement content selected was the amount of cement that gave a peak cohesion value for 12 percent emulsion and met the requirements for a quick set, quick traffic system.

The mixing time test is used to ensure adequate time for mixing and application of the slurry. ISSA TB 102 recommends a minimum of 120 seconds of mix time. The sections of the test used were 4.1-4.5. Interpretation of the results were based on section 5.1.1.

The asphalt content is selected using the 6-day soak WTAT and the LWT. The WTAT is used to determine the minimum asphalt content. Two soaking periods are used in the testing procedure, 1-hour and 6-day. ISSA TB 100 recommends the maximum allowable abrasion loss as 538 g/m^2 (50 g/ft^2) for the one-hour soak. For the 6-day soak, the recommended maximum allowable loss is 807 g/m^2 (75 g/ft^2).

The LWT is used to determine the maximum asphalt content. ISSA TB 109 recommends a maximum allowable sand adhesion of 538 g/m^2 (50 g/ft^2). The optimum emulsion content is then selected by combining the graphs of the WTAT data and the LWT data as described earlier and illustrated Figure 16. If the window between the minimum and the maximum content is greater than 3 percent, the optimum is selected 1.5 percent below the maximum. If the window is less than 3 percent, the optimum is selected in the middle of the range.

Materials

The material used in the mix design evaluation was representative of the material used in construction in the field. All materials met the specifications given in TxDOT draft micro-surfacing procedure, March 1993. The emulsion used in all projects was CSS-1P or CSS-1hP. The aggregate was TxDOT Grade II for coarse graded surface coarse. The mineral filler was non-air entrained, lump free portland cement. Distilled water was used in the preparation of the samples. Only set retarding additives approved for the project were used, if needed. Table 9 gives the location site and material supplier for the three selected project sites.

Test procedures used in the TTI laboratory for micro-surfacing mixture design are described in Report 1289-1. One exception to the procedures was that the wet cohesion test was performed with material passing a 9.5 mm (3/8 in) sieve and a 10 mm (0.39 in) sample mold. A minimum of three samples were tested at each formulation. All percentages were based on the dry weight of aggregate.

The material tests performed were gradation of the aggregate and distillation of the emulsion to determine the percent residual asphalt cement (RAC). Aggregate gradation was determined using TxDOT test procedure Tex 200-F (28). The aggregate gradation results are given in Table 10 and shown in Figures 35-37.

Table 9. Description of Materials for the 1993 Projects

LOCATION	AGGREGATE	ASPHALT EMULSION	MINERAL FILLER
Brownwood District	Capitol Aggregates (Delta Materials) Marble Falls, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion Waco, TX CSS-1hP	Portland Cement Type I
Dallas District	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion Waco, TX CSS-1hP	Portland Cement Type I
Dallas District	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Koch Material Company Salina, KS CSS-1P	Portland Cement Type I
Tyler District	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion Waco, TX CSS-1hP	Portland Cement Type I
Tyler District	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Koch Material Company Salina, KS CSS-1P	Portland Cement Type I

Table 10. Aggregate Gradation for 1993 Projects

Sieve Size		Tx Grade II Specification Percent Retained	Brownwood Near Commanche	Dallas Near Rockwall	Tyler Near Rusk
mm	in				
9.50	3/8	0-1	0	0	0
4.75	#4	6-14	12.7	11.6	11.6
2.36	#8	35-55	46.2	49.9	49.9
1.18	#16	54-75	67.1	67.5	67.5
0.60	#30	65-85	77.5	75.8	75.8
0.30	#50	75-90	83.5	81.2	81.2
0.15	#100	82-93	87.1	89.9	89.9
0.075	#200	85-95	92.6	95.2	95.2

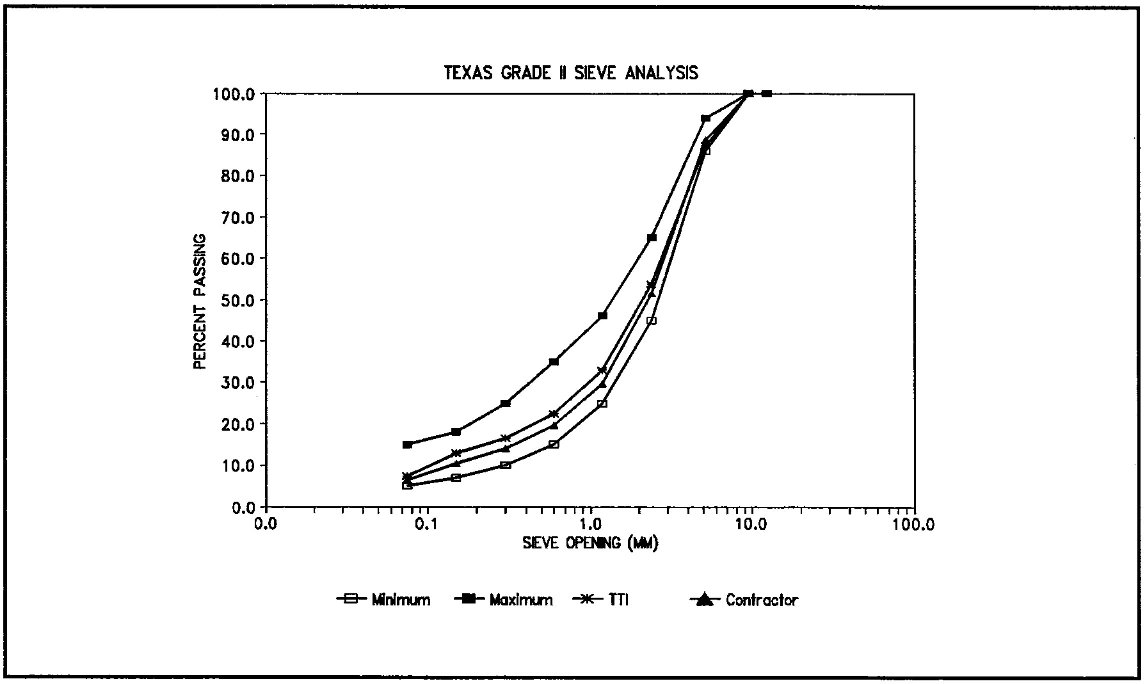

Figure 35. Aggregate Gradation used in TTI's Mixture Design for the Brownwood District Project and the Gradation from the Mixture Design supplied by the Contractor

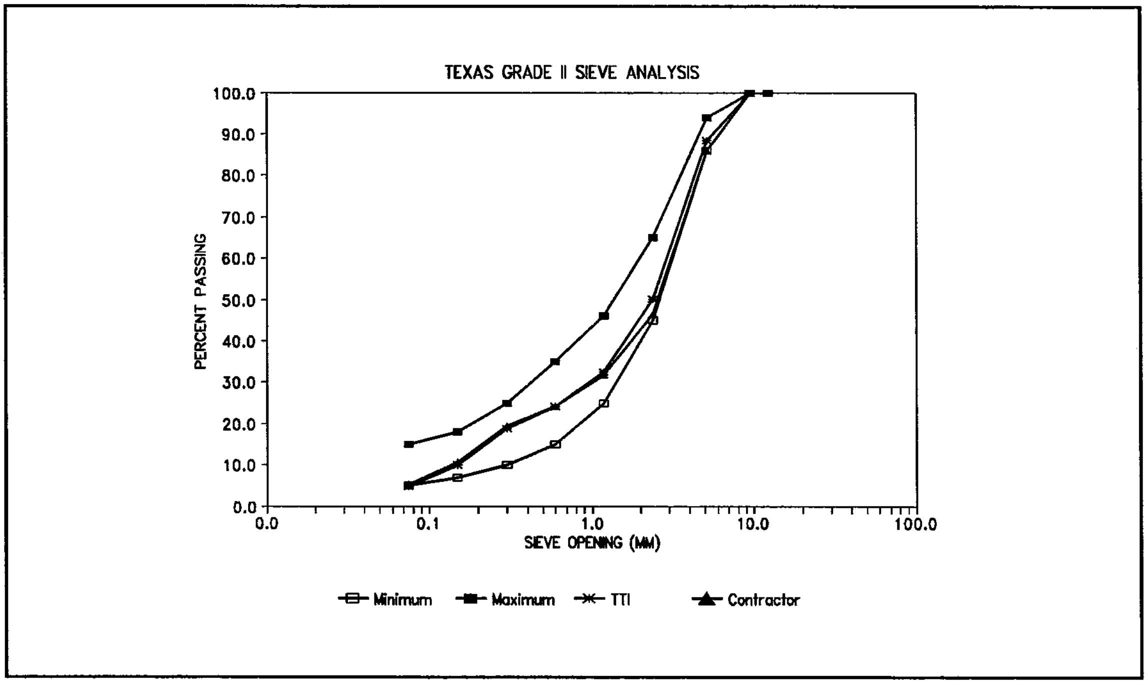

Figure 36. Aggregate Gradation used in TTI's Mixture Design for the Ergon emulsion for the Dallas and Tyler District Projects and the Gradation from the Ergon Mixture Design supplied by the Contractor

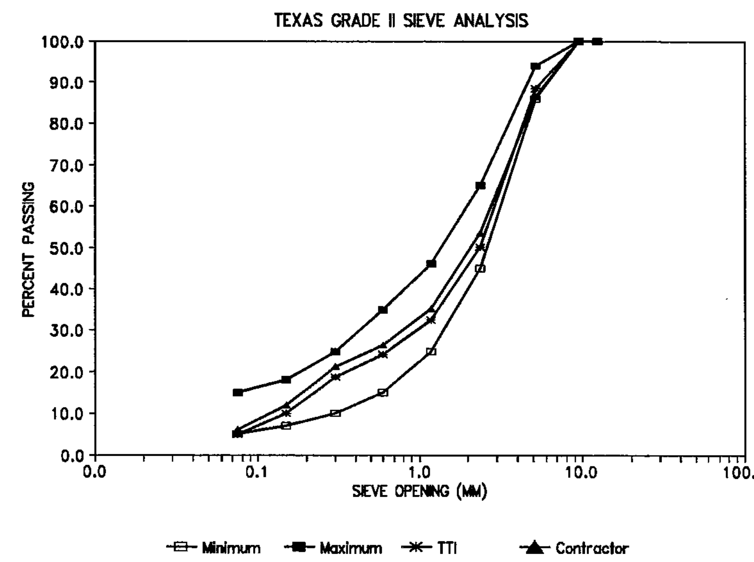

Figure 37. Aggregate Gradation used in the TTI Mixture Design for the Koch emulsion for the Dallas and Tyler District Projects and the Gradation from the Koch Mixture Design supplied by the Contractor

RAC was determined using ASTM D-244 oven evaporation procedure. The percent RAC was 63.6 percent for the Ergon CSS-1hP for projects in Brownwood, Tyler, and Dallas and 65 percent for the Koch CSS-1P for the Tyler and Dallas projects.

Mixture Design Results and Discussion

The mix design results are summarized in Table 11. The results for each site are described in the following sections. Table 12 summarizes the mixtures and compares the TTI developed mixture designs to the material supplier developed mixture designs.

Brownwood Results - The three emulsion contents selected for testing were 10, 12 and 14 percent. The percent RAC of the asphalt emulsion was determined to be 63.6 percent. The asphalt cement contents were 6.4, 7.6 and 8.9 percent, respectively. Three trial water contents were tested: 8, 10 and 12 percent. The wet cohesion test was performed with cement content varying from 0.25 to 1.5 percent and for each variation in water and emulsion contents. The results from the cohesion tests are represented graphically in Figures 38-46. Based on the operator's judgement of consistency and the results of the cohesion tests, the optimum water content selected was 8 percent. The wet cohesion test data indicate that the slurry system will be sensitive to small variations in

Table 11. Mix Design Results for Selected Projects To Evaluate ISSA Mix Design Procedures

Test	Specifications	District of Project		
		Brownwood	Dallas	Tyler
Wet Cohesion ISSA TB 139 @ 30 minutes @ 60 minutes	minimum 12 kg-cm minimum 20 kg-cm	0.75% Portland Cement @ 12% Emulsion	1.00% Portland Cement @ 12% Emulsion	0.75% Portland Cement @ 12% Emulsion
Mixing Time @ 25° C (77° F) ISSA TB 102	minimum 120 seconds	> 180 second	> 180 second	> 180 second
1 hour soak Wet Track Abrasion Test ISSA TB 100 minimum residual asphalt cement	maximum 538 g/m^2 (50 g/ft^2) abrasion loss	5.8%	@ 9% water - 5.4% @ 8% water - 5.6% @ 7% water - 5.8%	@ 10% water - < 5.2% @ 8% water - < 6.5% @ 7% water - < 6.5%
6 day soak Wet Track Abrasion Test ISSA TB 100 minimum residual asphalt cement	maximum 807 g/m^2 (75 g/ft^2) abrasion loss	6.6%	@ 9% water - 6.6% @ 8% water - 7.5% @ 7% water - 7.7%	@ 10% water - 5.5% @ 8% water - 6.0% @ 7% water - 6.1%
Loaded Wheel Test ISSA TB 109 maximum residual asphalt cement	minimum 538 g/m^2 (50 g/ft^2) adhered sand	7.2%	@ 9% water - < 5.1% @ 8% water - 8.9% @ 7% water - > 8.9%	@ 10% water - 5.4% @ 8% water - 6.9% @ 7% water - 9.1%
Optimum Residual Asphalt Cement		6.8%	----	----

Table 12. Comparison of TTI and Contractor Mixture Design (all Quantities are Based on Dry Weight of Aggregate)

Location	Tester	Residual Asphalt Cement Percent	Mineral Filler Percent	Water Percent
Brownwood	Contractor	7.47	1.00	7.5*
	TTI	6.8	0.75	*
Dallas (Ergon)	Contractor	7.39	0.75	7.0*
	TTI	7.0**	1.00	*
Dallas (Koch)	Contractor	7.5 ± 0.5	2.0 ± 0.25	9 - 13
	TTI	6.6**	0.75	*
Tyler (Ergon)	Contractor	7.39	0.75	7.0*
	TTI	8.3**	1.00	*
Tyler (Koch)	Contractor	7.5 ± 0.5	2.0 ± 0.25	9 - 13
	TTI	8.2**	0.75	*

* As needed for consistency

** These values are not optimum RAC contents, test sections were constructed at these values

portland cement content. The peak in the cohesion data for 8 percent water and 7.6 percent RAC (12 percent Emulsion) was then selected as the optimum portland cement content. The selected optimum mineral filler was 0.75 percent portland cement. The optimum water and portland cement contents selected were used in all subsequent testing.

The mixing test was performed for the formulations described above. All three RAC contents, 8 percent water and 0.75 percent portland cement had greater than 180 sec mix time.

The WTAT yielded a minimum percent residual asphalt cement content of 5.8 percent for a 1-hour soak and 6.6 percent for a 6-day soak. The results are graphed in Figure 47. There was no correlation between the 1-hour soak and the 6-day soak.

The LWT results were inconclusive. Due to insufficient time to rerun the test before the treatment had to placed in the field, the data for the 6.4 percent RAC content was discarded and the data for the 7.6 and 8.9 percent RAC content was used to select the maximum RAC content. The maximum RAC content was 7.2 percent. The optimum RAC content selected was 10.8 percent. This was selected based on the 6-day soak WTAT results and the LWT results excluding the 6.4 percent RAC content results. The results are graphed in Figure 48.

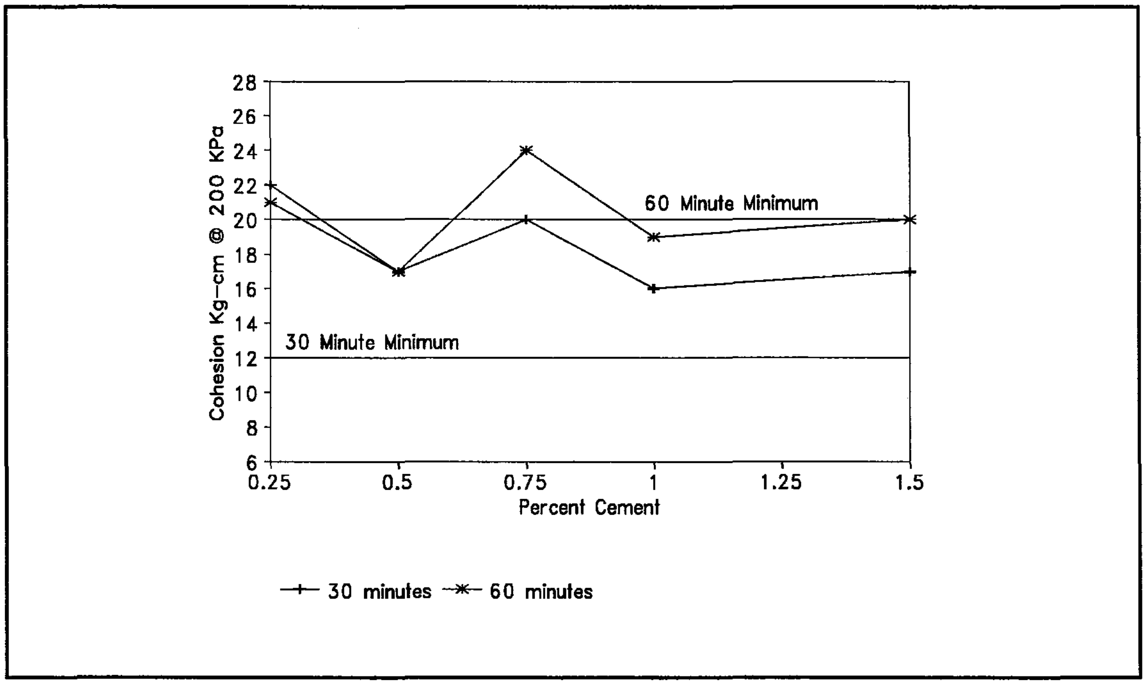

Figure 38. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.4% RAC and 8% Water for the Brownwood District Project

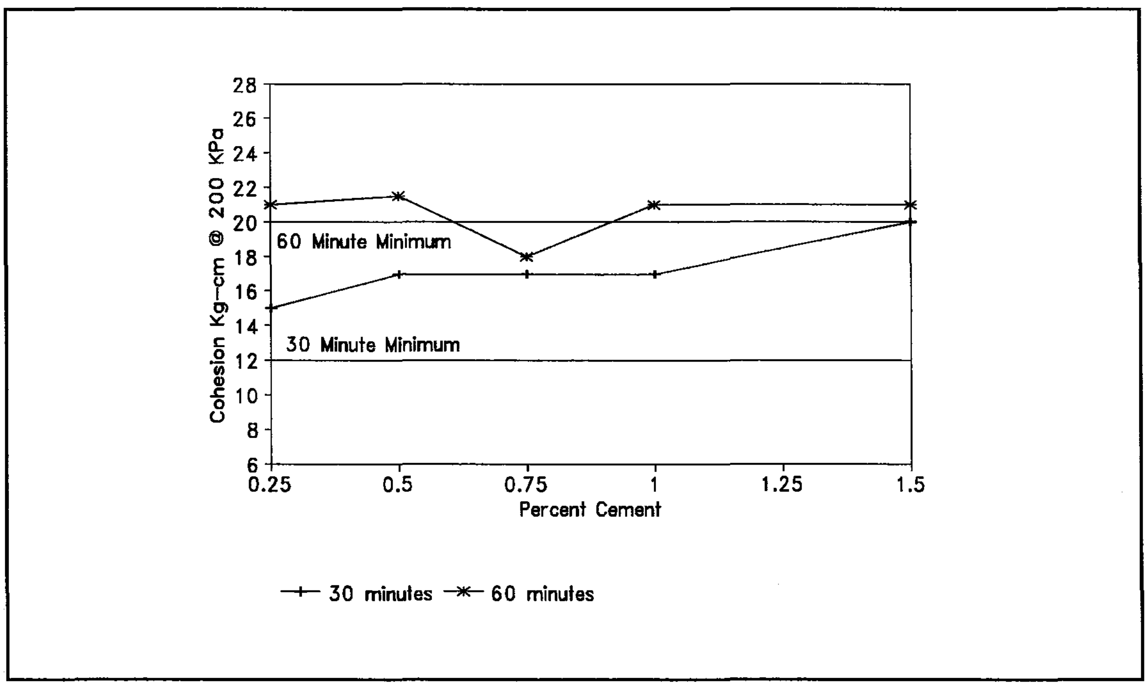

Figure 39. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.4% RAC and 10% Water for the Brownwood District Project

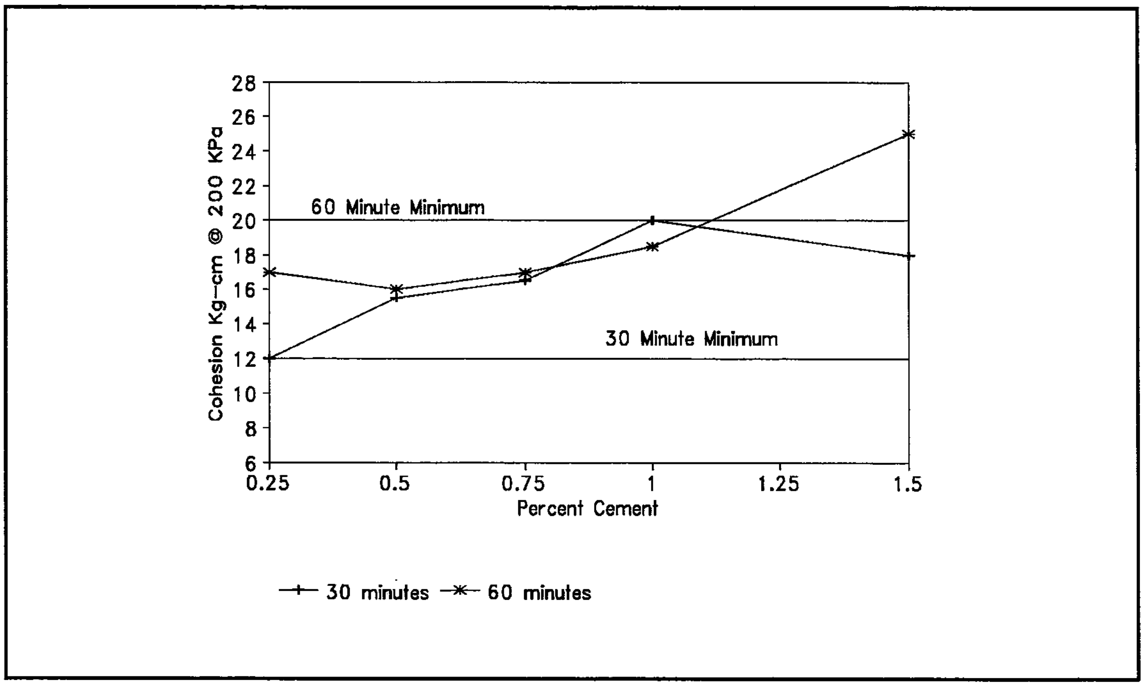

Figure 40. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.4% RAC and 12% Water for the Brownwood District Project

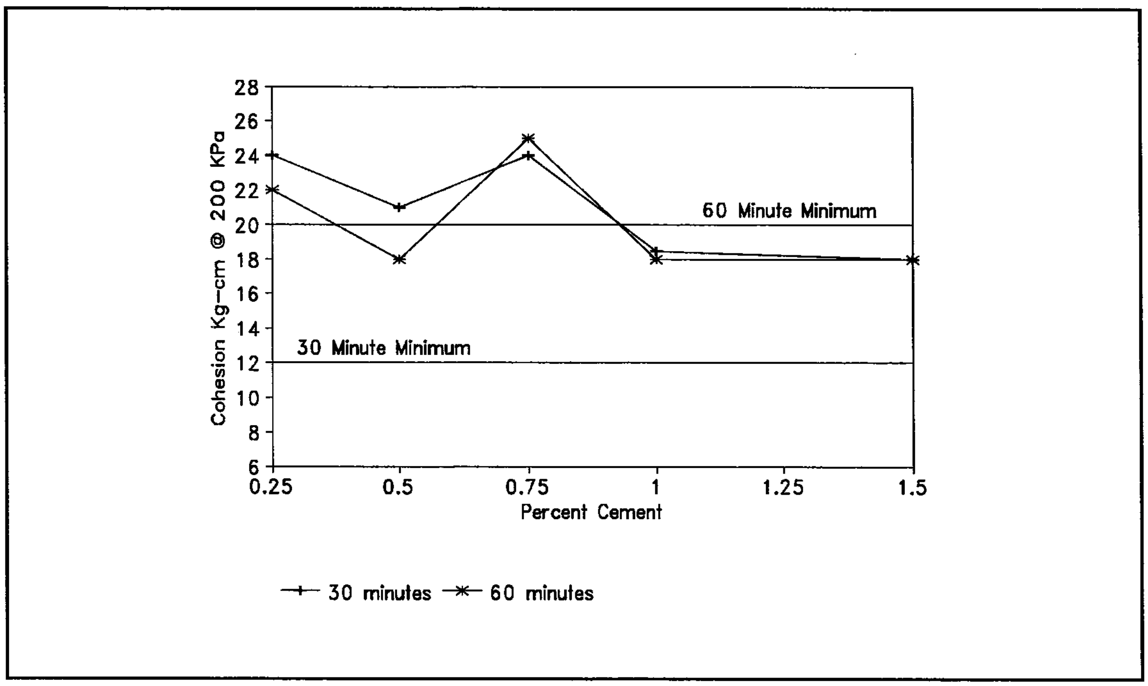

Figure 41. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.6% RAC and 8% Water for the Brownwood District Project

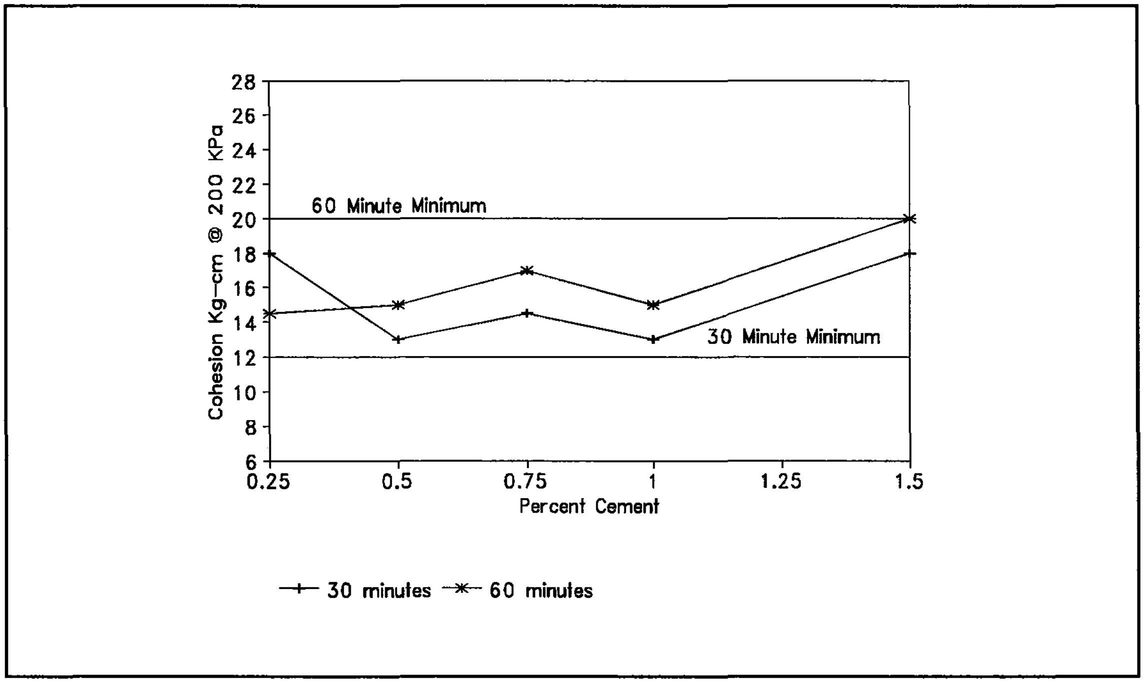

Figure 42. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.6% RAC and 10% Water for the Brownwood District Project

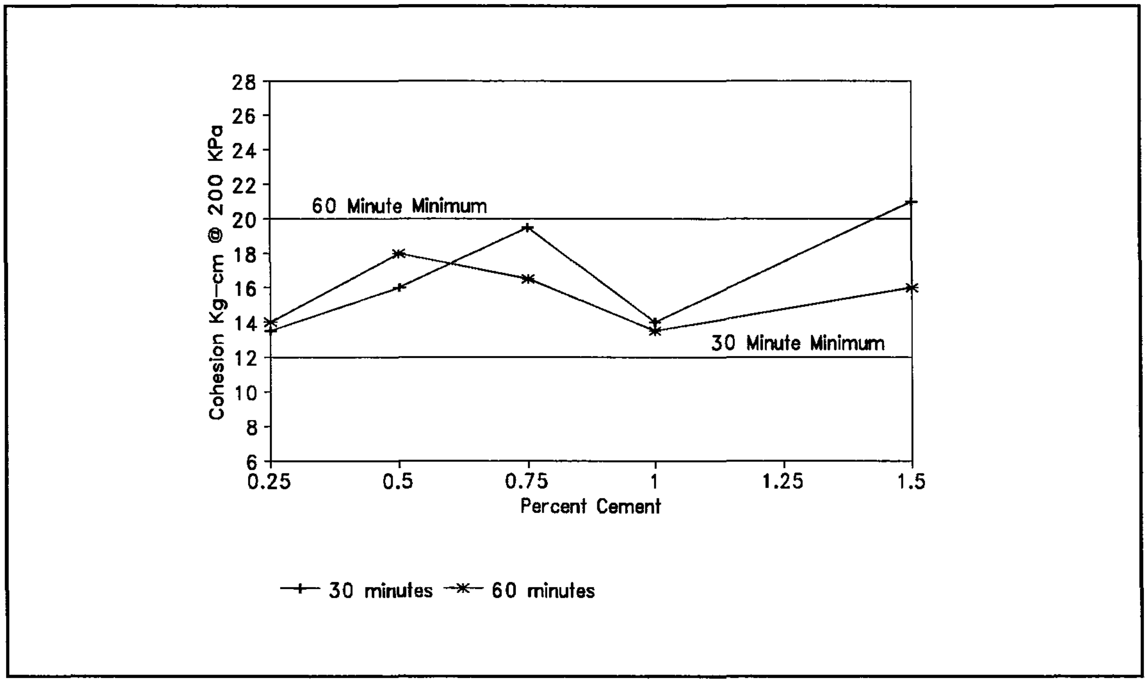

Figure 43. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.6% RAC and 12% water for the Brownwood District Project

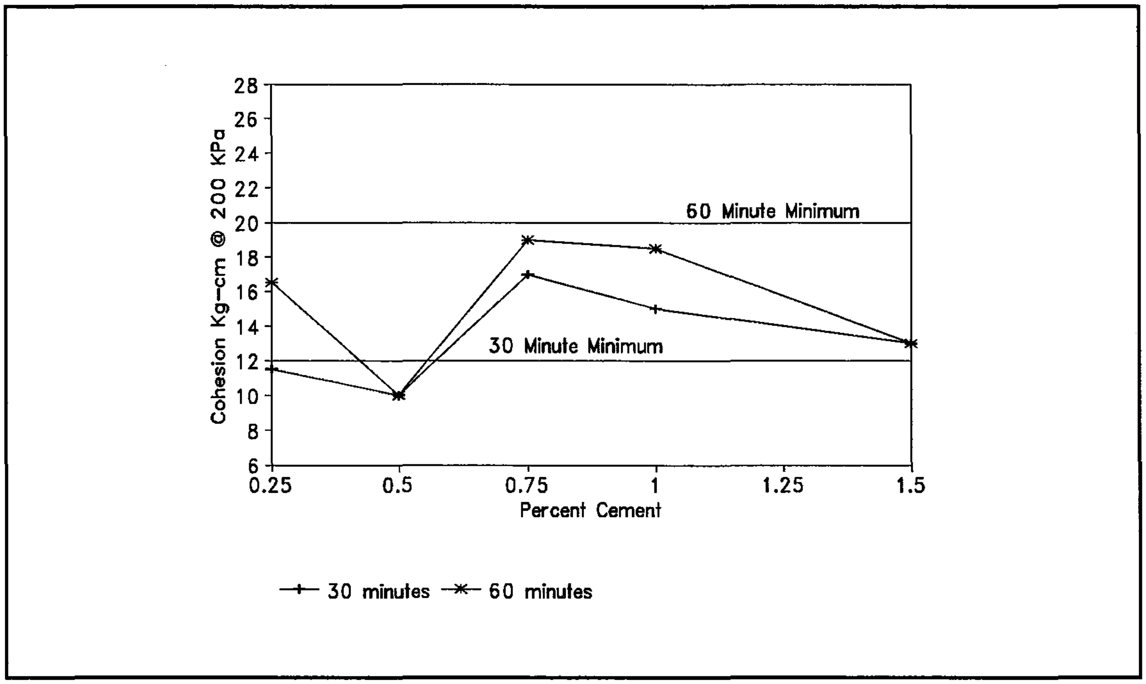

Figure 44. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.9% RAC and 8% Water for the Brownwood District Project

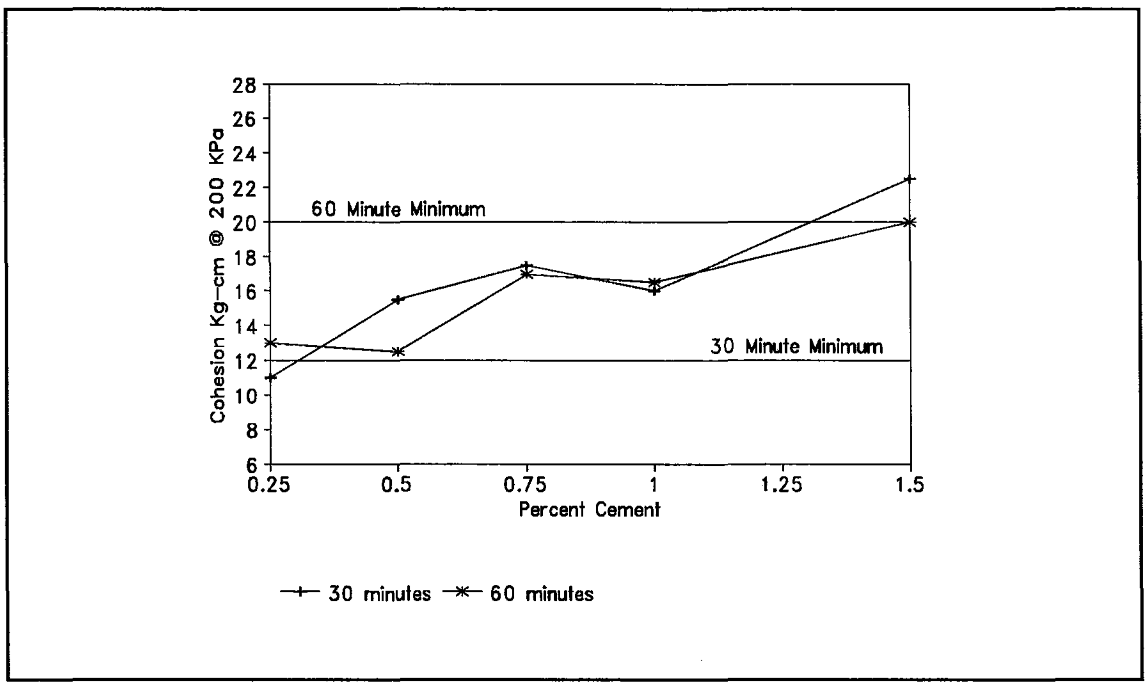

Figure 45. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.9% RAC and 10% Water for the Brownwood District Project

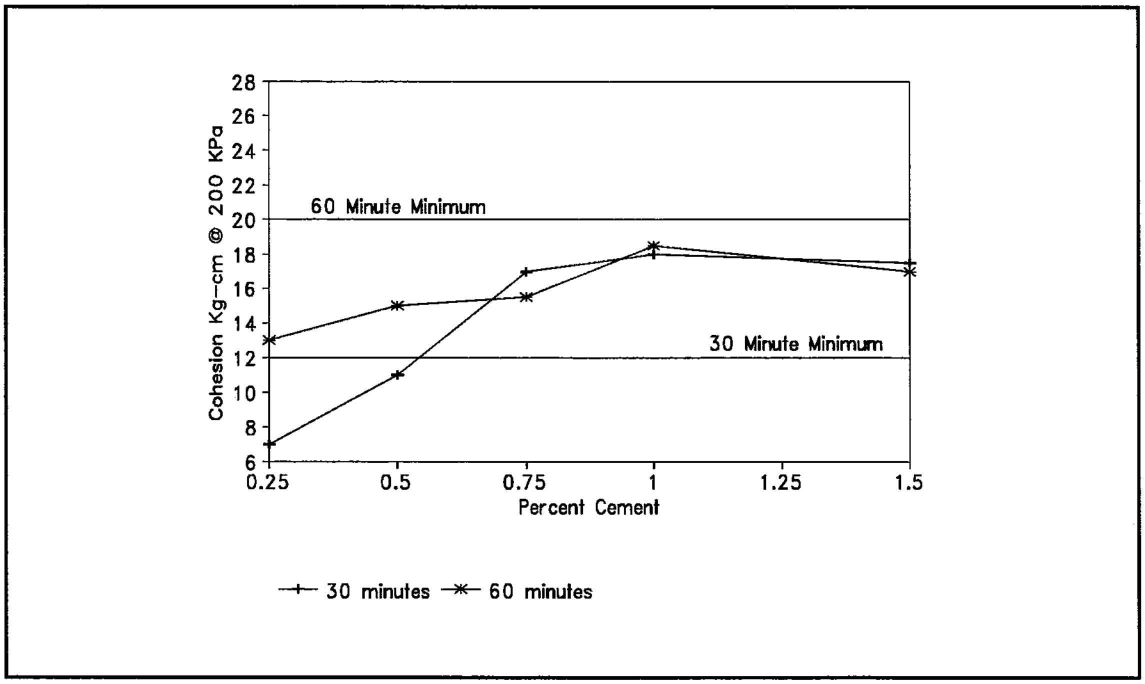

Figure 46. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.9% RAC and 12% Water for the Brownwood District Project

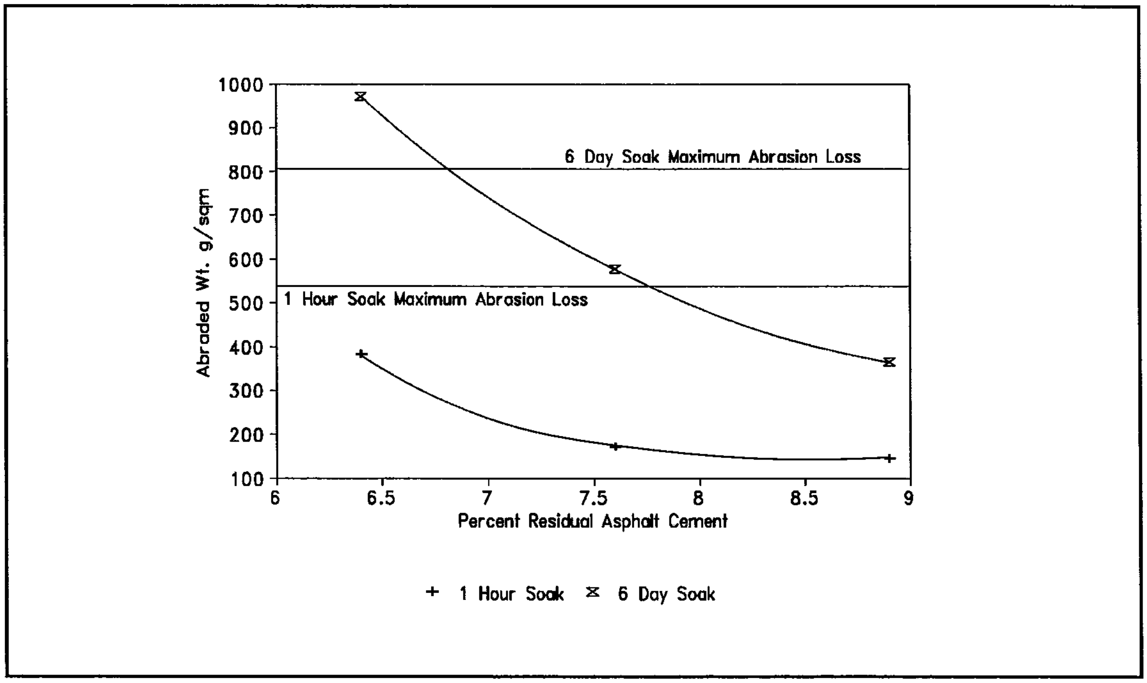

Figure 47. Minimum RAC using Abrasion Loss by one-hour and six-day soak WTAT for the Brownwood District Project

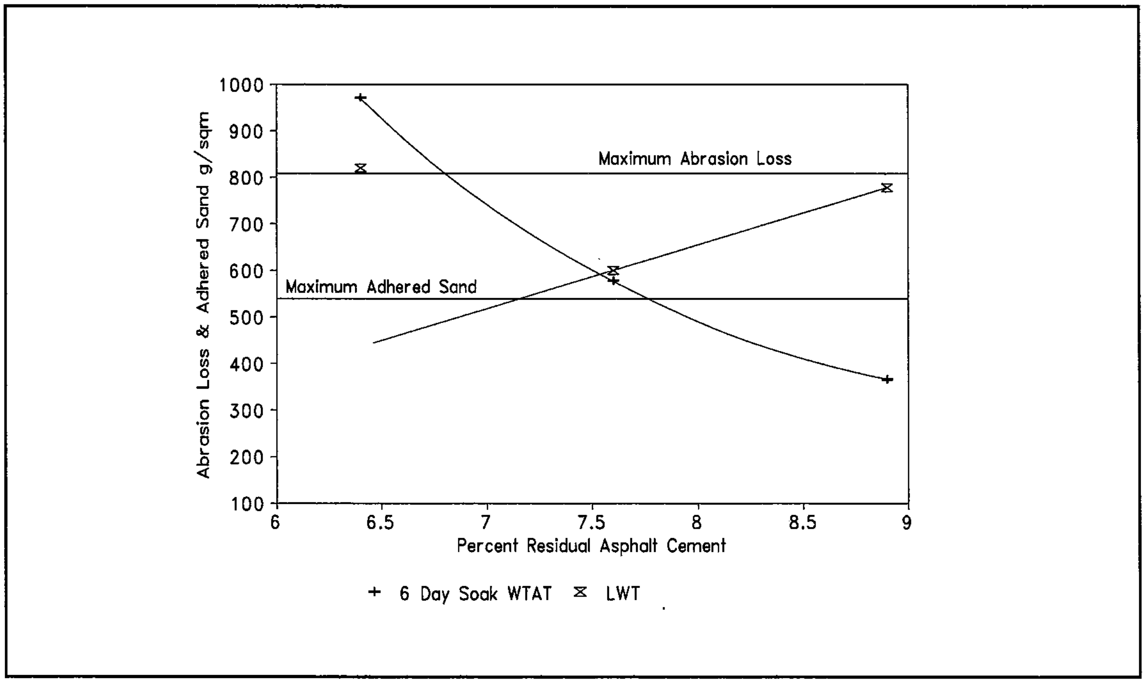

Figure 48. Optimum RAC using six-day soak WTAT and Sand Adhesion by LWT for the Brownwood District Project

Dallas and Tyler Results - Ergon Emulsion The three trial emulsion contents selected for testing were 10, 12 and 14 percent. RAC of the asphalt emulsion was determined to be 63.6 percent. The RAC contents of the mixtures were 6.4, 7.6 and 8.9 percent, respectively. The two trial water contents tested were: 9 and 12 percent. The wet cohesion test was performed with the cement varying from 0.25 to 1.0 percent for each variation in water and emulsion content. Optimum water content selected was 9 percent, based on operator's judgement of consistency and data from the wet cohesion test. The wet cohesion test results are given graphically in Figures 49-54. The slurry system did not show much change in cohesion values over the tested range of portland cement contents. Optimum mineral filler selected was 1.0 percent. The optimum cement content was selected using the 9 percent water and 7.6 percent RAC (12 percent emulsion) data that yielded the highest cohesion values as shown in Figure 51. The optimum water and portland cement contents selected were used in all subsequent testing.

The mixing test was then performed to insure at least 120 sec mix time. All three mixes had greater than 180 sec mix time.

During the evaluation it was found that none of the samples passed the LWT, and the RAC contents were changed to 5.1 (8 percent emulsion), 7.0 (11 percent emulsion) and 8.9 percent (14 percent emulsion) for the remainder of the testing. The WTAT

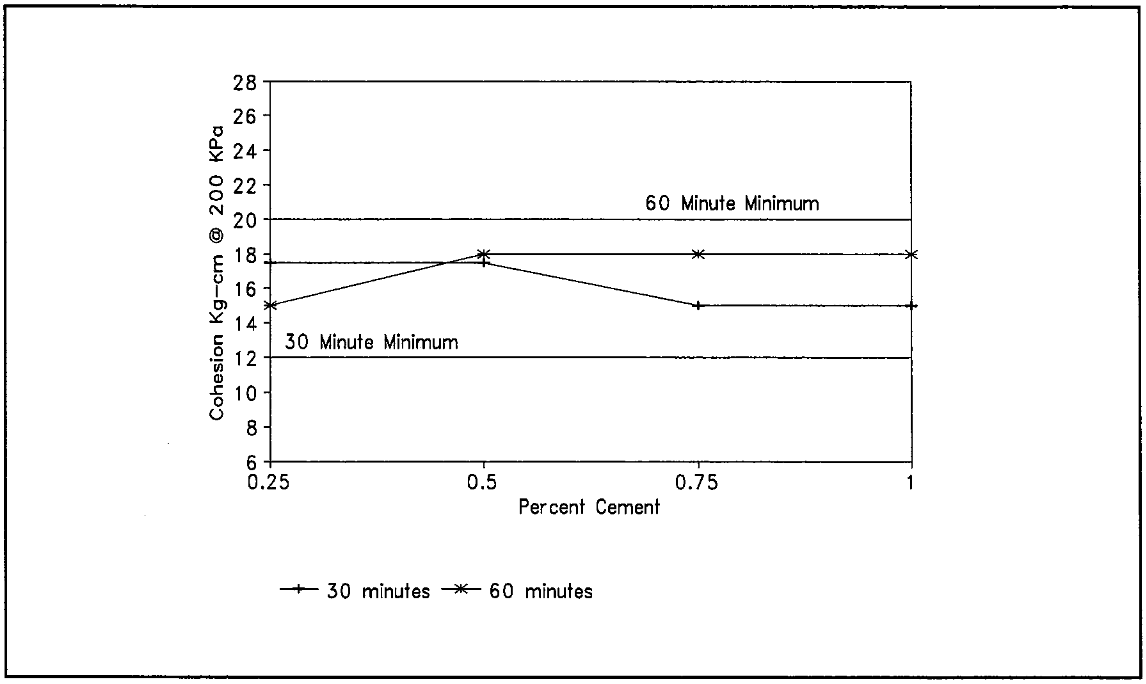

Figure 49. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.4% RAC and 9% Water for the Ergon Emulsion for the Dallas and Tyler District Projects

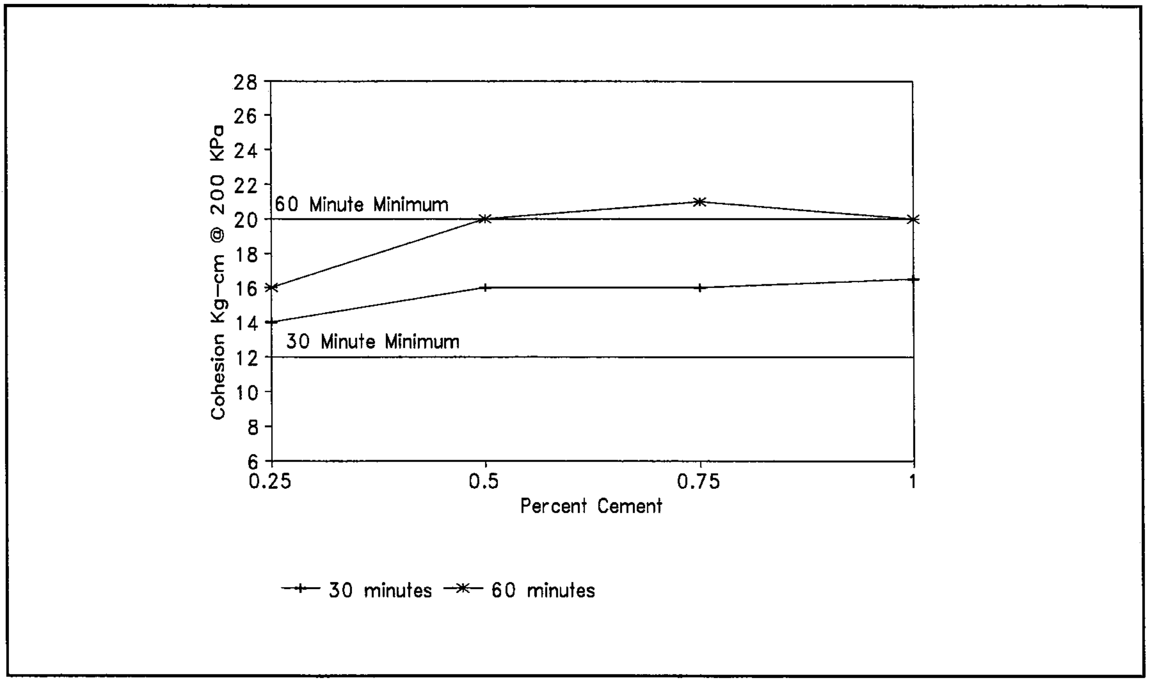

Figure 50. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.4% RAC and 12% Water for the Ergon Emulsion for the Dallas and Tyler District Projects

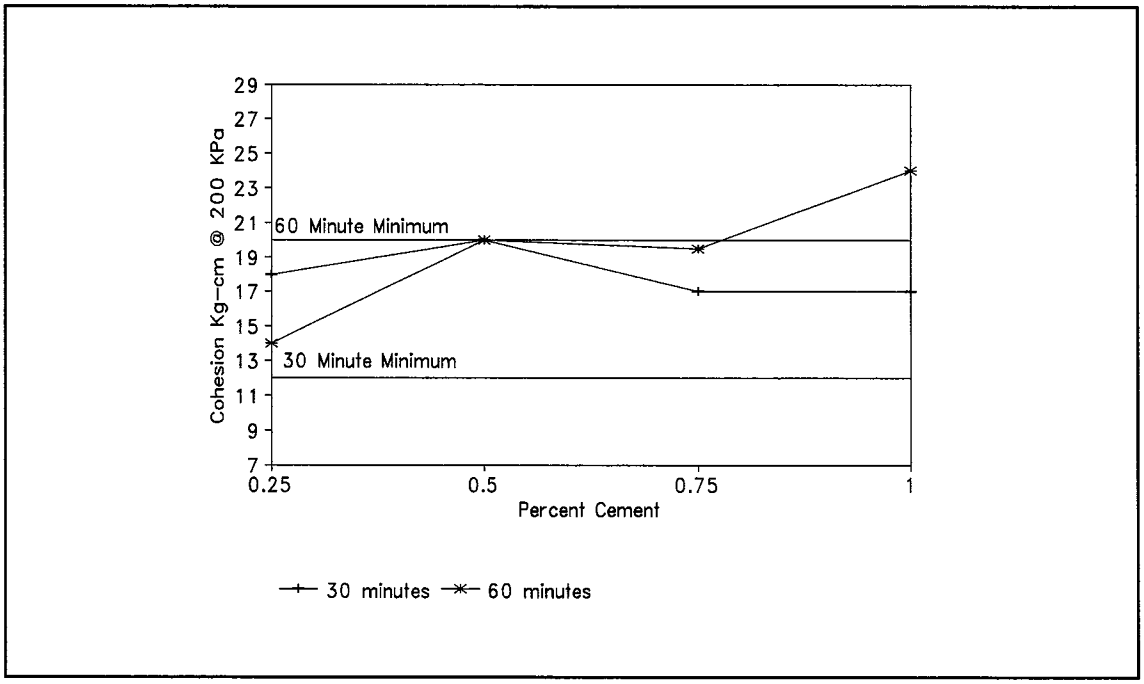

Figure 51. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.6% RAC and 9% Water for the Ergon Emulsion for the Dallas and Tyler District Projects

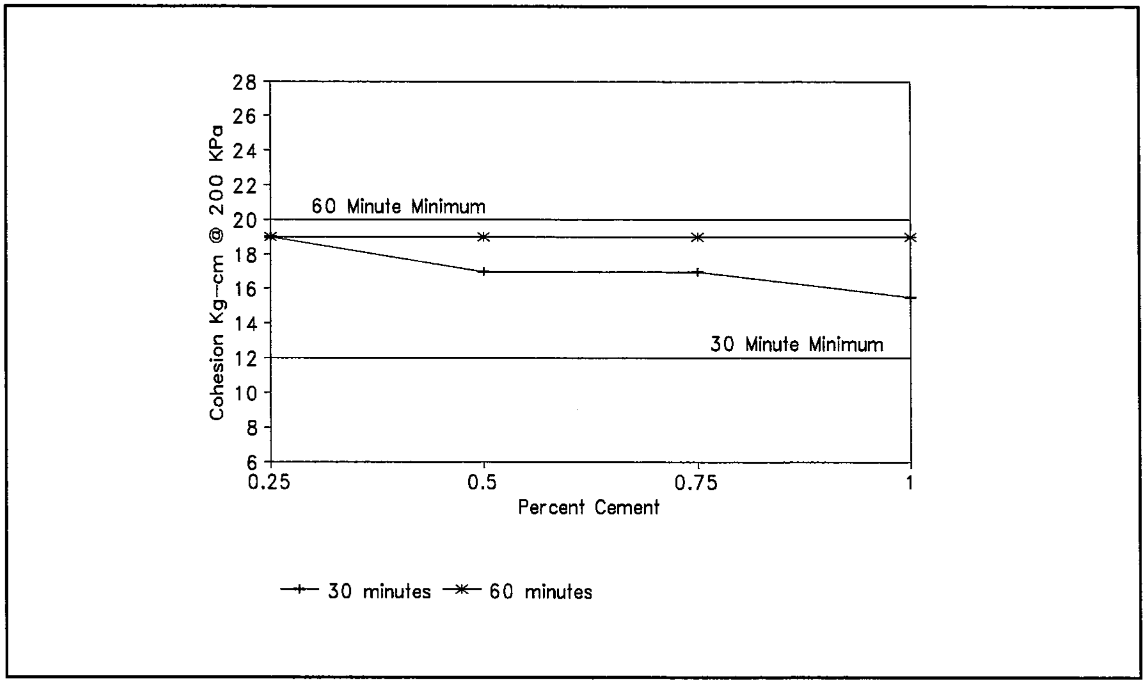

Figure 52. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.6% RAC and 12% Water for the Ergon Emulsion for the Dallas and Tyler District Projects

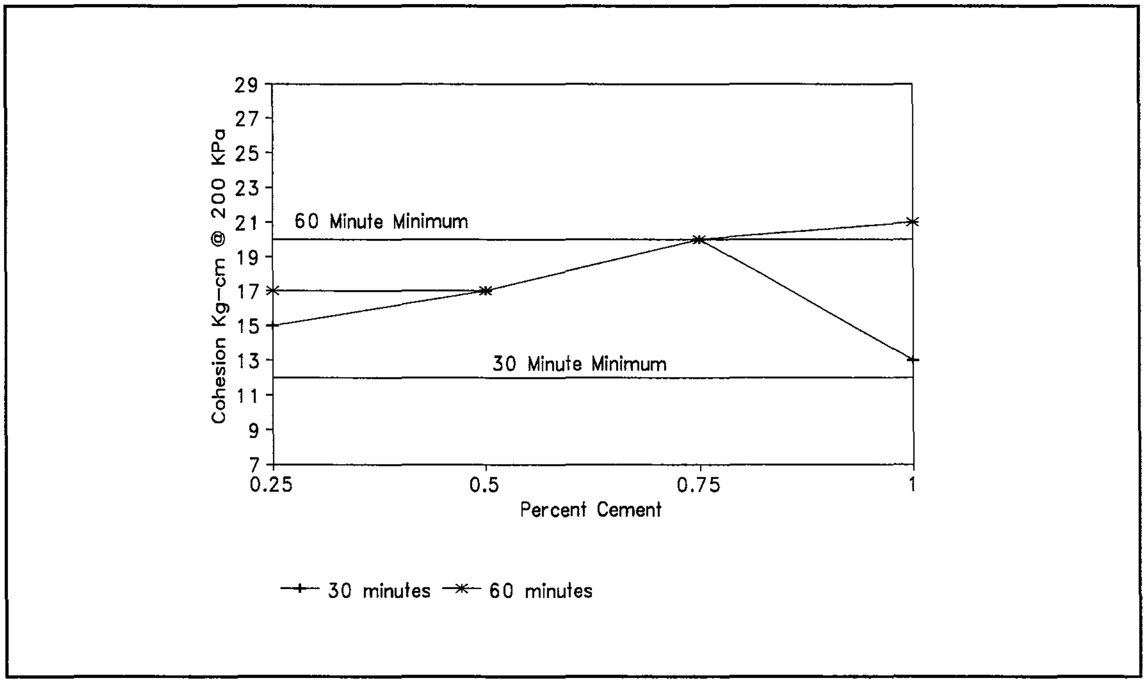

Figure 53. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.9% RAC and 9% Water for the Ergon Emulsion for the Dallas and Tyler District Projects

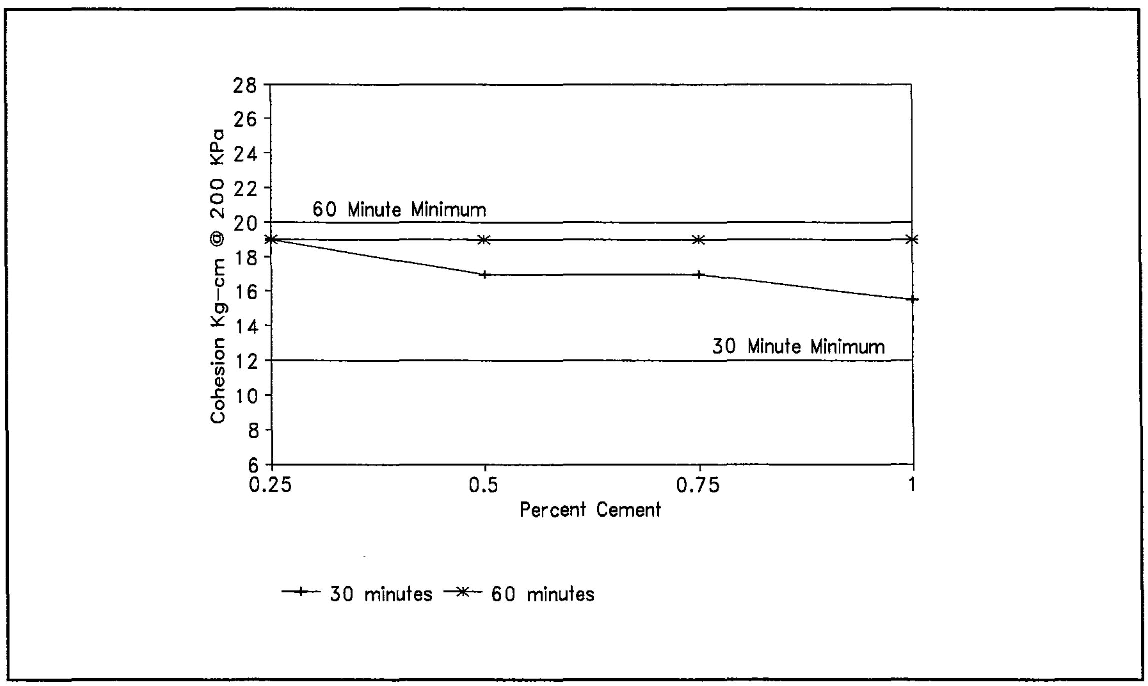

Figure 54. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.9% RAC and 12% Water for the Ergon Emulsion for the Dallas and Tyler District Projects

yielded a minimum percent RAC of 5.5 percent for 1-hour soak and 6.6 percent for 6-day soak. The results are plotted in Figure 55.

A maximum RAC content of less than 5.1 percent was obtained from the LWT. The slurry system yielded a lower maximum than the minimum content of 6.6 percent RAC as shown in Figure 56. Therefore, an optimum RAC content was not selected.

Previous work performed on the impact of material variations showed water content impacts the results of the WTAT and LWT. These tests were rerun at 1.0 percent portland cement and water contents of 8 and 7 percent. The results of the WTAT and LWT are tabulated in Table 13 and given graphically in Figures 57-59. The water content had a minor effect on the WTAT. The WTAT results in Figures 57 and 58 show a small increase in abrasion loss with a decrease in water content.

The LWT showed a large impact with 1 percent variation in water content as shown in Figure 59. This indicates that the asphalt content determined based on the LWT is a function of water content. Water content is changed in the field to modify total fluidity to provide the needed consistency to allow the material to be spread by the spreader box and to provide the desired surface texture. The operator makes those changes as needed, and there is no change in emulsion content as the water content is changed. The water must be changed in the field to keep fluidity constant when changes in surface moisture, changes in aggregate moisture, and changes in humidity occur.

Although there was no true optimum RAC selected for the site, a low RAC of 7.0 percent and a mineral filler content of 1.0 percent were selected for use on the Dallas project and a high RAC of 8.3 percent and a mineral filler content of 1.0 percent were selected for the Tyler project. This was done to determine the impact of varying the emulsion content. The contractors and material suppliers coordinated an experiment on the project by placing their normal mixture with Ergon supplied emulsion and TTI specified emulsion and mineral filler contents.

<u>Koch Emulsion</u> The three initial trial emulsion contents were 10, 12, and 14 percent. The RAC content of the emulsion was 65 percent. The RAC contents were 6.5, 7.8, and 9.1 percent. The three initial trial water contents were 8, 10, and 12 percent. The wet cohesion tests were performed with the above trial contents with the cement content varied from 0.25 to 1.5 percent. The data from the wet cohesion tests are graphed in Figures 60-68. The optimum water content of 10 percent was selected based on the operator's judgement of consistency and the wet cohesion data. The peak in the wet cohesion data for 10 percent water and 7.8 percent RAC (12 percent emulsion) was selected as the optimum. The optimum mineral filler was 0.75 percent portland cement was selected based on Figure 64. All subsequent testing was performed using the optimum water and portland cement contents.

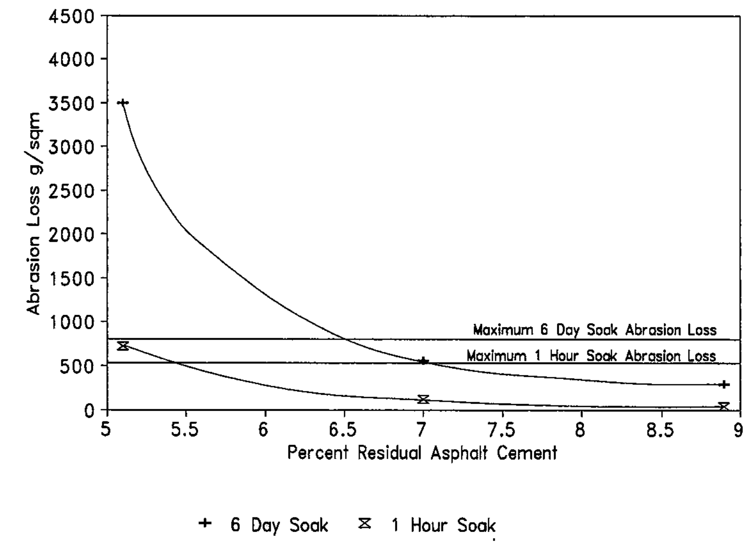

Figure 55. Minimum RAC using Abrasion Loss by one-hour and six-day soak WTAT for the Ergon Emulsion for the Dallas and Tyler District Projects

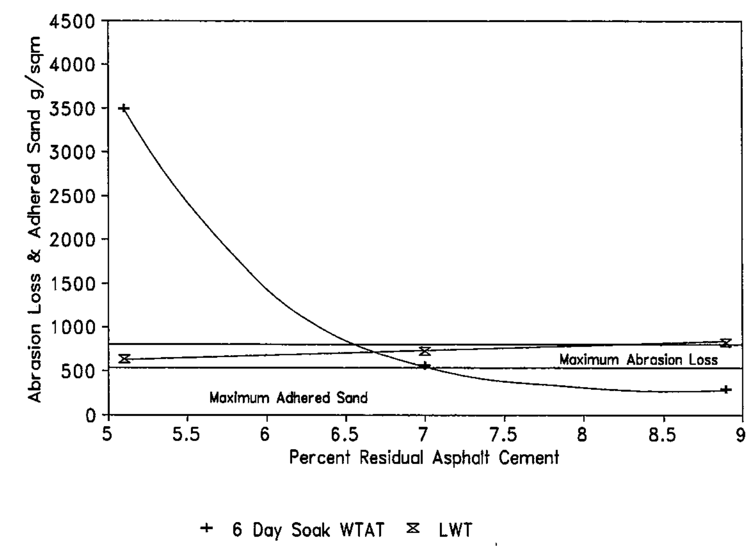

Figure 56. Optimum RAC using six-day soak WTAT and Sand Adhesion by LWT for the Ergon Emulsion for the Dallas and Tyler District Projects

Table 13. WTAT and LWT Results for Varied Water Contents for Ergon Emulsion for the Dallas and Tyler District Projects

Water Content (percent)	1-hour soak Wet Track Abrasion Test ISSA TB 100 minimum residual asphalt cement (percent)	6-day soak Wet Track Abrasion Test ISSA TB 100 minimum residual asphalt cement (percent)	Loaded Wheel Test ISSA TB 109 maximum residual asphalt cement (percent)
9.0	5.4	6.6	Less Then 5.1
8.0	5.6	7.5	8.9
7.0	5.8	7.7	Greater Then 8.9

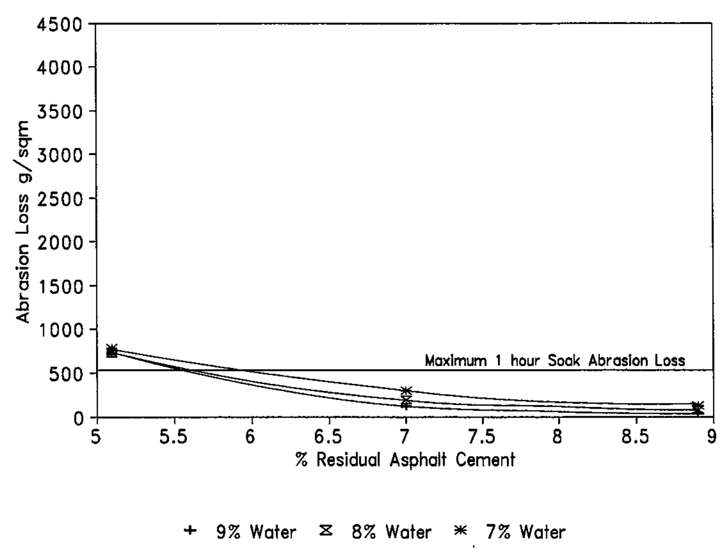

Figure 57. One-hour soak WTAT Results for varied Water Content for the Ergon Emulsion for the Dallas and Tyler District Projects

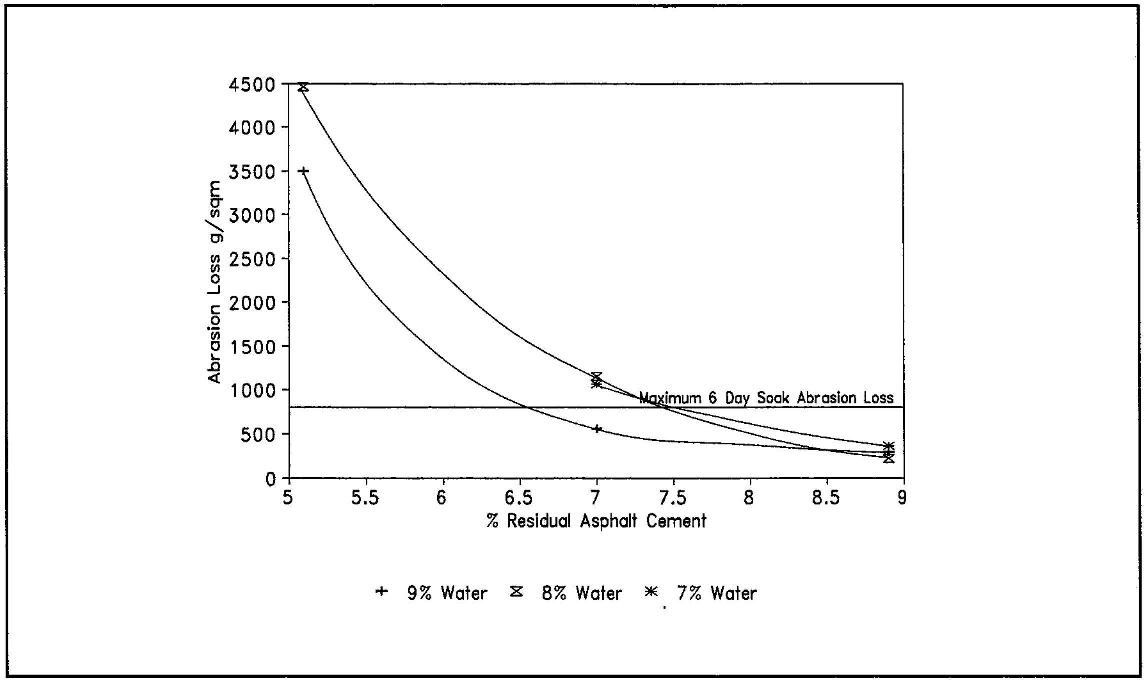

Figure 58. Six-day soak WTAT Results for varied Water Content for the Ergon Emulsion for the Dallas and Tyler District Projects

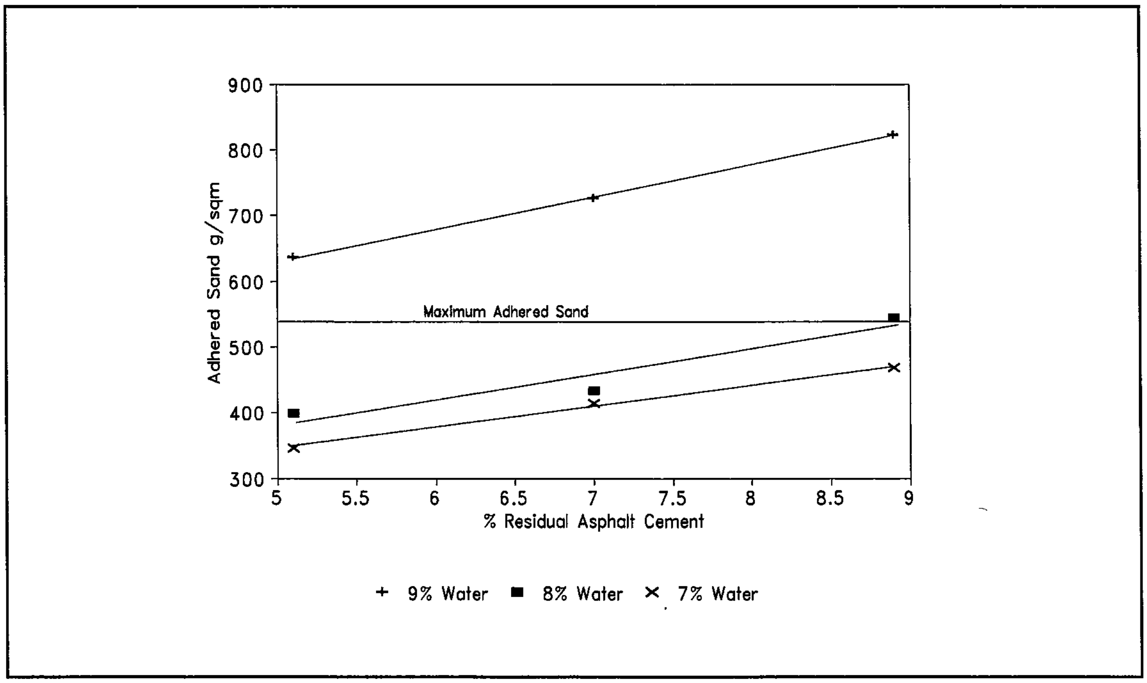

Figure 59. Results of LWT for varied Water Contents for the Ergon Emulsion for the Dallas and Tyler District Projects

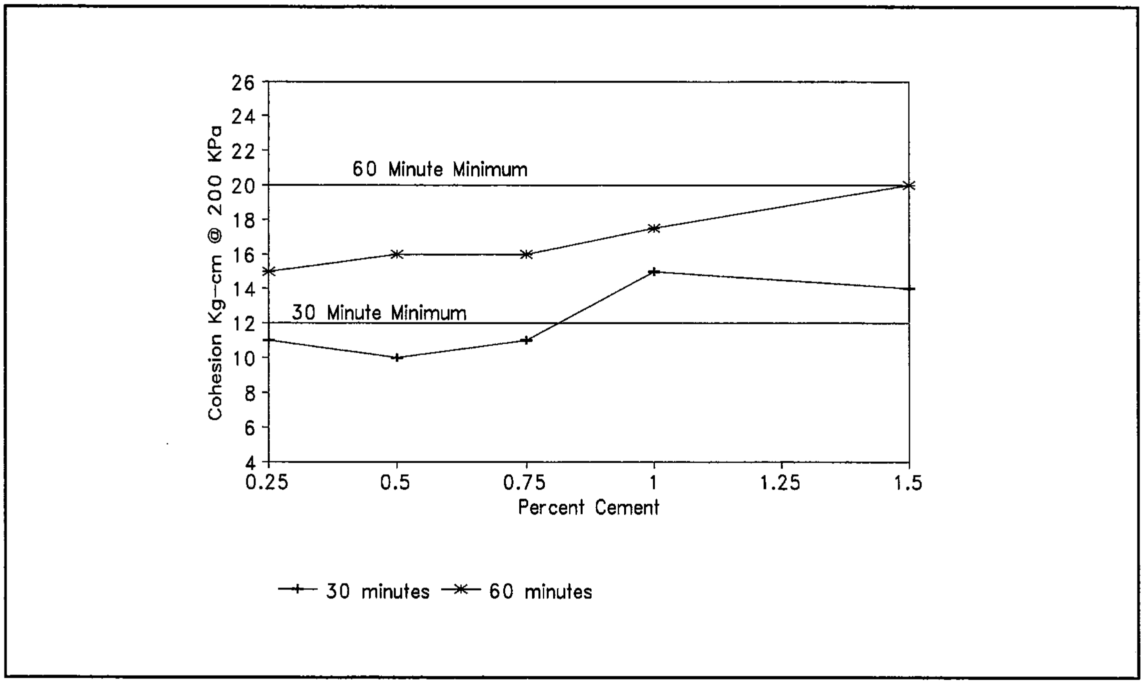

Figure 60. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.5% RAC and 8% Water for the Koch Emulsion for the Dallas and Tyler District Projects

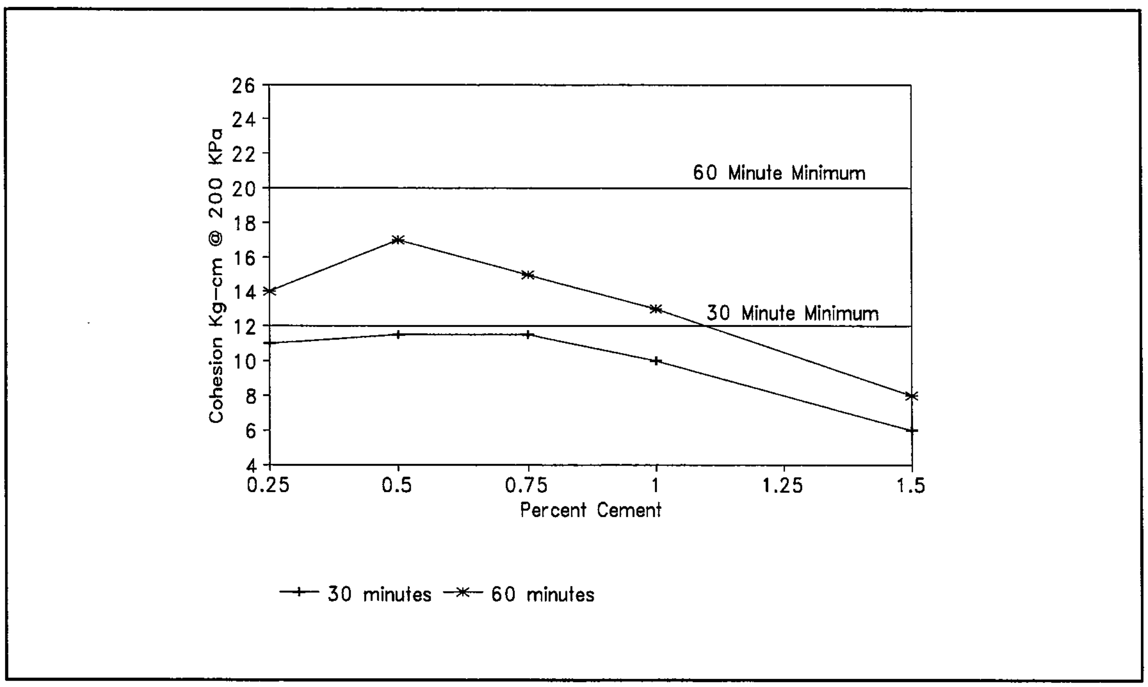

Figure 61. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.5% RAC and 10% Water for the Koch Emulsion for the Dallas and Tyler District Projects

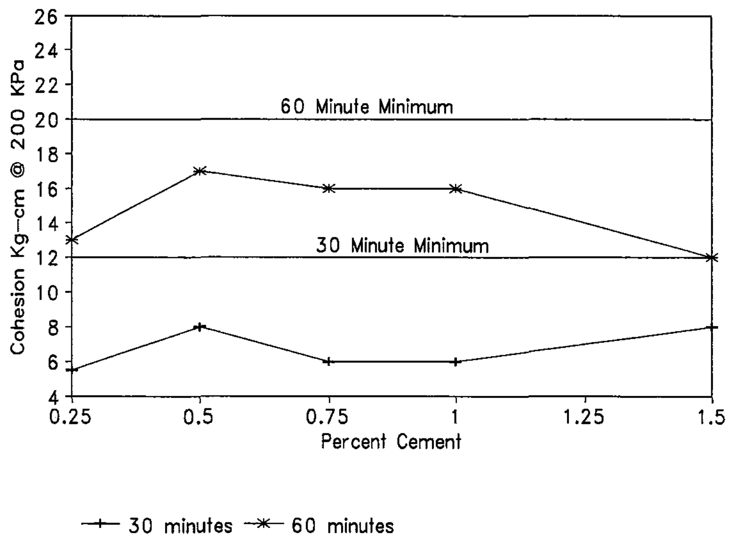

Figure 62. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.8% RAC and 8% Water for the Koch Emulsion for the Dallas and Tyler District Projects

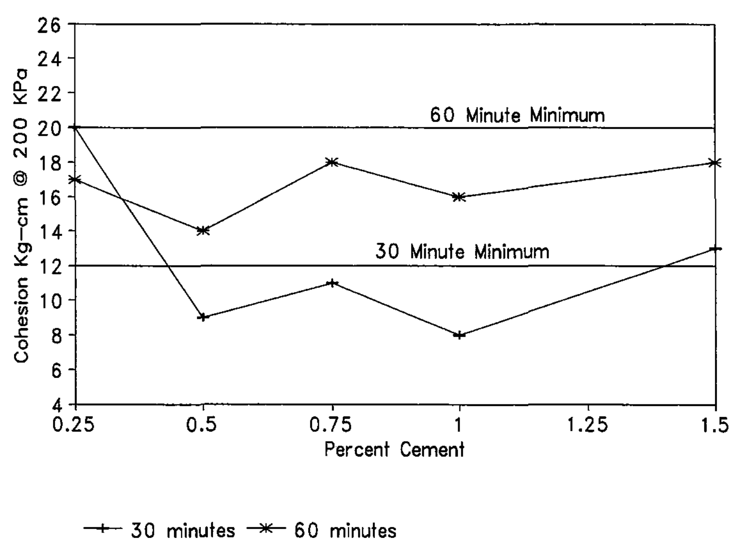

Figure 63. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.8% RAC and 8% Water for the Koch Emulsion for the Dallas and Tyler District Projects

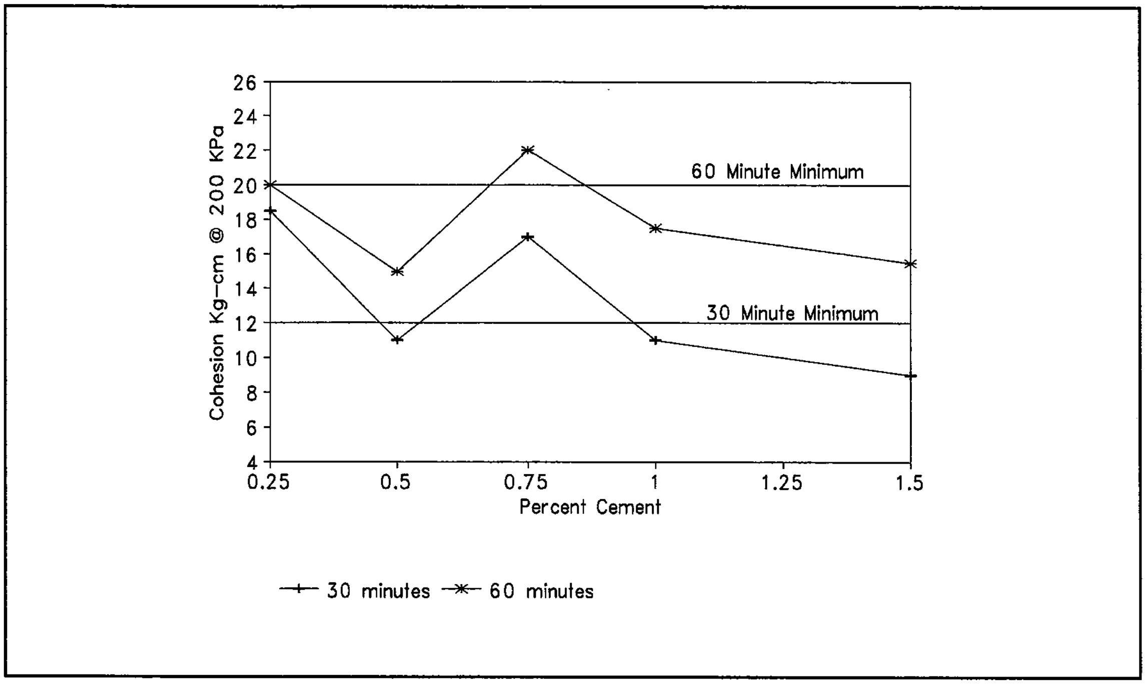

Figure 64. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.8% RAC and 10% Water for the Koch Emulsion for the Dallas and Tyler District Projects

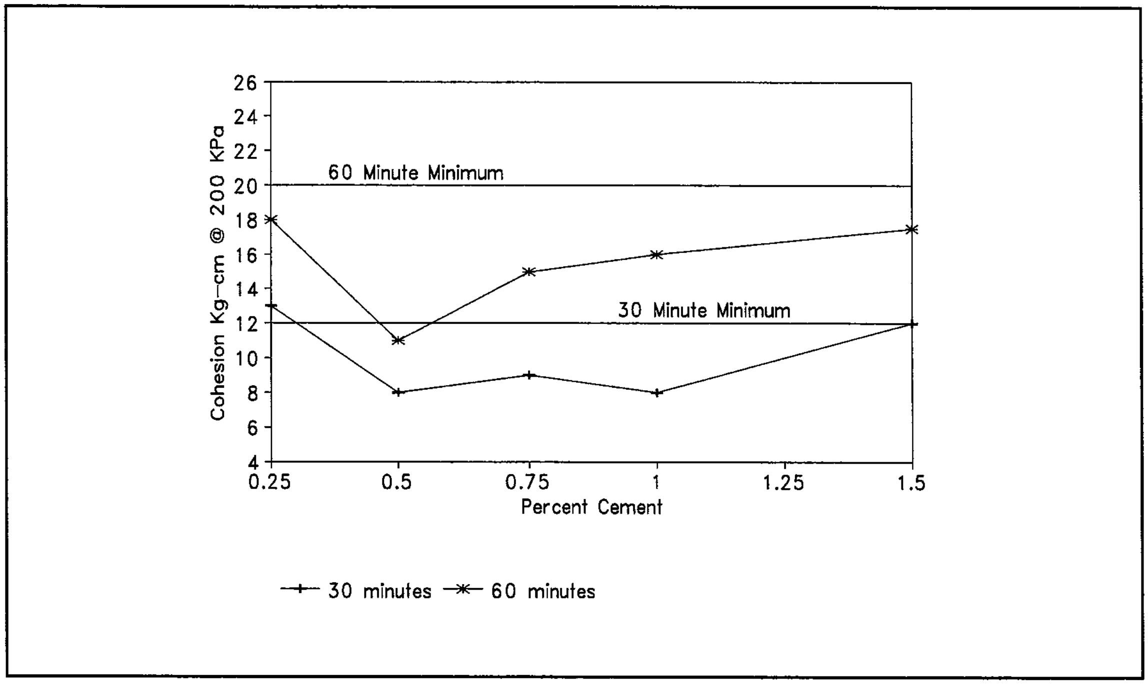

Figure 65. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.8% RAC and 12% Water for the Koch Emulsion for the Dallas and Tyler District Projects

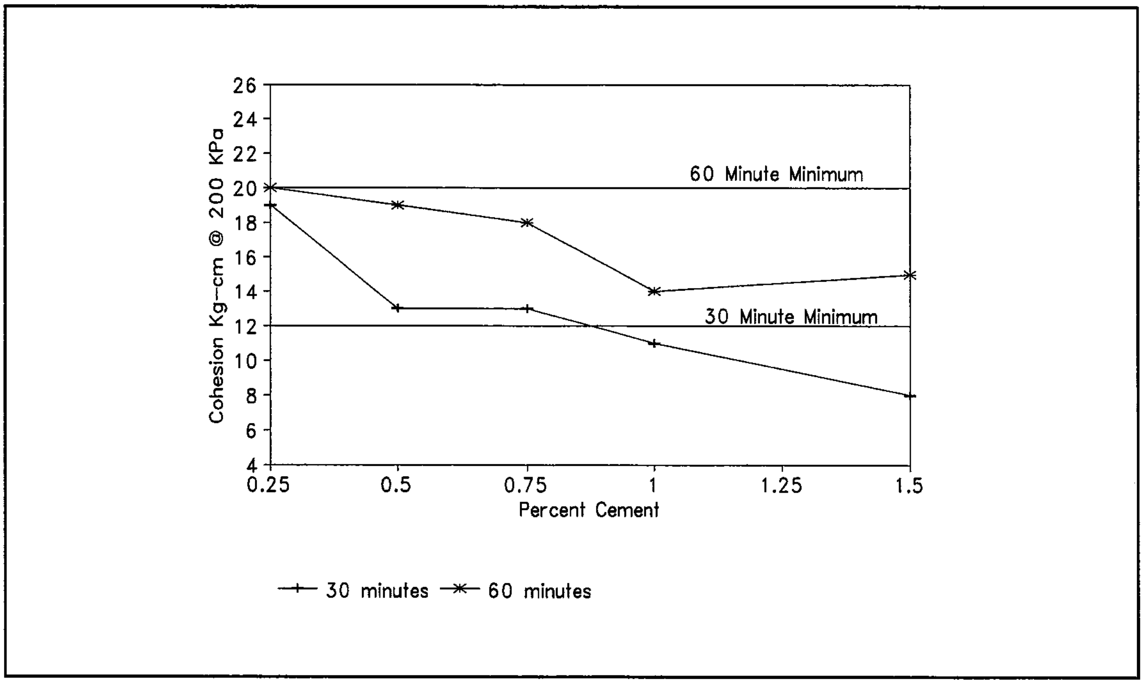

Figure 66. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 9.1% RAC and 8% Water for the Koch Emulsion for the Dallas and Tyler District Projects

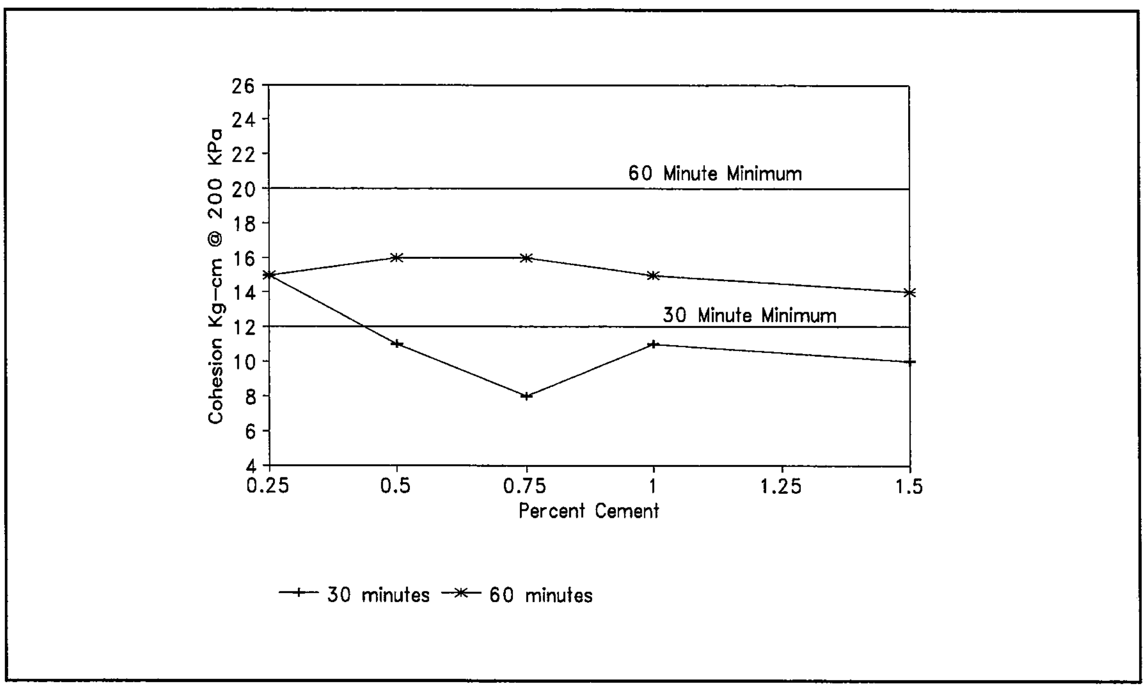

Figure 67. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 9.1% RAC and 10% Water for the Koch Emulsion for the Dallas and Tyler District Projects

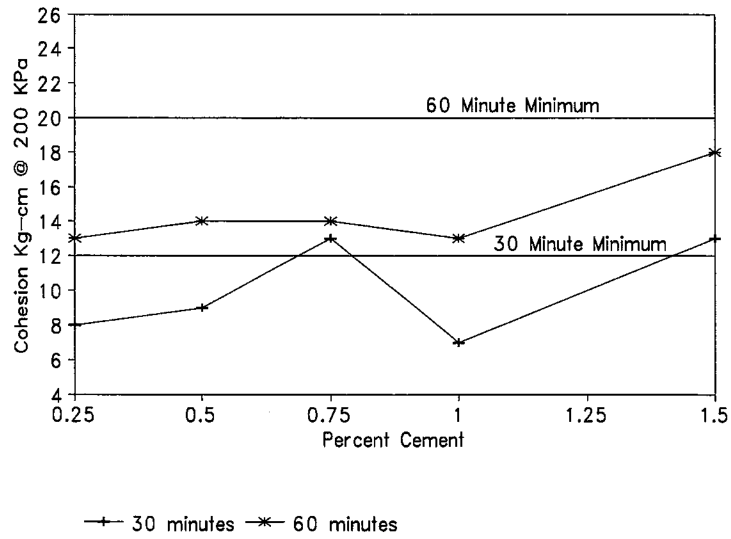

Figure 68. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 9.1% RAC and 12% Water for the Koch Emulsion for the Dallas and Tyler District Projects

The mixing test was then conducted to insure a minimum of 120 sec mix time. All three trial RAC contents had greater than 180 sec mix time.

The WTAT results indicate that all initial trial RAC contents were below the maximum abrasion loss. The WTAT was then rerun at 5.2 percent RAC (8 percent emulsion). The 1-hour soak WTAT yielded a minimum less than 5.2 percent RAC. The 1-hour soak WTAT was not performed until an unacceptable RAC content was found, because 5.2 percent is already below the minimum RAC content specified in Specification and Guidelines for Micro-surfacing Use. The specification gives a acceptable range as 6.0 to 9.0 percent. The 6-day soak WTAT samples gave a minimum RAC content of 5.7 percent. The results are graphed in Figure 69.

The LWT results gave a maximum RAC content of 5.4 percent as shown in Figure 70. This was considered an unacceptable micro-surfacing system based on minimum required RAC in specifications. In addition, the maximum RAC content from LWT was lower than the minimum RAC content determined from the WTAT. The RAC selection criteria is between maximum based on the LWT and the minimum based on the WTAT. Obviously, there was a problem using this approach.

The water content was lowered to 7 and 8 percent and the LWT and WTAT were conducted again. The portland cement content was maintained at 0.75 percent.

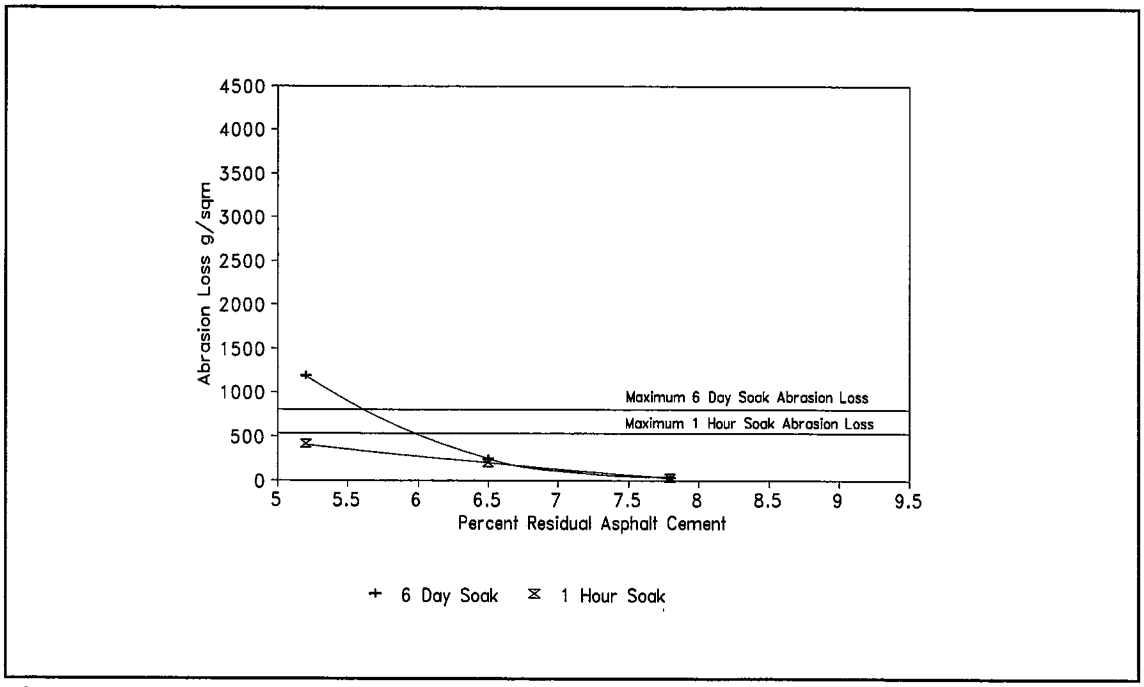

Figure 69. Minimum RAC using Abrasion Loss by one-hour and six-day soak WTAT for the Koch Emulsion for the Dallas and Tyler District Projects

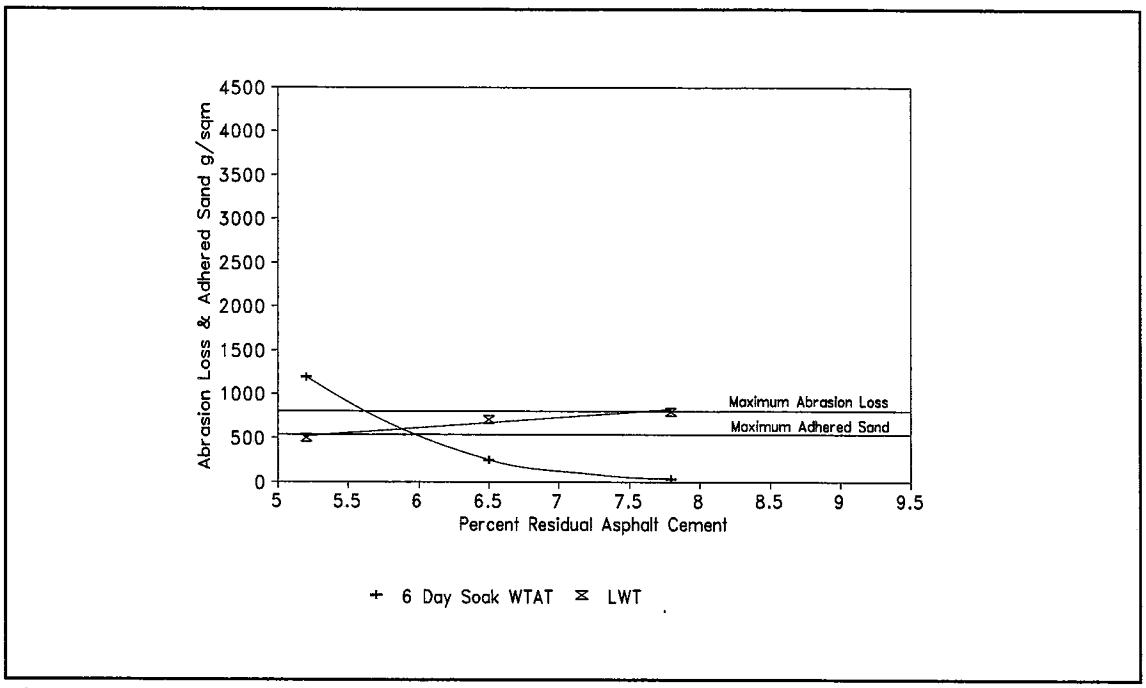

Figure 70. Optimum RAC using six-day soak WTAT and Sand Adhesion by LWT for Koch Emulsion for the Dallas and Tyler District Projects

The 8 percent emulsion (5.2 percent RAC) at the lower water contents could not be mixed for 120 seconds. The trial emulsion contents were changed to 10, 12, and 14 percent which gives RAC contents of 6.5, 7.8, and 9.1 percent, respectively. The WTAT results were all below the minimum values for 1-hour soak and 6-day soak WTAT. A lower trial RAC content of 5.2 percent was tested for the 6-day soak WTAT to obtain a loss greater than 806 g/m^2 (75 g/ft^2). Molding the 5.2 percent RAC samples at 7 and 8 percent water content required the addition of 0.03 percent additive to increase the break time. The 1-hour soak WTAT results showed small variation with small variations in water content. The results are tabulated in Table 14 and graphed in Figures 71-73.

The results from the Koch emulsion WTAT and LWT showed the same trend as that shown in the mix design for the Ergon emulsion. As the water content decreased, the abrasion loss increased and as the water content decreased, the sand adhesion decreased.

This trend could be caused by the RAC content being distributed differently. At lower water contents, the sample surface tends to be coarser indicating that the RAC and fines are settling to the bottom of the sample. This coarser surface leads to a higher abrasion loss. The sand adhesion decrease is due to the asphalt draining to the bottom of the sample. At high water contents, the sample surface can become flushed resulting in more sand adhesion, all based on changes in total fluid content, not just changes in RAC. Figure 74 is a photograph showing the variation obtained in surface texture of WTAT samples with water contents varying from 6 to 12 percent.

Although there was no true optimum residual asphalt selected for the site, a low residual asphalt content of 6.6 percent and a mineral filler content of 0.75 percent were selected for use on the Dallas project and a high residual asphalt content of 8.2 percent and a mineral filler content of 0.75 percent were selected for the Tyler project to determine the impact of varying the emulsion content from that provided by the contractor and material suppliers. The contractors and material suppliers coordinated an experiment on the project by placing their normal mixture using Koch supplied emulsion and Ergon supplied emulsion and TTI specified emulsion and mineral filler contents.

Conclusions

The project staff immediately made the decision that a test that is sensitive to water content could not be used as the basis for selecting asphalt content unless the water content could be fixed and not be a variable. The entire concept of mixture design was then reevaluated to determine the best approach. However, the mixtures being used in the field were performing well if they were properly placed. The mixture design procedure selected must give optimum RAC similar to those designated by the emulsion suppliers.

Based on the three micro-surfacing systems used to evaluate the ISSA Mix Design procedures the following conclusions are made:

Table 14. WTAT and LWT Results for varied Water Contents for Koch Emulsion for the Dallas and Tyler District Projects

Water Content (percent)	1-hour soak Wet Track Abrasion Test ISSA TB 100 minimum residual asphalt cement (percent)	6-day soak Wet Track Abrasion Test ISSA TB 100 minimum residual asphalt cement (percent)	Loaded Wheel Test ISSA TB 109 maximum residual asphalt cement (percent)
10.0	less then 5.2	5.5	5.4
8.0	less then 6.5	6.0	6.9
7.0	less then 6.5	6.1	9.1

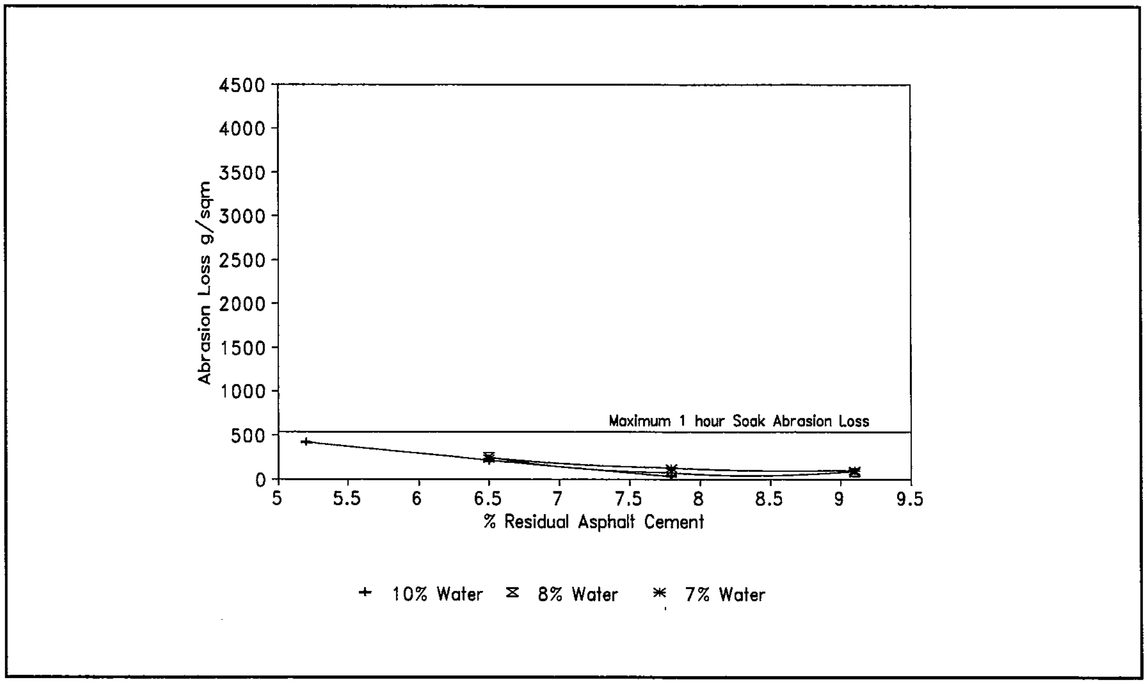

Figure 71. Six-day soak WTAT Results for varied Water Content for the Koch Emulsion for the Dallas and Tyler District Projects

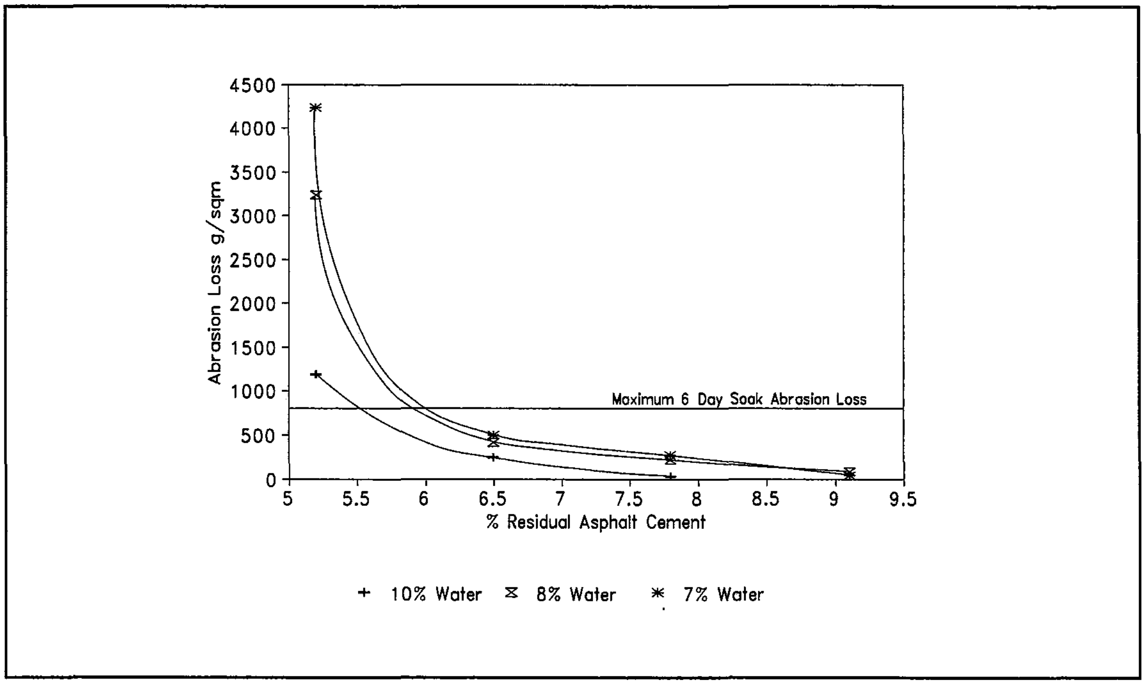

Figure 72. Six-day Soak WTAT Results for varied Water Content for the Koch Emulsion for the Dallas and Tyler District Projects

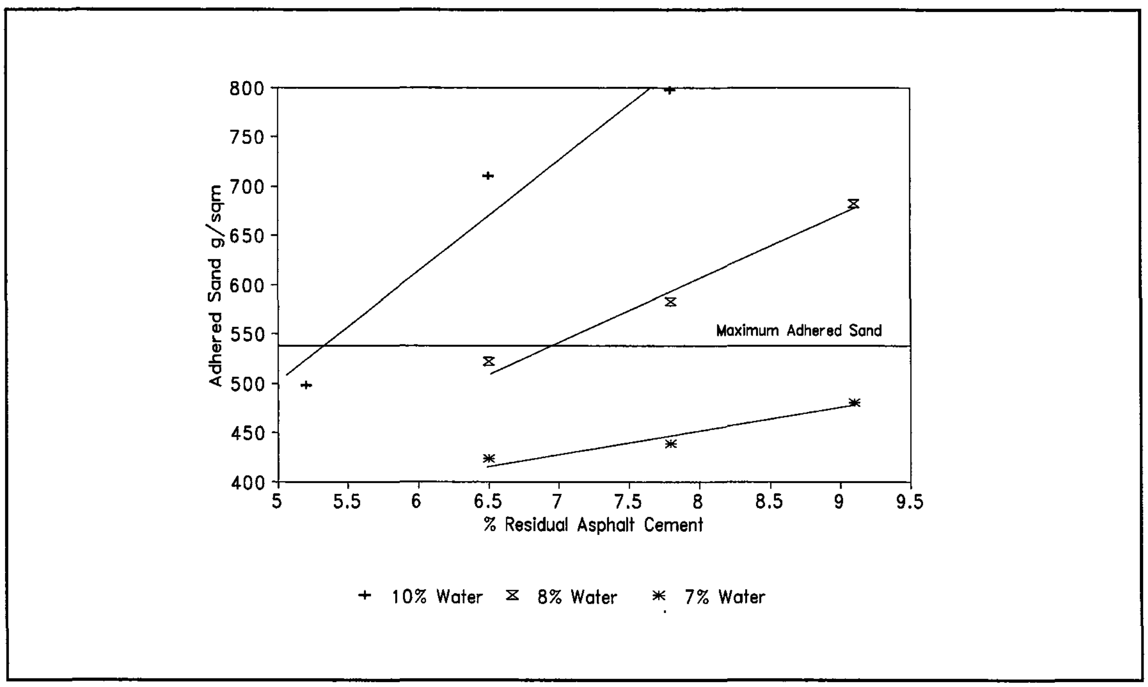

Figure 73. Results of LWT for varied Water Contents for the Koch Emulsion for the Dallas and Tyler District Projects

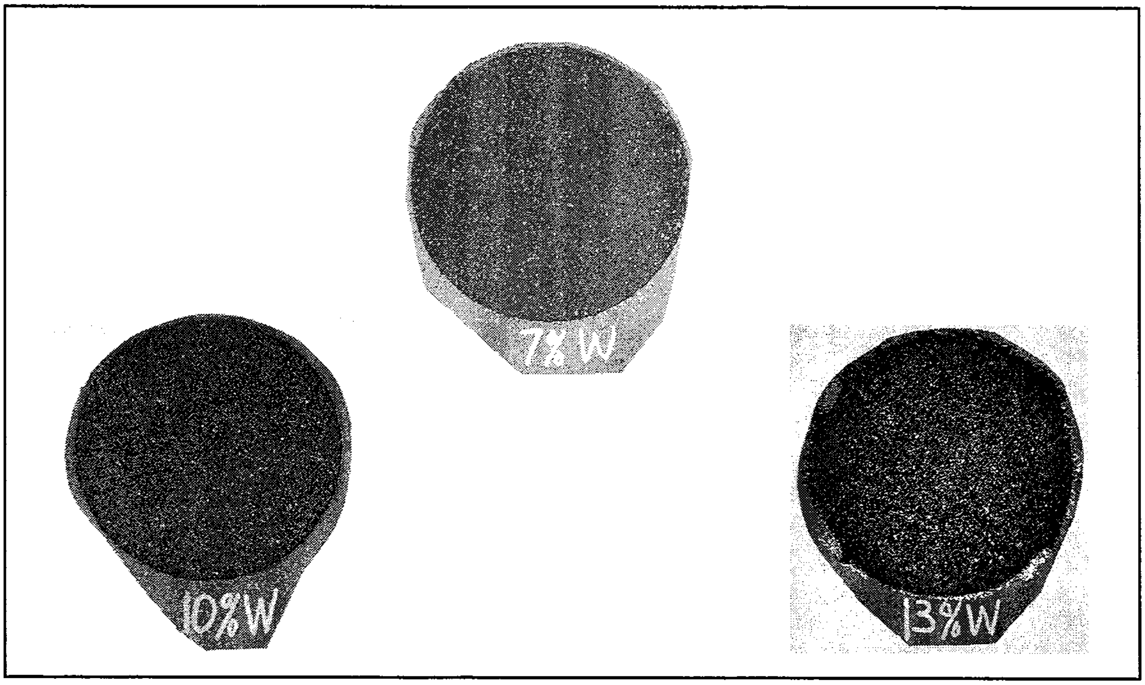

Figure 74 Variation in Surface Texture of WTAT Specimen

1.) There is no agreement between the minimum RAC content found using the 1-hour soak and 6-day soak WTAT;

2.) The LWT showed a large variation in results with small variations in water contents;

3.) Without a method for selecting the proper consistency, the mixture design procedure is inadequate for selecting the optimum RAC content;

Based on the three mix designs performed to evaluate the ISSA mix design procedure, the following recommendations were made;

1.) Further research was needed to develop a test method to select the proper consistency (i.e., water content) of the micro-surfacing system;

2.) The LWT should be discontinued due to the impact of water content and based on the results of the repeatability test; and

3.) The data suggest that there is a need to replace the method used to select the optimum RAC content.

FALL 1993 EVALUATION OF TTI MODIFICATION OF ISSA MIX DESIGN PROCEDURE

The ISSA mix design procedure was modified by eliminating the loaded wheel test (LWT) and the 1-hour soak wet track abrasion test (WTAT). A volumetric determination of the theoretical optimum residual asphalt cement (RAC) content was added to the procedure. The ISSA test procedures kept in the mix design procedure are used more as performance tests than mix design tests (13). The following is an outline of the modified mix design.

The first phase of the mix design was to determine the trial RAC contents. The trial optimum RAC contents were determined using the centrifuge kerosene equivalent (CKE) method based on ASTM D5148-90. The appendix to ASTM D5148-90 is used to determine an approximate bitumen ratio (ABR). This procedure is designed for hot mix asphalt concrete. For micro-surfacing, an additional 1.5 percent RAC content is required to provide values similar to those designated by the emulsion suppliers. This addition corrects for the different viscosity due to the polymer modified asphalt emulsion and because the aggregate is 100 percent crushed. Trial mixtures were tested at the ABR + 1.5 percent value, ± 0.5 percent RAC content and ± 1.0 percent RAC content. These trial RAC contents were used in the remaining test procedures.

The next phase of the mix design procedure was to determine the water content. An optimum water content was determined for each trial emulsion content with 1.0 percent portland cement. The optimum water content was selected using ISSA TB 102, sections 4.1-4.5 and 5.1.1. The optimum water content was selected at the minimum water content that resulted in a mix time equal to or greater than 150 seconds. The water content selected as optimum was judged by the operator for consistency. If there seemed to be excessive fluids, the mixing time test was rerun with a small amount of additive. All subsequent tests were performed at these water contents. If any additive was used in the mixing time test, it was reported and the additive content was used in all subsequent tests.

The wet cohesion test was used to select the minimum mineral filler that met the specifications for a quick set, quick traffic system. The portland cement contents tested were 0.25 to 2.0 percent. The test was performed for each RAC content with the appropriate water and additive contents selected above. The lowest portland cement content for each RAC content that gave a torque of 16 kg-cm at 30 minutes and 20 kg-cm at 60 minutes was selected for all subsequent testing.

The 6-day soak WTAT was performed for each RAC content with the optimum water and minimum portland cement contents determined for each RAC content. The optimum RAC content was selected at 0.5 percent higher than the lowest RAC content that passed the WTAT with an abrasion loss less than 806 g/m^2 (75 g/ft^2) for a 6-day soak.

Four projects sites were selected to evaluate the TTI modified mix design procedure. The projects were completed in late summer, early fall of 1993. The project sites were located in the following districts: Houston, San Antonio, Bryan and Corpus Christi.

Materials

The material used in the mix design evaluation was representative of the material used in construction in the field. All materials met the specifications given in TxDOT draft micro-surfacing procedure, March 1993. The emulsion used in all projects was CSS-1P or CSS-1hP. The aggregate was Texas Grade II for coarse graded surface coarse. The mineral filler was non-air entrained, lump free portland cement. Distilled water was used in the preparation of the samples. Only set retarding additives approved for the project were used if needed. Table 15 gives the location site and material supplier for the four selected project sites.

ISSA test procedures used in the TTI laboratory for micro-surfacing mixture design are described in Report 1289-1 (27). One exception to the procedures was that the wet cohesion test was performed with material passing a 9.50 mm (3/8 in) sieve and a 10 mm sample mold. A minimum of three samples was tested at each formulation. All percentages are based on the dry weight of aggregate. The procedure for the volumetric determination of theoretical residual asphalt cement content is described in Chapter 6.

The material tests performed were gradation of the aggregate and distillation of the emulsion to determine the percent residual asphalt cement (RAC). Aggregate gradation was determined using TxDOT test procedure Tex 200-F (28). A comparison of the aggregate gradation used in the TTI modified mixture design and that used in the contractor's mix design is graphed in Figures 75-78.

The RAC was determined using ASTM D-244 oven evaporation procedure for percent residue. The RAC was 65.4 percent for the Ergon CSS-1hP for projects in Houston and San Antonio, 64.8 percent for the Jean Lefebvre Emulsion for the Corpus Christi project and 64.4 percent for the Koch CSS-1P for the Bryan project.

Mix Design Results and Discussion

The mixture design results are summarized in Table 16 and gives a comparison between the TTI modified mixture design and the mix design supplied by the contractor. This shows that the TTI optimum RAC values were close to those provided by the emulsion suppliers. The results for each site are described in the following sections.

Table 15. Description of Materials for the Projects

LOCATION	AGGREGATE	ASPHALT EMULSION	MINERAL FILLER
Corpus Christi District	Capital Aggregates (Delta Materials) Marble Falls, TX Texas Grade II coarse graded surface aggregate	Jean Lefebvre Technology Orlando, Fl	Portland Cement Type I
San Antonio District	Capital Aggregates McDonna, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion Waco, TX CSS-1hP	Portland Cement Type I
Houston District	Capital Aggregates (Delta Materials) Marble Falls, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion Waco, TX CSS-1hP	Portland Cement Type I
Bryan District	Capital Aggregates (Delta Materials) Marble Falls, TX Texas Grade II coarse graded surface aggregate	Koch Material Company Salina, KS CSS-1P	Portland Cement Type I

Table 16. Mix Design Results and Comparison of TTI and Contractor Mixture Design, all Quantities are Based on Dry Weight of Aggregate

Location	Tester	Residual Asphalt Cement Percent	Mineral Filler Percent	Water Percent
Corpus Christi	Contractor	7.2	1.00	10.0
	TTI	7.0	1.00	*
San Antonio	Contractor	6.35	1.00	6.5*
	TTI	6.7	1.75	*
Houston	Contractor	7.47	1.00	7.5*
	TTI	7.5	0.75	*
Bryan	Contractor	7.7 ± 0.5	1.8 ± 0.25	9 - 13
	TTI	7.0	2.00	*

* As needed for consistency

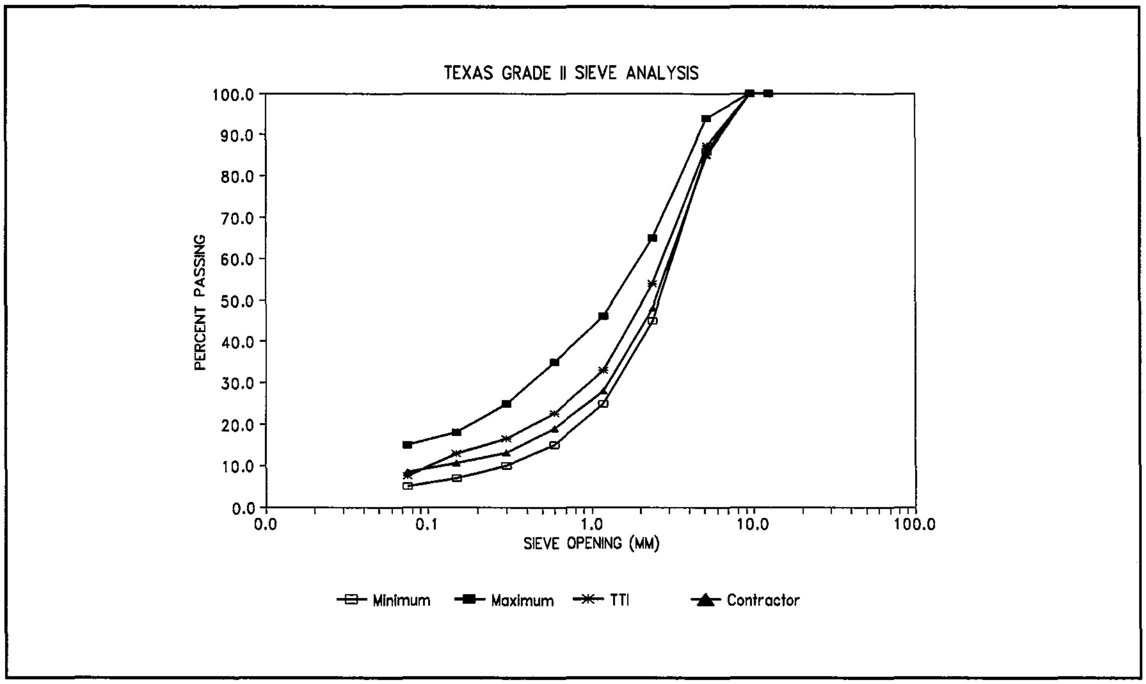

Figure 75. Aggregate Gradation used in TTI Mixture Design for the Corpus Christi District Project and the Gradation from the Mixture Design supplied by the Contractor

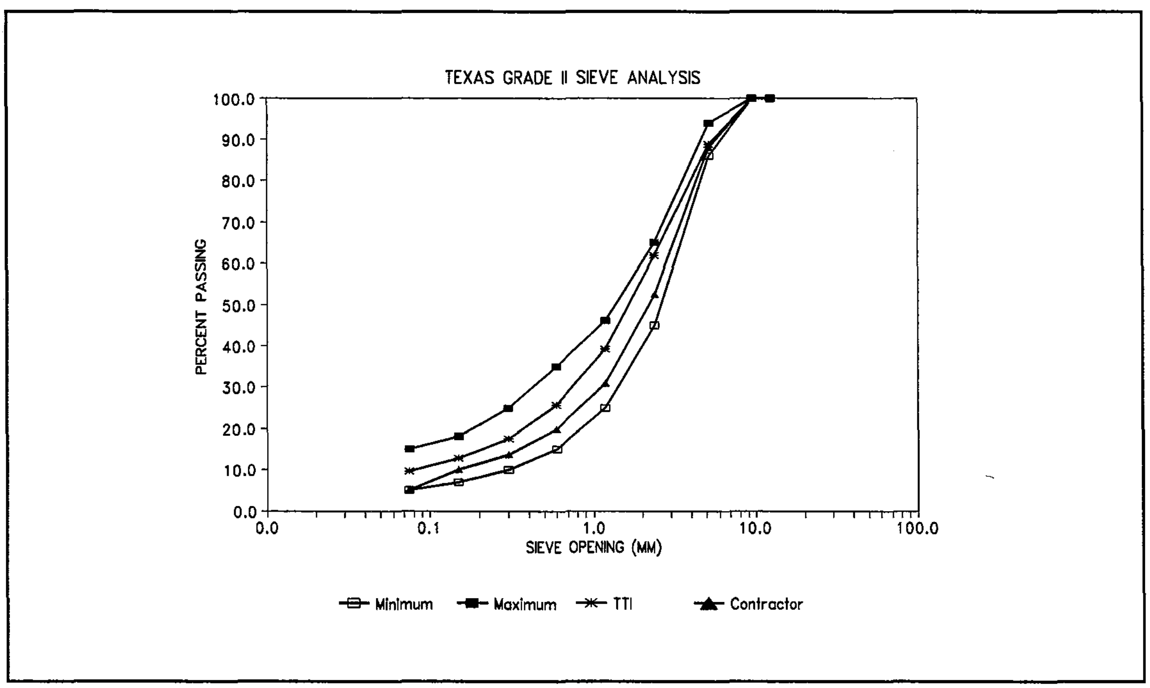

Figure 76. Aggregate Gradation used in TTI Mixture Design for the San Antonio District Project and the Gradation from the Mixture Design supplied by the Contractor

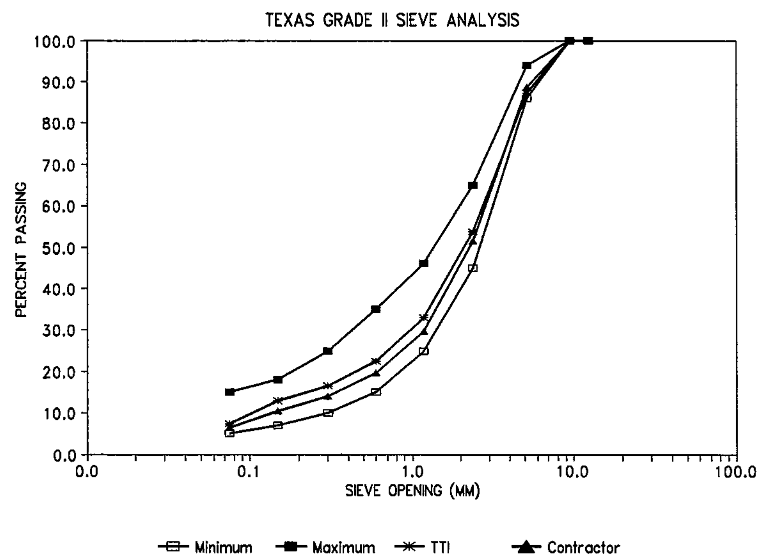

Figure 77. Aggregate Gradation used in TTI Mixture Design for the Houston District Project and the Gradation from the Mixture Design supplied by the Contractor

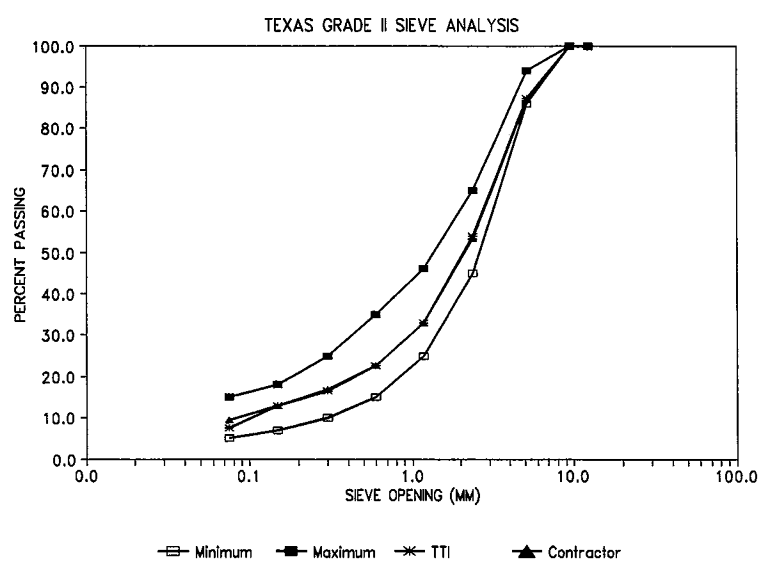

Figure 78. Aggregate Gradation used in TTI Mixture Design Procedure for the Bryan District Project and the Gradation from the Mixture Design supplied by the Contractor

Corpus Christi - The mixture design for this project site was done under guidelines for ISSA mixture design procedure and was redone using TTI modified mixture design. The following is the ISSA mixture design results. The three initial trial emulsion contents were 9, 11 and 13 percent. The percent residue of the emulsion was 64.8 percent. The respective trial RAC contents were 5.8, 7.1, and 8.4 percent.

The optimum water contents were 14 percent at the 5.8 percent RAC, 14 percent at the 7.1 percent RAC and 12 percent at the 8.4 percent RAC. The wet cohesion test was performed at the following portland cement contents: 0.5, 0.75, 1.0, 1.5, and 2.0 percent. The wet cohesion test results are graphed in Figures 79-81. The optimum portland cement contents were 1.0 percent for all RAC contents. All subsequent testing was performed at these quantities.

The WTAT results are graphed in Figure 82. The minimum RAC content was 5.8 percent for the 1-hour soak and 6.5 percent for the 6-day soak.

The LWT and 6-day soak WTAT results are graphed in Figure 83. The maximum RAC was 8.4 percent. The optimum RAC was 7.5 percent using the ISSA method for determining optimum RAC.

The following is the TTI modified mixture design results. The CKE procedure was performed to determine the approximate optimum RAC content of 7.5 percent. The 5 initial trial RAC contents were 6.5, 7.0, 7.5, 8.0, and 8.5 percent

The mixing time test was rerun for the above RAC contents. The optimum water contents are given in Table 17.

The wet cohesion test was not rerun. The optimum portland cement content at all RAC contents was selected at 1.0 percent.

The WTAT was conducted at the above quantities. The minimum RAC content passing the WTAT was 6.5 percent as shown in Figure 84. The optimum was selected at 0.5 percent higher than the minimum RAC content giving an optimum RAC content of 7.0 percent.

San Antonio - The mixture design for this project was started under the ISSA mixture design guidelines and finished under TTI modified mixture design. Three trial emulsion contents, selected based on the contractor's mixture design, were 7, 9, and 11 percent. The percent residue of the emulsion was 63.9 percent. The respective RAC contents were 4.5, 5.8, and 7.0 percent.

The water content was selected for each trial RAC content by determining the minimum water content that gave a 150 second mix time with 1.0 percent portland

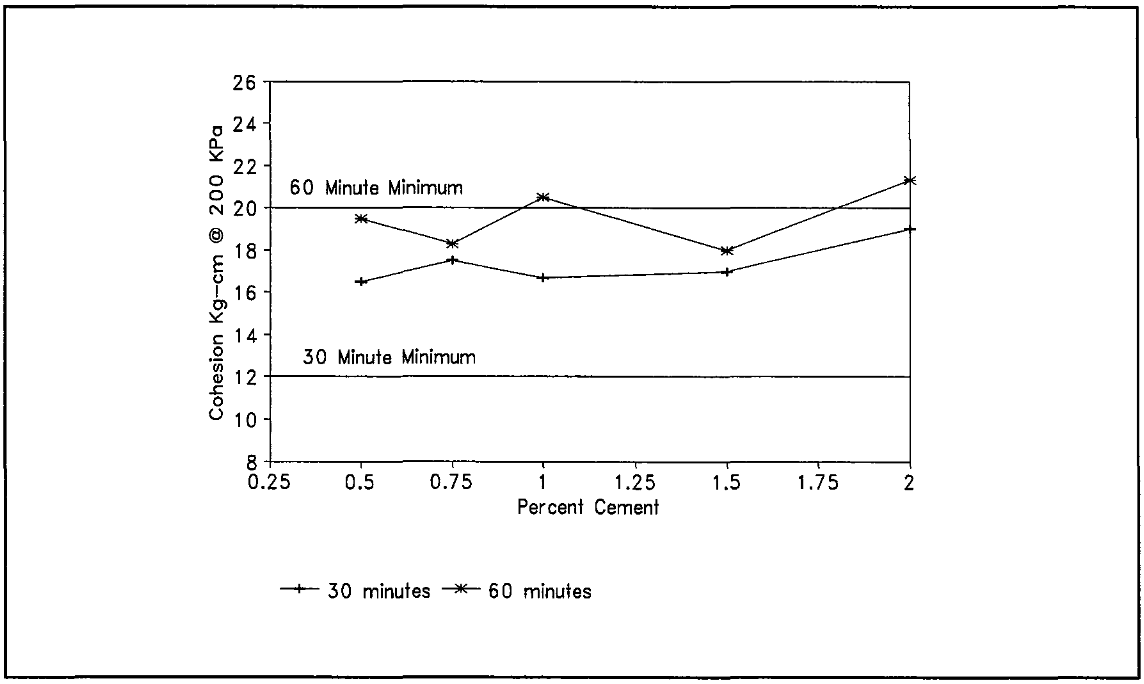

Figure 79. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 5.8% RAC and 14% Water for the Corpus Christi District Project

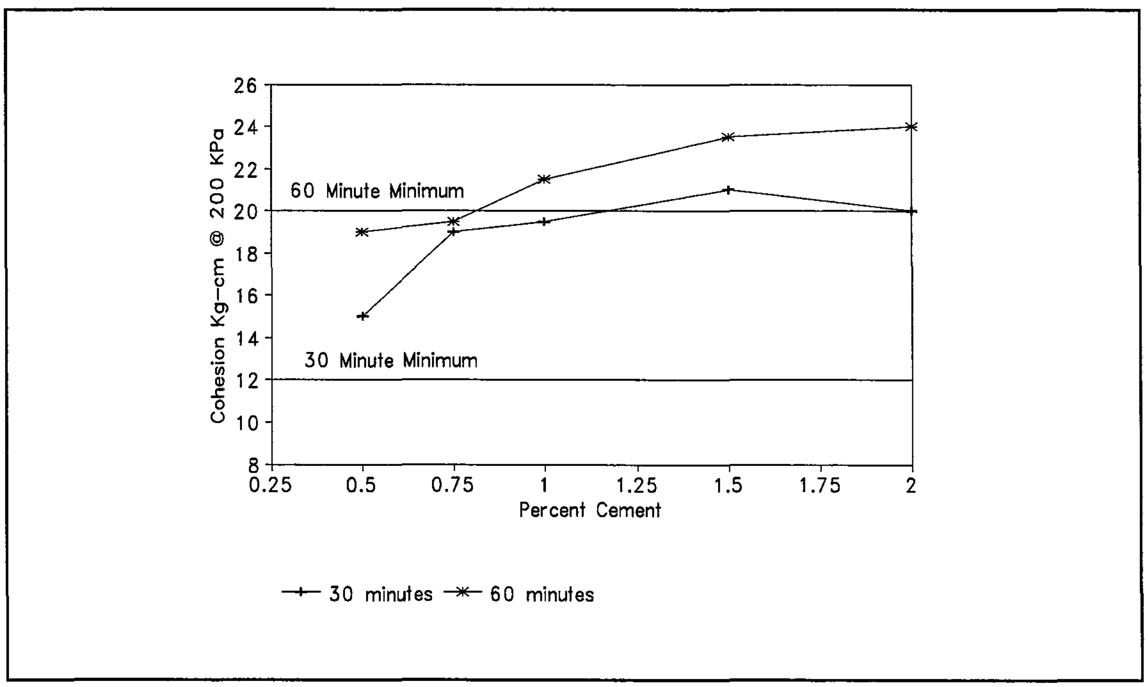

Figure 80. Wet Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.1% Residual Asphalt Cement and 14% Water for the Corpus Christi District Project

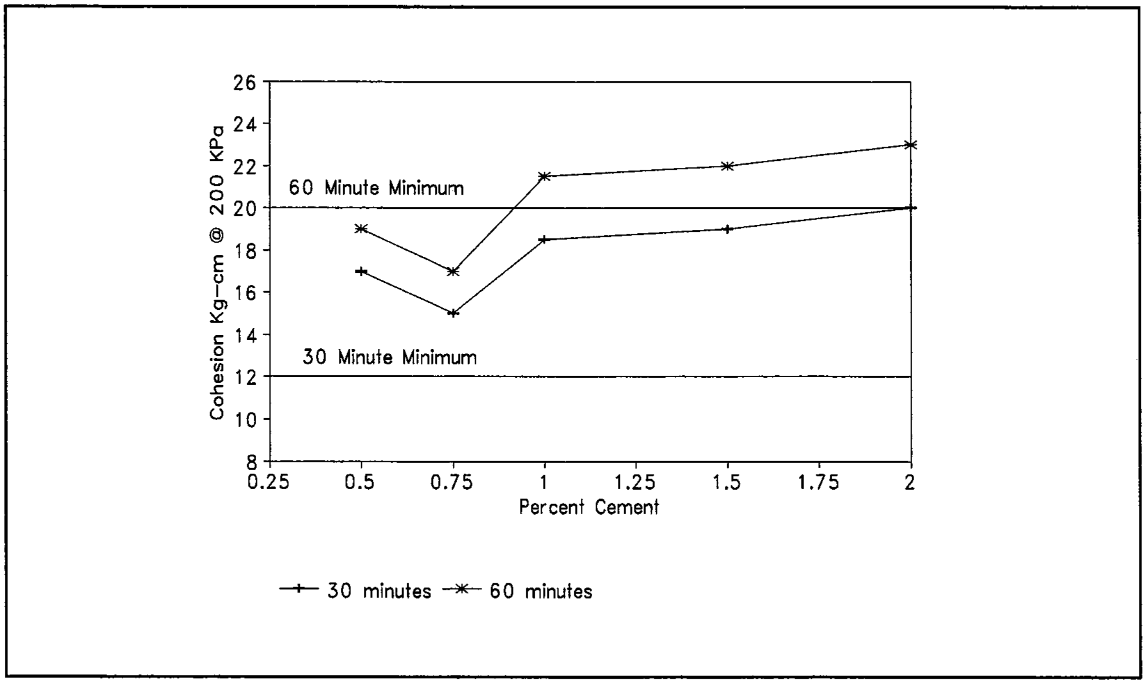

Figure 81. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.4% RAC and 12% Water for the Corpus Christi District Project

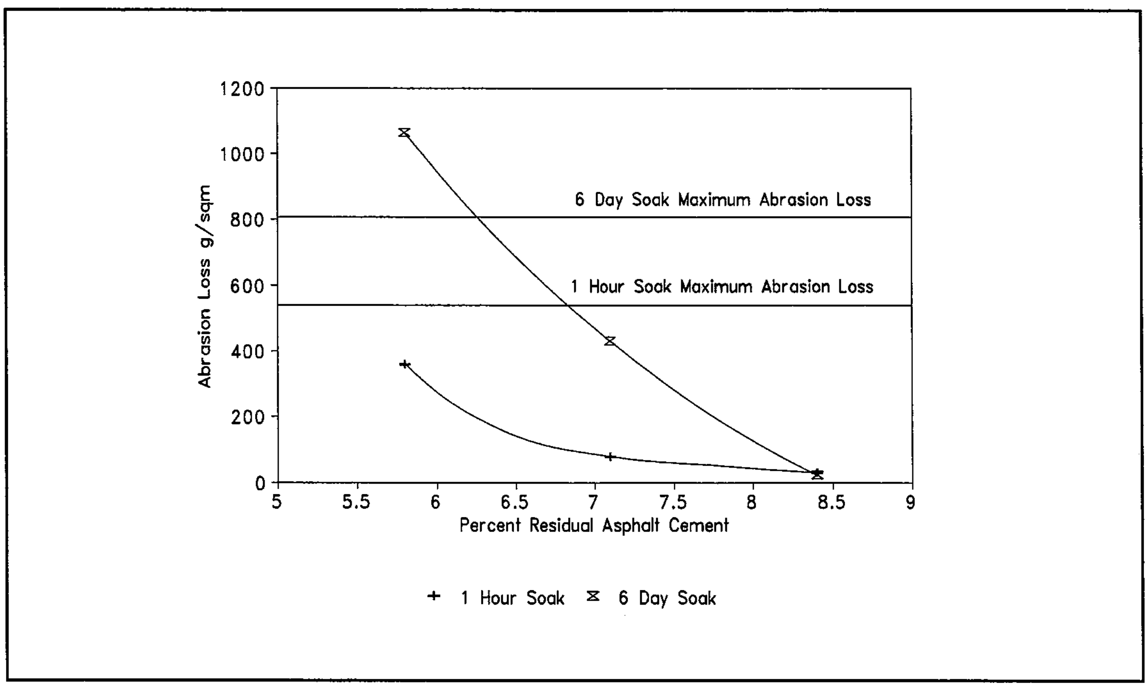

Figure 82. Minimum RAC using Abrasion Loss by one-hour and six-day soak WTAT for the Corpus Christi District Project

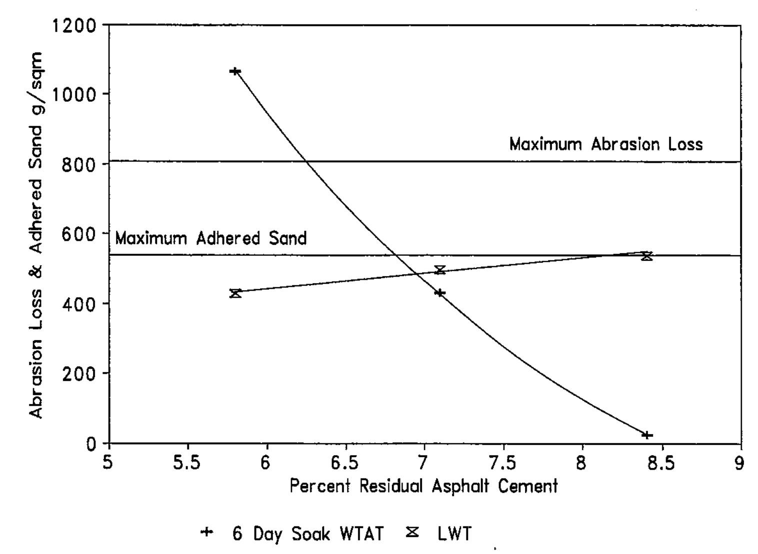

Figure 83. Optimum RAC using six-day soak WTAT and Sand Adhesion by LWT for the Corpus Christi District Project

Table 17. Water Content Selected for the Trial RAC Contents

RAC, percent	Water Content, percent
6.5	12.0
7.0	11.5
7.5	11.0
8.0	10.5
8.5	10.0

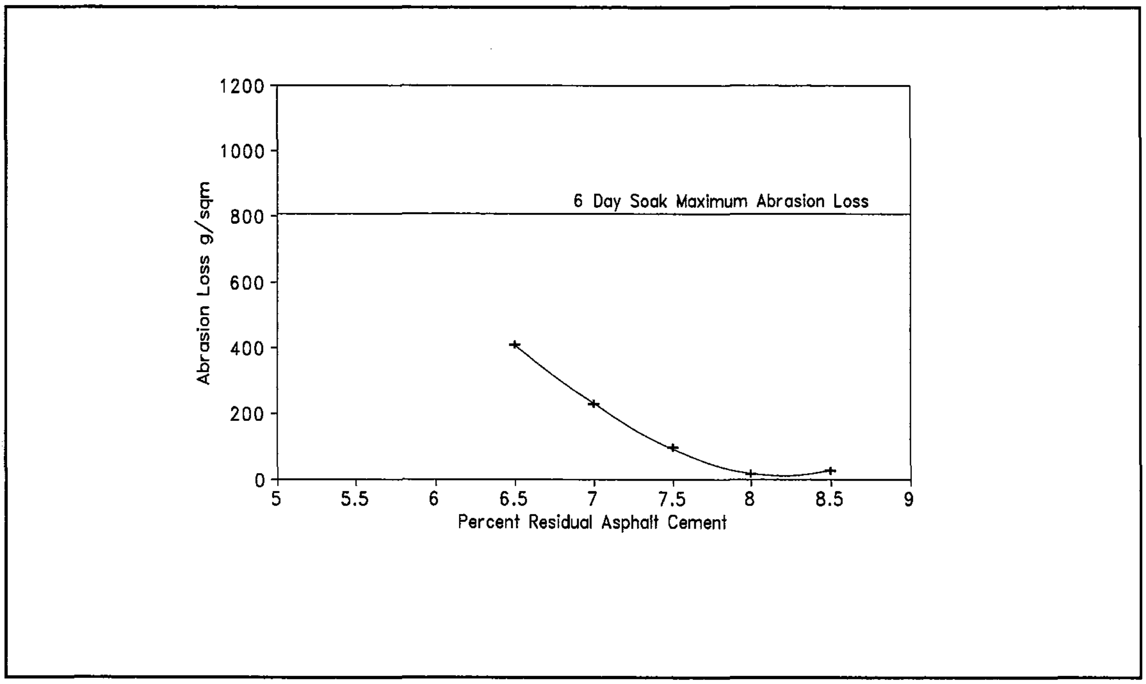

Figure 84. Minimum RAC using Abrasion Loss by six-day soak WTAT for the Modified TTI Mixture Design for the Corpus Christi District Project

cement. The water contents that gave a minimum 150 second mix time at 1.0 percent portland cement were judged to be excessive by the operator. The mixing time test was rerun with 0.02 percent additive. The water content that gave a minimum 150 second mix time with 0.02 percent additive had a better consistency. The selected water contents were 9 percent for 4.5 percent RAC, 7 percent for 5.8 percent RAC, and 7 percent for the 7.0 percent RAC content.

The wet cohesion test was performed at the above trial RAC contents and with the appropriate water content and additive. The results are graphed in Figures 85-87. The optimum portland cement content selected was the cement content that gave a peak in the data. All three trial RAC contents resulted with the peak at 1.75 percent portland cement; however, values were acceptable for all the trial RAC at 1 percent and above.

The 6-day soak WTAT was performed with the quantities determined above. The results are in Figure 88. The minimum RAC content was 5.2 percent. The optimum RAC content was selected by the method for the TTI modified mix design procedure using the CKE. The estimated optimum RAC content was determined to be 7.2 percent giving five trial RAC contents of 6.2, 6.7, 7.2, 7.7, and 8.2 percent. The optimum was selected at 0.5

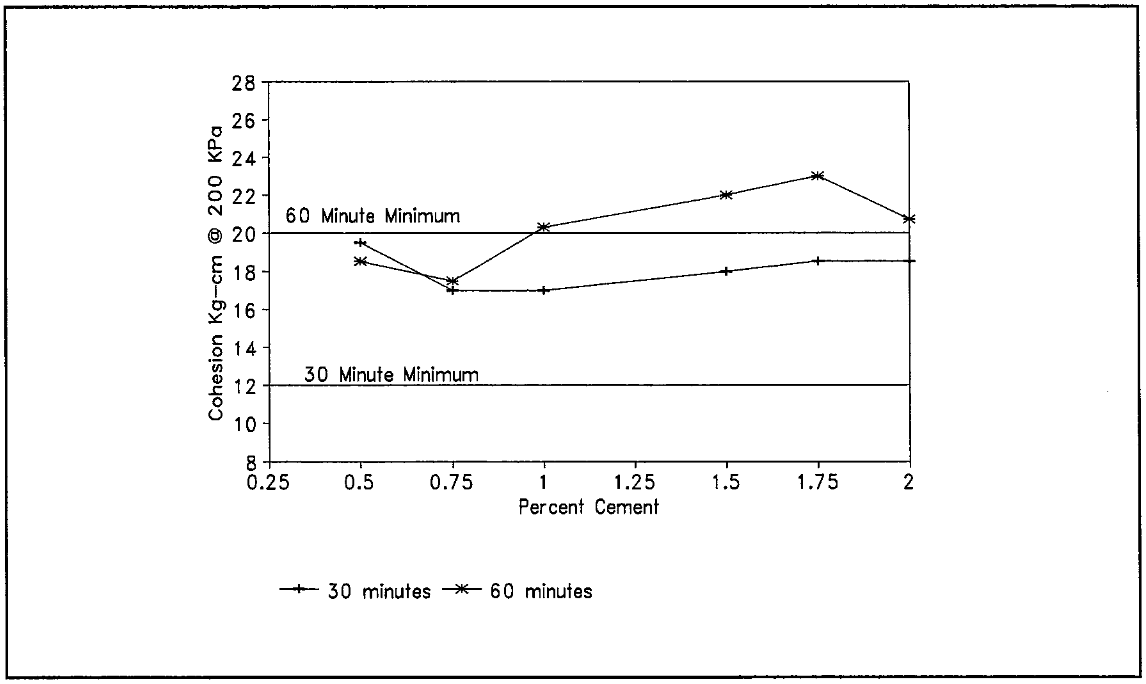

Figure 85. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 4.5% RAC and 9% Water for the San Antonio District Project

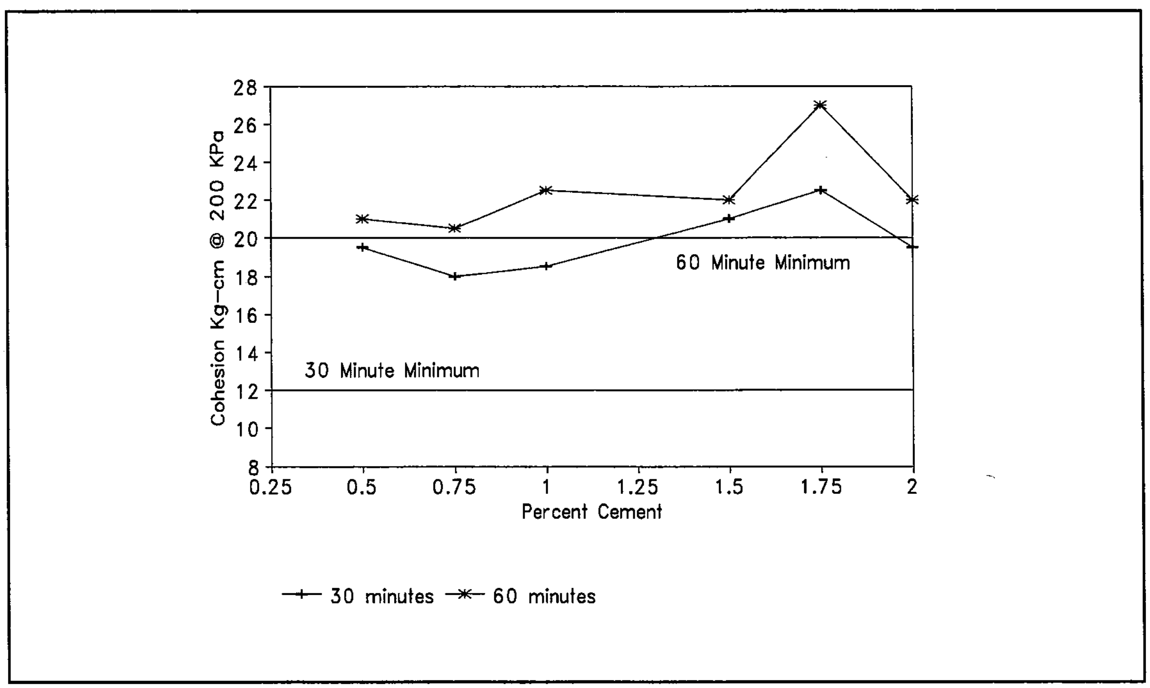

Figure 86. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 5.8% RAC and 7% Water for the San Antonio District Project

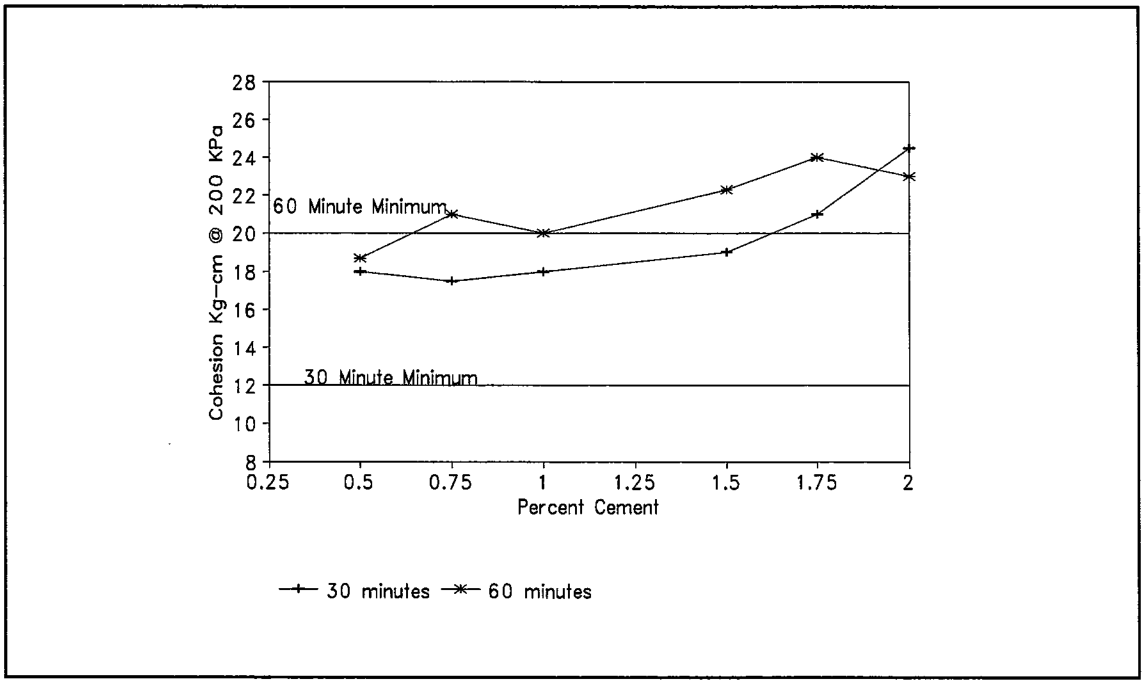

Figure 87. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.0% RAC and 7% Water for the San Antonio District Project

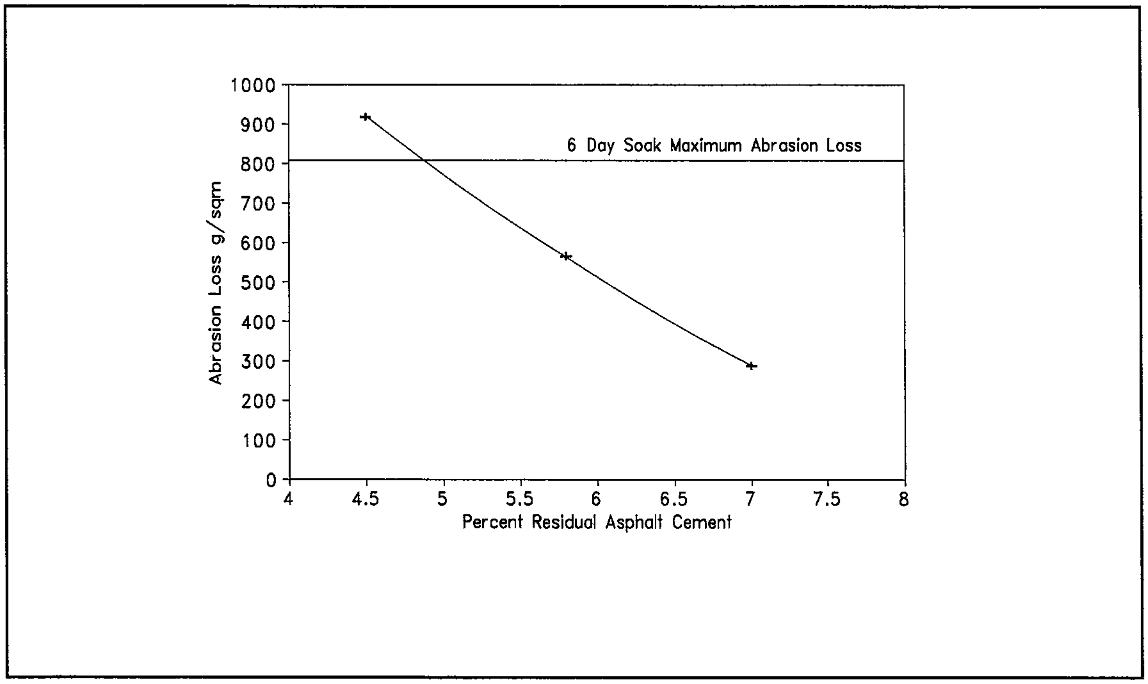

Figure 88. Minimum RAC using Abrasion Loss by six-day WTAT for the San Antonio District Project

percent higher than the lowest passing trial RAC. Since the minimum RAC content based on the WTAT of 5.2 percent was lower than the minimum of 6.2 percent selected using the CKE procedure, the optimum was selected as 6.7 percent (10.5 percent emulsion at 63.9 percent residue) which is 0.5 percent greater than the minimum.

Houston - The five trial RAC contents were 6.5, 7.0, 7.5, 8.0, and 8.5 percent based on an estimated optimum RAC content of 7.5 percent from the CKE procedure. The mixing time test was run to determine the minimum water content that gave 150 second or greater mix time for the trial RAC contents with 1.0 percent portland cement. Table 18 shows the results. All further testing was performed with the water contents determined in this step.

The wet cohesion test was performed at the trial RAC contents for 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, and 2.5 percent portland cement with the appropriate water content. The results are graphed in Figures 89-93. Table 18 gives the selected optimum cement content for each trial RAC content and the appropriate water content. All subsequent testing was performed at these quantities.

The results of the WTAT are graphed in Figure 94. The minimum RAC content passing the 6-day soak WTAT was 8.5 percent. If the optimum was selected at 0.5 percent higher than the minimum RAC content passing, the optimum would be 9.0 percent.

Selecting the optimum water content at the minimum water content that has a 150 second or greater mix time yielded water contents that were too low. The low water content resulted in excessive abrasion loss at the lower RAC contents. This again demonstrated the need for a better method of defining required fluid content.

Table 18. Optimum Portland Cement and Water Content for each Trial RAC Content for the Houston District

RAC, percent	Water Content, Percent	Portland Cement Content, percent
6.5	8.5	0.50
7.0	7.5	0.25
7.5	7	0.75
8.0	6.5	0.50
8.5	6.5	0.50

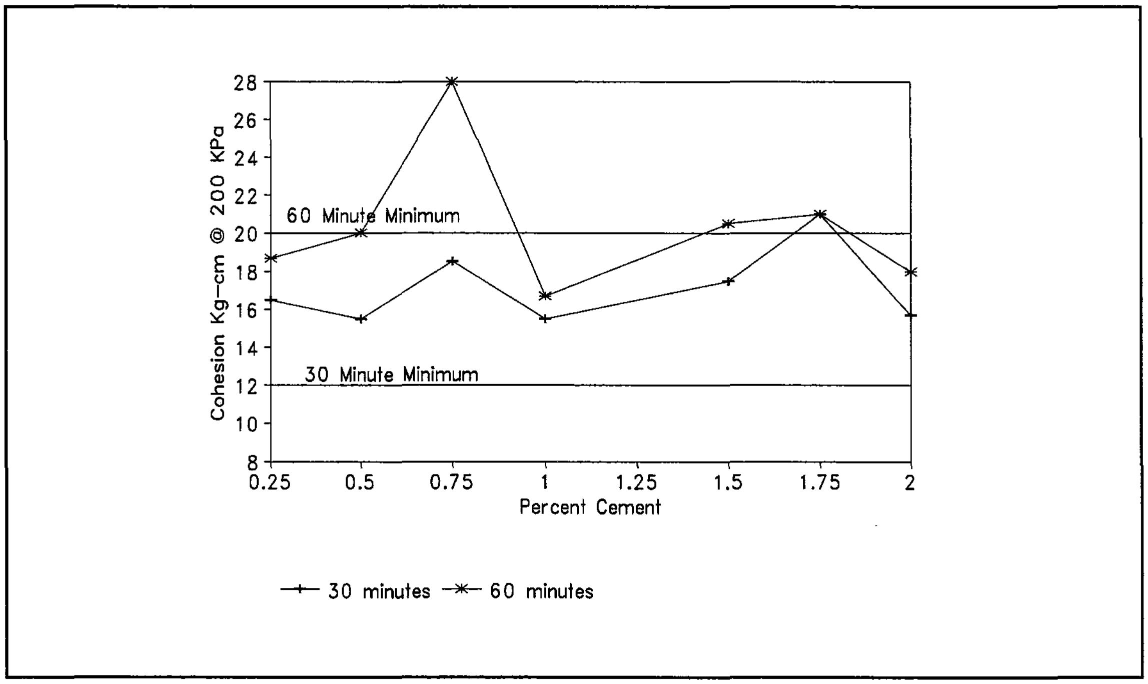

Figure 89. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.5% RAC and 8.5% Water for the Houston District Project

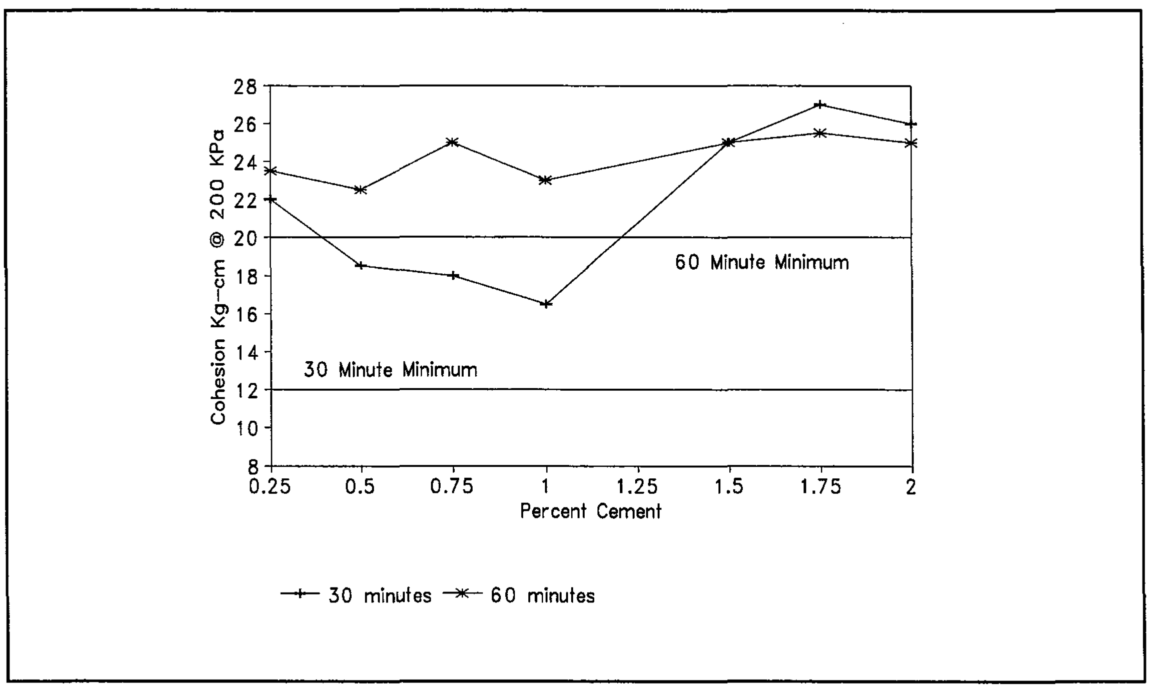

Figure 90. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.0% RAC and 7.5% Water for the Houston District Project

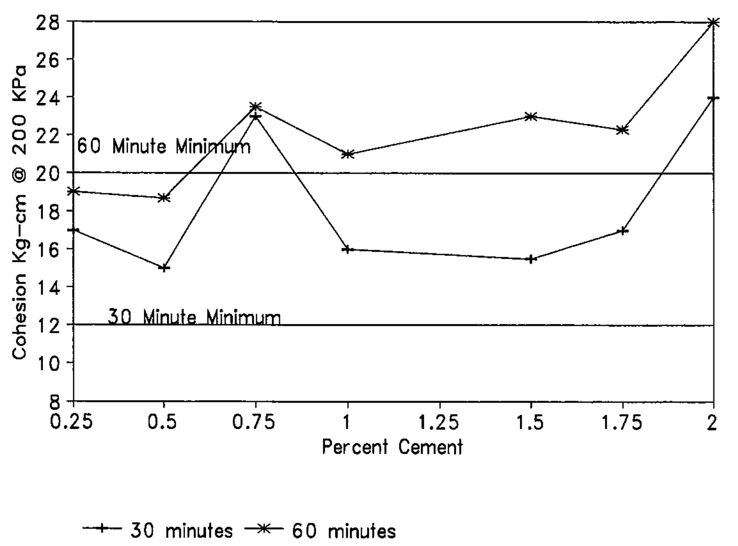

Figure 91. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.5% RAC and 7% Water for the Houston District Project

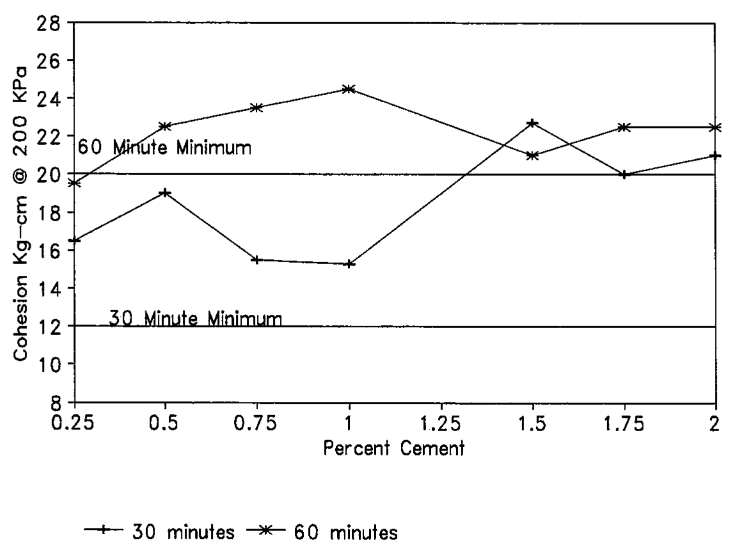

Figure 92. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.0% RAC and 6.5% Water for the Houston District Project

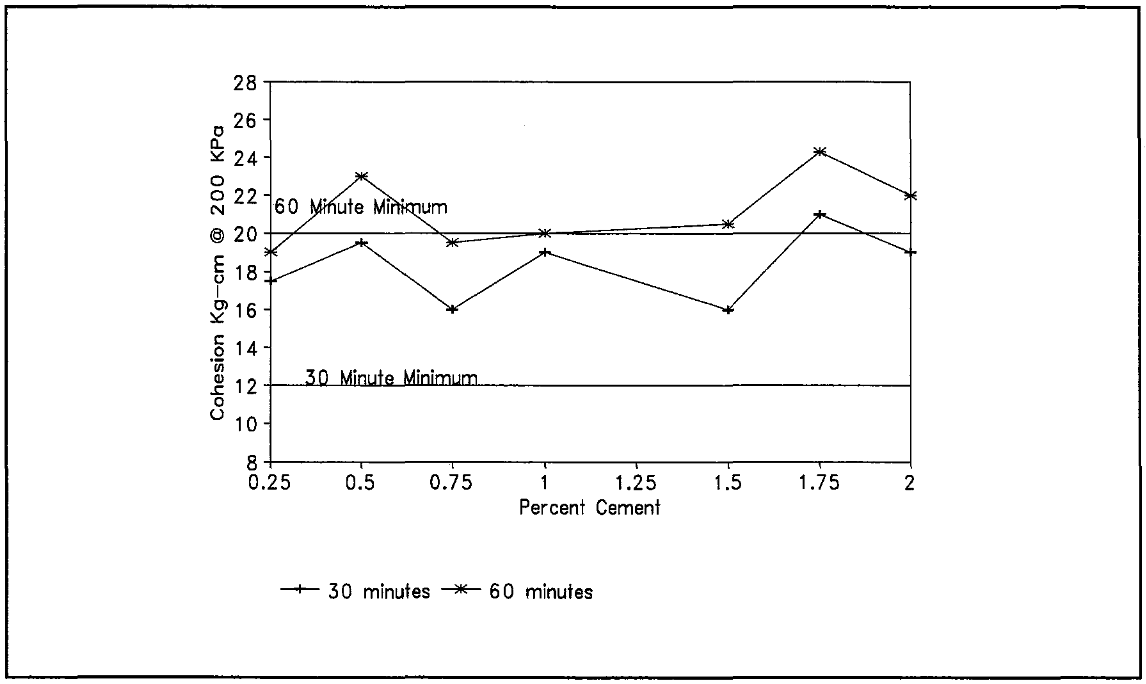

Figure 93. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.5% RAC and 6.5% Water for the Houston District Project

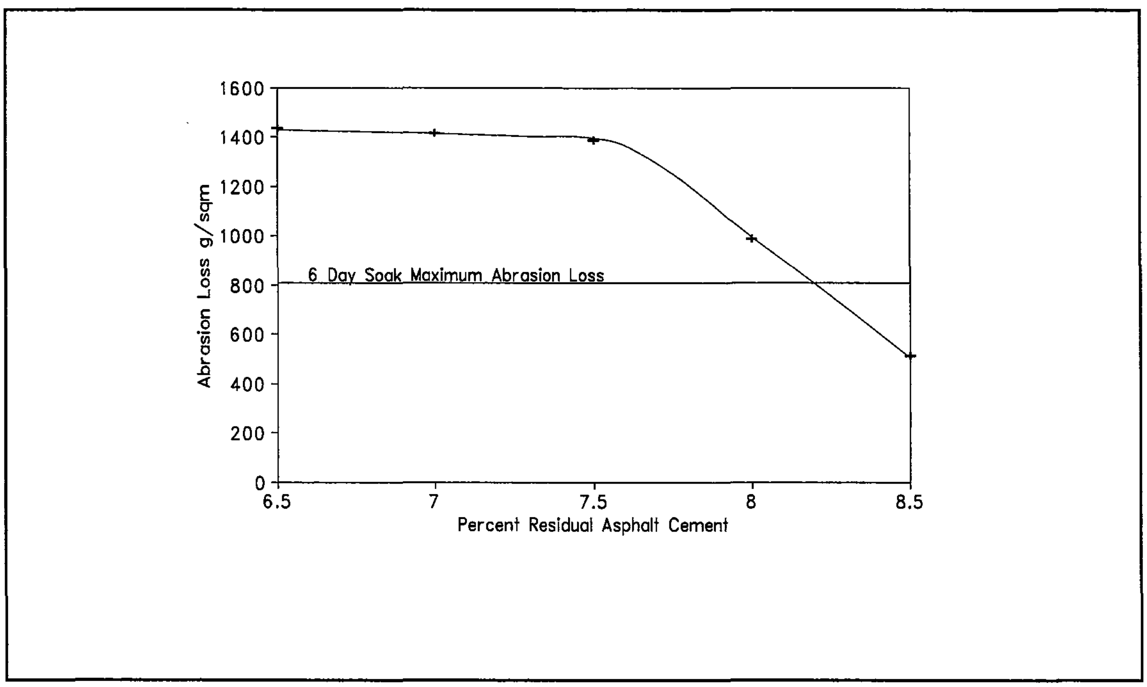

Figure 94. Minimum RAC Abrasion Loss by six-day WTAT with Water Contents of 6.5 to 8.5% for the Houston District Project

The water content was increased by 2.0 percent and the WTAT was rerun. The results are in Figure 95. The minimum RAC content found at the higher water contents was 7.0 percent. The optimum was then selected at 0.5 percent higher. The optimum was 7.5 percent RAC (11.7 percent emulsion at 64.4 percent residue).

Bryan - The five trial RAC contents were 6.5, 7.0, 7.5, 8.0, and 8.5 percent. The water contents selected for each RAC are given in Table 19. The mixing time test was run to determine the minimum water content that gave 150 second or greater mix time for the trial RAC contents with 1.0 percent portland cement. All further testing was performed with the water contents determined in this step.

The wet cohesion test was performed at 0.25,0.5, 0.75, 1.0, 1.5, and 2.0 percent cement. The results are given in Figures 96-100. All subsequent testing was done with the above quantities.

The 6-day soak WTAT results are given in Figure 101. The minimum passing RAC content was 6.5 percent. The optimum RAC content was selected at 7.0 percent.

Conclusions

Based on the four micro-surfacing systems used to evaluate the TTI modified mix design, the following conclusions were made.

1. Selecting the optimum water content based on a mixing time of 150 seconds proved ineffective. One slurry system had excessive fluids and another slurry system had insufficient fluids.

2. There is a need to develop a test to measure consistency of the slurry.

3. Optimum RAC can be determined using a combination of the WTAT and CKE which will be close to those emulsion suppliers would normally recommend.

SUMMER 1994 EVALUATIONS OF TTI MODIFIED MIX DESIGN WITH ADDITION OF MODIFIED CUP FLOW TEST

The TTI modified mixture design was used in the Summer of 1994 with the modification that the modified cup flow test was used to determine consistency. The modified cup flow test was used to determine an optimum water content for each trial RAC and trial portland cement content.

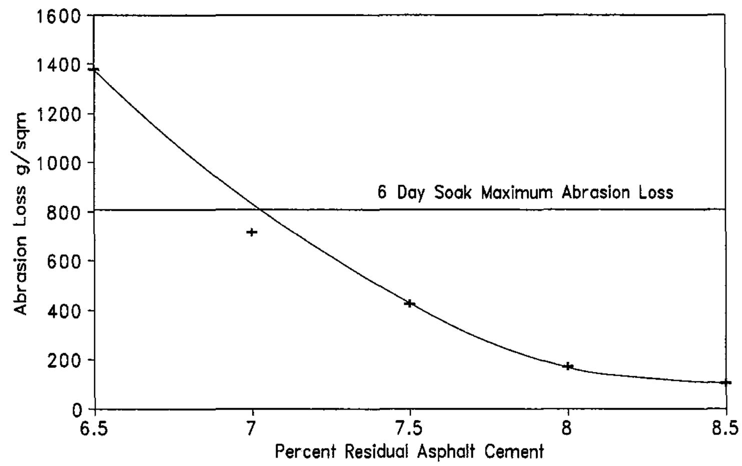

Figure 95. Minimum RAC using Abrasion Loss by six-day WTAT with Water Contents of 8.5 to 10.5% for the Houston District Project

Table 19. Optimum Portland Cement and Water Content for each Trial RAC Content for the Bryan District

RAC, Percent	Water Content, percent	Portland Cement Content, percent
6.5	8.5	2.00
7.0	8.3	1.75
7.5	8.0	2.00
8.0	7.8	2.00
8.5	7.5	2.00

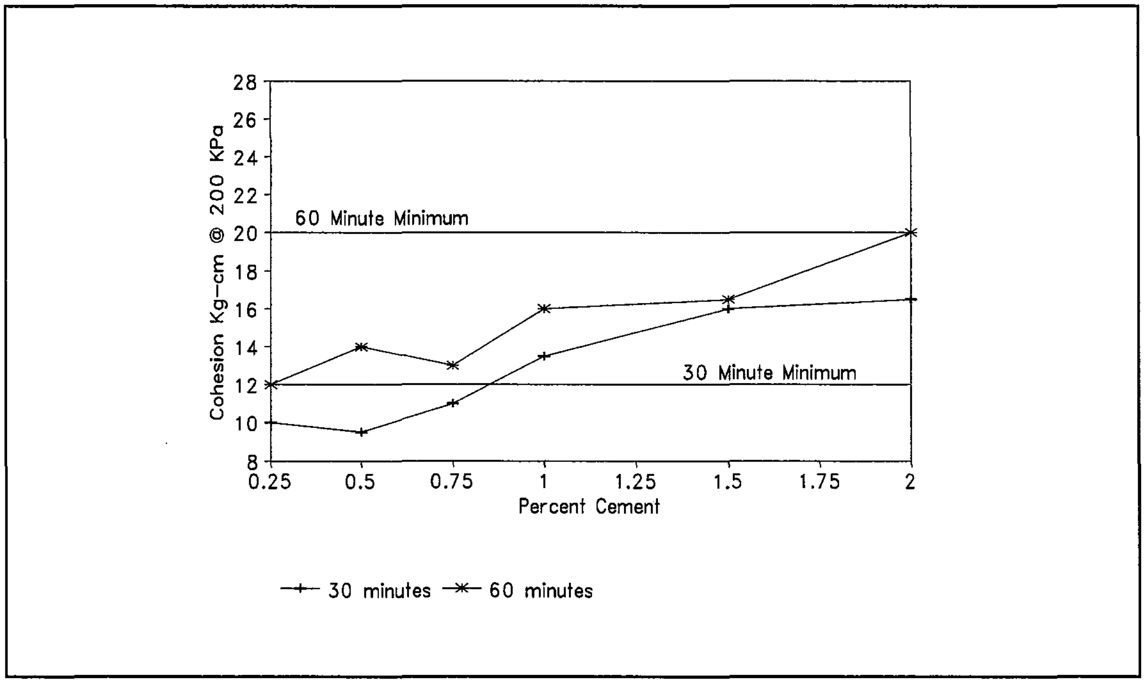

Figure 96. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.5% RAC and 8.5% Water for the Bryan District Project

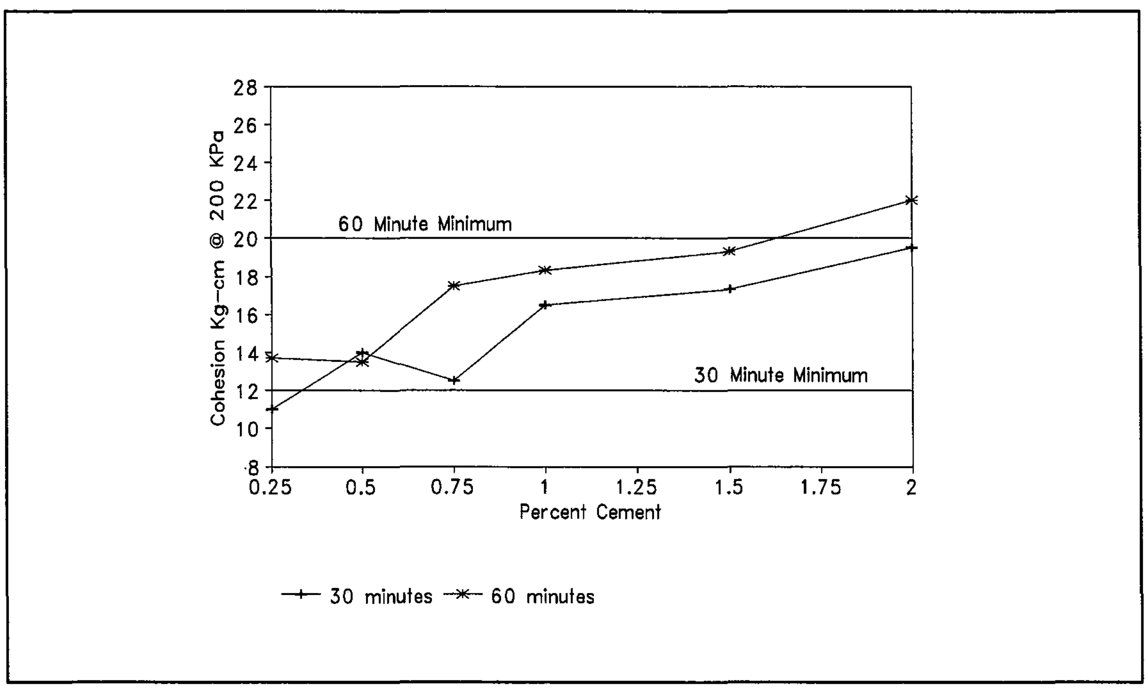

Figure 97. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.0% RAC and 8.3% Water for the Bryan District Project

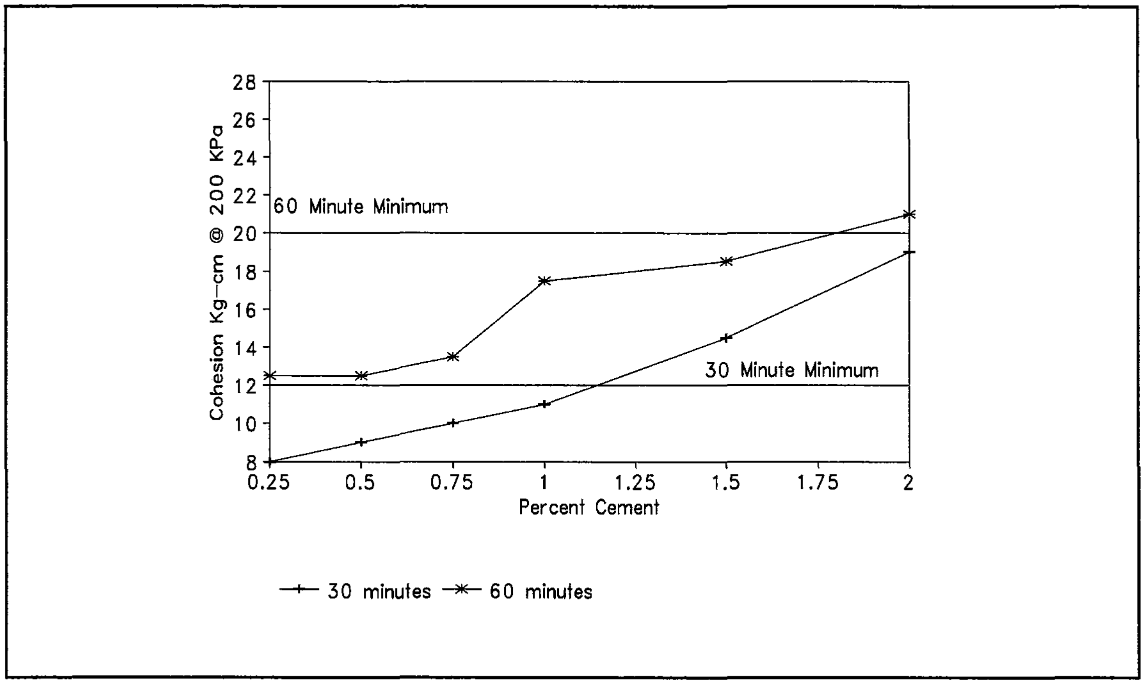

Figure 98. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.5% RAC and 8% Water for the Bryan District Project

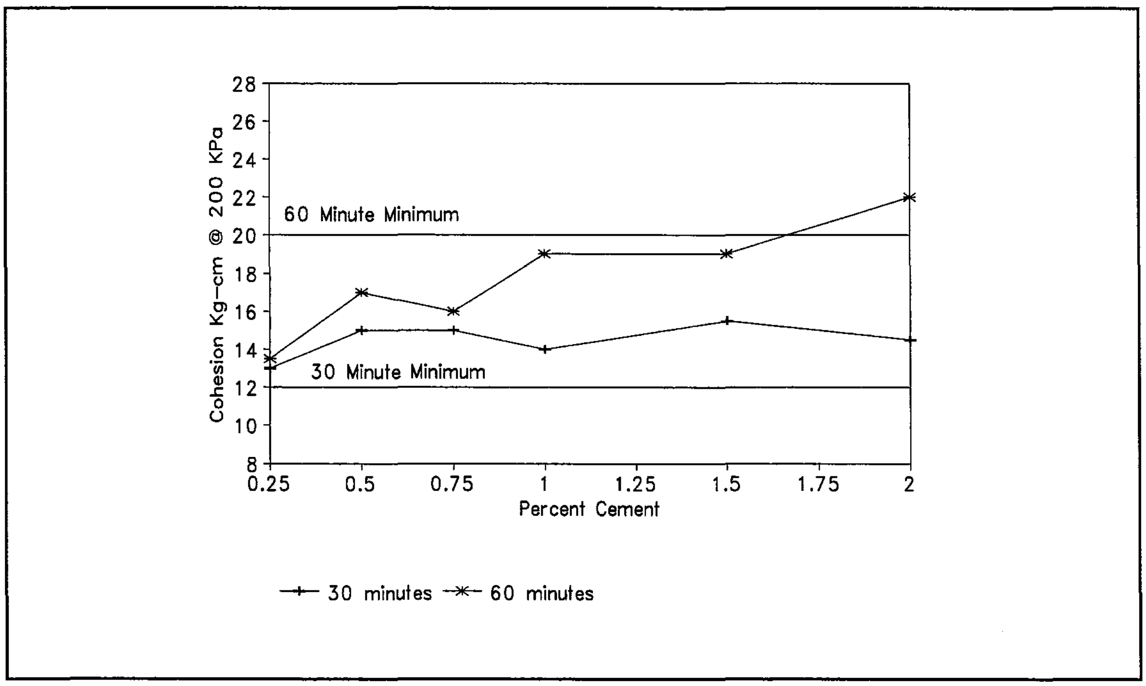

Figure 99. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.0% RAC and 7.8% Water for the Bryan District Project

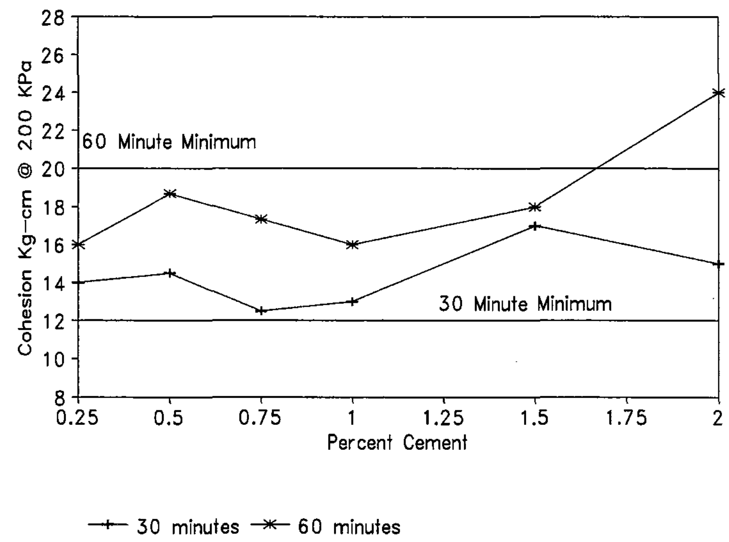

Figure 100. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 8.5% RAC and 6.5% water for the Bryan District Project

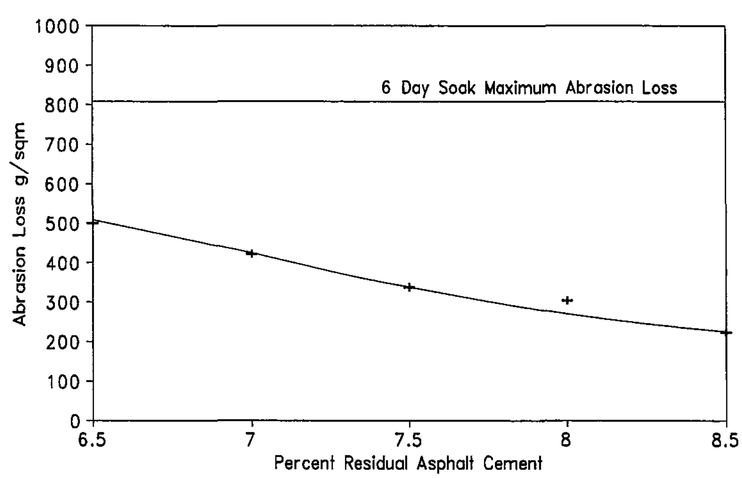

Figure 101. Minimum RAC using Abrasion Loss by six-day WTAT with Water Contents of 7.5 to 8.5% for the Bryan District Project

The modified cup flow test was used to determine the minimum water content that produced a 5 mm (0.2 in) or greater separation of fluids from solids. The optimum water content was then selected at 2 percent below this minimum water content.

Two mixture designs were conducted to evaluate the TTI modified mixture design with the addition of the cup flow test. One mix design was for two projects, one in the Dallas District and the other in Tyler District. The other mix design was for the Abilene District.

Materials

The material used in the mix design evaluation was representative of the material used in construction in the field. All materials met the specifications given in TxDOT draft micro-surfacing procedure, March 1993. The emulsion used in all projects was CSS-1P or CSS-1hP. The aggregate was Texas Grade II for coarse graded surface coarse. The mineral filler was non-air entrained, lump free portland cement. Distilled water was used in the preparation of the samples. Only set retarding additives approved for the project were used if needed. Table 20 gives the location site and material supplier for the four selected project sites.

Table 20. Description of Materials for the Projects

LOCATION	AGGREGATE	ASPHALT EMULSION	MINERAL FILLER
Abilene District	TransPecos Materials Vahalen, TX Texas Grade II coarse graded surface aggregate	Ergon Asphalt and Emulsion Waco, TX CSS-1hP	Portland Cement Type I
Dallas District	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Koch Material Company Salina, KS CSS-1P	Portland Cement Type I
Tyler District	Boorheim Field Inc. Paris, TX Texas Grade II coarse graded surface aggregate	Koch Material Company Salina, KS CSS-1P	Portland Cement Type I

ISSA test procedures used in the TTI laboratory for micro-surfacing mixture design are described in Report 1289-1 (27). One exception to the procedures was that the wet cohesion test was performed with material passing a 9.5 mm (3/8 in) sieve and a 10 mm (0.39 in) sample mold. A minimum of three samples was tested at each formulation. All percentages are based on the dry weight of aggregate. The procedure for the volumetric determination of the theoretical optimum RAC and the modified cup flow test are described in Chapter 6.

The material tests performed were gradation of the aggregate and distillation of the emulsion to determine the percent RAC. Aggregate gradation was determined using TxDOT test procedure Tex 200-F (28). A comparison of the aggregate gradation used in the TTI modified mix design and that used in the contractors' mix designs are shown in Figure 102 for the Dallas and Tyler Districts. Figure 103 is the aggregate gradation for the Abilene District.

The RAC was determined using the ASTM D-244 oven evaporation procedure for percent residue. The RAC was 64.8 percent for the Koch CSS-1P for the projects in Dallas and Tyler and 65.0 percent for the Ergon CSS-1hP for the Abilene project.

Mixture Design Results and Discussion

The mixture design results are summarized in Table 21 which gives a comparison of the TTI modified mixture design to the mixture design supplied by the contractor. The results for each site are described in the following sections.

Dallas and Tyler Results - The five trial RAC contents tested were 5.5, 6.0, 6.5, 7.0, and 7.5 percent. The modified cup flow test was conducted for each trial RAC content with portland cement contents of 0.5 to 2.0 percent. The minimum water content that gave 0.5 mm (0.2 in) or greater separation of fluids from solids is given in Table 22 with the selected optimum water contents. The optimum water content was selected at 2 percent below the minimum water content.

The mixing time test was run to determine the minimum water content that gave a 120 second mix time at the following cement contents: 0.5 to 2.0 percent. All selected water contents had greater than 120 second mix time.

The wet cohesion test was performed at the trial RAC contents for 0.25 to 2.5 percent portland cement. The cohesion values are shown in Figures 104-108. None of the trial mixtures passed the wet cohesion test. The portland cement content selected for further testing was the minimum content that had a maximum cohesion value or where the cohesion values leveled off. Table 23 gives the selected portland cement content with the appropriate water content determined from the modified cup flow test for each RAC content.

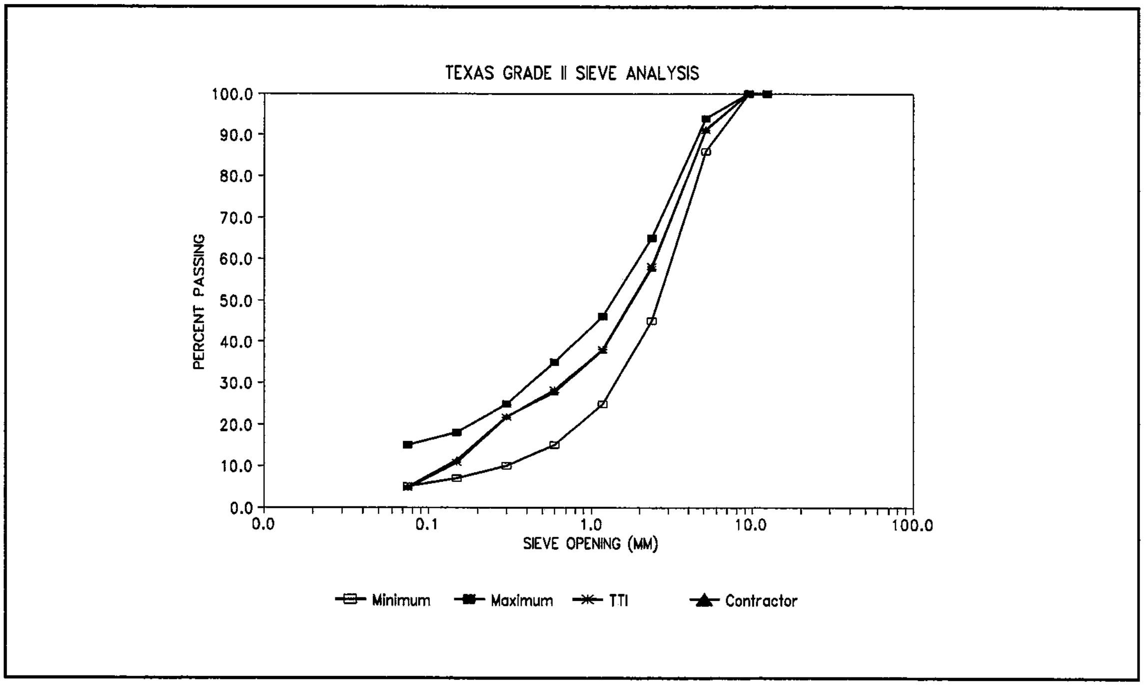

Figure 102. Aggregate Gradation used in TTI Mixture Design for the Dallas and Tyler District Projects and the Gradation from the Mixture Design supplied by the Contractor

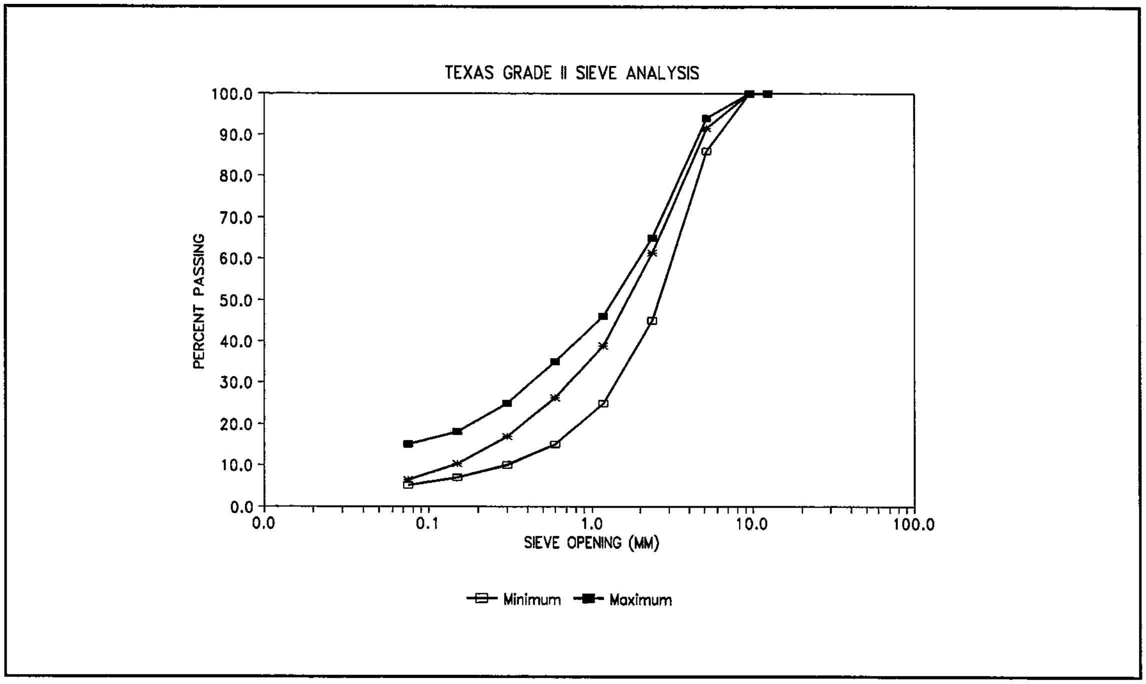

Figure 103. Aggregate Gradation used in TTI's Mixture Design for the Abilene District Project

Table 21. Mix Design Results and Comparison of TTI and Contractor Mixture Design, all Quantities are Based on Dry Weight of Aggregate

Location	Tester	Residual Asphalt Cement, percent	Mineral Filler, percent	Water, percent
Dallas and Tyler	Contractor	7.7 ± 0.4	2.0 ± 0.25	10 - 14
	TTI	7.0	2.00	*
Abilene	TTI	6.3	0.75	*

* As needed for consistency

The WTAT was then conducted to determine the minimum trial RAC content that passes with an abrasion loss less than 806 g/m^2 (75 g/ft^2). The results are shown in Figure 109. The minimum trial RAC content passing the WTAT was 6.5 percent. The optimum RAC content was selected 0.5 percent above the minimum RAC content passing the WTAT giving an optimum RAC of 7.0 percent.

Abilene Results - The five trial RAC contents tested were 5.8, 6.3, 6.8, 7.3, and 7.8 percent. The modified cup flow test was conducted for each trial RAC content with portland cement contents of 0.5 to 2.0 percent. The minimum water content that gave 0.5 cm or greater separation of fluids from solids is given in Table 24 with the selected optimum water contents. The optimum water content was selected at 2 percent below the minimum water content.

The mixing time test was run to determine the minimum water content that gave a 120 second mix time at the following cement contents: 0.5 to 2.0 percent. All selected water contents had greater than 120 second mix time.

The wet cohesion test was performed at the trial RAC contents for 0.25 to 2.5 percent portland cement. The cohesion results are shown in Figures 110-114. None of the trial mixtures passed the wet cohesion test. The portland cement content selected for further testing was the minimum content that had a maximum cohesion value or where the cohesion values leveled off. Table 25 gives the selected portland cement content with the appropriate water content determined from the modified cup flow test for each RAC content.

The WTAT was then conducted to determine the minimum trial RAC content that passes with an abrasion loss less than 806 g/m^2 (75 g/ft^2). The results are shown in Figure 115. The minimum trial RAC content passing the WTAT was 5.8 percent. The optimum RAC content was selected 0.5 percent above the minimum RAC content passing the WTAT giving an optimum RAC content of 6.3 percent.

Table 22. Selected Optimum Water Contents from the Modified Cup Flow Test for Dallas and Tyler Districts

RAC, percent	Portland Cement Content, percent	Minimum Water Content That Gives ≥ 5 mm Separation of Fluids from Solids, percent	Optimum Water Content, percent
5.5	0.50	13.5	11.5
	1.00	13.5	11.5
	1.50	13.5	11.5
	2.00	13.5	11.5
6.0	0.50	12.5	10.5
	1.00	13.0	11.0
	1.50	13.0	11.0
	2.00	13.5	11.5
6.5	0.50	12.0	10.0
	1.00	12.5	10.5
	1.50	13.5	11.5
	2.00	13.0	11.0
7.0	0.50	11.0	9.0
	1.00	12.0	10.0
	1.50	12.0	10.0
	2.00	12.0	10.0
7.5	0.50	11.0	9.0
	1.00	12.0	10.0
	1.50	12.0	10.0
	2.00	13.0	11.0

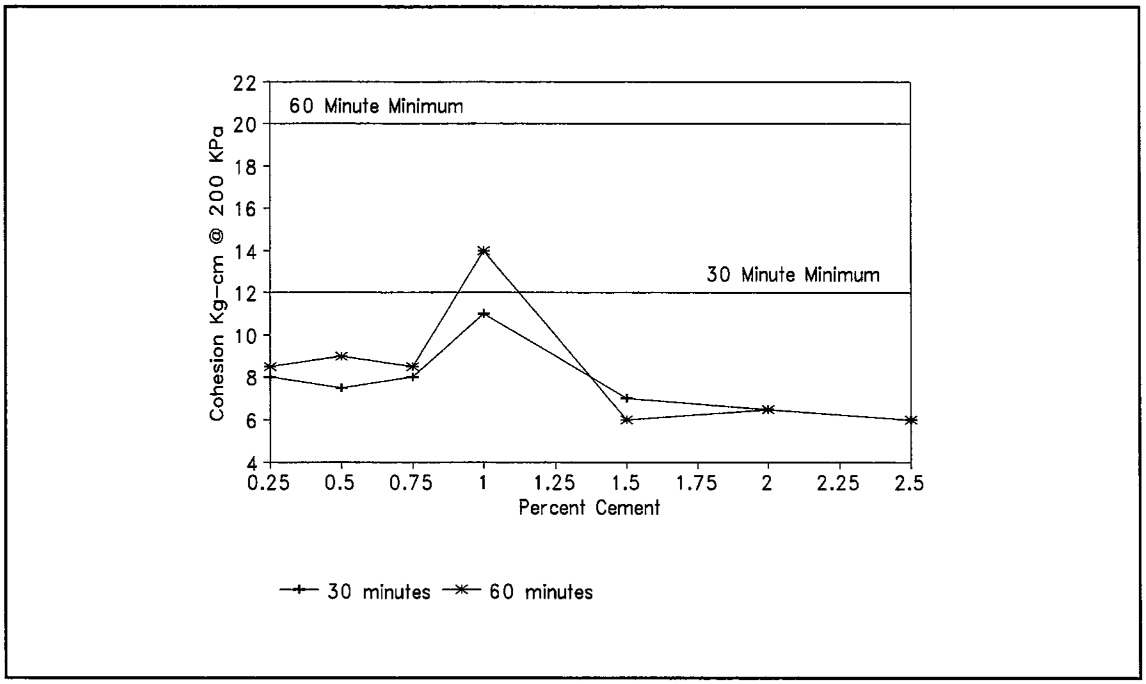

Figure 104. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 5.5% RAC and 11.5% Water for the Dallas and Tyler District Projects

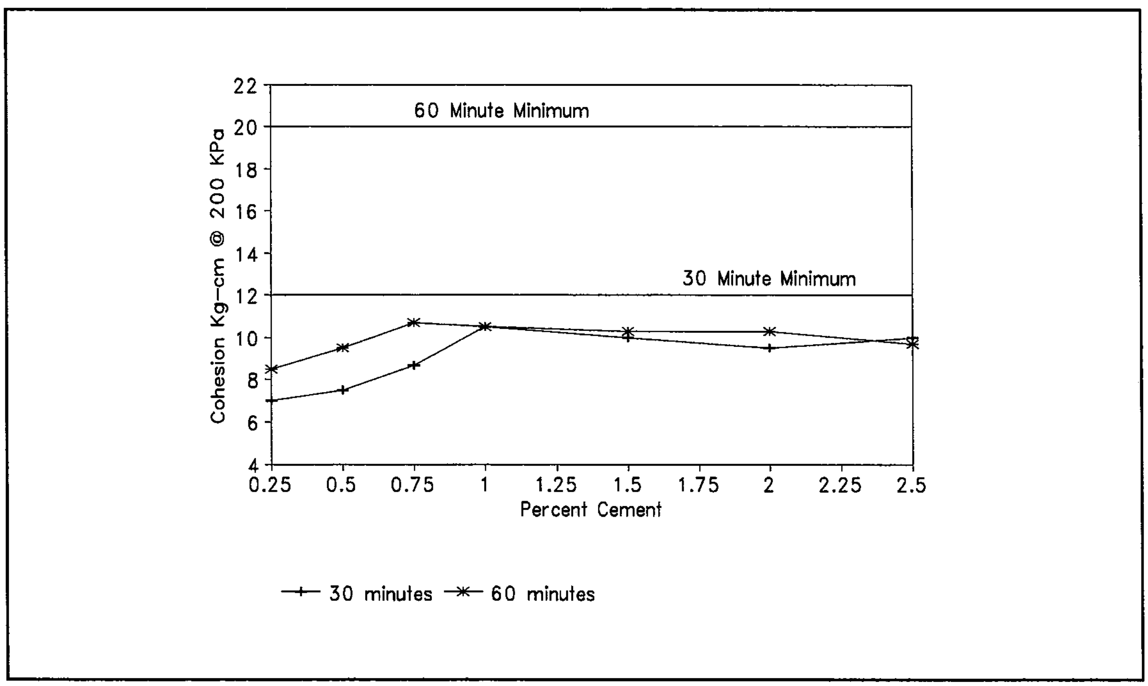

Figure 105. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.0% RAC and 10.5-11.5% Water for the Dallas and Tyler District Projects

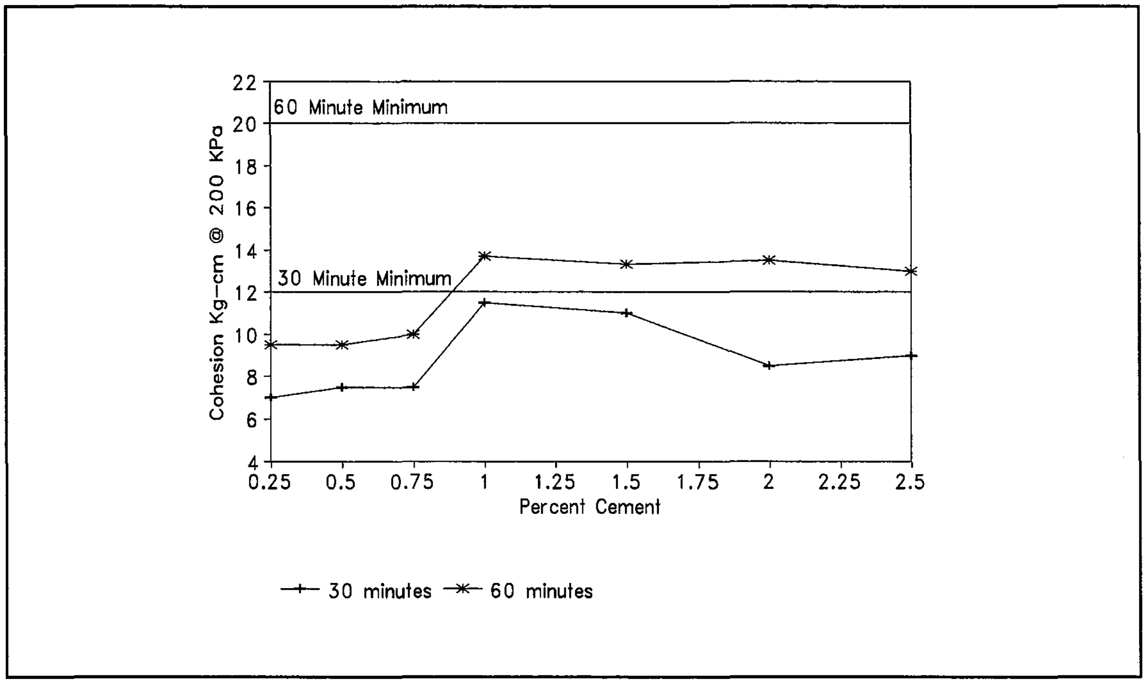

Figure 106. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.5% RAC and 10-11.5% water for the Dallas and Tyler District Projects

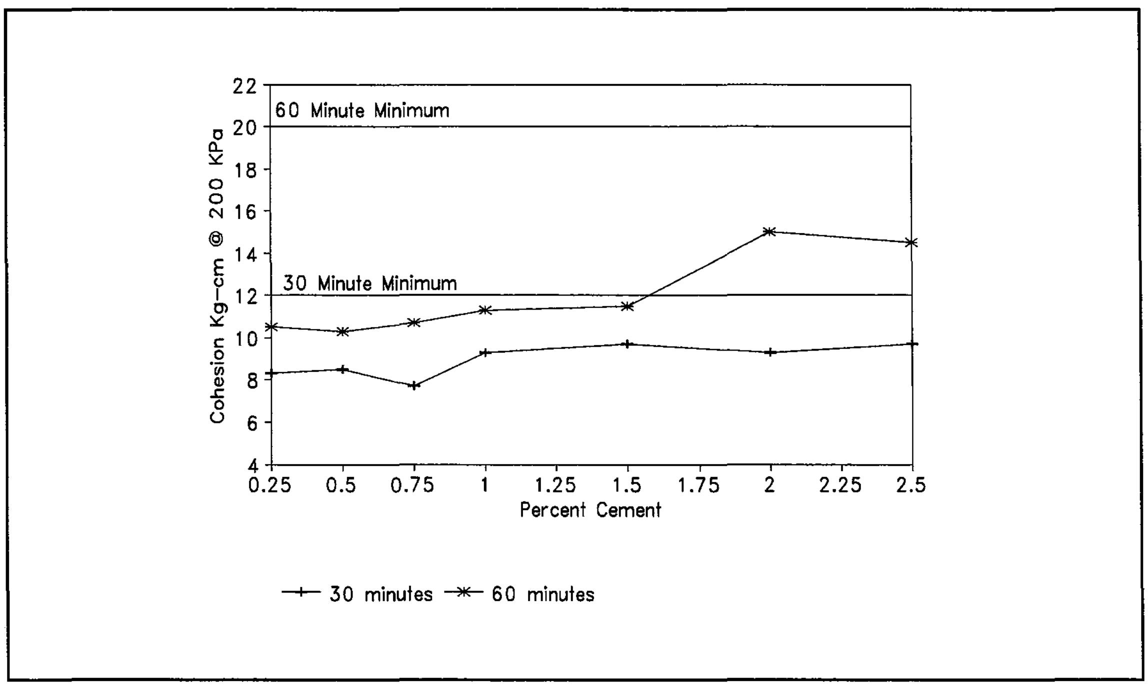

Figure 107. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.0% RAC and 9-10% Water for the Dallas and Tyler District Projects

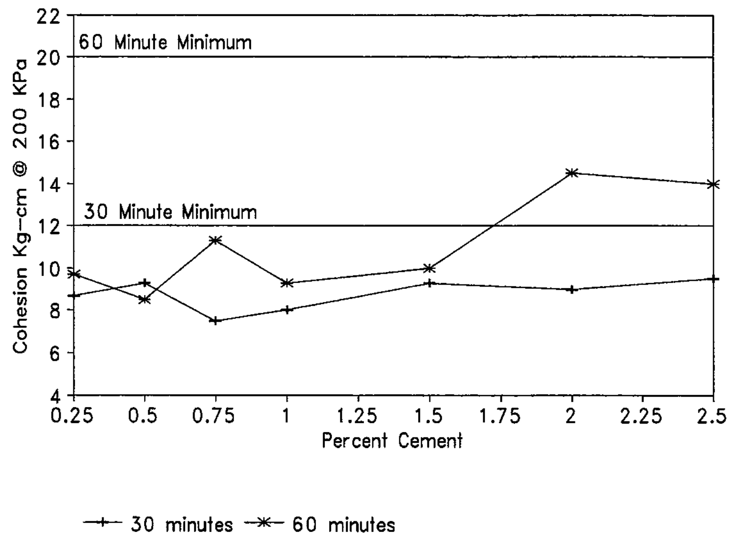

Figure 108. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.5% RAC and 9-11% Water for the Dallas and Tyler District Projects

Table 23. Selected Optimum Portland Cement Content and Water Content for Each Trial RAC for Dallas and Tyler Districts

RAC, percent	Optimum Water Content, percent	Optimum Portland Cement Content, percent
5.5	11.5	1.00
6.0	11.3	0.75
6.5	10.5	1.00
7.0	10.0	2.00
7.5	11.0	2.00

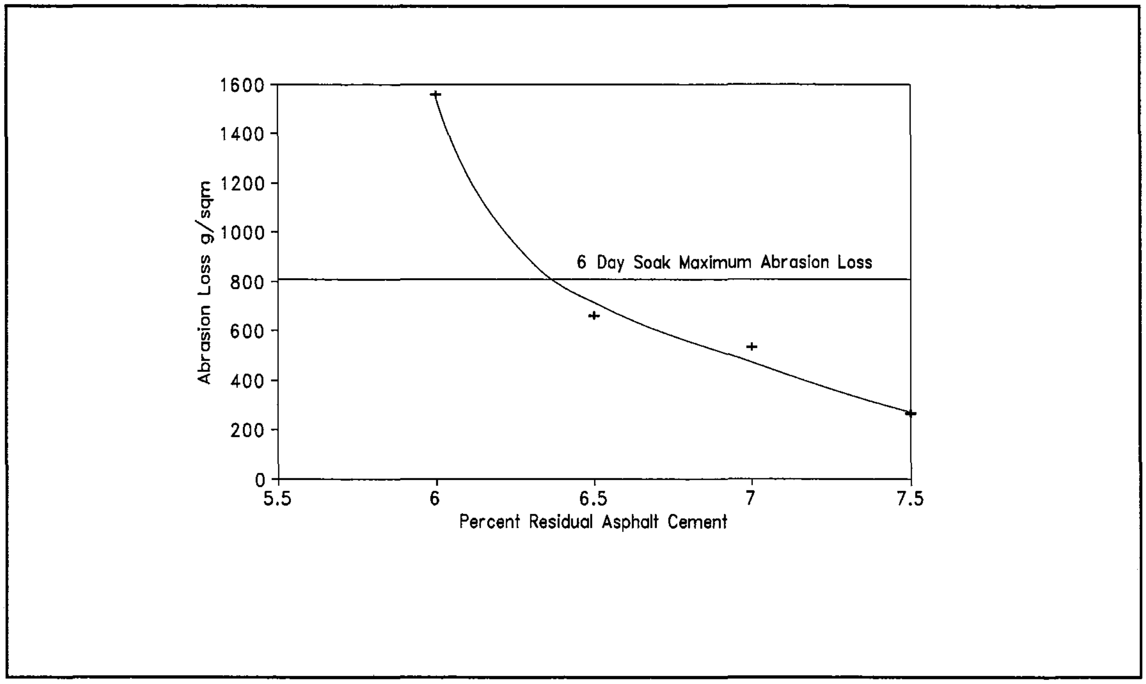

Figure 109. Minimum RAC using Abrasion Loss by six-day WTAT with Water Contents of 9-11.5% for the Dallas and Tyler District Projects

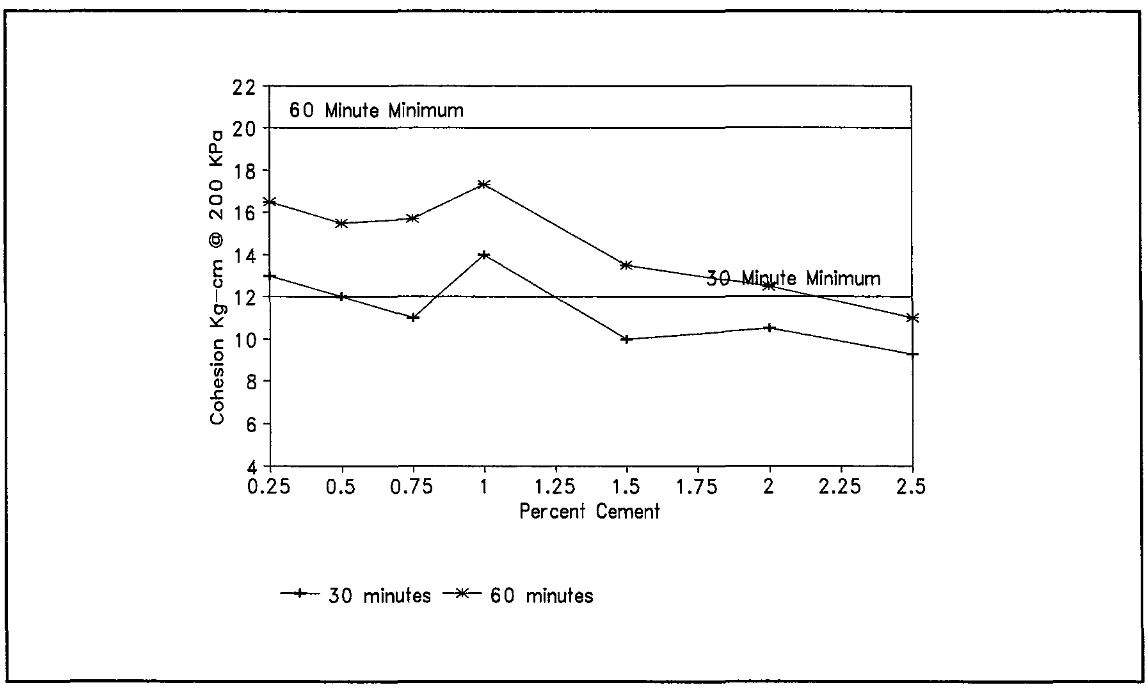

Figure 110. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 5.8% RAC and 10-11% Water for the Abilene District Project

Table 24. Selected Optimum Water Contents from the Modified Cup Flow Test for Abilene District

RAC, percent	Portland Cement Content, percent	Minimum Water Content That Gives ≥ 5 mm Separation of Fluids from Solids, percent	Optimum Water Content, percent
5.8	0.50	12.0	10.0
	1.00	12.0	10.0
	1.50	13.0	11.0
	2.00	13.0	11.0
6.3	0.50	11.0	9.0
	1.00	11.0	9.0
	1.50	12.0	10.0
	2.00	12.0	10.0
6.8	0.50	11.0	9.0
	1.00	12.0	10.0
	1.50	12.5	10.5
	2.00	12.5	10.5
7.3	0.50	11.0	9.0
	1.00	12.0	10.0
	1.50	12.5	10.5
	2.00	12.5	10.5
7.8	0.50	11.0	9.0
	1.00	12.0	10.0
	1.50	12.5	10.5
	2.00	12.5	10.5

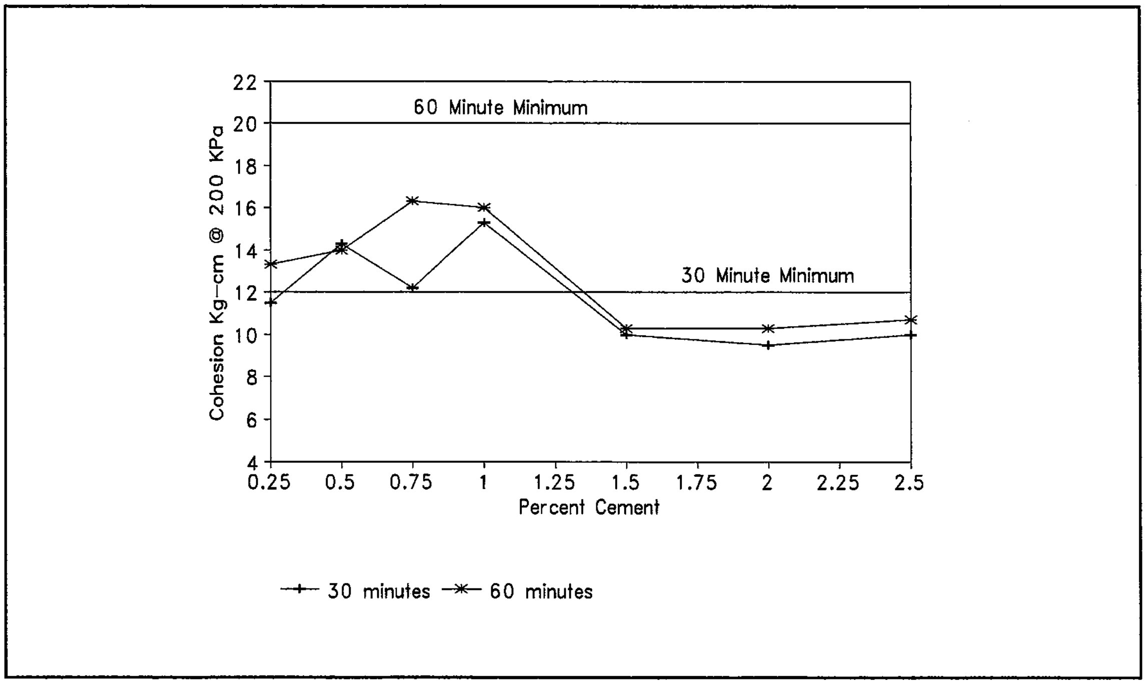

Figure 111. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.3% RAC and 9-10.5% Water for the Abilene District Project

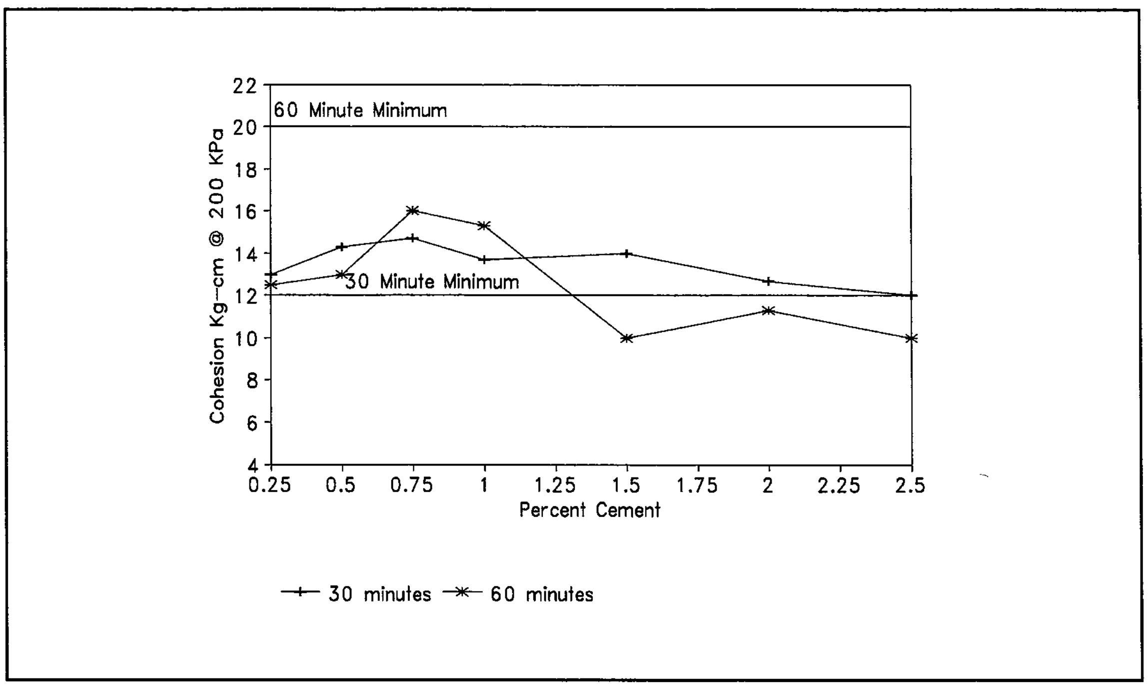

Figure 112. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 6.8% RAC and 9-10.5% Water for the Abilene District Project

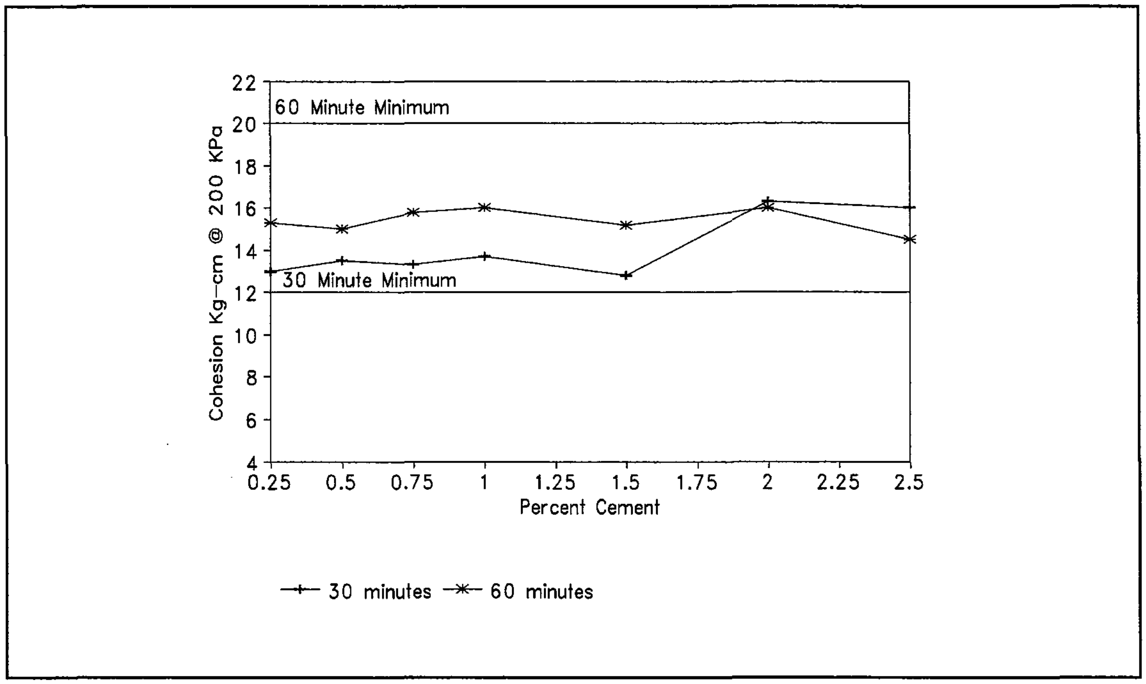

Figure 113. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.3% RAC and 9-10.5% Water for the Abilene District Project

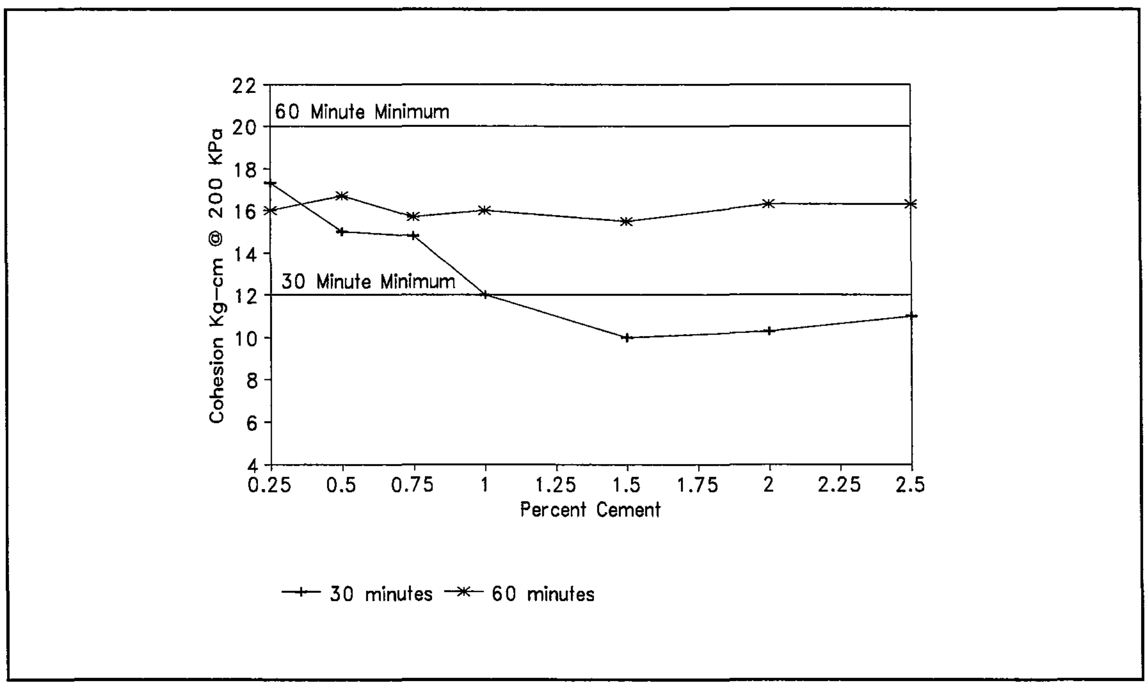

Figure 114. Cohesion Test Results at 30 and 60 minutes for varied Portland Cement Contents and 7.8% RAC and 9-10.5% Water for the Abilene District Project

Table 25. Selected Optimum Portland Cement Content and Water Content for Each Trial RAC for Abilene District

RAC, percent	Optimum Water Content, percent	Optimum Portland Cement Content, percent
5.5	10.0	1.00
6.0	9.0	0.75
6.5	9.5	0.75
7.0	9.0	0.25
7.5	9.0	0.25

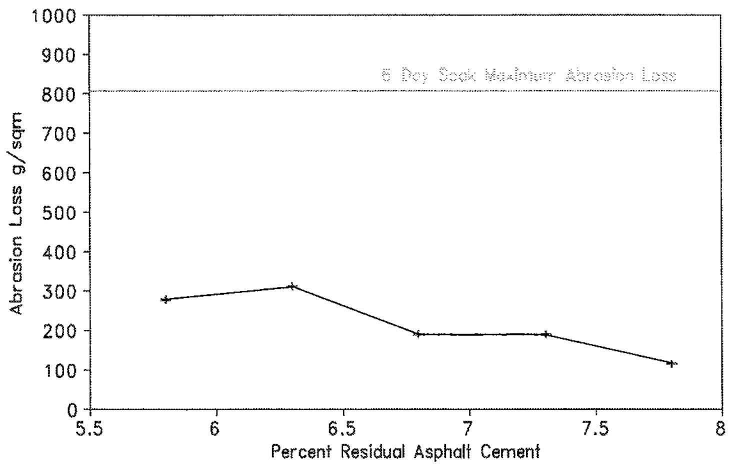

Figure 115. Minimum RAC using Abrasion Loss by six-day WTAT with Water Contents of 9-10.5% for the Abilene District Project

Conclusions

Based on the results of the mixture design tests conducted in 1994, the following conclusions were made.

1. The modified cup test can be used to select a reasonable consistency at which all remaining tests can be conducted.

2. The CKE and WTAT can be used to determine an optimum RAC close to the values recommended by the emulsion suppliers.

3. The emulsion suppliers change their formulation so that the emulsion has adequate break time during the hot part of the summer which may lead to the material not meeting the minimum cohesion values in the laboratory. As long as the mixture can be opened to traffic in the desired time, this is not a problem.

4. The peak point or values where cohesion levels off can be used to select the cement content even if the values are less than the minimum.

CHAPTER 5
DEVELOPMENT OF NEW MIXTURE DESIGN AND TESTS

SELECTING DESIRED CONSISTENCY

Some ISSA members use the cone consistency test (ISSA TB106) to select the water content (13). This test has been demonstrated to behave erratically with quick set, quick traffic systems. This was noted in the tests conducted by the project staff in the Fall of 1992 and was further confirmed in the laboratory of one of the material suppliers. A method must be available to select the water content at which all tests are conducted to reduce operator dependent subjectivity and to ensure that mixture design tests conducted to determine RAC are independent of water content.

Three types of tests were examined for measuring consistency including penetration, vane shear, and flow on an inclined plane. Penetration tests were conducted using a Vicat Apparatus or a penetrometer with a grease penetration cone. The Vicat Apparatus was based on ASTM C187-88, "Normal Consistency of Hydraulic Cement". This test was used to measure the penetration of a plunger in a set time. The Vicat Apparatus is shown in Figure 116. Three different weight plungers were used in the testing, a standard Vicat plunger weighing 300 g, a solid aluminum plunger weighing 85 g, and a hollow aluminum plunger weighing 45 g.

A second penetration test used a penetrometer as specified in ASTM D5 with the following modifications. The plunger was replaced with an aluminum shaft. The needle was replaced with a grease penetrometer cone that met the specification for ASTM D217, Optimal Penetrometer Cone. The total weight of plunger and penetrometer cone was 80 grams. The test was performed by releasing the plunger for a set time. The penetrometer and grease penetrometer are shown in Figure 117.

The vane shear test used a 4-blade vane placed in the slurry and rotated. The torque required to rotate the vane was then recorded. The Vicat apparatus was modified to be used in the vane shear test. The plunger was replaced with a shaft. The 4-blade vane was attached to the bottom of the shaft, and the top of the shaft was fitted with a bolt head. A torque wrench was placed on the bolt head and used to rotate the vane 90° to 120° in 1 second. Figure 118 shows the configuration of the blade used in the procedure.

The cup flow test measured the distance that the slurry would flow down a 15° inclined plane in 10 seconds. The inclined plane consisted of an aluminum sheet with a scale in cm inscribed on it to measure the flow as shown in Figure 119. Additives were used in the mix to give a minimum of 240 second mixing time before breaking. If separation of solids and liquids occurred, it was noted.

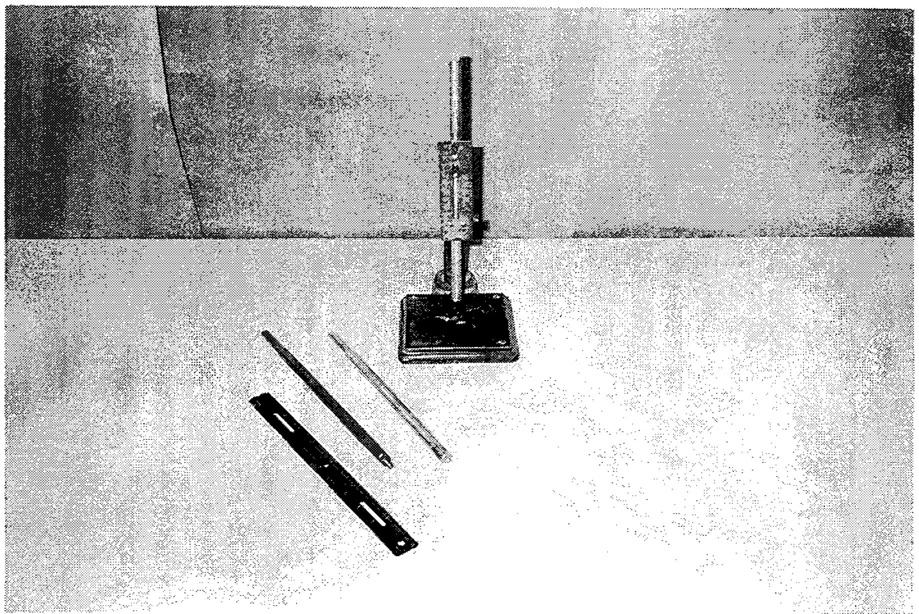

Figure 116. The Vicat Apparatus and Penetration Plungers

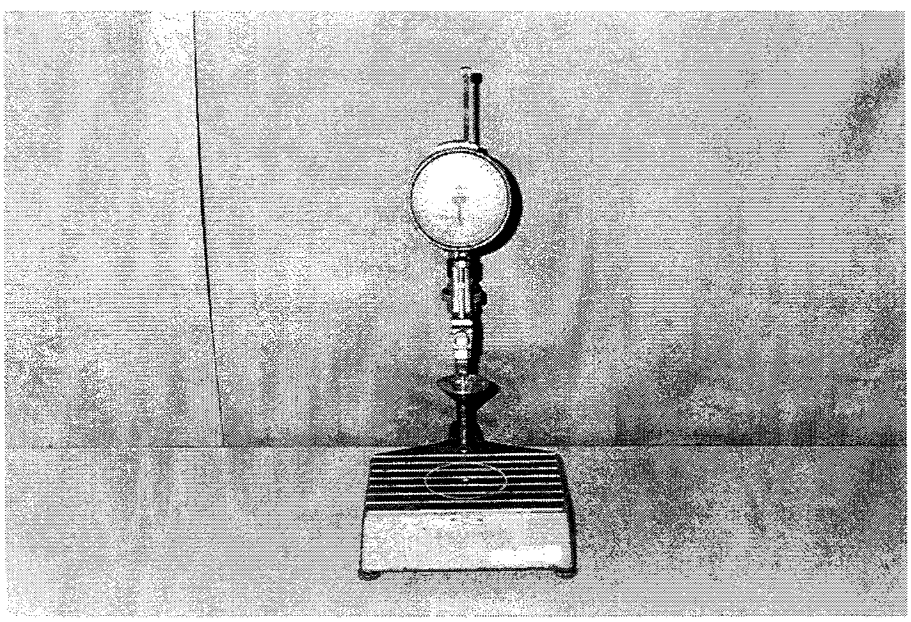

Figure 117. Penetrometer and Grease Penetration Cone Used In Penetration Test

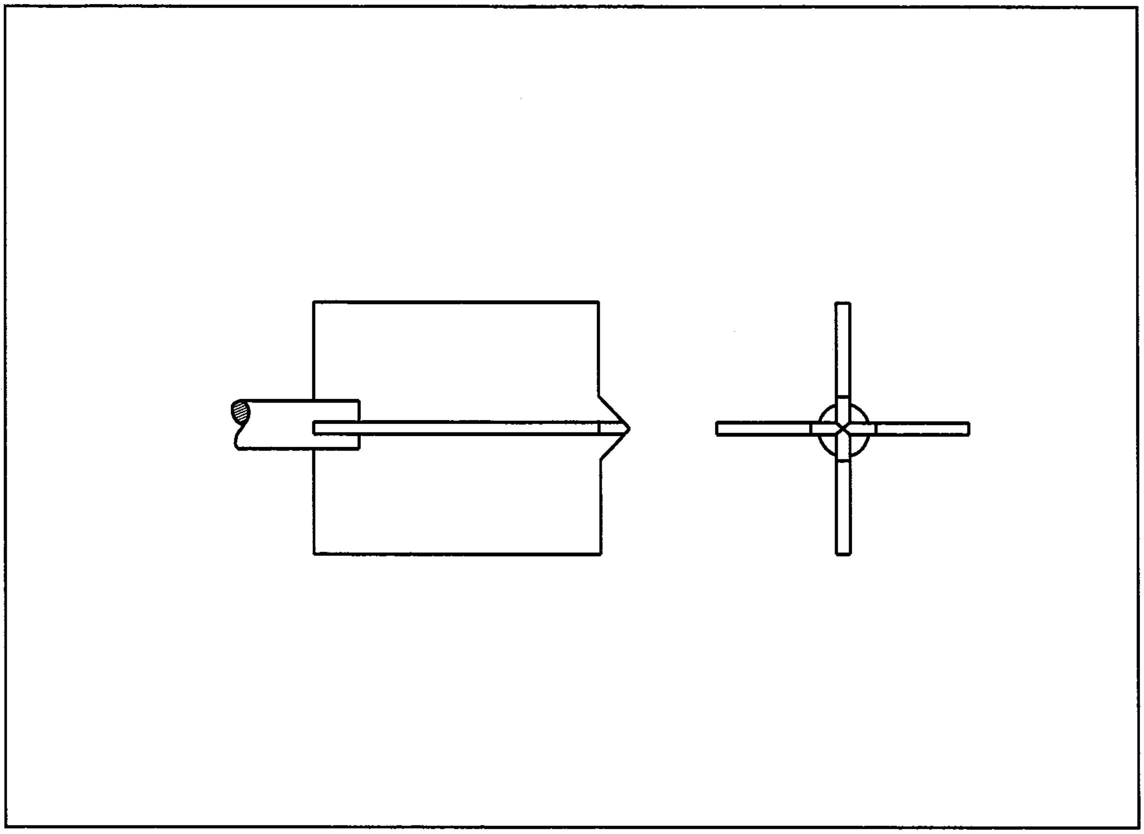

Figure 118. Configuration of 4-Blade Vane Shear Used In Vane Shear Test

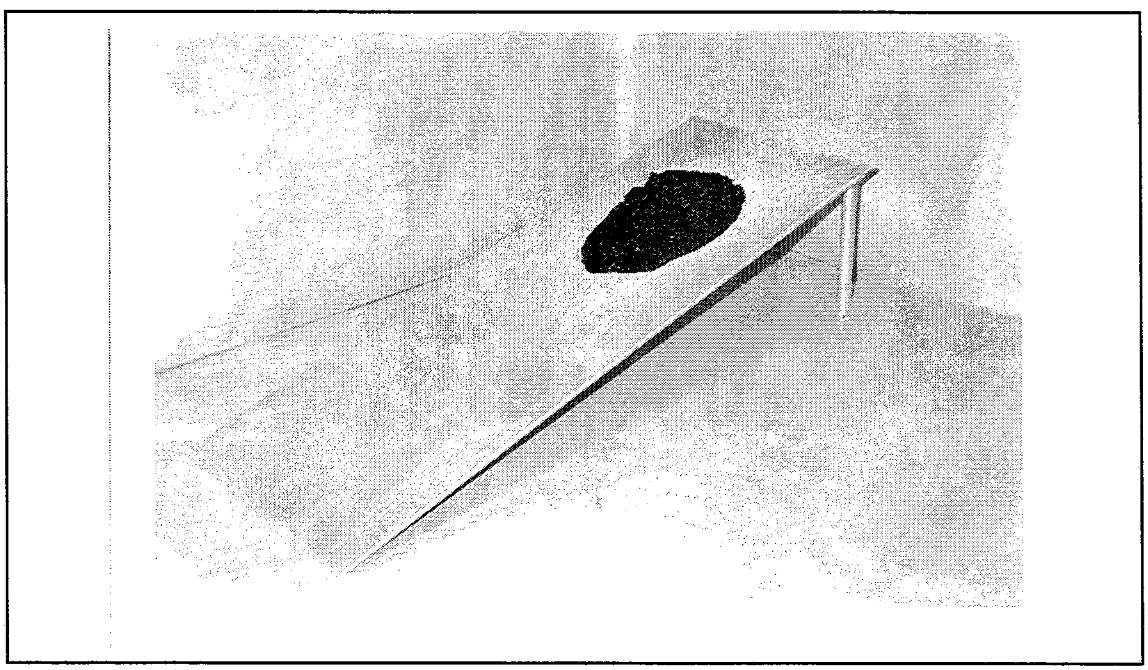

Figure 119. The 15° Incline Plane Showing the Inscribed Scale Used to Measure the Flow of the Slurry

The cup flow test was modified to determine the water content that produced a 5 mm (0.2 in) or greater separation between solids and liquids after the slurry had been released for 120 seconds. Figure 119 shows this separation of fluids and solids.

Materials

The materials used in the consistency tests were representative of the materials currently being used in Texas. All materials met the specifications given in TxDOT draft micro-surfacing procedure, March 1993. The emulsion used was CSS-1P or CSS-1hP. The aggregate was Texas Grade II for coarse graded surface coarse. The mineral filler was non-air entrained, lump free portland cement. Distilled water was used in the preparation of the samples. Only set retarding additives approved for micro-surfacing were used if needed. Table 26 gives a description of the material and the suppliers for the material used in the consistency tests.

Procedures

The following procedures were used to evaluate mixture consistency.

Penetration Test Using VICAT Apparatus

The aggregate was separated using 9.5 mm (3/8 in), 4.75 mm (#4) and 2.36 mm (#8) sieves. The aggregate was recombined to obtain a 200 g sample meeting the desired gradation. The appropriate portland cement was weighed into the sample and dry mixed for 60 seconds. If any liquid additive was to be added, it was premixed with distilled water. Water was added and the aggregate was mixed for 60 seconds or until the aggregate was uniformly wetted. The emulsion was carefully weighed into the cup and mixed for 30 seconds.

The mixture was poured into a 177 ml (6 oz) tin. The surface was leveled off by lightly tapping the container 3 times. The sample was centered under the plunger. The plunger was lowered until it was in contact with the surface of the sample. The meter was zeroed. The plunger was released for 5 seconds, and the penetration was recorded. The whole process was completed within 60 seconds of the addition of the emulsion.

Penetration Test Using Grease Penetrometer Cone

Sample preparation was the same as used for penetration test using the Vicat Apparatus except that 400 g of aggregate was used. The slurry was poured into a 473 ml (16 oz) deli container. The container was centered under the cone. The penetrometer was zeroed and lowered until the point of the cone came in contact with the sample surface. The plunger was released for 5 seconds, and the penetration was recorded. The test procedure was completed within 60 seconds of the addition of the emulsion.

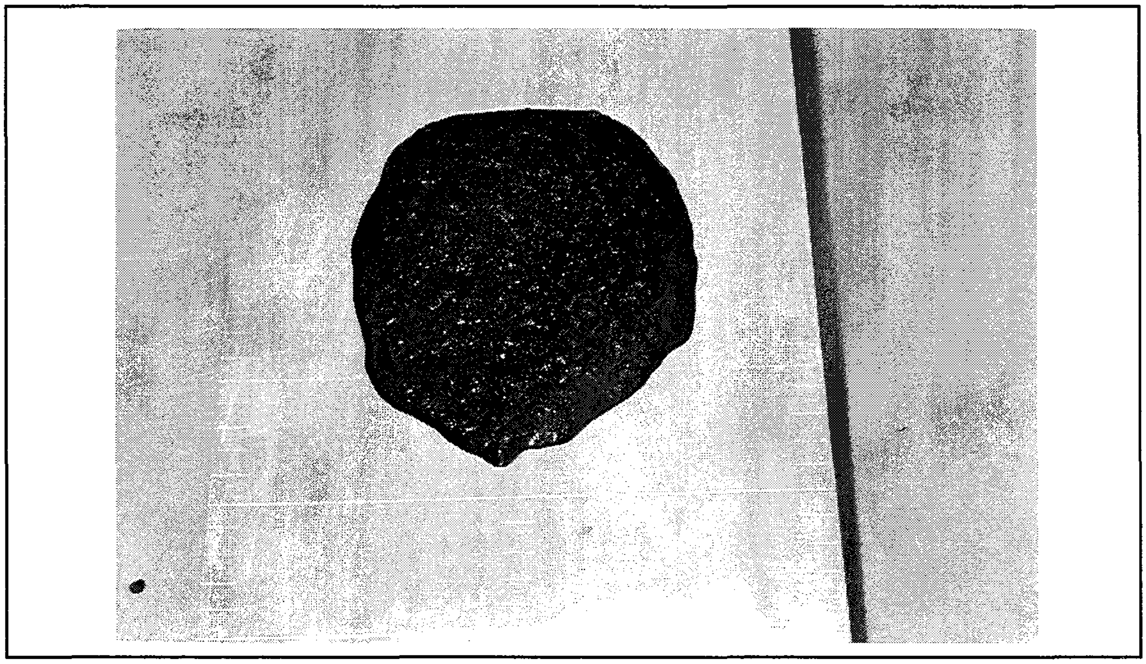

Figure 120. Illustrated above is the Separation of Fluids and Solids

Table 26. Description of Materials used in the Consistency Test

MATERIAL	AGGREGATE	ABBREVIATION
Texas Grade II coarse graded surface aggregate	Capital Aggregates (Delta Materials) Marble Falls, TX	Delta
Texas Grade II coarse graded surface aggregate	Boorheim Field Inc. Paris, TX	BF
Texas Grade II coarse graded surface aggregate	TransPecos Materials Vehalen, TX	Trans
CSS-1hP	Ergon Asphalt and Emulsion Waco, TX	Ergon
CSS-1P	Koch Material Company Salina, KS	Koch

Vane Shear Test

Sample preparation was the same as for the penetration test using Vicat Apparatus. The slurry was poured into a 177 ml (6 oz) tin. The surface was leveled off using a spatula. The 4-blade vane shear was lowered into the tin until the point came in contact with the bottom of the tin. The torque wrench was zeroed and placed on the top of the rod attached to the 4-blade vane. The torque wrench was then twisted 90° to 120° in 1 second, and the torque was recorded.

Cup Flow Test on Inclined Plane

Sample preparation was the same as for penetration test using Vicat Apparatus. The inclined plane was positioned over the cup. The cup and inclined plane were then inverted and set on a level surface. The cup was held against the plate and tapped lightly on the bottom 2 times. The cup was removed vertically and a stop watch was started. After 10 seconds, the flow down the inclined plane was measured and recorded to the nearest 5 mm (0.2 in). Any separation of liquids and solids was recorded.

Modified Cup Flow Test on Inclined Plane

The procedure is the same as the cup flow test on inclined plane except the distance of the flow is not measured. The slurry was allowed to flow for 120 seconds or until flow stopped. The lowest water content that gave 5 mm (0.2 in) or greater separation of fluids from solids after 120 seconds was recorded.

Results

The penetration tests were inconclusive. The penetration test with Vicat Apparatus using even the lightest plunger penetrated to the bottom of the sample container. The penetration test with the grease penetrometer cone resulted in the plunger traveling the maximum distance allowed by the penetrometer. The penetration test would require a larger surface area on the plunger or cone to prevent it from penetrating through the mix.

The vane shear test had problems similar to the penetration test. The torque wrench used in the test was the same wrench used in the wet cohesion test, but it was not sensitive enough to measure the torque readings of about one kg-cm. A hand held viscometer was not powerful enough to rotate the shear vane. The Torvane device was not sensitive enough to identify differences. To obtain a torque wrench capable of measuring the difference between mixes would cost more than $1000. This test was not pursued further due to the cost of a suitable torque wrench.

Figure 121 shows the results from the cup flow test for the Delta Material Aggregate and Ergon Emulsion CSS-1hP. The data shows that as the emulsion content increased the flow increased, even if the total fluids remained the same. The objective was to select an

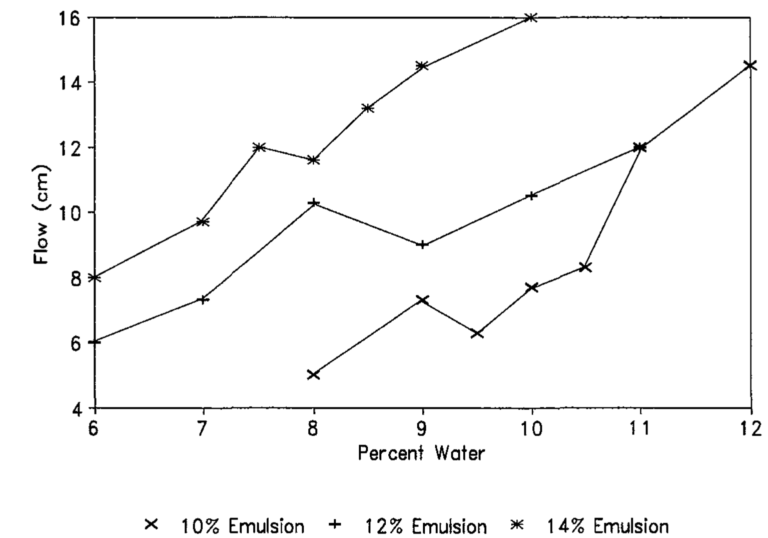

Figure 121. Results from the Cup Flow Test for the Delta Aggregate and Ergon Emulsion and 1.0% Portland Cement

acceptable range for the flow. Due to the large differences in flow for different emulsion contents, no acceptable range was selected. The data in Figure 121 exhibited an unexpected trend. The flow increased as the water content increased to a certain point. At this point, the flow dropped off with an increase in water content. The flow then increased again as the water content increased. It was suggested that the point at which the flow decreased with increasing water content might be the optimum. The test was then performed using two other aggregates and two different emulsions. Figure 122 shows the results at 12 percent emulsion and 1.0 percent portland cement for the different materials. The trends seen in the Delta/Ergon samples were also exhibited in the TransPecos/Ergon and the Boorheim Fields/Ergon samples. The Delta/Koch samples did not exhibit a drop in flow as the water content increased. The drop in the flow with increase water content was only exhibited for the aggregates mixed with Ergon emulsion. This eliminated the possibility of selecting the point where the flow decreased as the optimum water content. Various methods to identify a relationship between emulsion content, water content, and total fluids were considered. None proved successful.

The modified cup flow test was performed at three emulsion contents of 10, 12 and 14 percent and four portland cement contents of 0.5, 1.0, 1.5, and 2.0 percent. The water content was varied until a separation of fluids and solids greater than 5 mm (0.2 in) was obtained. A combination of two aggregates and two emulsions were used in the evaluation. The mixing test was performed and additive was added until a mix time

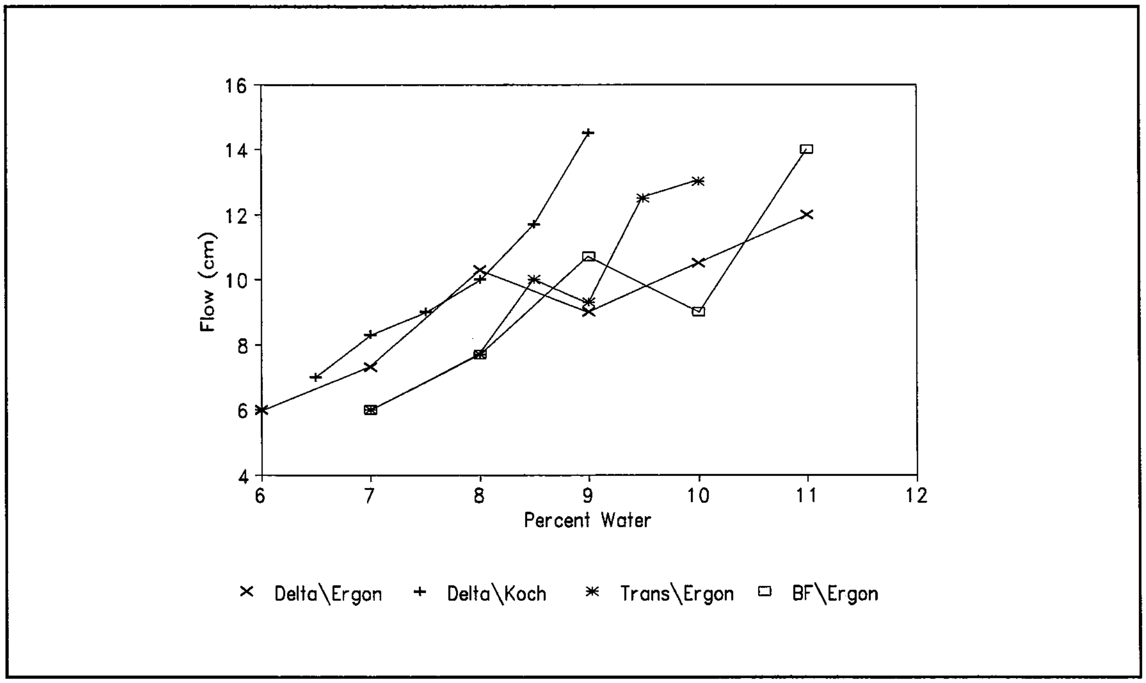

Figure 122. Cup Flow Test Result for Different Aggregate and Emulsion Sources at 12% Emulsion and 1.0% Portland Cement

greater than 240 seconds was obtained. This amount of additive was then used in the modified cup flow test. The results are tabulated in Table 27. The optimum water content was selected 2 percent below the water content that gave equal or greater than 5 mm (0.2 in) separation of fluids and solids. The 2 percent below the water content where separation takes place was selected by molding and examining wet track abrasion test samples. Three criteria placed on the selection were that the surface of the sample not be flushed, excessive fluids along the edge should not be present after molding the sample in compliance with ISSA TB100, and the surface texture should be uniform and smooth.

The modified cup flow test is recommended for selecting water the content at which the remainder of the mixture design tests that evaluate micro-surfacing mixture will be conducted. A draft laboratory protocol for the test is presented in Appendix A.

VOLUMETRIC DETERMINATION OF THEORETICAL OPTIMUM RESIDUAL ASPHALT CEMENT CONTENT

With the exclusion of the LWT due to its variability and sensitivity to changes in water content, a new method had to be developed to select the optimum RAC content. A volumetric design was evaluated. Two methods of volumetric determination of theoretical optimum RAC content were examined, ISSA TB 118, Surface Area Method of Slurry Seal Design, and ASTM D5148-90, Standard Test Method for Centrifuge Kerosene Equivalent.

Table 27. Water Content that gives a 5 mm or Greater Separation of Fluids and Solids using the Modified Cup Flow Test

Aggregate	Emulsion	Portland Cement Content, percent	Water Content, percent		
			10% Emulsion	12% Emulsion	14% Emulsion
Delta	Ergon	0.5	12	10	9
		1.0	12	10	11
		1.5	12	12	12
		2.0	12	13	12
Delta	Koch	0.5	11	10	9
		1.0	11	10	10
		1.5	12	10	11
		2.0	12	11	11
TransPecos	Ergon	0.5	12	12	11
		1.0	12.5	12	11
		1.5	13	13	12
		2.0	13.5	13	13
TransPecos	Koch	0.5	12	11	11
		1.0	13	12	11
		1.5	13.5	13	12
		2.0	13.5	13	12

The two methods were evaluated by comparing the results of the volumetric determination of optimum RAC content to the mix designs supplied by the contractors for projects evaluated in the Spring and Summer of 1993.

ISSA TB 118, Surface Area Method of Slurry Seal Design

ISSA TB 118 uses a surface area calculation to determine the amount of asphalt required to coat the particles with a specified film thickness. The amount of asphalt cement required is then adjusted for the amount of asphalt cement absorbed by the aggregate (29).

The theoretical optimum residual asphalt cement content or bitumen ratio (BR) is calculated using the following equation:

$$BR = SAB + KA \quad (1)$$

where:

KA	=	kerosene absorbed in percent of dry weight of aggregate
SAB	=	surface area bitumen in percent dry weight of aggregate
SAB	=	CSA x t x 0.02047 x SG_b
CSA	=	corrected surface area m^2/kg (ft^2/lb of dry aggregate)
CSA	=	surface area x 2.65/apparent specific gravity
t	=	bitumen film thickness in microns
SG_b	=	specific gravity of bitumen
0.02047	=	a correction factor for units in equation

SAB is the RAC content required to coat the aggregate particles with a specified film thickness. This coating would be assumed to be the same thickness for aggregate particles of all sizes. ISSA TB 118 recommends a film thickness of 8 microns. The surface area of the aggregate is determined by multiplying a surface area factor by the percent aggregate passing the corresponding sieve. The total surface area of the aggregate is obtained by summing these calculated values.

KA is the RAC content needed to compensate for the amount of asphalt absorbed by the aggregate. The KA is determined using the kerosene absorption from ASTM D5148-90 (CKE).

ASTM D5148-90, Standard Test Method for Centrifuge Kerosene Equivalent

ASTM D5148-90, Standard Test Method for Centrifuge Kerosene Equivalent (CKE) was developed to determine the asphalt cement content for dense graded asphalt concrete. The CKE furnishes an index factor (K) which gives an indication of particle roughness and surface capacity. The approximate bitumen ratio (ABR) is determined by using the surface area and K with the design chart in Figure X1.1 in the appendix of ASTM D5148-

90. According to Hveem, the film thickness is an inverse function of surface area. Smaller particles require a thinner film to maintain stability than larger particles (30). This is adjusted for in the design charts.

Materials

The materials used in the volumetric determination of theoretical optimum RAC content were representative of the material currently being used in Texas. All materials met the specifications given in TxDOT draft micro-surfacing procedure, March 1993. The emulsion used was CSS-1P or CSS-1hP. The aggregate was Texas Grade II for coarse-graded surface coarse. The mineral filler was non-air entrained, lump free portland cement. Distilled water was used in the preparation of the samples. Only set retarding additives approved for micro-surfacing were used if needed. Table 28 gives a description of the material and the suppliers for the material used in the volumetric determinations.

Procedures

ISSA TB 118

The surface area of the aggregate was determined by multiplying the surface area factors from ASTM D 5148-90 by the percent aggregate passing the corresponding sieve. The total surface area was found by summing the calculated values.

The kerosene absorption was determined using ASTM D5148-90. This consisted of taking 100 g of aggregate passing the 4.75 mm (#4) sieve and saturating it with kerosene through capillary suction. The sample was centrifuged at 400 times the value of gravity for 2 minutes. The kerosene absorption was the amount of kerosene retained by the aggregate after centrifugation. The required bitumen was then calculated using equation 1 above.

ASTM D5148-90

The surface area of the aggregate was determined by multiplying the surface area factors from ASTM D-5148-90 by the percent aggregate passing the corresponding sieve. The total surface area was found by summing the calculated values.

The CKE was determined by taking 100 g of aggregate passing the 4.75 mm (#4) sieve and saturating it with kerosene through capillary suction. The sample was centrifuged at 400 x gravity for 2 minutes. The CKE was the amount of kerosene retained by the aggregate after centrifugation. The CKE was corrected for specific gravity of the aggregate. The corrected CKE, surface area and percent aggregate passing the 4.75 mm (#4) sieve was used to determine the surface factor (K_f). There is a separate oil absorption test for the coarse material. The procedure notes that if less than 20 percent of

Table 28. Description of Materials used in Volumetric Determination of Theoretical Optimum RAC Content

MATERIAL	AGGREGATE	ABBREVIATION
Texas Grade II coarse graded surface aggregate	Capitol Aggregates (Delta Materials) Marble Falls, TX	Delta
Texas Grade II coarse graded surface aggregate	Boorheim Field Inc. Paris, TX	BF
Texas Grade II coarse graded surface aggregate	TransPecos Materials Vehalen, TX	Trans
CSS-1hP	Ergon Asphalt and Emulsion Waco, TX	Ergon
CSS-1P	Koch Material Company Salina, KS	Koch

the aggregate is coarse material, K_f is used for the surface factor for the mixed fine and coarse material (K_m). The design chart in Figure X1.1 was used to determine the ABR.

Results

The results of the volumetric procedures and a comparison of the calculated optimum RAC content and the RAC contents from the contractors mix designs for several of the projects evaluated in spring and summer 1993 are given in Table 29. The results are discussed for each method in the following paragraphs.

Table 29. Percent Residual Asphalt Cement Content Calculated from the Volumetric Procedures and the Optimum Given in the Contractors Mix Design

Aggregate	ISSA TB 118 Bitumen Film Thickness (microns)			ASTM D5148-90	ASTM D5148-90 + 1.5%	Koch Mix Design	Ergon Mix Design
	4	6	8				
Delta	7.6	9.6	11.6	5.8	7.2	--	6.35
Boorheim Fields	7.6	9.5	11.3	6.0	7.5	7.7	7.47
Capital	6.7	8.3	9.8	5.7	7.1	7.5	7.39

ISSA TB 118 Results

The calculated theoretical optimum RAC content using ISSA TB 118 gave higher RAC contents than the contractors' mix designs when reasonable film thicknesses were used. Different design thicknesses were evaluated to see how they compared to the contractors mix design. No one film thickness resulted in agreement with the contractors mix design.

The results of this test were very sensitive to change in aggregate gradation, especially the smaller sizes. If the mineral filler is included as part of the aggregate gradation, a 1 percent increase in mineral filler resulted in about a 1 percent increase in the RAC content.

ASTM D5148-90

This procedure estimated the optimum RAC content lower than recommended in the contractors' mixture designs. This procedure was not as sensitive to small changes in gradation as the ISSA TB 118 procedure. A 1 percent increase or decrease in mineral filler changed the calculated optimum RAC content by less than 0.2 percent. This procedure takes in to account that as the surface area increases, film thickness decreases. By taking the approximate bitumen ratio calculated in the procedure and adding 1.5 percent RAC content, the values were similar to those recommended by the contractors' mixture designs.

MIXTURE DESIGN USING THE TEXAS GYRATORY COMPACTOR

The researchers used TxDOT's standard hot mix asphalt concrete (HMAC) procedures in an attempt to determine optimum asphalt content for micro-surfacing. The idea was that, at optimum asphalt content, the standard compaction procedure would yield some particular air void content which would correlate with the optimum binder content for micro-surfacing (as in the case for HMAC). Micro-surfacing mixtures were prepared in the laboratory in the usual fashion at several emulsion contents then partially or fully dried and compacted at different temperatures. Subsequent testing of compacted specimens revealed this method to be unsatisfactory for routine use in determining optimum asphalt content.

Six different micro-surfacing mixtures were tested. These six mixtures were produced using aggregates from three different sources (Boorheim-Fields, Delta, and TransPecos) and emulsions from two sources (Koch Materials and Ergon, Inc). Each mixture was prepared at three different emulsion contents. After mixing the components of the micro-surfacing, the wet mixture was spread out in a pan and for at least overnight at ambient temperature. Then, mixtures were further dried for four hours in a forced air oven at 60°C (140°F) while stirring periodically. Compaction was achieved using the Tex-205-F procedure at three different temperatures (121°C, 60°C, and 25°C [250, 140, and 77°F]).

Air void contents and Hveem stabilities of the resulting specimens were measured. Indirect tension testing was performed on the specimens molded at 121°C (250°F).

The mixtures tested and the test results for the mixtures compacted at 121°C (250°F) are shown in Table 30. The middle emulsion content in each cell is the "optimum" emulsion content as determined by laboratory testing and verified by field applications. At optimum binder content, air void content of the compacted mixtures varies from 2.9 percent to 5.3 percent. Figure 123 illustrates the fact that there is no simple relationship between air void content of the gyratory compacted specimens and optimum emulsion content.

Several TxDOT area offices have reported very low Hveem stabilities of gyratory compacted micro-surfacing. Table 30 and Figure 124 show that, when all the water is evaporated from the mixture and standard HMAC compaction procedures are used, Hveem stabilities of micro-surfacing at optimum binder content usually meets the criterion for hot mix (minimum Hveem stability 35). Tensile strengths are also comparable to those normally observed for HMAC as shown in Figure 125.

Specimens compacted at 60°C (140°F) with optimum asphalt content yielded air void contents from 4.3 percent to 8.1 percent as shown in Table 31. There appeared to be no correlation between air void content and optimum asphalt content. Compaction at the lower temperature gave Hveem stabilities for these specimens of 35 or less.

Specimens compacted at 25°C (77°F) with optimum asphalt content produced air void contents from 13.2 to 16.1 percent as shown in Table 32. Again, no correlation between air void content and optimum asphalt content was observed.

Although the results of this experiment were disappointing, it showed that it is possible to prepare specimens using the gyratory compactor. This is useful information. Drying of micro-surfacing mixtures in accordance with the above procedure and compaction using the gyratory compactor at 38°C (100°F) should produce specimens with approximately seven percent air voids. This should provide a process for preparing micro-surfacing specimens in the laboratory that simulate field mixtures after significant traffic that can be used for testing in accordance with Tex-531-C.

Table 30. Results of Tests on Micro-Surfacing Mixtures Compacted at 121°C (250°F)

Type Aggregate	Type Emulsion	Emulsion Content, percent	Residual Asphalt Content, percent	Air Void Content, percent	Hveem Stability, percent	Indirect Tension,	
						kPa	psi
Boorheim Fields	Koch	9.7	6.3	5.3	44	1234	179
		10.7	6.9	3.6	40	1117	162
		11.7	7.6	3.0	41	1234	179
	Ergon	9.7	6.2	5.4	45	1248	181
		10.7	6.9	3.6	39	1268	184
		11.7	7.5	2.6	36	1351	196
Delta	Koch	10.7	6.9	6.0	48	1082	157
		11.7	7.6	4.5	44	1117	162
		12.7	8.2	3.8	37	1048	152
	Ergon	10.7	6.9	3.6	45	1110	161
		11.7	7.5	2.9	34	1255	182
		12.7	8.2	1.7	31	1144	166
Trans-Pecos	Koch	10.6	6.8	6.9	40	786	114
		11.6	7.4	4.6	39	834	121
		12.6	8.1	2.6	36	855	124
	Ergon	9.6	6.2	7.9	37	820	119
		10.6	6.8	5.3	39	841	122
		11.6	7.4	4.9	39	807	117

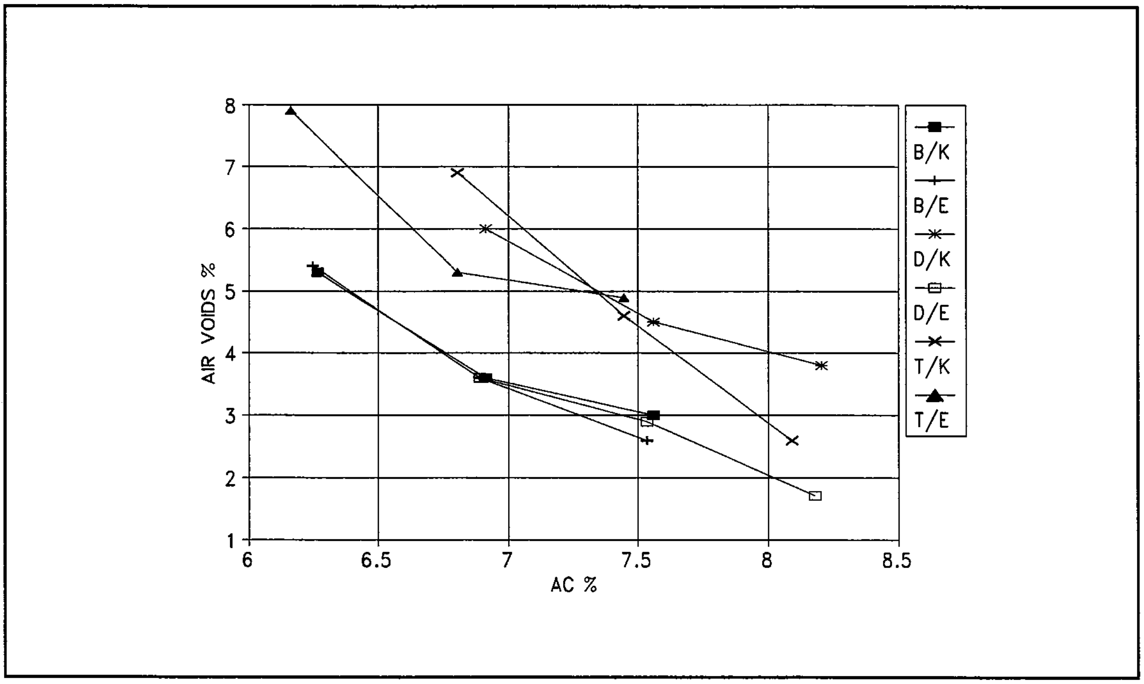

Figure 123. Air Voids versus Residual Asphalt Cement Content, Compacted at 121°C (250°F)

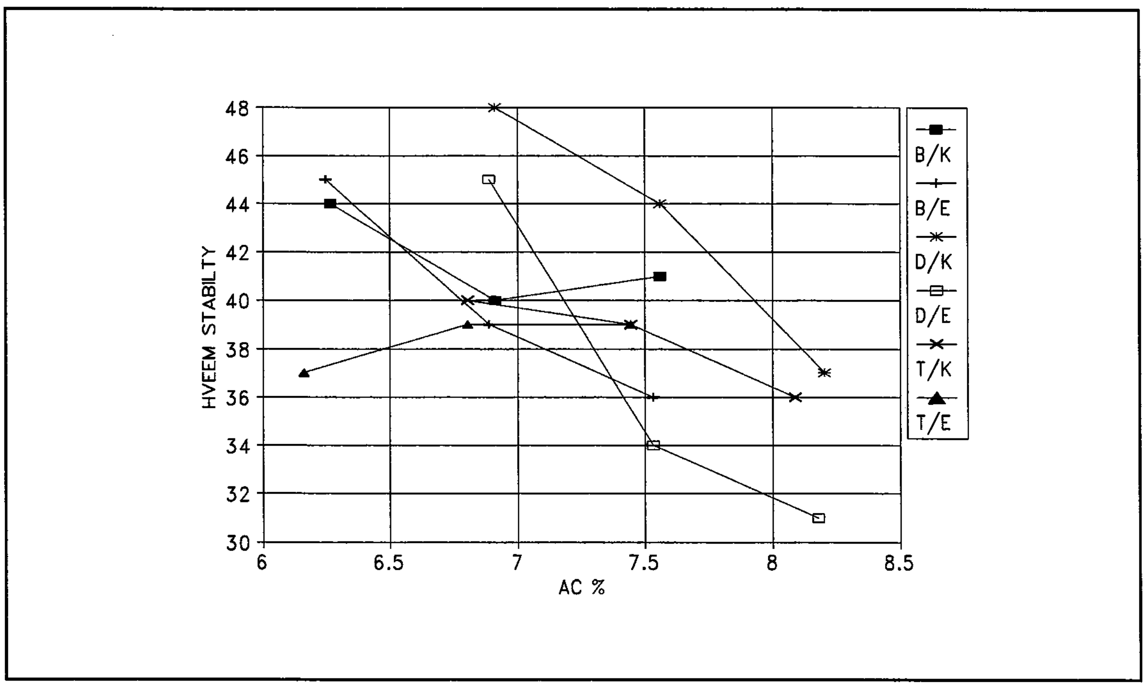

Figure 124. Hveem Stability versus Residual Asphalt Cement Content, Compacted at 121°C (250°F)

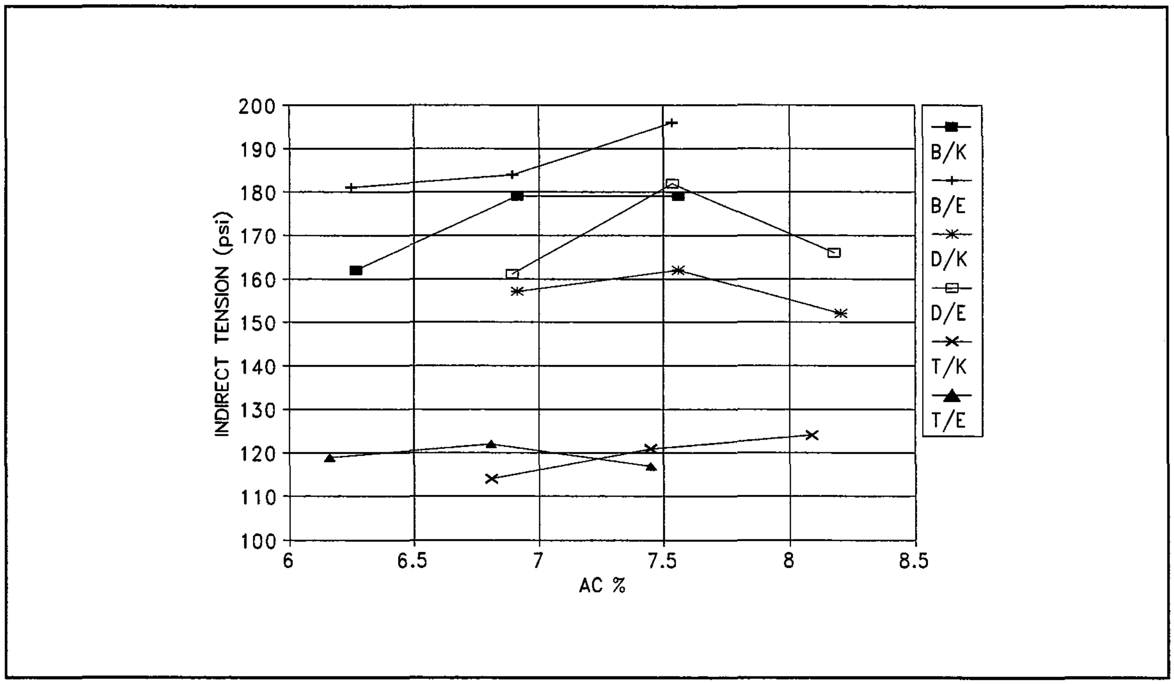

Figure 125. Tensile Strength versus Residual Asphalt Cement Content, Compacted at 121°C (250°F)

Table 31. Results of Tests on Micro-Surfacing Mixtures Compacted at 60°C (140°F)

Type Aggregate	Type Emulsion	Emulsion Content, percent	Residual Asphalt Content, percent	Air Void Content, percent	Hveem Stability, percent
Boorheim Fields	Koch	9.7	6.3	4.1	21
		10.7	6.9	4.3	28
		11.7	7.6	4.9	34
	Ergon	9.7	6.2	4.2	14
		10.7	6.9	4.5	24
		11.7	7.5	4.8	34
Delta	Koch	10.7	6.9	7.7	34
		11.7	7.6	8.1	35
		12.7	8.2	8.6	35
	Ergon	10.7	6.9	5.1	19
		11.7	7.5	5.3	20
		12.7	8.2	5.6	22
Trans-Pecos	Koch	10.6	6.8	4.7	31
		11.6	7.4	5.3	33
		12.6	8.1	5.5	35
	Ergon	9.6	6.2		
		10.6	6.8		
		11.6	7.4		

Table 32. Results of Tests on Micro-Surfacing Mixtures Compacted at 25°C (77°F)

Type Aggregate	Type Emulsion	Emulsion Content, percent	Residual Asphalt Content, percent	Air Void Content, percent	Hveem Stability, percent
Boorheim Fields	Koch	9.7	6.3	14.0	21
		10.7	6.9	14.2	21
		11.7	7.6	14.5	21
	Ergon	9.7	6.2	13.4	18
		10.7	6.9	13.5	19
		11.7	7.5	13.7	20
Delta	Koch	10.7	6.9	13.0	19
		11.7	7.6	13.2	20
		12.7	8.2	13.4	21
	Ergon	10.7	6.9	15.7	17
		11.7	7.5	16.1	17
		12.7	8.2	16.5	17
Trans-Pecos	Koch	10.6	6.8	13.7	22
		11.6	7.4	15.0	22
		12.6	8.1	15.7	23
	Ergon	9.6	6.2		
		10.6	6.8		
		11.6	7.4		

CHAPTER 6
SPECIFICATIONS

INTRODUCTION

A specification was developed to facilitate the purchase of work or materials from a supplier (31, 32). The specification should include requirements that will ensure that the material, product, system, or service purchased satisfies the purchaser (31).

Material and workmanship (methods and materials) specifications describe "the kinds and types of materials to be provided, their physical and performance properties, their sizes and dimensions, the standards of installation and workmanship, and inspection and tests required for verification of quality" (33, pg 63). The supplier is responsible for providing the materials and work that meet the specification requirements; the owner or the owner representative (the engineer) is normally responsible for the adequacy of the end product. Therefore the engineer must prepare the specifications in enough detail to assure that the materials and work provided will give the desired end product (33).

Performance or end result specifications describe "the required performance or service characteristics of the finished product or system without specifying in detail the methods used in obtaining the desired end result" (33, pg 62). This type of specification makes the contractor responsible for obtaining satisfactory results. The construction methods and procedures are left up to the contractor (33).

It is the responsibility of those who write specifications to ensure that all parts of the documents can be clearly interpreted without ambiguity, keeping in mind the final objectives of the specifications. The following requirements should be met:

a. materials, products, systems, or services required should be available in such quantities that they can be provided on a reasonable schedule;

b. they can be safely provided to meet the service needs and aesthetic demands of the user;

c. one or more contractors (suppliers, producers, etc.) can be found to provide them; and

d. the material, product, system, or service provided in accordance with the specification should be durable and economical.

The specification adopted should address the particular application for which the micro-surfacing will be used and suggest types and/or grades of materials that will provide optimum performance in any given situation. It presently appears that the contractor should have primary responsibility for mixture design and that the Department should be equipped with test procedures and evaluation methods to verify that the optimum design has been selected and is being maintained by the contractor during the prosecution of the project.

METHODS AND MATERIALS SPECIFICATION

The recommended methods and materials type of specification is included in Appendix B. Major changes from pervious versions include the following.

1. The amount of polymer in the residual asphalt cement can be determined using Texas Test Method TEX-533-C or the new gel permeation chromatography procedure described in Appendix C. The amount of natural rubber polymers asphalt residue from emulsions cannot be accurately determined using Texas Test Method TEX-533-C. An investigation determined that the gel permeation chromatography procedure described in Appendix C gives reasonably accurate information on natural rubber modifiers in asphalt emulsions.

2. There are no requirements for testing the residue of the emulsion after distillation. The properties of the base asphalt should be similar to the properties of the residual except for the effect of the polymer modifiers since the asphalt is not heated in a hot mix asphalt plant. Most of the polymer modifiers are added by co-milling, e.g., they are added to the asphalt during the emulsification process. The polymer modifiers are not added to the asphalt and then emulsified, which means that there is no way of testing the properties of polymer modified asphalt except after the emulsification occurs. Our investigation showed that all of the current distillation methods significantly alter the properties of the asphaltic materials. This work is described in Appendix D. Therefore, the researcher recommend that all required tests be conducted on the base stock asphalt; however, it will not show the effect of the polymer modifier. One method suggested by emulsion manufacturers is to air dry the emulsion on a glass or metal plate at room temperature until the water is fully evaporated. A sample of the residual asphalt cement is then removed, taking care not to heat it, and tested using the dynamic shear rheometer (DSR) which requires a sample of less than one gram. This procedure should be investigated for future use when the DSR equipment is available.

3. The requirement for Hveem stability was removed. Our investigation determined that there was no method to mold a sample of micro-surfacing mixture in an approach similar to construction in the field and achieve consistent Hveem stability numbers. Based on our experience with distillation of the polymer modified binders, we are convinced that any process which heats the material to a temperature needed to mold samples in a standard method will significantly alter the properties of the asphalt binder.

4. Because it is difficult to accurately determine the asphalt content of mixtures containing polymer modified asphalt cements using the vacuum or centrifuge devices, it is recommended that asphalt content of mixtures be determined using

the nuclear asphalt content gage. However, more work needs to be completed on how to prepare samples with emulsions for testing. Table 33 shows the results from a particular project where the asphalt content was measured with nuclear asphalt content gages and calculated from field reports. The design residual asphalt content was 6.8 percent. The asphalt content measured with the nuclear asphalt content gage was consistently higher than that calculated from field measurements. Field measurements can be inaccurate from day to day because of failure to account for returned loads, etc., but on the average over the whole project, they will be reasonably accurate. Since the nuclear asphalt content gage measures the presence of hydrogen instead of asphalt cement, there is concern that all of the water is not being removed from the sample before testing. The project team found that it takes more time than most district personnel are using to remove all water from a sample containing emulsions. The confidence intervals provided in Table 33 also indicate that the allowable tolerances in the specification may not be achievable. However, until the problems with the measurement equipment and preparation procedures are eliminated, it will not be possible to determine what that allowable tolerance should be.

5. Since there is no actual extraction with the nuclear asphalt content gage, it is recommended that aggregates from the stockpiles be used for acceptance and evaluation of the aggregates. Allowable tolerances for the aggregates were not changed based on observed variation on projects that appear to be performing well. Table 34 shows the variations from two such projects were generally within the recommended ranges. The "2s" interval is based on 1.96 times the standard deviation as recommended by Reference 34. Because of the small amount passing the 4.75 mm (# 4) sieve, the variation is sometimes slighty greater than the 5 percentage points allowable.

6. The mixture design requirements were modified to match the draft mixture design procedure found in Appendix A. This mixture design is based on selecting the minimum acceptable residual asphalt cement content; therefore, there is no test for the maximum value. We are retaining the limitation of 0.5 percent variation from that minimum. Based on field evaluation of mixtures, the portland cement content used for testing the material in the laboratory is considered the minimum. The contractor should be allowed to increase that value up to a maximum of 2.5 percent.

7. A section on workmanship was added. This portion attempts to describe the properties expected in the finished surface. This could be used as the acceptance criteria for the surface in an end-result type of specification.

Table 33. Mean Values and Variation in Residual Asphalt Content Measured with Nuclear Asphalt Content Gage and Calculated from Field Measurements

Test Method	Mean AC Content (%)	AC Content Standard Deviation	AC Content Variation One Way Confidence Intervals (+/-)			
			99.5% Confi-dence	99.0% Confi-dence	95.0% Confi-dence	90.0% Confi-dence
Nuclear Gage	7.438	0.670	1.728	1.561	1.105	0.857
Field Calculations	7.030	0.462	1.192	1.077	0.762	0.592

Table 34. Distribution and Confidence Intervals of Aggregate from Acceptable Micro-Surfacing Project

Sieve Size		Tyler District, 1994			Waco District, 1994		
mm	in	Mean % Passing	% Passing Standard Deviation	2s Interval	Mean % Passing	% Passing Standard Deviation	2s Interval
12.5	1/2	0	0	0	0	0	0
9.5	3/8	0	0	0	0	0	0
4.75	# 4	10.42	3.07	6.01	10.49	1.80	3.53
2.36	# 8	41.04	1.40	2.74	43.77	2.48	4.86
1.18	# 16	59.17	1.23	2.41	66.10	1.74	3.41
0.60	# 30	69.17	1.06	2.07	78.01	1.42	2.79
0.30	# 50	75.79	0.88	1.72	84.46	1.34	2.62
0.150	# 100	88.42	1.14	2.23	88.10	1.20	2.35
0.075	# 200	94.42	0.73	1.43	91.63	0.84	1.65

End-Result Specifications

Although developing an end result specification was a goal of this study, not enough is known about which tests reliably predict performance of micro-surfacing to develop such a specification at the current time. A draft specification using the materials and methods approach was developed. In addition, the project staff participated in a FHWA study to draft an end-result with warranty specification. By placing a warranty on the specification, it is not as important to have models that can predict the life of the micro-surfacing to use end-result type specifications. Instead, the desired result of the micro-surfacing at the end of the treatment application is defined, and a final result at the end of some designated time period is also defined.

Based on the researchers' experience and recommendations of other agencies working with FHWA on end-result specifications with warranty, a warranty period of two years is recommended (35). The warranty should basically warrant workmanship and materials. Most micro-surfacing projects that fail due to materials or workmanship normally fail during construction or during the first severe climatic cycle. Since some locations in Texas do not experience a severe climatic cycle every year, a two-year period is recommended. One of the concerns about warranties is that the underlying pavement will fail due to structural inadequacy but may be interpreted as problems with the treatment. Most micro-surfacing treatments are expected to perform for five to seven years, but it is difficult to predict the performance of many pavements beyond two to five years without a significant amount of testing and evaluation. Therefore, the two-year warranty period seems like an appropriate compromise on time.

It is recommended that the Department investigate the feasibility of using the FHWA Guide Warranty Specification for Micro-Surfacing as a trial end-result specification with warranty (35).

CHAPTER 7
QUALITY CONTROL AND ASSURANCE

INTRODUCTION

In addition to specifications and mixture design procedures, quality assurance guidelines are needed to ensure that the micro-surfacing placed in the field meets the requirements of the specifications. Quality assurance tests include materials acceptance tests, field tests, and evaluations. Acceptance and quality assurance tests are fairly well established for the primary individual components of micro-surfacing: asphalt emulsion, mineral aggregate, and mineral filler. However, tests and acceptance criteria are not as well established for the mixture itself. Set time, break time, cure time, and resistance to wear were considered appropriate factors to consider for field evaluation.

True quality assurance would define the tests that the contractor should complete and the tests the Department use to verify the information collected by the contractor. In this set, a minimum number of tests based on the experience of the project staff was developed. Considerable study and development will be required to determine the distribution of testing requirements.

EVALUATION OF TESTS

The study evaluated several tests for use in the field. Those that gave reasonable information for reasonable effort and costs were included in the recommended quality assurance guidelines. Those tried in the field and not recommended include the following.

Mixture Design Tests

Early in the project, the project staff tried to collect samples in the field to mold samples that would be tested in the laboratory using the ISSA mixture design tests. Samples of the mixture from the application machine were taken. Cohesion, wet track abrasion, and loaded wheel test samples were molded from this mixture at the job site. They were to be tested in the laboratory. However, this concept was abandoned after attempts at a couple of test sites. The mixture in the field is set to break at about 30 to 60 seconds after leaving the spreader box. After taking the samples, the project staff did not have adequate time to properly mold them. The project staff also found that how well the samples are molded has an impact on the test results. Because of these problems, we felt that the test results on this type of sample might be more affected by the molding process than the properties of the mixture.

Mixture Strength

The study team wanted to determine the strength of the micro-surfacing in the field and evaluate the time at which the strength was capable of withstanding traffic. Two tests were evaluated.

Field Cohesion Test

Alpha Labs in Ohio makes a field cohesion test device similar to the device used in ISSA Test No. 139 described earlier. The device is self-contained with a small air tank and compressor that operates using a 12-volt system on an automobile. After the air tank is filled, more than 20 tests can be completed before the air tank must be recharged. The bottom plate sits on the pavement surface, and the ram goes through a hole in the bottom plate to the pavement surface. The field test procedures are otherwise the same as ISSA Test No. 139 except that the test is completed on the in-situ pavement surface.

The test is relatively simple to complete; however, practically none of the mixtures tested reached the require 12 kg-cm at 30 minutes. Then they would transition to a full spin condition, still with a relatively low value. This would indicate that the micro-surfacing is ready for traffic, but it did not give much information on the strength.

The project team also found from contractors and suppliers that a simple test can be completed with no special equipment that will indicate when traffic can be applied, although, in a somewhat more subjective manner. If the inspector places the full weight of his body on the sole of the shoe on the mixture for two seconds without picking up mixture, then the pavement can be opened to straight traffic. If the inspector places the full body weight on the heel of one shoe on the mixture and twists the heel with only minor surface marks, the mixture can be opened to turning traffic without significant damage. This simple test gives adequate information on opening time without special equipment.

Vane Shear Test

The vane shear test evaluates the shear strength of a material by placing a segmented vane in the material, rotating it, and measuring the torque required to generate rotation. Although the concept is reasonable, the application in the field proved cumbersome. The vanes must be placed in the micro-surfacing before the emulsion in the micro-surfacing has broken; otherwise, the vanes will disrupt the surface. They must remain in the surface until the testing is complete.

The Torvane device was evaluated for measuring the torque. When the Torvane was used in the field, the shear strength of micro-surfacing typically exceeded the limits of the Torvane within one-half to one hour after application. Because the micro-surfacing is a thin layer, when the shear strength nears the limit of the Torvane device, the shear vanes generally raise over the aggregate and out of the surface when they are rotated. This results in inaccurate shear strength measurements.

It is suggested that the Field Cohesion Test Device be used to keep the shear vanes from twisting out of the micro-surfacing and to measure greater torque. It is possible that this approach could be used to evaluate the gain in strength during the application phased. However, to get the ultimate strength that we would like to have requires that the vane be placed in the surface and remain in place until full strength is developed. This would require at least one day, and probably several. The project team did not feel that it would be realistic to mold shear vanes in the pavement surface and measure the shear one or more days later. So the evaluation of vane shear tests to determine ultimate strength was abandoned.

QUALITY ASSURANCE GUIDELINES

Micro-surfacing as a material appears to violate many of the rules TxDOT inspectors have developed over the years to insure that quality hot mixed asphalt concrete pavements are constructed. Guidelines were developed to give direction for the checks and tests that should ensure that a quality micro-surfacing treatment is provided by the supplier and contractor.

The proposed quality assurance guidelines are presented in Appendix E. They were developed based on reviews of available guidelines, including those provided by ISSA (36), and discussions with engineers, inspectors, contractors, and suppliers. The guidelines reflect the requirements of the specifications, and are currently based on the materials and methods type of specification described earlier, but they can be converted for use with end-result specifications.

The guidelines include laboratory tests before and during the treatment application, checks by the inspectors during the treatment application, and some general discussions of problems that may be encountered with recommendations on how to correct them.

Before Construction

Checks and tests conducted before construction are completed to determine the acceptability of the materials and mixtures. The before-construction checks and tests are generally considered materials acceptance and mixture verification testing. Sometimes, trial work may be required to ensure that the contractor can provide the product specified, especially if a new material or method is proposed.

Materials Acceptance Tests

In materials acceptance testing, the basic materials proposed for use by the contractor are tested to determine that they meet the specification requirements. The material may be submitted by the contractor or collected by a TxDOT representative. Materials to be tested include:

- polymer-modified emulsified asphalt; and
- aggregate.

Materials to be certified as meeting requirements include:

- mineral filler;
- additives; and
- water.

Mixture Design Verification

In the mixture design verification, TxDOT will conduct a series of tests on the micro-surfacing mixture to verify that the mixture design submitted by the contractor meets required standards. Once the mixture design is approved, all mixtures must meet the resulting job mixture formula within allowable tolerances. This is described in more detail in Appendix F.

The test requirements are based on the analysis of testing procedures completed by the project staff. The basic test used to determine acceptability of the mixture is the Wet Track Abrasion Test presented in Appendix A, which is an adaptation of the ISSA test described in ISSA-TB-100. The test will be conducted using the mixture quantities provided by the contractor and material suppliers. The material loss shall have maximum values of 807 g/m^2 (75 g/ft^2) after six days of soaking.

During Construction

The checks and tests conducted during construction are completed to ensure that the materials being placed meet the requirements established in the specifications and approved in the before construction materials and mixture design acceptance checks and tests. Samples are normally collected by TxDOT inspectors from the construction site and from the materials stockpile locations. Actual laboratory testing may be conducted at District or Materials and Test Division Laboratories. The following checks and tests are recommended for micro-surfacing.

Materials Tests

Tests are conducted on samples of the materials taken from the materials storage or the micro-surfacing application machine. The following materials should be sampled and tested:

- polymer-modified emulsified asphalt cement, and
- aggregate.

The following materials will be checked to see if they meet the certification requirements:

- mineral filler, and
- additives.

Water will only be sampled if there appears to be a problem that could be caused by the water being used.

Mixture Composition

Mixture samples will be taken from the mixing unit discharge in a manner such that the complete discharge stream is included in the sample. The residual asphalt content of the paving mixture will be determined using the nuclear asphalt content gage.

Weather Limitations

Limitations were placed on the weather that have been found to cause problems.

Workmanship

Workmanship requirements were established to provide guidance on how to determine the acceptability of the existing surface. The topics include:

- surface preparation,
- time to open to traffic,
- finished surface,
- joints and seams,
- edges, and
- ruts.

Possible Problems and Corrections

Since micro-surfacing is a new material to many Department inspectors, a section on problems that have been encountered and corrective actions was included in the guidelines. It is assumed that those responsible for inspection will have a set of these guidelines with them during micro-surfacing construction and they can refer to them when they encounter a problem. It is not intended for the inspector to make decisions for the contractor based on the information presented. Rather, the material is provided so that the inspector can determine if the contractor is making reasonable modifications to his work to correct problems. Problems discussed include:

- time to opening to traffic too long,
- surface preparation,
- finished surface,
- joints/seams,
- edges, and
- ruts.

QUALITY ASSURANCE CHECKLIST

To assist field personnel in completing quality assurance checks in the field, a check list was prepared. This check list addresses the following topics:

- surface preparation,
- finished surface,
- joints/seams,
- edges, and
- ruts.

The checklist should make it easier for the inspector to make field checks and to record the results of those checks. The checklist is provided in Appendix G.

CHAPTER 8
USAGE GUIDELINES

Micro-surfacing can be used as a surface seal on asphalt concrete pavement. It can be used to establish a skid resistant surface on pavements. It can be used to fill ruts in asphalt concrete pavements. It has been used to seal cracks by some agencies. It has also been used to surface bridge decks. Because of its sealing capabilities and resistance to plastic deformation, it may have other applications such as replacement of overlays under overpasses where vertical clearance is limited, replacement of seal coats on high volume highways, and arresting severe ravelling of hot mix asphalt concrete.

Usage guidelines were developed based on information from other agencies using micro-surfacing, recommendations from Department personnel experienced in using micro-surfacing, and the project staff's experience developed in the project. Special consideration was given to identifying those pavement types, conditions, and problems that should not normally be addressed with micro-surfacing.

The recommended usage guidelines are provided in Appendix H. They are prepared as a short, stand-alone document. It is expected that the guidelines will be used by design and pavement management engineers in selecting treatments to address maintenance and rehabilitation needs of existing pavements. The guidelines address the following items.

- short description of micro-surfacing;
- use as a surface treatment;
- use as a rut filler;
- types of pavements on which the treatment would be appropriate;
- requirements of the pavement for treatment with micro-surfacing;
- recommended analysis procedures to determine that micro-surfacing is appropriate for a selected section of pavement;
- layer thicknesses; and
- time to opening to traffic.

CHAPTER 9
COST EFFECTIVENESS

INTRODUCTION

Cost effectiveness requires information about costs and performance of the treatment being analyzed. Cost information varies dramatically among agencies, and the costs for the treatments constructed in this study are not representative of normal preventive maintenance treatment costs. This study primarily defines the effectiveness of the treatments.

DEFINING TREATMENT EFFECTIVENESS

Pavement maintenance treatment "effectiveness" has been defined differently in several pavement management systems (37). One of the most common measures of effectiveness used in this type of analysis is the impact of the treatment on pavement life (38). Of course, pavement life is not well-defined, and that is why there are differing definitions of effectiveness. Pavement life is often defined in terms of serviceability (SI); however, low surface friction can also lead to the end of a safe and serviceable pavement life. In general, all measures that can define the end of life to a safe and serviceable pavement should be included.

No matter what the measure, a minimum acceptable condition must be defined. When the condition of the pavement reaches that level, the pavement is considered to have reached the end of its serviceable (useful) life. This minimum acceptable level can vary among agencies and among classes of roads within an agency. Effectiveness of the preventive maintenance treatment can be determined based on how long it took a treated section to reach the minimum acceptable level.

The condition of several sections of micro-surfacing should be evaluated each year until the condition of the pavement reaches a state that pavement with the micro-surfacing must be removed from service by additional maintenance, rehabilitation, or reconstruction. It is expected that this type of information will be produced by the TxDOT Supplemental Maintenance Effectiveness Research Program. At that point, the lives of micro-surfacing applied to pavements in different condition levels in different environments in Texas can be reasonably estimated.

During this study, the project staff evaluated several newly constructed and existing pavements with micro-surfacing. In addition, information from other agencies was gathered, as described in Chapter 2. Based on this information, micro-surfacing should be expected to provide reasonable service for five to seven years when placed on pavements in appropriate condition as discussed in the guidelines for use.

CALCULATING COST EFFECTIVENESS

If the life in years is used as the measure of effectiveness, it can be used with life-cycle cost analysis concepts and agency costs for the treatments to determine cost effectiveness (37, 38).

In the long term for comparison with other treatments, the Department should select an analysis period appropriate for all of the treatments and strategies of combined treatments for the analysis. A simplifying assumption that can be used is to assume that the treatment can be repeated indefinitely. This allows the calculation of equivalent uniform annual costs. This calculation will give the information in dollars per year of life so that the analysis can be made based on an annual cost. This would generally limit comparison of the cost effectiveness to other treatments that last approximately that same period of time.

It is assumed that all treatment costs are in current costs and, therefore, are considered the present value of the treatment costs. If not, the present value of future costs are calculated using the following equation (39):

$$P = F\left[\frac{1}{(1+i)^n}\right]$$

where:

P = present value of the treatment
F = future cost of the treatment to be applied at some future time
n = number of years until the treatment will be applied
i = interest of discount rate used by the Department for economic analysis

The equivalent uniform annual cost is found using the following equal payment series sinking fund formula (39):

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

where:

A = equivalent uniform annual cost
P = present cost (value) of the treatment
n = number of years over which micro-surfacing is expected to perform
i = interest or discount rate used by the Department for economic analysis

ESTIMATES OF COST EFFECTIVENESS

Near the end of the project, the cost of micro-surfacing was about \$0.0827 per kg (\$75 per ton) for moderate sized projects, not considering traffic control and assuming the treatments were placed during normal day light hours. Larger projects generally result in lower costs around \$0.0661 per kg (\$60 per ton), and smaller projects or projects restricted to night construction generally result in higher costs up to about \$0.0937 per kg (\$85 per ton).

The cost per square meter depends on the application rate. The application rate varies depending on the condition of the surface, the presence of ruts, and the number of applications. A single application will typically require 13.6 to 16.3 kg/m^2 (25 to 30 lb/yd^2). Applications using the rut box followed by full coverage of the surface will typically require 24.4 to 27.1 kg/m^2 (45 to 50 lb/yd^2). Applications of a scratch course followed by a full coverage can require 19.0 to 24.4 kg/m^2 (35 to 45 lb/yd^2).

The estimated unit costs in dollars per square meter are shown on the y-axis of Figure 126 for different purchase costs in dollars per kg. Different application rates in kilograms per square meter (lb/m^2) provide different unit costs as shown by the different curves. The unit costs varied from a low of \$0.748/m^2 (\$0.625/yd^2) to a high of \$2.960/m^2 (\$2.475/yd^2).

The equivalent uniform annual costs will vary depending on the interest and the life of the pavement as well as the unit costs. Figure 127 shows the annual cost in dollars per square meter per year for different purchase costs for four cases of life and interest rates when the application rate is 16.3 kg/m^2 (30 lb/yd^2), which is typical for a single application. Figure 128 shows the annual cost in dollars per square meter per year for different purchase costs for four cases of life and interest rates when the application rate is 24.4 kg/m^2 (45 lb/yd^2), which is typical for a double application. A separate curve is provided on each figure for each of the following:

- five year life with three percent interest
- five year life with five percent interest
- seven year life with three percent interest
- seven year life with five percent interest

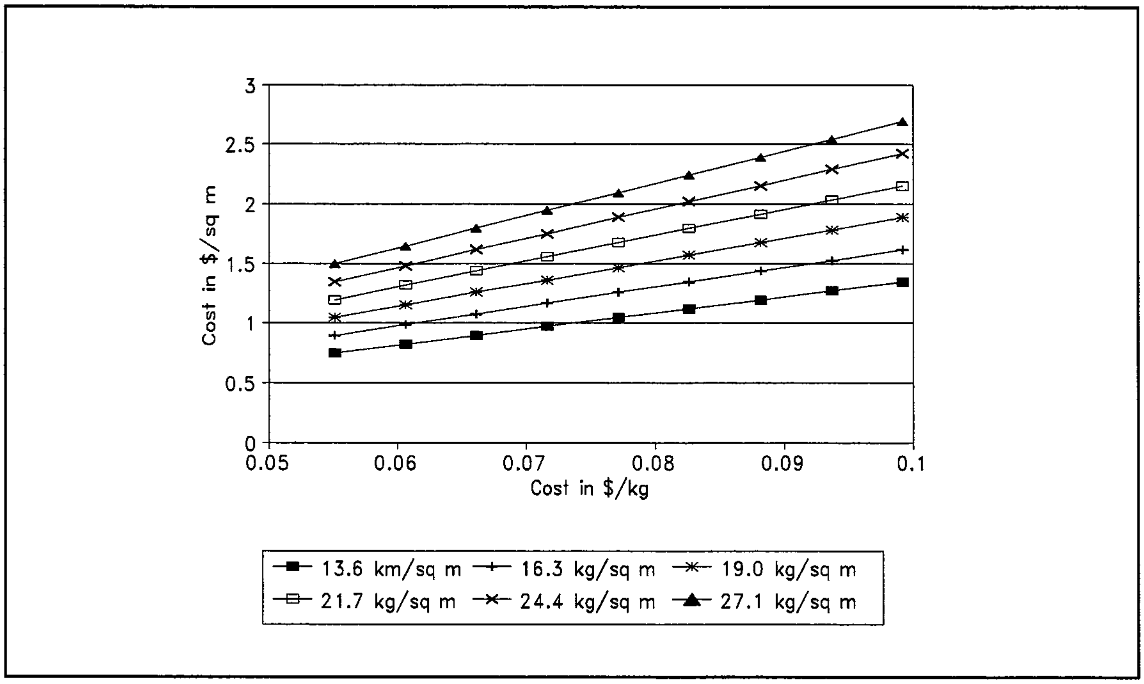

Figure 126. Unit Costs in $/sq m for Different Purchase Costs in $/kg at Different Application Rates in kg/sq m

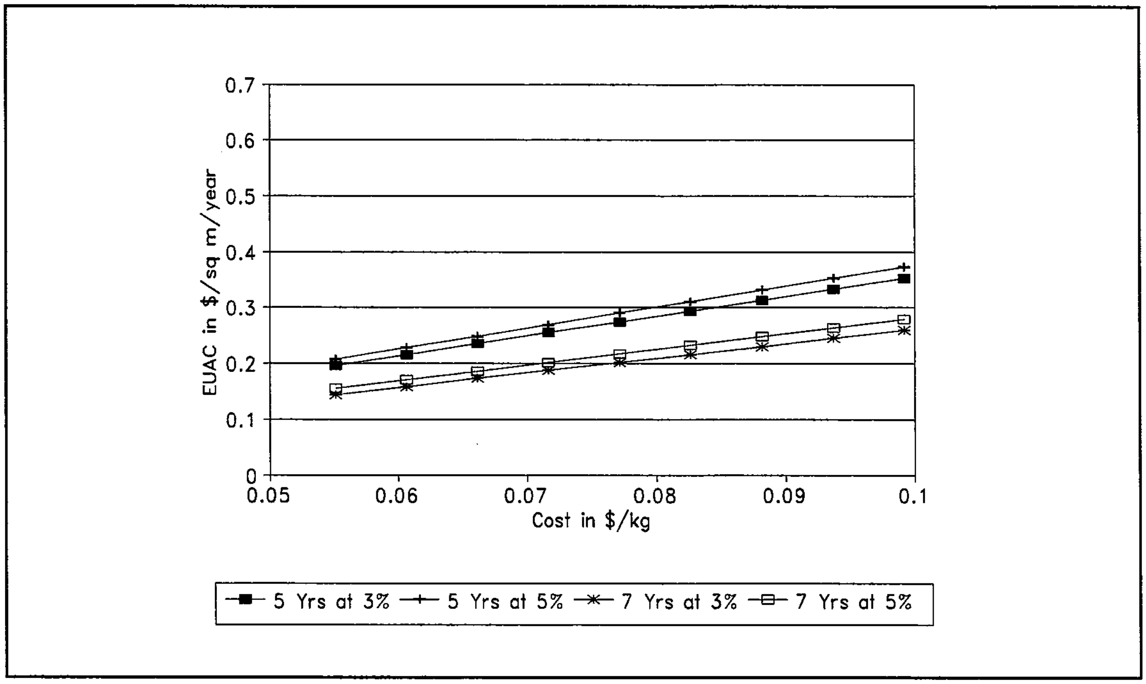

Figure 127. Annual Costs in $/sq m for Different Purchase Costs in $/kg for Different Lives and Interest Rates when Micro-Surfacing is Applied at a Rate of 16.3 kg/sq m

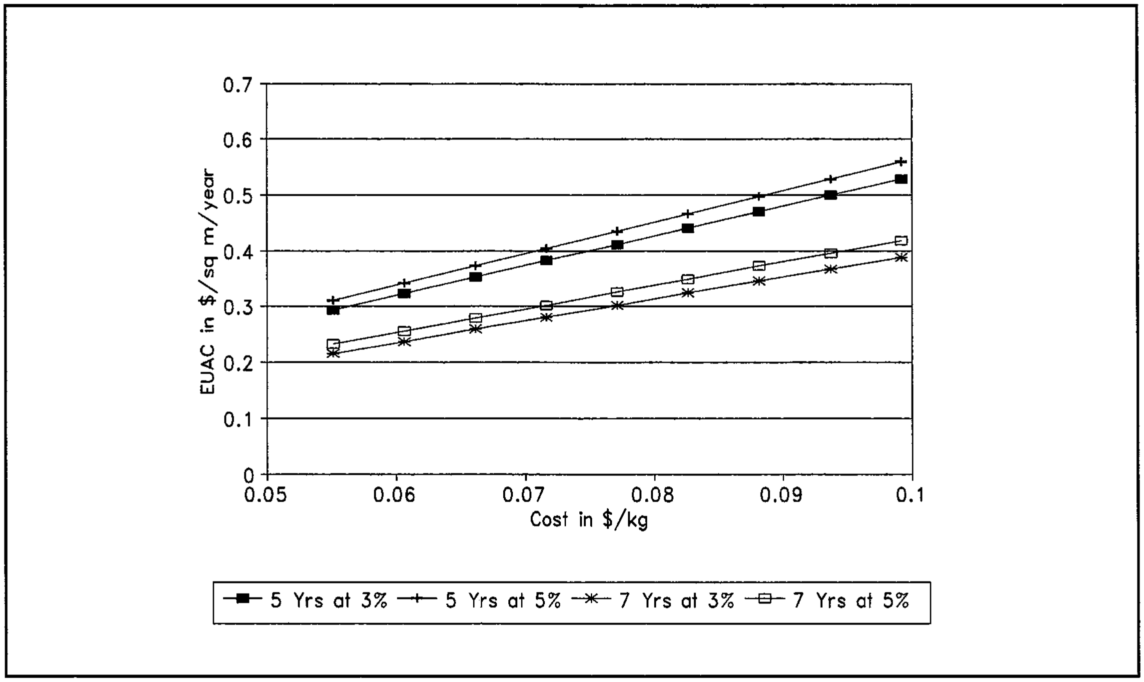

Figure 128. Annual Costs in $/sq m for Different Purchase Costs in $/kg for Different Lives and Interest Rates when Applied at 24.4 kg/sq m

The annualized costs for these applications vary from $\$0.144/m^2$ ($\$0.120/yd^2$) per year to $\$0.373/m^2$ ($\$0.312/yd^2$) per year for application rates of 16.3 kg/m^2 (30 lb/yd^2). They varied from $\$0.216/m^2$ ($\$0.181/yd^2$) per year to $\$0.560/m^2$ ($\$0.468/yd^2$) per year for application rates of 24.4 kg/m^2 (45 lb/yd^2).

CHAPTER 10
FIELD EVALUATIONS

INTRODUCTION

The project staff visited several construction sites during the course of the project. These visits provided valuable information on problems that should be covered in the specifications, methods that can be used to correct construction problems, and how to construct a quality micro-surfacing. The field projects also served as a laboratory to try mixture designs and the QA checklist. The following sections give a brief description of most field evaluations. The staff also made visits to a few sites where only discussions with contractor and Department personnel and visits to the construction site were completed.

SUMMER 1992

Hearne

The construction site is located in the Bryan District on State Highway 6 just south of Hearne. Work was completed in October, 1992. The pavement had considerable alligator and longitudinal cracking in the wheel paths, most of which had been covered with crack sealing material the previous year. A single layer of micro-surfacing was applied using Delta Materials aggregate from Capitol Aggregates with Ergon emulsion.

The contractor had considerable equipment and construction problems during the project. The stockpile area was near the center of the project; however, at one time there were so many supply trucks inoperative that the micro-surfacing application equipment had to stop and wait for trucks to return. Each time the application equipment stops, the crew must clean the last few meters of material from the surface to make a straight joint. They must also clean the spreader box to remove material that builds up on the box. If the box is not thoroughly cleaned, the built up material will break loose and fall into the mixture creating tear marks. At other times, the application equipment was inoperable.

Several tear marks developed during the construction. During the project, the project staff found that most of the tear marks were caused by two materials. Because there was so much crack sealing material on the existing surface, sometimes the application equipment would tear loose some of the crack sealing material and drag it through the mixture, causing drag marks. Most of the other drag marks were caused by build up of emulsion and fines in the spreader box, which would then drop into the mixture, catch on the rear of the box, and drag along creating marks. The crew would try to break the material loose from inside the box, remove it from the surface after the box had passed over it, and repair the mark with a squeegee.

Waco

A section of Interstate 35, in the Waco District south of Waco was treated with micro-surfacing. The contract concluded in August 1992. The micro-surfacing used Delta Materials aggregate from Capital Aggregates with Ergon emulsion. The outside lane had been surface recycled in 1992. The TxDOT district personnel stated that they had determined that micro-surfacing works best when the existing surface is well prepared.

The contractor was having difficulty in constructing transverse joints that were not rough. The TxDOT personnel suggested that the contractor try metal sheeting to help get straight smooth joints. When the application was stopped, a straight cut was made across the lane and all material beyond that cut was removed. When application began, a metal sheet, generally sheet metal about 4 m by 1 m (14 ft by 3 ft), was placed on the existing micro-surfacing with the edge at the same location as the cut. The spreader box was placed partly on that sheet. When application began, the material was placed partly on the metal sheet and partly on the uncoated pavement surface. After the spreader box moved along the road, the metal was removed and the material on the metal sheet was discarded. This left a straight, smooth joint.

Rockwall

The construction site was on State highway 66 in the Dallas District near Rockwall. The project used Boorheim Fields aggregate and Ergon emulsion. A scratch coat was applied to fill minor rutting before the application of a final surface coarse.

The contractor used a rubber strike-off with a burlap drag finish. At the time of the project staff visit, the equipment was not operating due to a mechanical failure. The contractor staff explained the calibration procedures to the project staff. It is apparent that calibration is very important to the success of a micro-surfacing project.

The mobile micro-surfacing machine used on this project has a constant rate emulsion pump. The pump was connected to the main jack shaft and always provided the same quantity of emulsion for each rotation of the shaft. The mixture was controlled by setting the feed gates for the aggregate and the portland cement. Each of these had a gate with a given width that can be set at different heights. The higher the opening, the more aggregate or cement was fed into the continuous mixture pug mill.

The calibration was completed by running aggregate through the plat at three different gate openings and determining the amount each gate setting provides for each rotation of the shaft. This same process was repeated with the portland cement. The emulsion quantity was determined as the average of three different tests with the machine. All measurements were made in weight, and all mixture quantities were based on dry weight of the aggregate.

Brownwood

The micro-surfacing work was carried out in the Brownwood District on US 377 near Brownwood. The project used Delta Materials aggregate from Marble Falls with Ergon emulsion was used on the project. A scratch coat was applied to fill minor ruts before the application of a full width surface course.

The contractor was only working from about 5:30 am until noon because of the high temperatures. Apparently, the contractor had problems with the micro-surfacing breaking in the box later in the afternoon on the project before the project staff visited the site. It was obvious that the expertise of the crew has a big impact on how well the work is completed.

The primary operator of the mobile micro-surfacing mixing machine set the controls so that the desired amount of emulsion and cement were placed in the mixing box (continuous mix pug mill) with the aggregate to meet the job mixture formula. These settings were based on the calibration of the equipment, and, if the calibration was incorrect, the mixture would not be correct. The operator added water to the mixture to provide the desired consistency. Since there was no measure of consistency used in the field, the operator made the decision about consistency based on his experience. As the moisture in the aggregate, the humidity, temperature, and road condition changes, the operator changed the amount of water to keep the consistency relatively constant. When the temperature was high, the moisture in the road surface was low and the surface was hot. This caused the emulsion in the micro-surfacing to break on contact with the road surface. A light spray of water was normally applied to the road surface just in front of the spreader box to help avoid this problem in hot weather.

The emulsion in the micro-surfacing must break fast enough to allow adequate strength to develop so that traffic can be placed on it in less than an hour. However, if the emulsion breaks too quickly, it can break in the spreader box, which will not allow the material to be spread evenly on the pavement surface. Even if the material does make it out of the box, the crew needs some time to correct small drag marks and smooth the edge of longitudinal joints. Most operators try to have the emulsion break at about 30 to 60 seconds after it has left the spreader box. As the temperature increases during the day, the operator will have to add set retarding additive to keep the desired break time. If the day becomes too hot, the additive may not provide the results desired.

As the season changes, the emulsion suppliers change the properties of the emulsion so that it will continue to provide the desired properties. Early in the season, they will formulate it so that it will break more quickly at a given temperature than during the hotter part of the summer. As the fall season approaches, they will again change the properties so that it will break more quickly at that given temperature.

The work was going smoothly while the project staff was present. The contractor used a rubber strike-off with a burlap drag to finish the surface.

Brownfield

The construction site was located in the Lubbock District on US highway 180 near Brownfield. The project used a crushed rhyolite aggregate supplied by TransPecos Materials and Koch emulsion. A scratch coat was applied to fill minor ruts followed with the application of a final surface course. The surface had light to moderate bleeding in the wheel paths.

The work was progressing satisfactorily. The contractor was using a rubber strike-off with a burlap drag. When the supply trucks would pull away from the micro-surfacing machine, occasionally one of them would loose a small amount of aggregate. This would leave a spot about 0.1 m^2 (1 ft^2) in area which would then be paved over with the micro-surfacing. This raised questions about whether that would lead to a loss of bond between the micro-surfacing and the pavement surface in those areas where this occurred.

The emulsion supplier will provide a different formulation of emulsion for different aggregates. The TransPecos material acts enough differently than most other aggregates used in Texas that the emulsion supplier often formulates the emulsion specifically for that aggregate to ensure that the contractor can place it in the field.

SPRING 1993

Comanche

The construction site was located in the Brownwood District on US 67, North of Comanche from the intersection with TX 36. A test section was defined for future evaluation from TRM 540+1.00 to 540+1.20. The Southbound lane was the TTI mix and the Northbound lane was the standard Ergon mix. The TTI designed optimum RAC content selected was 10.8%. This test section was evaluated again in 1994. At that time there was no discernable difference between the TTI and the Ergon designed mixtures.

The contractor had several equipment problems, but the Resident Engineer was pleased with the final product. Several combinations were used to develop a final finish, and the following describes the findings as provided by Mr. Larry Smith.

1. Rubber primary screed with rubber secondary screed and no burlap drag - This system gave a good texture but left what looked like oil streaks. The streaks were still visible one year later but had no adverse affect on the surface. The system is susceptible to drag marks and requires close monitoring to correct them.

2. Rubber primary screed with rubber secondary screed with a 0.6 m (2 ft) burlap drag - The system worked well but the burlap drag left some oil streaks and minor drag marks.

3. Steep primary screed with rubber secondary screed with a 1.2 m (4 ft) burlap drag - This system gave the best finish of all three observed in the District during that construction season. It produced no oil streaks, removed minor drag marks, and provided a coarser finished surface texture than the other systems. However, the application rate was harder to control.

Dallas and Tyler Mixtures

Ergon Emulsion - Although there was no true optimum residual asphalt selected for the site, a low asphalt content of 7.0 percent and a mineral filler content of 1.00 percent were selected for use on the Dallas project and a high asphalt content of 8.3 percent and a mineral filler content of 1.00 percent were selected for the Tyler project to determine the impact of varying the emulsion content from that provided by the contractor and material suppliers. The contractors and material suppliers coordinated an experiment on the project by placing their normal mixture using Koch supplied emulsion and Ergon supplied emulsion and TTI specified emulsion and mineral filler contents.

Koch Emulsion - Although there was no true optimum residual asphalt selected for the site, a low asphalt content of 6.6 percent and a mineral filler content of 0.75 percent were selected for use on the Dallas project and a high asphalt content of 8.2 percent and a mineral filler content of 0.75 percent were selected for the Tyler project to determine the impact of varying the emulsion content from that provided by the contractor and material suppliers. The contractors and material suppliers coordinated an experiment on the project by placing their normal mixture using Koch supplied emulsion and Ergon supplied emulsion and TTI specified emulsion and mineral filler contents.

This was an example of the type of assistance we received from all emulsion suppliers and contractors. They willingly assisted by providing the material and applying mixtures that required them to make changes to their equipment and materials. This slowed their production and interrupted their normal work activities. But they were always ready to help in any way possible.

Rockwall

The Dallas District project was placed on FM 3097 between FM 740 and FM 549 in Rockwall County during June 1993. This is a low-volume, rural two lane road without paved shoulders.

This road had received considerable maintenance since construction resulting in significantly different surface textures on the pavement. Some of the road had been chip sealed, some had old blade patches, some had new blade patches. There were occasional locations of rutting up to 30 mm (1.2 in). There some locations with low severity alligator cracking in the wheel path. There was cracking along the edge in several locations.

There were four test sections defined for the four mixtures placed. Condition information before application was take. The sites are all in the west bound lane. The TTI mixture with Ergon emulsion test site is from TRM 606+0.10 to TRM 606-0.10. The Ergon designed mixture test site is from TRM 606-0.40 to TRM 606-0.60. The TTI designed mixture with Koch emulsion is from TRM 606-1.2 to TRM 606-1.4. The Koch designed mixture test section is from TRM 606-1.5 to TRM 606-1.7.

The work went smoothly. There were no personnel and little equipment problems. Even though there was only a single layer placed, the final surface looked relatively good. The difference in the underlying surface resulted in different surface texture in some locations. There were a few locations where hand work was completed that did not have the same appearance as the surrounding surface. The contractor used a rubber strike-off with a burlap drag finish.

Rubber latex strings often developed along the back side of the strike-off. They did not appear to cause a problem, and the crew thought they were normal. They seemed to have more of them with the Koch emulsion than the Ergon emulsion.

Late one afternoon, it started raining while construction was in progress. The work was halted, and no further work was completed that day. There was no apparent damage to the surface.

The contract called for the application of micro-surfacing for some distance into side roads and driveways. The application machine was heavy enough to cause shear failures in the driveways in a couple of instances.

The test sites were reinspected in 1994. Some of the alligator cracking had started to reappear. Most of the edge cracking had reflected through. The differences in surface caused by the underlying layers could still be seen in some instances. The unsightly hand work areas were less apparent but could be identified during the walking survey. There was no discernable difference between the surface appearance of the four test sections.

Rusk

The Tyler District project was on US 69 in Cherokee County between Rusk and Jacksonville. The pavement is four lane divided with an outside shoulder on the south bound section but no shoulder on the north bound section. The should on the south bound section had a rounded 50 to 75 mm (2 to 3 in) drop-off in some locations. The existing surface was hot mix asphalt with a lightweight aggregate chip seal that had been in place for several years.

Rut filling was placed in the outside lane and a scratch course in the inside lanes, both followed with a full width surface course. The work went smoothly except for a problem that developed with the additive feed line that developed when the contractor switched from one emulsion and additive to another. The contractor used a rubber strike-off with a rubber secondary strike-off. The secondary strike-off allowed the crew to correct drag marks between the strike-offs and provide an excellent final surface. The edges were very straight and there were practically no tear marks. When a problem develops, the contractor does not try to patch a damaged area after the emulsion has broken. After the surface has adequately cured, the application machine is used to place a full width patch over the damaged area. The two joints will generally look much better than a hand worked area after the micro-surfacing has broken.

No strings of latex developed from the primary or secondary strike-off. The operator and supervisor stated that they used additive to ensure that these did not develop. The crew stated that if the latex strings develop, they will drop off and create drag marks.

The TxDOT personnel reported that there was a problem meeting the sand equivalency requirements a few times during the project. The contractor stated that they knew about the sand equivalency problems before the inspectors did because they could tell by the way the mixture was working. Contact was made with the aggregate supplier, and no further problems were reported. The inspectors and the contractor seemed to working together well.

As in the Rockwall site, four test sections were located. The Koch developed test section is in the outside north bound lane from TRM 364+0.40 to TRM 364+0.20. The TTI designed test section is located in the outside north bound lane from TRM 362+1.7 to TRM 362+1.5. The TTI designed Ergon mixture is in the outside south bound lane from TRM 364+0.10 to TRM 364+0.30. The Ergon designed mixture is from TRM 364+0.80 to TRM 364+1.00.

During the application of the test sections, the work went well. The mixtures and surface generally looked good. When the TTI designed Koch mixture was sampled, it appeared that the emulsion was not coating or bonding to the aggregate as it did in the other test sections. In this section, the emulsion content was increased, but the amount of portland cement was reduced from 2.00 percent to 0.75 percent. It was hot 32°C (90° F) or above, and the contractor was using considerable additive. It appears that the cement helps the bonding between the aggregate and the emulsified asphalt cement. Late the next day the mixture was still in place and exhibited no problems, but the aggregate did not appear to be well coated when dug from the mixture.

This operation appeared to be very well organized. The contractor matched the application speed to the rate at which the delivery trucks could provide the aggregate, emulsion and water from the stock pile location near Rusk. They felt that slowing speed was a better option than stopping which requires considerable time to clean the spreader box, and clean the joint area.

This site was reinspected in 1994. Some cracking in the outer wheel path in the north bound lane was reflecting through. There was one area where rutting was starting to redevelop. There was no discernable differences between the four test sections. These was a slight amount of raveling developing near the centerline on the inside lane in the south bound direction. Material was removed from the section that experienced the bonding problem the previous year, and the material appeared to be bonded and performing similar to the mixtures in the other test sections.

FALL 1993

Houston

This project was in the Houston District on I-45 north of Houston from FM 1960 south to AirTex Road in the southbound lanes. All work was completed at night between the hours of 10 pm and 5 am. This is an asphalt concrete overlay over jointed portland cement concrete pavement. A test site was located in the outside southbound lane from mile marker 65 to mile marker 65 + 0.20.

This project was going well. There were no equipment or personnel problems. The mixture looked good; however, it was difficult to see drag marks and other small imperfections because the work was completed at night.

The micro-surfacing equipment used on this project was equipped with a computerized readout device that provided information on the application rate including the amount of each material being used. It could also provide cumulative information. This type of equipment could be set up to provide records of machine operations that could be used in quality assurance types of specifications.

The project was inspected again in 1994. The cracks from the reflective cracks in the asphalt concrete created by the underlying portland cement concrete had reflected through in most locations. There appeared to be some small shear failures developing along the centerline joint; it is possible that this joint is breaking down or that the asphalt is starting to strip in that area. There are other locations near that area on I-45 where that area has been replaced in relatively new asphalt concrete over portland cement concrete. There were no other problems noticed.

San Antonio

This project was placed in the San Antonio District on I-410 on all lanes between I-10 and I-37 on the southwest side of San Antonio in September 1993. A test site was defined in the outside southbound lane from mile marker 37 to mile marker 37+0.2.

The contractor was experiencing considerable personnel problems. Practically the entire crew was new to micro-surfacing. The supervisors had considerable construction experience, but no micro-surfacing experience. This contractor sold the equipment and quit contracting for micro-surfacing in Texas at the beginning of the next construction season.

The project was using Ergon emulsion with a Capitol flint type of aggregate. The Ergon mixture design required 10.25% emulsion and 0.75% cement. Because they had previously experienced problems with set time in the mixture, they had changed the cement content to 1.25%. The TTI mixture design called for 10.5% emulsion and 1.25% cement. Since the TTI mixture was so similar to the mixture design they were using and the crew was having so much difficulty, the project staff did not have them change their mixture design.

The project did not have a pleasing final appearance. The edges were very crooked. There were several drag marks of reasonably large size in some areas. There were places with unsightly handwork marks. This location was visited again in 1994, and the problems with the surface identified in 1993 were still readily apparent in 1994. However, the material seemed to be performing well.

The TxDOT project personnel were having a difficult time with the project because of all of the contractor problems. When the project staff was on site, the TxDOT inspectors basically wanted the project to finish so that they could put a bad experience behind them. This kind of experience leads to the feeling that "if this is the kind of problems we have with micro-surfacing, we won't use it again because we don't need the problems." That appeared to be the attitude developing with the TxDOT staff on the project.

Alice

This project was in the Corpus Christi District on US 281 south of Premont. The work was completed during September 1993. The project used an emulsion with an EVA polymer modifier supplied by Prime Materials based on a Jean Lefebvre design. Synthetic fibers were used in a part of the project injected with a feeder from Jean Lefebvre. Three test section were defined. The section in the outside north bound lane from TRM 702+0.20 to 702+0.00 is the standard mix design. The test section in the outside lane from TRM 700+1.95 to 700+1.85 is the full fiber section. The test section in the inside lane from TRM 700+1.95 to 700+1.85 is another standard mixture design section with lower traffic.

The TTI mixture design required the same quantities that were being used on the project, and no adjustments were made in the quantities. The existing pavement was an old hot mixed asphalt concrete pavement with an old seal coat. There were ruts 3 to 9 mm (1/8 to 3/8 in) deep with a few flushed spots. There were some transverse cracks and a few longitudinal cracks. Few cracks were open because of the "crack healing" that often occurs with a rich seal coat during the summer.

The contractor's crew were well organized, and the equipment worked well. A modern continuous mixture machine was being used that had both a primary and secondary rubber strike off screed.

The fiber feeder arrived about 1 pm. It was mounted, calibrated, and ready to apply micro-surfacing by 2:30 pm. The control section was placed, and then the fiber feeder was engaged to trickle in the fiber gradually until the full feed rate was reached. As the fibers were introduced into the mixture, the mixture appeared to be a little dryer than the mixture without fibers and appeared to have more texture. The machine operator thought that the fibers had less tendency to stick to the spreader box. Some of those experienced with mixtures on the site wondered whether the fibers were absorbing enough of the emulsion that this would create a bonding problem.

The contractor was using both the primary and secondary screed for most of the test sections. In the full fiber section, the secondary screed was raised for a few feet to determine the effects. It appeared to have little effect on the texture, but it did not appear to provide the same transverse profile. There were more surface blemishes that required hand work in that area.

The crew stopped once in the fiber section to clean the spreader box, creating a transverse joint. From that point northward, there was only half the fiber content compared to the application to the joint.

The condition of the test section were evaluated twice during 1994. In April, there was no apparent difference in the non-fiber and fiber test sections in the north bound lanes. There was some reflective cracking in each with some stains at the cracks indicating pumping. The test section area appeared to have the most cracking in the construction section. The contractor and TxDOT personnel picked the cracked area to see the impact of the fibers on cracking resistance. The test section was slightly lighter in color than the remainder of the project indicating the possible initial stages of raveling. The remainder of the project did not show that impact.

In August 1994, a second evaluation was completed. At this time the third test section was identified adjacent to the fiber section to determine if the constructed test sections were performing differently than the remainder of the construction project. A slight difference in color was noticeable between the outside and inside lanes, but there was no dramatic difference in raveling among the test sections. The fiber and non-fiber test sections appear to be performing about the same. A considerable amount of cracking has developed in both test sections in the outside lane. Many of the cracks show stains indicating pumping action.

SUMMER 1994

Belton

This project was in the Waco District on I-35 between Belton and Temple. The work was completed during May 1994. The project used Ergon emulsion and Delta Material from Capital Aggregates.

The work was going well. The contractor was using an application machine that has a computerized read out of all materials used by the machine. The spreader box is an adjustable box that can be used to put a slight crown in the wheel path to compensate for future compaction by traffic. The contractor used a continuous mixture machine on the mainline work. He used a batch machine on the ramps.

The work was going smoothly. The edge lines were straight, and there were practically no tear marks. The crew was well-organized and there were no equipment problems. The TxDOT staff and the contractor seemed to working well together as a team to produce a good product.

The project staff tried the first draft of the QA check list on the project, and they trained the Bell Area Office inspectors in its use. They felt the concept of a checklist was good and could be helpful in inspection. The laboratory personnel were very conscientious in completing their work and helping the project staff.

Hamilton

This project was in the Waco District on US 281 from Hamilton to Evant. The work was completed in June 1994. The project used Ergon emulsion and Delta Material from Capital Aggregates. Rut filling was completed on parts of the road and a scratch course was placed on the remainder. The entire surface was then covered with a final surface course.

The crew had some problems controlling the rut filling spreader box. It would swing from side to side until they found the correct adjustment for the connecting chains. The weather was hot and the crew was having problems with the mixture after about 2 or 3 pm. They were trying different additives, and some seemed to work better than others in keeping the mixture workable during the hottest part of the day.

Except for the number of transverse joints created by the additive problem, the surface looked good with few drag marks. The drag marks created by the additive problems were covered by subsequent applications. The TxDOT personnel from the Batesville Area Office questioned how they could account for the amount of mixture that was wasted during the stops, starts, and reapplication due to these problems.

The TxDOT inspection staff was concerned that the surface did not have a uniform texture. This would be expected when a single course is placed because the surface texture of the final course is affected by the surface texture of the underlying course. However, when a scratch course is placed, the surface course is expected to have a relatively uniform course. This should be checked in the future to see if the difference in surface texture was temporary or permanent.

The project staff tried the first draft of the QA check list on the project in a test section just south of Hamilton. They trained the Batesville Area Office inspectors in its use, and they felt the concept of a checklist was good and could be helpful in inspection. They were working well with the contractor and appeared to be trying to get the best possible job.

Several transverse joints were measured using a 1.2 m (4 ft) straight edge. Those that had 6 mm (1/4 in) or more height measured with a 1.2 m (4 ft) straight edge placed with one end on the joint perpendicular to the direction of the joint in the wheel path could be felt when driven over with a standard automobile at normal speeds.

Comanche

The project was in the Brownwood District located on TX 36 west of Comanche for about 4.8 km (3 mi) from the intersection with US 67 in the south edge of Comanche from TRM 372 + 0.60 to TRM 374 +1.70. This was one of several sections the contractor was completing for the Brownwood District. The project used Ergon Emulsion and Delta Material from Capitol Aggregates.

The contractor had several problems, including changes in key personnel. This included the project supervisor who was replaced during the project, micro-surfacing operator, micro-surfacing machine driver, truck drivers, and others. The entire crew seemed disorganized. The equipment was inoperable for much of the time this project staff was on the job site. This contractor sold the micro-surfacing equipment and quit working in micro-surfacing after completing this project.

They placed a scratch coat to fill existing ruts 5 to 8 mm (3/16 to 5/16 in) followed by a final surface application. The project staff used the second generation QA check list on the project and trained the TxDOT inspectors from Brownwood in their use. We laid out a test section just west of US 67 in the west bound, inside lane including measuring before application rutting.

The TxDOT inspectors were trying hard to get a good job, but they were frustrated by the constant problems that the contractor was experiencing.

The project staff checked the transverse joints in micro-surfacing farther west on TX 36 that had been completed by the contractor a few days earlier. In 8.8 km (5.5 mi), there were ten observable joints westward and five were felt riding in a standard automobile. Going East there were six joints, and five were felt. From measuring joint elevations, the staff determined that they could feel joints that had 6 mm (1/4 in) or more height measured with a 1.2 m (4 ft) straight edge placed with one end on the joint perpendicular to the direction of the joint. All measurements were completed in the wheel path.

LaVon

This project was completed in the Dallas District on TX 78 between Wylie and LaVon in Collin County, a two lane facility; however, it has quite heavy traffic on it. The project used Koch emulsion with Boorheim Fields aggregate in July and August 1994.

The work appeared to be going smoothly, and the surface looked good. However, while the project staff was present, the equipment broke down, and the contractor shut down the operation for the remainder of the week.

The project staff trained the TxDOT personnel from the North East Dallas Office in the use of the second generation QA check list.

Tyler

Two projects were reviewed in this district. In this contract, the District required the contractor to have an independent testing laboratory take the material samples, complete the required material quality control tests, and provide the results to the District. This appeared to be working; however, the independent laboratory was using extraction equipment to determine asphalt content that would not be expected to provide reasonable values. The results that the staff reviewed on the project site seemed very erratic. Several of them were considerably higher than would be expected. Most results give low values because all of the polymer modified asphalt is not removed. It is possible that the laboratory personnel were not removing all of the water from the mixture before the extraction and were counting part of the water as asphalt content.

The concept of making the inspection part of the contract could be a step toward a full quality assurance program for micro-surfacing. The contractor becomes responsible for the quality control checks that must be made periodically. TxDOT becomes responsible for quality assurance by checking the quality control checks completed by the contractor and making a limited number of verification checks. The project in the Tyler District should provide a reasonable estimate of the costs to the contractor for the testing.

The first project was completed on US 69 between Rusk and Alto. This is a four lane divided facility, but the micro-surfacing was placed only on the north bound lanes except for a short section near the northern edge of Alto where all four lanes were covered. The project used Koch emulsion with Boorheim Fields aggregate in July 1994.

The work went smoothly with little personnel or equipment problems. The surface looks good and the edges are straight. Most of the transverse joints are smooth.

The project staff trained the TxDOT personnel from the Jacksonville Area Office in the use of the second generation QA check list. TxDOT personnel used the checklist for several days and provided information on acceptable work and recommendations on its use.

The second project was completed on TX 42 north of Calgary from TX 31 north towards Longview. This is a two lane facility that crossed I-20 and carries heavy traffic. The work was completed in August 1994 using Koch emulsion with Boorheim Fields aggregate.

The contractor was limited to having only one mile of pavement closed at any one time because of the traffic backup. This created a stop-and-go type construction activity that reduced production.

Ruts were filled with a rut box, and the entire surface was to be covered with a final surface course. This crew used struts to pull and control the motion of their rut box rather than chains. They had no problems controlling the application process.

The project appeared to be going well. There were no major crew or equipment problems. The project staff was only able to visit the site during the rut filling work.

CHAPTER 11
FORENSIC ANALYSIS

INTRODUCTION

Micro-surfacing is normally used as a maintenance or surface treatment for an existing pavement with an asphalt concrete surface. As a surface treatment, it provides a skid resistant surface. Micro-surfacing can also by used to fill ruts to reestablish the transverse profile of the pavement.

Usage guidelines were prepared to provide guidance for appropriate selection and application of micro-surfacing. It includes analysis procedures to be used when determining if micro-surfacing is appropriate for a section of pavement. Service life of micro-surfacing applied to pavements in the appropriate condition should be 5 to 7 years for relatively high traffic and may be longer for low to moderate traffic. The following information is provided to assist when micro-surfacing fails much more quickly than expected.

GENERAL

Experience with the micro-surfacing indicates that if there is a major problem with materials, construction, or workmanship, the problem will appear during construction. Those types of problems should be corrected by Department personnel during construction. This description covers the problems that occur after construction is complete.

Surface Loss

One problem found was loss of surface some months after construction. The first evaluation should be to determine where the surface is separating from the underlying pavement.

Stripping

If the delamination occurs within the underlying pavement, an investigation to determine if stripping is developing in the underlying asphalt concrete.

Structural Inadequacy

If the delamination occurs between the underlying pavement and the micro-surfacing, then an analysis to determine if the underlying pavement is causing the problem should be completed. Micro-surfacing used either as a surface treatment or rut filling does not add substantially to the structural capacity of the pavement.

If the pavement had substantial cracking in the wheel path prior to application of the micro-surfacing, there will probably be considerable vertical deflection in the wheel path. Since the micro-surfacing is a thin, somewhat stiff, layer compared to the cracked underlying pavement, the flexure may be too large for the micro-surfacing to withstand resulting in a cracking pattern and surface loss similar to that found in this hot mix asphalt concrete layers due to cracking in the underlying surface. In general, the surface of the micro-surface will appear to have alligator cracking and soil stains may be seen in the cracking. An investigation of the existing condition prior to treatment should be completed by reviewing TxDOT Pavement Management Information System (PMIS) records or other records such as files developed during construction. If the pavement was exhibiting wheel path or alligator cracking, then micro-surfacing was not an appropriate treatment.

To determine the structural capacity of the pavement, the falling weight deflectometer (FWD) should be used to test the pavement at locations where cracking has occurred and where has not developed. These tests should be made in the wheel path where cracking and surface loss is occurring, between wheel paths where no cracking is occurring, and in the wheel path where cracking has not developed. Cores should be taken at these same locations to determine layer thicknesses and determine the integrity of the existing pavement layers. The FWD results and layer thicknesses can then be used in evaluation procedures to determine the number of loads the pavement should be capable of carrying, and that can be compared to the traffic that has been carried by the pavement.

Rutting

Micro-surfacing is often used to fill ruts. However, filling ruts does not generally correct the basic problem. Ruts are symptoms of problems in the existing pavement. Ruts develop because of consolidation in the underlying pavement layers or because of instability in the pavement layers. Rut filling will only be successful if the rut is caused by mechanical compaction of the pavement structure. If the ruts are caused by an unstable pavement layer material or structurally deficient pavement, the source of the rutting problem will generally cause the rutting to return very quickly.

Some physical information can be used as an initial analysis. If the pavement surface was in service for several years prior to application of the micro-surfacing and developed relatively flat rutting, the rutting is probably due to consolidation within the lower pavement layers, and filling the rut with micro-surfacing should be expected to provide the desired transverse profile for five to seven years. If the pavement was in service for a short time before developing deep dual wheel track ruts in each wheel path, the pavement probably has an unstable surface layer, and filling the rut with micro-surfacing will probably not prevent the rutting from redeveloping within two to three years. If the existing pavement had significant alligator or other cracking in the wheel paths, then the pavement probably does not have adequate structural strength to prevent consolidation and possibly shear failures in the supporting subgrade.

An investigation of the existing condition prior to treatment should be completed by reviewing TxDOT Pavement Management Information System (PMIS) records or other records such as files developed during construction. If the pavement was exhibiting rutting with wheel path or alligator cracking, then micro-surfacing was not an appropriate treatment. A structural evaluation as described above for structural adequacy should be conducted.

If instability of the surface or other stabilized layers is suspected, cores from the wheel path where the rutting is developing, in the same wheel path but where rutting has not developed, and between the wheel path should be taken. These cores should be tested for creep and structural characteristics to determine if their mixture is adequately stable.

Raveling

Raveling generally occurs because of inadequate asphalt content or problems with aggregate segregation. The location and distribution of the raveling should be first determined.

Low Asphalt Content

If raveling develops because of low asphalt content, it will generally be widespread and cover the entire width of the affected lane. If this is present, several samples of the mixture can be taken so that an extraction can be completed to determine the residual asphalt content. The extraction should not be completed using the vacuum or the centrifuge extraction equipment because the polymers will tend to be trapped in the filters preventing full removal of the asphalt. Either the Soxhlet or ASTM D-2172-88, Test Method B (Reflux Extraction). If ASTM D-2172-88, Test Method B is used, the heat source should be turned off at the usual time and the solvent-soaked aggregate allowed to set overnight. The next morning, reflux should be run again until the filtrate is a straw color. This is to be repeated daily until the filtrate is straw color at the start of the distillation process. This will reasonably assure removal of all asphalt cement and polymer.

Segregation or Construction Problems

If the raveling occurs sporadically, then the application equipment or operator may have had difficulty in keeping a constant level of emulsion in the mixture. If this occurs, several samples should be taken in locations with and without raveling. The asphalt cement should be extracted from those samples with raveling and compared to that from samples that did not experience raveling.

Segregation of aggregate and possibly different amounts of asphalt cement may develop in different parts of the spreader box if it is not operating properly. If that occurs, raveling will develop along the edges of the application lanes while the center of the application lane will generally not exhibit raveling. If this is present, several samples should be taken in locations with and without raveling. The asphalt cement should be extracted from those samples with raveling and compared to that from samples that did not experience raveling.

CHAPTER 12
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Micro-surfacing can be used effectively in both preventive and corrective maintenance, primarily for restoring skid resistance, filling ruts to restore transverse surface profile, and to repair weathering and raveling. The micro-surfacing mixtures applied in Texas generally provide 5 to 7 years life if they are applied to pavements in the appropriate condition. Micro-surfacing should not be selected as the treatment if the primary problem is cracking, because the cracking will reflect through relatively quickly.

A few districts have applied micro-surfacing as a part of a Cape-seal. In this treatment, a chip seal is placed first, and then the chip seal is covered with micro-surfacing. It is possible that this treatment would give better crack protection, but performance needs to be evaluated over time.

The emulsion suppliers prepared the contractor supplied mixture designs for all of the projects evaluated in this project. These mixtures have generally provided the desired service. The most common mixture problems are related to the aggregate having too many fines or too many plastic fines based on a low sand equivalency value.

Other major problems are generally related to the construction process and the skill of the crews operating the equipment. The skill of these crews is critical to getting the desired final product. It does not seem possible to force a contractor to furnish a good crew with a methods and materials type specification.

Several of the laboratory tests used in the ISSA mixture design procedure are of questionable value and are quite variable. The micro-surfacing industry does not agree on a common mixture design approach. They appear to depend on experience in the field, and they try to identify materials and mixtures than can cause problems based on a series of tests. However, their tests do not set asphalt content based on a test that is independent of water content and other factors that would be expected in most asphalt mixture applications.

The mixture design procedure developed by the project staff (Appendix A) is a rational approach to determining the minimum amount of residual asphalt cement for a micro-surfacing mixture for the aggregates evaluated. The mixture design procedure should be evaluated over several years to ensure that it works with any other aggregates used for micro-surfacing in Texas.

Adopting end-result specifications with a warranty clause could reduce the need for the Department to spend as much time and effort testing materials and completing mixture design tests with specialized equipment not currently available in the Districts. The contract testing in the Tyler District will provide a reasonable estimate of the cost of inspection testing that the contractor would have to bear in such an approach. Equipment innovations give a constant record of the mixture proportions are based on the equipment settings. This would make calibration more critical than it is now, and it is extremely important now. Future changes to equipment may give measured quantities directly from the equipment.

It is currently impossible to distill a polymer-modified emulsion without unnaturally changing the properties of the residual asphalt binder. An end-result specification with warranty would remove the need for so much testing by defining an end product and requiring it to retain desired properties for a given period of time.

Heating required during all standard distillation procedures used to recover binders from polymer-modified asphalt emulsions apparently breaks down the polymer and lowers the viscosity of the residual binder.

It will be easier to implement an end-result specification with warranty for micro-surfacing than for hot mixed asphalt concrete. If micro-surfacing lasts through construction and the first severe environmental cycle, it generally gives the desired service for 5 to 7 years. By limiting the warranty to two years, many of the problems associated with the structural capacity of the pavement will be eliminated.

For an end-result with warranty specification to work, a partnering with industry will have to be developed. The industry and Department will have to agree jointly which projects can be warranted. The Department may want to use micro-surfacing as a "stop-gap" maintenance treatment on an inappropriate road surface to get two or three more years life, but that type of application should not be warranted.

Visiting several field sites provided the staff considerable knowledge to help develop usage and quality assurance guidelines. Continued evaluation of the performance of several of the test section developed during this project would provide important information on the performance on micro-surfacing in general and the impact of specific factors such as residual asphalt content, amount of mineral filler, specific conditions such as the presence of cracking, use of rut filling versus scratch course, traffic levels, and different surface condition, and the presence of fibers.

Field inspectors liked the concept of the quality assurance guidelines with problems and possible solutions. They liked having simple checklists for use in determining the acceptability of the finished surface.

The project staff could not quantify the quality of hand worked areas.

The gel permeation chromatography (GPC) can be used to determine the presence and quantity of natural rubber in a polymer-modified asphalt emulsion.

RECOMMENDATIONS

The following recommendations are based on the results of the study.

1. The methods and materials type specification developed in this project should be adopted for use in the Department.

2. Efforts to implement the end-result with warranty specification should be commenced.

3. The new mixture design procedure and mixture design verification procedure developed in this project should be adopted by the Department.

4. The new test procedures and appropriate protocols developed in this project should be adopted by the Department.

5. The quality assurance guidelines and checklists should be adopted by the Department and given the widest possible distribution.

6. Efforts to implement a true quality assurance program for micro-surfacing should be commenced.

7. The usage guidelines should be adopted by the Department and given the widest possible distribution.

8. The test sections at the following sites should be continued to be monitored until they reach a terminal condition, are removed, or are covered with another treatment:

    - Rockwall on FM 3097,
    - Rusk on US 69,
    - Houston on I-45,
    - Alice on US 281,
    - Comanche on US 67,
    - Comanche on TX 36,
    - Hamilton on US 281, and
    - San Antonio on I-410.

9. The forensic procedures should be tried on the first premature failure of micro-surfacing.

10. The cost-effectiveness approach should be used with the results from continued monitoring of the test sections and the TxDOT SMERP test sections to determine the cost-effectiveness of micro-surface treatments.

11. A suitable method for recovering polymer-modified asphalts from emulsions needs to be developed. A simple procedure involving painting emulsion onto a glass plate, drying in a vacuum desiccator, scraping off a small sample of binder, and testing using the dynamic shear rheometer, should be evaluated.

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APPENDIX A

DRAFT PROTOCOLS FOR

LABORATORY TESTS AND MIXTURE DESIGN

Protocols for the following are included in this appendix:

1. WATER CONTENT SELECTION USING MODIFIED CUP FLOW TEST
2. WET COHESION TEST
3. WET TRACK ABRASION TEST
4. MIXING TIME TEST
5. ESTIMATION OF OPTIMUM RAC CONTENT FOR MICRO-SURFACING SYSTEM
6. MICRO-SURFACING MIXTURE DESIGN

WATER CONTENT SELECTION USING MODIFIED CUP FLOW TEST

This procedure is used to determine the optimum water content for micro-surfacing slurry system. The concept for this test was taken from suggestions from several ISSA members. Extensive development was completed on it by the project staff.

SCOPE

This test method is used to measure the water content where separation of fluids and solids occur on a 15° inclined plane. The optimum water content for the micro-surfacing system is selected at 2% below the water content where separation equal to or greater then 5 mm (0.2 in) occurs.

APPARATUS

1. Mixing container - a 590 ml (20 oz) plastic drinking cup.

2. Mixing blade - a 150 mm (6 in) tongue depressor.

3. Stop watch or lab timer.

4. Balance capable of weighing 600 ± 0.1 g.

5. A stainless steel or aluminum inclined plane. The inclined plane should be 300 mm (12 in) wide by 600 mm (24 in) long and should be at a 15° angle.

SAMPLE PREPARATION

1. The Mixing Time Test should be performed to determine the amount of additive required to obtain a mixing time equal to or greater than 240 seconds. The test Modified Cup Flow Test should be performed at this amount of additive.

2. Carry out the test with all ingredients and room at 25°C ± 1.1°C (77°F ± 2°F).

3. Oven dry the aggregate to a constant weight. Sieve the oven dry aggregate using 9.5 mm (3/8 in), 4.75 mm (#4) and 2.36 mm (#8) sieves. Recombine the aggregate to obtain a 200 g aggregate sample.

4. Weigh 200 g of aggregate into a 590 ml (20 oz) plastic cup. Add the appropriate amount of cement and dry mix into the aggregate for 60 seconds.

5. Weigh in the desired amount of water and any liquid additive and mix for 60 seconds or until the aggregate is uniformly wetted. Add the required amount of emulsion.

6. The emulsion should be mixed for 30 seconds.

PROCEDURE

1. Place the inclined plane on top of cup. Invert the cup and inclined plane. Hold the cup to the inclined plane securely to prevent loss of fluids.

2. Place the inclined plane on a level surface. Tap lightly on the bottom of the cup 2 times.

3. Remove the cup vertically and start the timer.

4. After 120 seconds, observe the slurry and record if separation of fluids and solids is equal to or greater than 5 mm (0.2 in).

REPORT

Report the water content that gives a separation of fluids and solids equal to or greater than 5 mm (0.2 in). Also report the percentages of water, portland cement, emulsion and additives used.

WET COHESION TEST

The wet cohesion test presented here is based on ISSA TB139 with the following changes. The method of obtaining a representative aggregate sample was changed. The wet cohesion test is performed only at 30 and 60 minutes. The following sections were taken directly from ISSA TB139: the self calibration test (section 3.1-3.3) and the mode of rupture (note 1).

SCOPE

This procedure, which is a modification of ASTM D3910-90 and ISSA TB139, is used to select the percent portland cement for a given micro-surfacing system.

APPARATUS

1. Modified cohesion tester, similar to the ASTM D3910-80 with the following modifications:
   - a. 28.5 mm (1-1/8 in) double rod air cylinder with 8 mm (5/16 in) rods and 75 mm (3 in) stroke.
   - b. 6 x 28.5 mm (1/4 in x 1-1/8 in) 60 durometer neoprene rubber foot.
   - c. Air pressure regulator with a variable down stream bleed valve with exhaust port regulating valves.
   - d. Four-way directional control valve with exhaust port regulating valves.
   - e. Air pressure gauge with a 0 to 700 k Pa (0 to 100 psi) pressure gauge.
   - f. 700 kPa (100 psi) air supply.
   - g. Torque meter capable of measuring and marking at least 35 kg-cm torque.

2. 100 mm x 100 mm (4 in x 4 in) square cut from 14 kg (30 lb) saturated roofing felt to be used as sample mounting pads.

3. 6 mm x 60 mm diameter and 10 mm x 60 mm diameter specimen molds.

4. 4.75 mm (#4) and 9.5 mm (3/8 in) ASTM E-11 sieves.

5. Plastic, 591 ml (20 oz) cups for mixing.

6. Steel spatula for mixing and for scraping off neoprene foot.

7. Scale capable of weighing 600 ± 0.1 grams.

8. Wash bottle with a very fine spout.

9. Forced draft oven controlled at 60°C ± 3°C.

10. For Calibration:
    a. 20-30 mesh standard ASTM C-190 Ottawa Sand.
    b. 220 grit silicon carbide "3-M" brand sand paper.
    c. 100 grit silicon carbide "Carborundum" brand sand paper.
    d. Load cell to periodically check the cohesion meter pressure.

CALIBRATION

1. A series of tests may be made with 220 grit sand paper until a series of 10 tests read a constant average within a 0.3 kg-cm range.

2. After the rubber disc is "polished" with the 220 grit sand paper to a constant reading, the 20-30 mesh Ottawa sand (ASTM C190 Standard Sand) contained in a 1 cm mold, and the 100 grit sand paper may be tested and the calibration readings recorded.

3. The dry aggregate used for the test mix should be tested as in step 2 and recorded on the cohesion graph.

SAMPLE PREPARATION

1. Oven dry the aggregate to a constant weight.

2. Sieve the oven dry aggregate using 9.5 mm (3/8 in), 4.75 mm (#4) and 2.36 mm (#8) sieves. Recombine the aggregate using the material passing the 4.75 (#4) sieve for grade I and the 9.5 mm (3/8 in) sieve for grade II to obtain a 200 g aggregate sample.

3. Weigh 200 g of aggregate into the plastic cup. Add the appropriate amount of cement and dry mix into the aggregate for 60 seconds. Add the desired water and any liquid additive and mix for 60 seconds or until the aggregate is uniformly wetted. Add the required amount of emulsion and mix for 30 seconds.

4. Center the 6 mm mold for grade I or 10 mm mold for grade II on the 10 cm x 10 cm roofing felt disc.

5. Pour the slurry into one side of the mold. Level off the sample with the spatula blade held perpendicular to the mold surface. The sample should be leveled off in one pass using a sawing motion to avoid segregation. This step should be completed within 45 seconds of the addition of the emulsion.

6. Remove the mold and allow the sample to cure for 30 minutes and/or 60 minutes at room temperature (25° C). For 24 hour cured samples, the sample should be placed in 60° C (140° F) oven for 24 hours.

PROCEDURE

1. Center the sample under the neoprene foot. Set the air pressure at 200 kPa. Zero the torque wrench and place it on top of the cylinder rod.

2. Lower the foot against the sample at a rate of 8 to 10 cm per second.

3. After 5 to 6 seconds of compaction, twist the torque wrench in a smooth, firm, horizontal motion through a 90 to 120° arc within 0.5 to 0.7 seconds. Care should be taken to prevent pressing down on the rod when using the torque wrench.

4. Note the mode of rupture of the sample. The modes of rupture are given in figure 2.

REPORT

Report the torque reading for 30 minutes and 60 minutes and the mode of rupture. Mode of rupture is defined in Figure A-1.

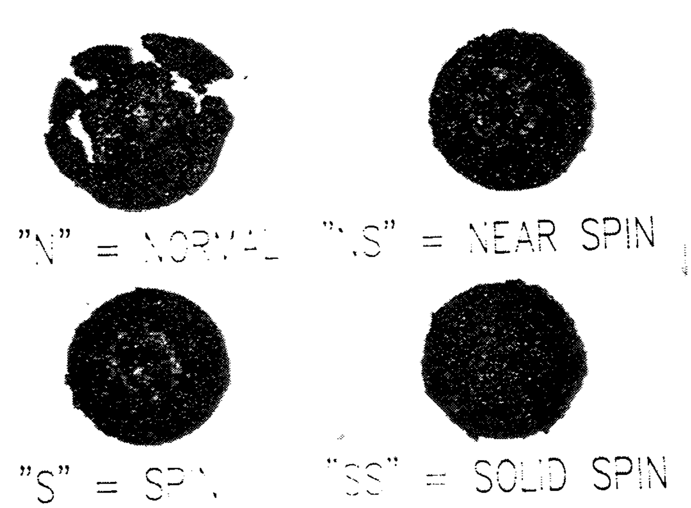

Figure A-1. Mode or Rupture for Cohesion Test Samples

WET TRACK ABRASION TEST

The wet track abrasion test (WTAT) is based on ISSA TB100. The following modifications were made. The method used to obtain a representative aggregate sample was changed. ISSA TB100 allows the sample surface to be leveled with a squeegee or a wooden dowel rod. In the procedure presented here, the wooden dowel rod is used.

SCOPE

This procedure, which is a modification of ASTM D3910-90 and ISSA TB100, is used for determining the minimum asphalt content for a given micro-surfacing system.

APPARATUS

1. Balance capable of weighing 5,000 ± 0.1 grams.

2. Planetary type mechanical mixer such as Hobart C-100, N-50, or A-120.

3. A 2.27 kg abrasion head, a 300 mm diameter rust resistant flat bottom pan and quick clamp mounting plate.

4. 300 x 300 mm (12 x 12 in) square cut from 14 kg (30 lb) saturated roofing felt.

5. Rust resistant round bottom bowl for mixing slurry.

6. A raised lip sample mold of the following dimensions: a depth of 6.35 mm (1/4 in) and a diameter of 279 mm (11 in) for the C-100 and A-120 mixers and 254 mm (10 in) for the N-50 mixer.

7. A strike-off wooden dowel rod that is 25 mm (1 in) diameter by 400 mm (15.7 in) long.

8. Forced draft oven controlled at 60°C ± 3°C (140° F ± 5° F).

9. Constant temperature water bath controlled at 25°C ± 1°C (77°F ± 2°F).

10. A 127 mm (5 in) length of reinforced rubber hose equivalent to Parker 290 Ozex General Purpose Hose with 19 mm (3/4 in) inside diameter with 6.25 mm (1/4 in) wall thickness.

11. A wooden block to support the mounting plate during testing.

SAMPLE PREPARATION

1. Sieve the oven dry aggregate using 9.5 mm (3/8"), 4.75 mm (#4), and 2.36 mm (#8) sieves. Using only the material passing the 4.75 mm (#4) sieve, recombine the aggregate in proper proportions to maintain desired gradation and to obtain an 800 g sample (700 g using the N-50 machine).

2. Weigh the 800 g of aggregate into the mixing bowl. Add the portland cement and dry mix for 60 seconds or until uniformly distributed. Add the desired water and any liquid additive and mix for 60 seconds or until the aggregate is uniformly wetted. Finally, add the required amount of emulsion and mix for 30 seconds.

3. Center the mold on the 300 x 300 mm (12 x 12 in) square disc roofing felt. Immediately pour the slurry into one side of the mold.

4. Level off the sample with the wooden dowel rod using a sawing motion. The sample should be leveled off in one pass to avoid segregation. This step should be completed within 45 seconds of the addition of the emulsion.

5. Remove the mold and place sample in the 60 °C (140° F) oven and dry to constant weight (a minimum of 15 hours drying time).

PROCEDURE

1. Remove the dried sample from the 60°C oven, allow to cool to room temperature.

2. Remove excessive felt by cutting around the sample, staying at least 10 mm away from the edge of the sample.

3. Weigh the sample and place in a 25°C (77° F) water bath filled with distilled water for 6 days.

4. Remove the sample and place in flat bottom pan. Clamp sample to mounting plate using the quick connection clamp.

5. Cover the sample with 6 mm ± 0.5 mm (0.25 in ± 0.02 in) of 25°C (77° F) distilled water.

6. Place fresh hose onto the abrasion head. It is permissible to use a hose section 4 times by rotating the hose 90° after each test to have a new section of hose in contact with the sample.

7. Lock the abrasion head on the shaft of the mixer. Raise the mounting plate until the rubber hose is floating freely in contact with the sample surface. Insert the wooden support block under the platform.

8. Switch the mixer on low speed for the time given in Table 1 for the machine being used.

Table A-1. Correction Factors to Correlate all Results to the C-100 Abrasion Loss

Model	Running Time	Conversion Constant g/ft2	Conversion Constant g/m2	C-100 Correction Factor
C-100	5 min ± 2 sec	3.06	32.9	1.00
A-120	6 min, 45 sec ± 2 sec	2.78	29.9	1.17
N-50	5 min, 15 sec ± 2 sec	3.48	37.5	0.78
Modified N-50	5 min, 15 sec ± 2 sec	3.06	32.9	0.78

9. Remove the sample and wash off loose debris with slow-running, room temperature water. Place the washed sample in 60°C (140° F) oven and dry to constant weight.

10. Remove the dry sample and allow to cool to room temperature. Weigh dry sample and calculate loss.

CALCULATION

Calculate the loss of material abraded in g/ft^2 or g/m^2 (wear value).

$$\text{wear value} = (A - B) * C * D$$

Where:
A = Initial dry specimen weight
B = Abraded dry specimen weight
C = Conversion constant from table A-1
D = C-100 correction factor from table A-1

REPORT

Report the wear value in g/m2 (or g/ft^2), machine used, running time and soaking period.

Example: The 6-day soak, wet track abrasion wear value is 644 g/m^2 (59.8 g/ft^2), using a N-50 machine for 5 minutes and 15 seconds.

MIXING TIME TEST

The mixing time test is based on ISSA TB102 sections 4.1-4.5 and 5.1.1. The following modifications were made to the procedure. Instead of using a specified amount of emulsion, water and cement, the quantities used in the mix design should be used in this test.

SCOPE

This test is a modification of ISSA TB102. This test determines the minimum water content that gives 120 seconds mix time. The 120 second mix time insures adequate time to mix and place the slurry.

APPARATUS

1. Mixing container - a 590 ml (20 oz) plastic drinking cup.

2. Mixing blade - a 150 mm (6 in) tongue depressor.

3. Stop watch or lab timer.

4. Balance capable of weighing 600 ± 0.1 g.

SAMPLE PREPARATION

1. Carry out the test with all ingredients and room at 25° C ± 1.1° C (77°F ± 2° F).

2. Oven dry the aggregate to a constant weight. Sieve the oven dry aggregate using 9.5 mm (3/8 in), 4.75 mm (#4) and 2.36 mm (#8) sieves. Recombine the aggregate to obtain a 200 g aggregate sample.

3. Weigh 200 g of aggregate into a 590 ml (20 oz) plastic cup. Add the appropriate amount of cement and dry mix into the aggregate for 60 seconds.

4. Weigh in the desired amount of water and any liquid additive and mix for 60 seconds or until the aggregate is uniformly wetted. Add the required amount of emulsion.

PROCEDURE

1. After the emulsion has been added, start the timer and mix the slurry at 60-70 rpm. Continue mixing until the emulsion has broken.

2. Record the time when the emulsion breaks.

REPORT

The time at which the emulsion breaks should be reported with the percent portland cement, water, emulsion and additive if used.

ESTIMATION OF OPTIMUM RAC CONTENT FOR MICRO-SURFACING SYSTEM

This test is performed as outlined in ASTM D5148-90. The appendix to ASTM D5148-90 is used to determine an approximate bitumen ratio (ABR). This procedure is designed for hot mix asphalt concrete. For micro-surfacing, an additional 2% residual asphalt content is required. This addition corrects for the different viscosity due to the polymer modified asphalt emulsion and because the aggregate is 100% crushed.

SCOPE

This procedure uses the ASTM D5148-90 Standard Test Method for Centrifuge Kerosene Equivalent (CKE) to estimate the optimum residual asphalt cement content for a given micro-surfacing system.

PROCEDURE

1. Perform the procedure as outlined in ASTM D5148-90.

2. Figure X1.1 of ASTM D5148 can be used to determine the approximate bitumen ratio (ABR). This ABR is for hot mix asphalt concrete. The optimum residual asphalt for the micro-surfacing is ABR + 2%. This adjustment is to compensate for 100% crushed material and the viscosity of the polymer modified asphalt emulsion.

DETERMINING OPTIMUM RAC CONTENT FOR MICRO-SURFACING SYSTEM

This mixture design procedure uses the Centrifuge Kerosene Equivalent test to estimate an initial asphalt content. Tests are then conducted on the mixture of polymer modified asphalt cement, aggregate, portland cement, water, and set retarding additive. The water content at which the testing is conducted is established using the mixing test and the modified cone test. The cement at which the remainder of the testing is conducted is established using the cohesion test. The optimum residual asphalt cement content is established using the wet track abrasion test.

SCOPE

This procedure provides the means to determine the proper proportion of approved aggregate, mineral filler, water, asphalt emulsion and additive which will produce a mix that meets specification requirements.

PROCEDURE

1. Obtain representative aggregate, mineral filler (portland cement) and emulsion. The following quantities are required: 45 kg (100 lb) of aggregate, 1 l (1 qt) of portland cement and 8 l (2 gal) of emulsion. Dry the aggregate to a constant weight.

2. Determine the sieve analysis as outlined in Tex-200-F and bulk or apparent specific gravity as outlined in Tex-201-F and Tex-202-F.

3. A large number of small aggregate samples is required. Separate the aggregate using 9.5 mm (3/8 in), 4.75 mm (#4) and 2.36 mm (#8) sieves. Recombine the aggregate to obtain samples with the proper gradation. This reduces segregation, since splitting out 30-50, 200 g samples would lead to a loss of the minus #200 sieve material.

4. Determine percent residual asphalt cement content of emulsion as outlined in Tex-521-C.

5. Estimate the optimum asphalt content using the procedure in Estimation of Optimum RAC Content for Micro-surfacing System. The CKE furnishes an index factor (K) which gives an indication of particle roughness and surface capacity. Determine the approximate bitumen ratio (ABR) using the surface area and K with the design chart in Figure X1.1 in the appendix of ASTM D5148-90. To obtain the optimum residual asphalt cement content (RAC), add 2% to the ABR. Test the trial mixtures at the ABR + 2% value, at ± 0.5% RAC and ± 1.0% RAC.

6. Perform the Mixing Time Test at each RAC content with 0.5, 1.0, 1.5 and 2.0% portland cement to ensure there is adequate time to mix and apply the slurry. Start with a creamy mixture and incrementally decrease the water content at 1% increments. The minimum water content is the water content that has a 120 second mixing time.

7. Select the optimum water content using the Modified Cup Flow Test. Perform this test at each RAC content and with the following cement contents: 0.5, 1.0, 1.5, and 2.0%. Select an optimum water content for each combination of RAC and portland cement. Select the optimum water content at 2% below the water content that gives equal to or greater than 5 mm (0.2 in) separation of fluids and solids. The optimum water contents selected in this step must be greater than the minimum water content from step 6. If the optimum water content is less than the minimum water content, no further testing is done and a new mixture should be developed.

8. Perform the Wet Cohesion Test for each RAC content and the amount of water and additive selected in steps 5-7 and the following portland cement contents: 0.25, 0.5, 0.75, 1.0, 1.5, 2.0 and 2.5%. For each RAC content, select the lowest portland cement content that provides the minimum torque of 12 kg-cm at 30 minutes and 20 kg-cm at 60 minutes. Perform all subsequent testing at the portland cement contents selected in this step.

9. Conduct the Wet Track Abrasion Test (WTAT) for each RAC content with the appropriate water, portland cement and additive contents. Select the minimum acceptable RAC content that passes the WTAT with an abrasion loss less than 75 g/ft^2 (806 g/m^2) for a 6 day soak.

10. Select the optimum RAC content at 0.5% above the minimum RAC content that passes the WTAT.

REPORT

Report the optimum residual asphalt content, the corresponding emulsion content, the required minimum portland cement content selected in step 8 for the optimum residual asphalt content, the minimum water content for the optimum residual asphalt content, the optimum water content for the optimum residual asphalt content, and the aggregate gradation. All content values shall be in percent of weight of dry aggregate.

The results of each test will be provided with the final mixture design results which shall become the job mixture formula when approved.

APPENDIX B

RECOMMENDED METHODS AND MATERIALS SPECIFICATION

SPECIAL SPECIFICATION

ITEM

MICRO-SURFACING (POLYMER MODIFIED)

1. Description. This Item shall consist of a micro-surfacing system which shall be a mixture of cationic polymer modified asphalt emulsion, mineral aggregate, mineral filler, water and other additives mixed and placed on the paved surface in accordance with these specifications and to the dimensions as shown on the plans.

2. Materials.

(A) Asphaltic Material.
The asphalt material, designated as CSS-1P, shall be a cationic slow setting emulsion modified with an approved polymer. The polymer shall be incorporated by blending with the base asphalt prior to emulsification or it shall be co-milled with the asphalt to produce the finished emulsion. The distillation residue of the modified emulsion shall contain a minimum of 3.0 percent polymer by weight, as determined by Texas Test Method TEX-533-C or other analytical method approved by the Department. The emulsion supplier shall furnish the Department with a description of how the polymer modified emulsified asphalt cement is manufactured along with samples of the base asphalt and polymer used in the finished emulsion.

In addition, the emulsion shall be homogeneous, shall not show significant separation of polymer and shall comply with the following requirements:

	Min	Max
Viscosity, Saybolt Furol at 25° C (77°F), Sec.	20	100
Storage stability test, one day, percent	-	1
Particle charge test	Positive	
Sieve test, percent	-	0.1
Distillation:		
Oil distillate, by volume of emulsion, percent	-	½
Residue, percent	62	-

The base asphalt cement shall be meet the requirements of an AC-20 as defined by Item 300 of the Standard Specifications for Construction of Highways, Streets and Bridges.

(B) Mineral Aggregate.

(1) Description. The mineral aggregate shall all be generated by crushing operations from a single source and shall be composed of clean, tough, and durable particles of crushed traprock, crushed granite, crushed sandstone or other material approved by the Engineer. A sand equivalent of 70 or higher is required unless otherwise shown on the plans. The aggregate shall show a maximum weight loss of 25 percent when subjected to five cycles of conditioning using magnesium sulfate solution in accordance with Test Method Tex-411-A. The test shall be performed on the gradation to be used on the project.

The polish value for the aggregate shall not be less than the value shown on the plans when tested in accordance with Test Method Tex-438-A. The polish value test shall be performed on the parent rock. The Engineer may waive the polish value requirement for aggregates with known satisfactory performance history based on Department skid values.

(2) Grades. When tested by Test Method Tex-200-F, Part II, Washed Sieve Analysis, the gradation requirements shall be as follows:

Grade 1 (Fine Graded Surface Course)	Percent Aggregate By Weight
Retained on 9.50 mm (3/8 in) sieve	0
Retained on 4.75 mm (No. 4) sieve	0-2
Retained on 2.36 mm (No. 8) sieve	10-25
Retained on 1.18 mm (No. 16) sieve	25-50
Retained on 0.60 mm (No. 30) sieve	50-70
Retained on 0.30 mm (No. 50) sieve	65-82
Retained on 0.15 mm (No. 100) sieve	79-90
Retained on 0.075 mm (No. 200) sieve	85-95

Grade 2 (Coarse Graded Surface Course)	Percent Aggregate By Weight
Retained on 12.5 mm (½ in) sieve	0
Retained on 9.50 mm (3/8 in) sieve	0-1
Retained on 4.75 mm (No. 4) sieve	6-14
Retained on 2.36 mm (No. 8) sieve	35-55
Retained on 1.18 mm (No. 16) sieve	54-75
Retained on 0.60 mm (No. 30) sieve	65-85
Retained on 0.30 mm (No. 50) sieve	75-90
Retained on 0.15 mm (No. 100) sieve	82-93
Retained on 0.075 mm (No. 200) sieve	85-95

(3) Mineral Filler. Mineral filler shall be non-air-entrained Portland cement which is free of lumps or foreign matter meeting the requirements of Item 524 of the Texas Standard Specifications for Construction of Highways, Streets and Bridges or, if approved by the engineer, hydrated lime meeting the requirements of Item 264 of the Texas Standard Specifications for Construction of Highways, Streets and Bridges.

© Water. The water shall be potable and shall be free of harmful soluble salts.

(D) Other Additives. The contractor shall define what type of additives will be used with the micro-surfacing to control set time by chemical composition, brand name and additive designation or other acceptable method.

3. Paving Mixture.

(A) Mixture Design.

The mixture design and resulting job mix formula shall be supplied by the Contractor. The following shall be required in the mix design provided by the contractor. The mix design shall show the results of the Wet Track Abrasion Test run in accordance with the test method described in Appendix A shall have a maximum value of 807 g/m^2 (75 g/ft^2) after six days of soaking. The mix design shall show the source of the aggregate to be used in the mix, the results of aggregate tests, mix compatibility tests, and mix design gradation. The mix design shall show the type of asphalt emulsion, the percent of residual asphalt cement, the grade of the base stock asphalt cement, the type of emulsifying agent, the type of the polymer, and the manufacturer of the emulsified asphalt cement. The mix design shall show the percent asphalt emulsion to be included in the mix as percent of dry aggregate weight and allowable variation. The mix design shall show the type of mineral and\or chemical fillers and the percent of each as percent of dry aggregate weight and allowable variation. The mix design shall show the percent water by weight of dry aggregate at which tests were conducted, the maximum and minimum allowable percent of water in the mixture, any special requirements of the water, and allowable variation. The mix design shall show allowable additives and allowable percentage of additives by weight of dry aggregate to control mixing and breaking.

These mix design requirements are subject to verification by testing of laboratory produced mixes or trial batch material prior to placement of project material.

(B) Composition of Mixture. The polymer modified micro-surfacing shall consist of a uniform mixture of aggregate and CSS-1P emulsion and mineral filler, water and field control additive as required. The emulsion and aggregate must be compatible so that a complete, uniform coating of the aggregate will be obtained in the mixing process. The mixture must have sufficient working life to allow for proper placement at the existing ambient temperature and humidity. When the paving mixture is placed with the relative humidity at not more than 50 percent and ambient air temperature of at least 24°C (75°F), it must cure sufficiently that uniformly moving traffic can be allowed in one hour with no damage to the surface. Locations subject to sharp turning or stopping and starting traffic may require additional curing.

The job mix formula shall meet with the approval of the Engineer; and the proportions to be used shall be within the following limits:

Residual Asphalt	- 6.0 to 9.0 percent by weight of dry aggregate
Mineral Filler (Portland Cement)	- 0.5 to 2.5 percent by weight of dry aggregate

The mixture shall be designed so that the mineral aggregate will produce a gradation which conforms to the limitations for the master grading for the type specified herein. The gradation will be determined in accordance with Test Method Tex-200-F (Washed Sieve Analysis) and shall be based upon aggregate and mineral filler. The aggregate shall not vary from the design gradation by more than the tolerances which follow. The material passing the 0.075 mm (No. 200) sieve is further restricted to conform to the limitations for the master grading for the type specified.

© <u>Determination of Mixture Composition and Tolerances</u>:
Determination of aggregate gradation may be based on sieve analysis of representative samples taken from the stockpile at the job site. The amount of mineral filler added to the mix shall be included in determining the total minus 0.075 mm (No. 200) sieve aggregate fraction.

The asphalt content may be determined in accordance with Test Method Tex-228-F or ASTM D-2172-88, Test Method B (Reflux Extraction). If ASTM D-2172-88, Test Method B is used, the heat source should be turned off at the usual time and the solvent-soaked aggregate allowed to set overnight. The next morning, reflux should be run again until the filtrate is a straw color. This is to be repeated daily until the filtrate is straw color at the start of the distillation process. This will reasonably assure removal of all asphalt cement and polymer. If the bituminous material recovered during the extraction process is allowed to soak in the solvent overnight, then extracted asphaltic material will not be acceptable for recovery or testing.

Mix samples will be taken from the mixing unit discharge in a manner such that the complete discharge stream is included in the sample. Mix samples shall be dried to constant weight at 110° C ± 5° C (230° F ± 10° F) prior to determination of asphalt content. The residual asphalt content of the paving mixture shall not vary from the design amount by more than the allowed tolerance and is also restricted to conform to the master limits.

Sieve Size	Allowable Tolerance, Percent by Weight or Volume as Applicable
Passing 9.50 mm (3/8 in) sieve	Plus or minus 5
Passing 4.75 mm (No. 4) sieve	Plus or minus 5
Passing 2.36 mm (No. 8) sieve	Plus or minus 5
Passing 1.18 mm (No. 16) sieve	Plus or minus 5
Passing 0.60 mm (No. 30) sieve	Plus or minus 3
Passing 0.30 mm (No. 50) sieve	Plus or minus 3
Passing 0.15 mm (No. 100) sieve	Plus or minus 3
Passing 0.075 mm (No. 200) sieve	Plus or minus 2
Residual Asphalt Content	Plus or minus 0.5 by wt.

4. Equipment. All equipment for the handling of all materials and mixing and placing of the mixture shall be maintained in good repair and operating condition and is subject to the approval of the Engineer. Any equipment found to be defective and potentially affecting the quality of the paving mixture shall be replaced. All scales used in weighing aggregate and emulsion shall conform to the requirements of the Item, "Weighing and Measuring Equipment".

The material placed on mainline roads shall be mixed by a self-propelled micro-surfacing mixing machine which shall be a continuous flow mixing unit able to accurately deliver and proportion the aggregate, emulsified asphalt, mineral filler, field control additive and water to a revolving multi-blade mixer and discharge the mixed product on a continuous flow basis. The machine shall have sufficient storage capacity for aggregate, emulsified asphalt, mineral filler, field control additive and water to maintain and adequate supply to the proportioning controls. The machine shall be equipped with opposite side driving stations to optimize longitudinal alignment. The machine shall be equipped to allow the mix operator to have full hydrostatic control of the forward and reverse speed during application of the micro-surfacing material. The material placed on leave-outs, ramps and other short sections can be placed using single batch type equipment that meets all of the other requirements described above.

Individual volume or weight controls for proportioning each material to be added to the mix shall be provided. Each material control device shall be calibrated and properly marked. The calibration shall be completed in the presence of Department personnel within 60 days of the construction. The aggregate feed to the mixer shall be equipped with a revolution counter or similar device so the amount of aggregate used may be determined at any time. The emulsion pump shall be a positive displacement type and shall be equipped with a revolution counter or similar device so that the amount of emulsion used may be determined at any time. The water pump and additive feed system shall be equipped in such a way that the amount of water and additive being used may be determined at any time.

The mixing machine shall be equipped with a water pressure system and nozzle type spray bar to provide a water spray immediately ahead of and outside the spreader box. It also shall be equipped with an approved fines feeder that shall provide a uniform, positive, accurately metered, predetermined amount of the specified mineral filler.

5. Stockpiling and Storage.

(A) Aggregate Storage. If the mineral aggregates are stored or stockpiled, they shall be handled in such a manner as to prevent segregation, mixing of the various materials or sizes, and contamination with foreign materials. The grading of aggregates proposed for use and as supplied to the mixing plant shall be uniform. Suitable equipment of acceptable size shall be furnished by the Contractor to work the stockpiles and prevent segregation of the aggregates. The aggregate shall be passed over a scalping screen prior to transfer to the micro-surfacing mixing machine to remove oversize material.

(B) Storage of Asphaltic Materials. The asphaltic material storage shall be ample to meet the requirements of the plant. All equipment used in the storage and handling of asphaltic material shall be kept in a clean condition at all times and shall be operated in such manner that there will be no contamination with foreign matter.

6. Construction Methods.

(A) General. It shall be the responsibility of the Contractor to produce, transport, and place the specified paving mixture in accordance with these specifications and as approved by the Engineer. The cured mixture shall adhere fully to the underlying pavement.

(B) Weather Limitations. The material shall be spread only when the atmospheric temperature is at least 10°C (50°F) and rising and the weather is not foggy or rainy and there is no forecast of temperatures below 0°C (32°F) within 24 hours or rain within 12 hours after mix placement.

© Surface Preparation. The area to be surfaced shall be thoroughly cleaned of all vegetation, animal carcasses, loose aggregate and soil. Water used in pre-wetting the surface ahead of an outside the spreader box shall be applied at a rate to dampen the entire surface without any free flowing water ahead of the spreader box.

(D) Spreading Equipment. The paving mixture shall be spread uniformly by means of a mechanical type spreader box attached to the mixer, equipped with augers, paddles or other devices to agitate and spread the materials throughout the box. The box must be clean and free of excess buildup of micro-surfacing before application begins. The spreader box used must be capable of obtaining the desired lines and grade as shown on the plans. A front seal shall be provided to insure no loss of the mixture at the road contact surface. The rear seal shall act as a final strike off and shall be adjustable. The mixture shall be spread to fill cracks and minor surface irregularities and leave a uniform skid resistant application of aggregate and asphalt on the surface. The spreader box and rear strike-off shall be so designed and operated that a uniform consistency is achieved to produce a free flow of material to the rear strike-off. The seam where two spreaders join shall be neat appearing and uniform.

(E) Ruts. When required on the plans, before the final surface course is placed, preliminary micro-surfacing material shall be required to fill ruts, utility cuts, depressions in the existing surface, etc. Ruts of 12 mm (½ in) or greater depth shall be filled independently with a rut filling spreader box either 1.5 to 2 m (5 to 6 ft) in width. For irregular or shallow rutting less than 12 mm (½ in) depth, a full-width scratch coat pass may be used as directed by the Engineer. Each individual rut fill, utilizing a rut filling spreader box shall be crowned to compensate for traffic compaction. Ruts that are in excess of 20 mm (3/4 in) depth will require multiple placements with the rut filling spreader box to restore the original cross section. Maximum micro-surfacing thickness applied as rut filling in a single lift shall not exceed 20 mm (3/4 in). Maximum micro-surfacing placed full width of a lane shall not exceed 20 mm (3/4 in) in any location across the lane. At the end of construction, the transverse profile shall show no rutting in the wheel paths and no more than a 6 mm (1/4 in) height above the desired profile.

(F) Workmanship.

Finished Surface

The finished micro-surfacing shall have a uniform texture free from excessive scratch marks, tears or other surface irregularities. Excessive tear marks are considered four marks that or more 12 mm (½ in) wide or wider 150 mm (6 in) or more in length per 11 sq m (120 sq ft) or any marks 25 mm (1 in) wide or wider, 100 mm (4 in) or more in length. The mixture shall adhere fully to the underlying pavement within one hour after application. The mixture shall provide a uniform skid resistant surface with a skid number of 43 or greater as measured using ASTM E 274 at 64 km/hr (40 mi/hr).

Joints/Seams

The longitudinal and transverse joints shall be neat appearing and uniform. No excessive buildup, uncovered areas or unsightly appearance will be permitted on longitudinal or transverse joints. Longitudinal joints shall be placed on lane lines when possible. Gaps between applications will not be permitted. Joints without gaps will be considered acceptable if no more than a 12 mm (½ in) space exists between the pavement surface and a 1.2 m (4 ft) straight edge placed perpendicular on the longitudinal joint nor 6 mm (1/4 in) for a transverse joint.

Edges

The edges of the micro-surfacing shall be uniform and neat appearing along the roadway centerline, lane lines, shoulder or curb lines. The edge shall vary no more than plus or minus 75 mm (3 in) from a 30 m (100 ft) straight line on a straight section or from a 30 m (100 ft) arc of the design curve on a curved section.

Handwork

Areas that cannot be reached with the mixing machine shall be surfaced using hand tools to provide complete and uniform coverage. The area to be hand worked shall be lightly dampened. Handwork shall be completed in a manner so that the finished surface is uniform in texture, dense and of overall good appearance comparable to that produced by the spreader box.

7. Measurement. Micro-surfacing (Polymer Modified) will be measured by the kg (ton) of the composite "micro-surfacing (polymer modified)". The composite micro-surfacing (polymer modified) mixture is hereby defined as the asphalt, aggregate and additives.

(A) Aggregate. The quantity of aggregate used in the accepted portions of the work shall be measured by net ticket weight of each individual load of aggregate shipped to the project based on the dry weight of aggregate. The aggregate will be weight at the contractor's stockpile site. The weight of mineral filler used shall be calculated and included in the total aggregate weight.

(B) Polymer Modified Asphalt Emulsion. The quantity of polymer modified asphalt emulsion in the accepted portion of the work shall be measured by kg (tons) of material based on the accepted load tickets issued from the manufacturer. At the completion of the project any unused emulsion shall be weighed back and that quantity deducted from the accepted asphalt emulsion quantity delivered.

8. Payment. The work performed and materials furnished as prescribed by this item and measured as provided under "Measurement" will be paid for at the unit price bid for "Micro-surfacing (Polymer Modified)", of the grade specified, which price shall be full compensation for furnishing all materials and performing all operations necessary to complete the work.

Micro-surfacing material required to repair deficiencies due to unsatisfactory workmanship shall not be paid for but shall be entirely at the Contractor's expense.

APPENDIX C

NATURAL LATEX CONTENT OF ASPHALT-LATEX EMULSIONS

USING

GEL PERMEATION CHROMATOGRAPHY (GPC)

INTRODUCTION

Micro-surfacing contains polymer-modified emulsified asphalt cement. The most widely used polymers in these binders are synthetic and natural latex. Compliance testing by TxDOT requires a test to detect the presence and measure the quantity of polymer in the asphalt emulsion. This is normally accomplished using TxDOT test method Tex-533-C, which uses the infrared spectrometer. However, natural rubber contains chemical species similar to the hydrocarbons in asphalt cement which confound the test results. Therefore, another test procedure was needed that could be used to quantify the natural rubber in micro-surfacing binders. The objective of the work reported herein is to develop a procedure to measure the amount of natural rubber in a modified emulsified asphalt. This work was not intended to be a major effort in the overall study, as a result, only limited testing was performed.

The molecular size of natural latex has been reported to be larger than that of typical paving grade asphalt. Therefore, the identification and quantification of the amount of natural latex in asphalt-latex mixture can be achieved by a gel permeation chromatography (GPC) method, which separates the chemical components into several fractions according to their molecular size. In this work, the GPC technique is employed to detect the presence and, more importantly, the amount of natural latex in a modified asphalt emulsion.

Some laboratories have experienced clogging of filters or GPC columns when working with natural rubber and typical solvents. This problem can be avoided by using very dilute solutions, heating the column, and/or selecting the correct solvent or blend of solvents.

INSTRUMENTATION AND EXPERIMENT

The GPC instrument used was a Waters LC system which contains Waters 600E system controller/solvent deliverer, Waters 700 Satellite Autosampler, and Waters 410 Differential Refractometer. Three GPC columns were connected in series for the analysis as follows:

1. Ultrastyragel with a particle size 7 μm and a pore size of 1000 Å in a 7.8 mm x 300 mm column from Waters,

2. Ultrastyragel with a particle size 7 μm and a pore size 500 Å in a 7.8 mm x 300 mm column from Waters, and

3. PL-gel pore size 50 Å particle size 5 μm 7.5x600 mm column from Polymer Laboratories LTD.

The operating conditions adopted for this experiment were:

- flow rate - 1.0 ml/min,
- injection volume - 100 μL, and
- column temperature - 40°C (104°F).

The materials tested were asphalt cement, natural latex, and natural latex modified emulsion. All these materials were supplied by Koch Materials Company of Salina, Kansas. The concentrations of asphalt-latex emulsion or asphalt cement in tetrahydrofuran (THF) used for analysis were approximately 25 mg/mL. In contrast, the concentrations of natural latex in THF were 0.24 mg/mL and 0.024 mg/mL, respectively, because higher natural latex concentrations cannot form homogeneous solutions, and, therefore, may be partially retained in the filters or clog the columns.

RESULTS

Typical GPC chromatograms of the asphalt-latex emulsion, asphalt cement, and natural latex are shown in Figure C-1. Latex elutes about 20.0 min after sample injection which is obviously earlier than asphalt cement. This indicates that the molecular sizes of latex is larger than the molecular sizes of asphalt cement. The amount of latex in asphalt-latex emulsion can be determined by comparing the peak height for the latex in a asphalt-latex mixture to that of a known concentration standard. A calibration curve for latex concentration in asphalt-latex emulsion is shown in Figure C-2 and the values are listed in Table C-1.

The amount of natural rubber in a latex modified asphalt emulsion can be determined based on the above calibration curve. The calculation procedure for weight percentage of latex in an asphalt-latex emulsion sample follows:

Sample Calculation:

0.5174 g asphalt-latex is dissolved in 10 mL THF
100 μL sample injection
RI response at latex peak is 18,666 μV

Mass of Sample injected:

$$\frac{0.5174 \text{ g}}{10 \text{ mL}} \times 100 \text{ } \mu\text{L} = 5.174 \times 10^{-3} \text{ g}$$

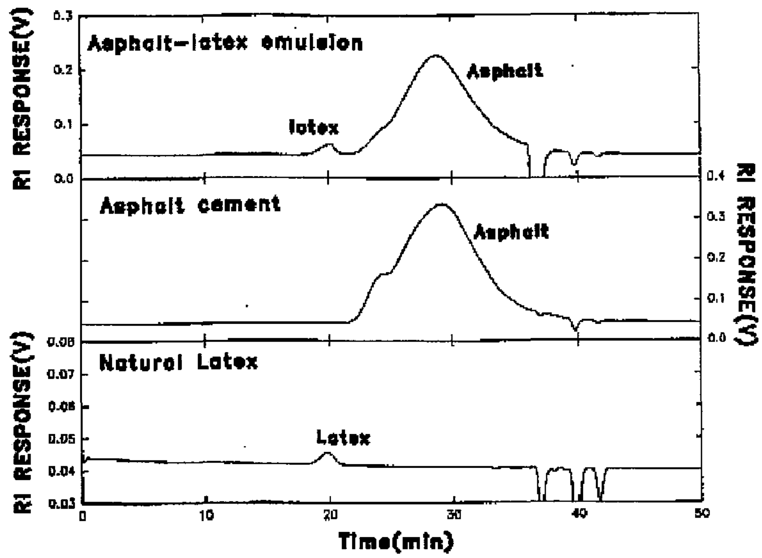

Figure C-1. Chromatograms of Asphalt-Latex Emulsion, Asphalt Cement, and Natural Latex

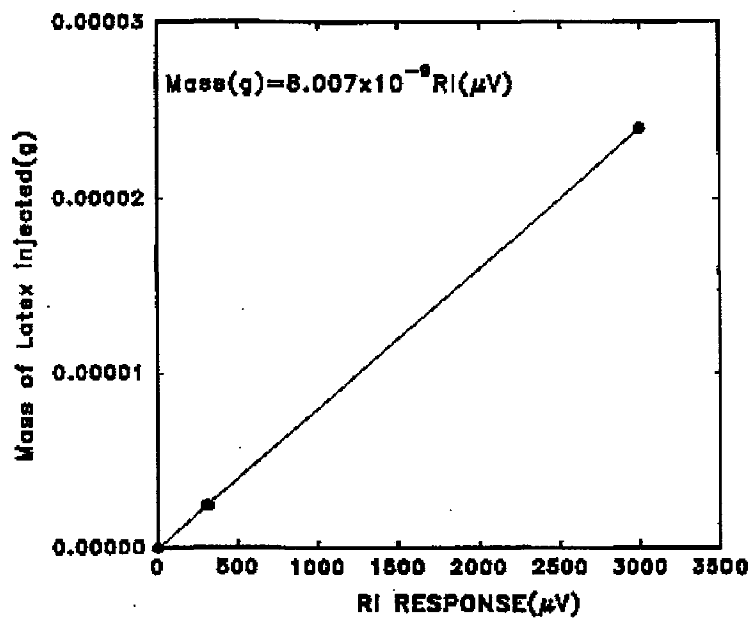

Figure C-2. Calibration Curve for Latex Concentration in Asphalt-Latex Emulsion

Table C-1. Latex Concentration Calibration.

Samples, grams latex/mL	RI Response, μV	Mass of Latex Injected, grams
Latex only 2.4×10^{-5} g/mL	316.5	2.4×10^{-6}
Asphalt-Latex 2.4×10^{-5} g/mL	304.3	2.4×10^{-6}
Asphalt-Latex 2.4×10^{-4} g/mL	2995.0	2.4×10^{-5}

* injection volume 100 μL

Mass of latex injected:

Based on calibration, the mass of latex injected is

$$8.007 \times 10^{-9} \left(\frac{g}{\mu V}\right) \times 18666\ (\mu V) = 1.4946 \times 10^{-4}\ g$$

Weight percentage of latex in asphalt-latex emulsion:

$$\%latex = \frac{\text{mass of latex injected}}{\text{mass of asphalt-latex sample injected}}$$

$$= \frac{1.4946 \times 10^{-4}\ g}{5.174 \times 10^{-3}\ g} \times 100\% = 2.9\%$$

It should be noted that the calculations shown above are an extrapolation of the calibration curve. Therefore, the accuracy of the results are dependent on the extent of linearity of calibration curve. Inclusion of some standard concentrations between 2.4×10^{-4} g/mL and 2.4×10^{-3} g/mL to produce the calibration curve is recommended. Latex concentrations of 2.4×10^{-3} g/mL or higher cannot form a homogeneous phase and thus cannot pass through the filter. It is, therefore, difficult to analyze samples of high concentration. However, the problem can be resolved by diluting the sample to a value within the range of calibration curve.

RECOMMENDATIONS

Based on a very limited investigation of the utility of gel permeation chromatography (GPC) as a tool for measuring the amount of natural rubber in modified emulsified asphalt, the following recommendations are submitted.

1. Use dilute solutions of natural rubber latex modified asphalt emulsions as described herein when using GPC to quantify natural rubber content of asphalt.

2. Although not addressed in this report, only neat modified emulsion should be used in this quantitative analysis; extracted and recovered binders should not be used. There is evidence from other research that heating, as required during recovery of extracted binders or during recovery of the asphalt from an emulsion, will cause chain sission of the rubber molecules. This may reduce the molecular size of the rubber and thus interfere with the GPC test results.

3. If GPC is adopted by the TxDOT as a method to quantify natural rubber latex in asphalt, more extensive investigations should be performed to produce a complete test protocol and to determine the effect on GPC of extraction and recovery of binder from micro-surfacing or of asphalt from an emulsion.

APPENDIX D

DISTILLATION OF POLYMER-MODIFIED ASPHALT EMULSIONS

INTRODUCTION

Micro-surfacing is a relatively new paving procedure in Texas. Currently, many highway agency materials laboratories are attempting to use test methods designed for hot asphalt pavements to evaluate micro-surfacing products. The study reported herein was part of a larger project to develop specifications and quality controls for micro-surfacing for the Texas Department of Transportation (TxDOT). This study dealt with the distillation of polymer-modified asphalt emulsions.

The objective of the study was to determine a method of distillation for polymer-modified asphalt emulsions that would minimize the changes in rheological properties of the polymer-modified asphalt residue. Five distillation procedures were investigated. Typical binder specification tests were used to compare the properties of the residue with the corresponding polymer-modified asphalt (base asphalt) that had not been emulsified. These tests included: penetration at 25°C (77°F), absolute viscosity at 60°C (140°F) and kinematic viscosity at 135°C (275°F). Although the ductility test is included in the TxDOT specification for asphalt residue recovered from modified emulsion used in micro-surfacing, it was not included in this study because of the relatively long time requirement for testing and the large quantity of material required.

MATERIALS

The emulsified asphalts selected for testing were products currently used in Texas. Six different sets of samples were tested. A description of the asphalt samples is presented in Table D-1. Four of the asphalt samples were polymer-modified and two were unmodified. Three types of polymers were used: natural Rubber Latex, styrene butadiene rubber latex (SBR), and styrene-butadiene-styrene block copolymer (SBS). Three polymer modified emulsions were produced by comilling asphalt, water, and emulsifying agent along with natural or synthetic rubber latex (an emulsion). The fourth asphalt sample was modified with SBR prior to emulsifying. For each polymer-modified emulsion, the corresponding polymer-modified base asphalt (not emulsified) was tested as a basis for comparison. Furthermore, emulsions containing no polymer were tested and compared with their corresponding base asphalts (not emulsified).

ASPHALT RECOVERY METHODS

Five methods of distillation were investigated. These included:

- ASTM D244,
- Tex 521-C,
- ISSA,
- California Test Method 331, and
- Rotavapor Procedure (modified new standard ASTM D5404).

Table D-1. Description of Emulsified Asphalt Samples Tested

Sample	Polymer	Method of Polymer Addition	Source
Trifinery AC-20	Natural Rubber	Asphalt and Latex Comilled	Koch
Trifinery AC-20	SBR	Asphalt and Latex Comilled	Koch
Styrelf Base	SBS	Asphalt Modified with Polymer prior to Emulsification	Elf
Ergon CSS-1P	SBR	Asphalt and Latex Comilled	Ergon
Ergon CSS-1	none	----	Ergon
Elf CSS-1	none	----	Elf

The ASTM D244 distillation procedure requires a metal still with a maximum temperature of 260°C (500°F) and a total time of one hour ± 15 minutes. A 200 gm sample of emulsion was placed in the still. A ring burner was used to heat the still 150 mm (6 in) from the bottom. When the sample reached 216°C (420°F), the ring burner was lowered to the bottom of the still. The temperature was raised to 260°C (500°F) and maintained for 15 minutes. The sample was then removed from the still and the rheological properties were measured.

Tex 521-C is essentially the same as the ASTM D244 procedure except that for polymer-modified asphalt emulsions, a maximum temperature of 350°F is used. The ISSA distillation procedure is also the same as the ASTM D244 procedure except that a maximum temperature of 138°C (280°F) is used.

California Test Method 331 is a simple oven evaporation procedure which uses a maximum temperature of 138°C (280°F) for a total heating time of three hours. Four 30 gm samples of emulsified asphalt were placed in eight ounce tins. The tins were placed in a 118°C (245°F) oven for 30 minutes. The temperature was then raised to 138°C (280°F) for 1½ hours. The samples were removed from the oven and stirred until foaming stopped. The samples were then placed in the 138°C (280°F) oven for an additional one hour period.

The Rotavapor apparatus uses a rotating distillation flask partially immersed in a hot oil bath. The emulsified asphalt in the flask is subjected to a partial vacuum and a flow of dry nitrogen gas. The maximum oil bath temperature was 138°C (280°F) and total time for the procedure was approximately 1½ hours. The initial settings for the vacuum, gas, rotation speed of the flask and oil bath temperature were 100 mm Hg, 500 ml/min, 40 rpm and 104°C (220°F), respectively. A 200 gm sample of emulsified asphalt was placed in the distillation flask. The flask was slowly lowered into the oil bath to a maximum depth of about 50 mm (2 in). After condensation of the water had slowed to one drop/min, the temperature was raised to 138°C (280°F). When the temperature reached 138°C (280°F), the vacuum was slowly increased to 600 mm Hg and the nitrogen flow was increased to 1000 ml/min. Nitrogen flow is designed to carry water molecules out of the distillation flask when very small quantities are being released from the asphalt near the end of the procedure. When no bubbling was observed for two minutes after stopping the flask rotation, the sample was removed.

In an attempt to reduce heat exposure time and thus reduce binder property changes during distillation, denatured alcohol was used to chemically break one polymer-modified emulsion sample (Ergon). Addition of alcohol caused the asphalt to rapidly flocculate and settle. Most of the water and alcohol was then decanted off. The remaining material was subjected to the distillation procedures described above to remove the residual water and alcohol trapped in the modified asphalt.

Heating to simulate the above distillation procedures was performed on polymer-modified base asphalt samples that had not been emulsified. This was done to determine the effect of heating as required by the various distillation procedures on resultant binder properties when no water or emulsifying agent was present.

Properties of residues from the distillation procedures were compared with their respective base asphalts using the following properties: penetration at 25°C (77°F), absolute viscosity at 60°C (140°F), and kinematic viscosity at 135°C (275°F). Standard ASTM test procedures were used for penetration (Tex 502-C or ASTM D5), absolute viscosity (Tex 528-C or ASTM D2171) and kinematic viscosity (Tex 529-C or ASTM D2170).

RESULTS AND DISCUSSION

Data from this test program is shown in Table D-2. To compare binder properties before and after the different distillation processes, a ratio was obtained by dividing the viscosity or penetration of the emulsion residue by the viscosity or penetration of its respective modified base asphalt. The desired value for this ratio is slightly greater than one, which indicates slight but inevitable hardening of the binder has occurred. Figure D-1 depicts the ratios of six asphalts for absolute viscosity at 60°C (140°F) as a function of distillation method. The ratios for kinematic viscosity

Table D-2. Data from Distillation and Testing of Emulsified Binders and Properties of Corresponding Base Asphalts

Sample Source	Sample Type	Distillation Method	Distillation Temperature °C	Distillation Temperature °F	Absolute Viscosity @ 60°C (140°F) (Poises)	Kinematic Viscosity @ 135°C (275°F) (Cst)	Penetration (1/10 mm)
Trifinery	AC-20 Base Asphalt	N/A*			2464	414	71
	AC-20 + Natural Rubber (Asphalt Cement)	N/A*			6959	1381	63
		Rotavapor	138	280**	8022	1572	56
		ASTM D244	260	500 Still	2755	578	70
		Tex-521-C	177	350 Still	6921	1174	53
		ISSA	138	280 Still	9582	1720	53
	Natural Rubber Modified Emulsion CSS-1P	Rotavapor	138	280**	7809	2076	64
		ASTM D244	260	500 Still	2774	557	72
		Tex-521-C	177	350 Still	8282	1655	65
		ISSA	138	280 Still	8428	2440	62
	AC-20 + Synthetic Rubber (Asphalt Cement)	N/A*		-	6648	1252	63
		ASTM D244	260	500 Still	4982	1095	67
		Tex-521-C	177	350 Still	7301	1495	59
		ISSA	138	280 Still	7497	1539	55
		Ca. Evaporation	138	280	7547	1698	57
	Synthetic Rubber Modified Emulsion CSS-1P	Rotavapor	138	280**	7864	2523	66
		ASTM D244	260	500 Still	4586	1105	70
		Tex-521-C	177	350 Still	6240	1499	66
		ISSA	138	280 Still	6646	1394	61
		Ca. Evaporation	138	280	10640	2222	56

* Base asphalt cement was not subjected to distillation
** Oil bath temperature

Table D-2. Data from Distillation and Testing of Emulsified Binders and Properties of Corresponding Base Asphalts (Cont'd)

Sample Source	Sample Type	Distillation Method	Distillation Temperature °C	Distillation Temperature °F	Absolute Viscosity @ 60°C (140°F) (Poises)	Kinematic Viscosity @ 135°C (275°F) (Cst)	Penetration (1/10 mm)
Elf	Styrelf Base Asphalt Cement	N/A* ASTM D244 ISSA	 260 138	- 500 Still 280 Still	1383 1025 1455	562 473 597	163 163 157
	Styrelf Emulsion CSS-1P	Rotavapor ASTM D244 Tex-521-C ISSA Ca. Evaporation	138 260 177 138 138	280** 500 Still 350 Still 280 Still 280	1673 780 1553 1823 2400	567 365 577 644 720	155 167 153 143 128
Elf	AC-10 Base Asphalt	N/A*		-	868	284	143
	Emulsion CSS-1 (No Polymer)	Rotavapor ASTM D244 Tex-521-C ISSA Ca. Evaporation	138 260 177 138 138	280** 500 Still 350 Still 280 Still 280	880 740 755 750 926	303 272 265 363 320	137 156 151 156 136

* Base asphalt cement was not subjected to distillation
** Oil bath temperature

Table D-2. Data from Distillation and Testing of Emulsified Binders and Properties of Corresponding Base Asphalts (Cont'd)

Sample Source	Sample Type	Distillation Method	Distillation Temperature °C	Distillation Temperature °F	Absolute Viscosity @ 60°C (140°F) (Poises)	Kinematic Viscosity @ 135°C (275°F) (Cst)	Penetration (1/10 mm)
Ergon	SBR Modified Asphalt Cement	N/A*		-	8334	1952	56
		ASTM D244	260	500 Still	6455	1022	54
		ISSA	138	280 Still	9122	1874	50
	SBR Modified Emulsion CSS-1P	Rotavapor	138	280**	23330	11000	49
		ASTM D244	260	500 Still	5754	1082	59
		Tex-521-C	177	350 Still	13935	3295	50
		ISSA	138	280 Still	11500	4656	54
		Ca. Evaporation	138	280	23805	15635	47
Ergon	AC-30 Base Asphalt	N/A		-	3119	398	66
	Emulsion CSS-1 (No Polymer)	Rotavapor	138	280**	13303	7539	42
		ASTM D244	260	500 Still	4191	539	66
		Tex-521-C	177	350 Still	7969	2664	55
		ISSA	138	280 Still	8794	6594	48
		Ca. Evaporation	138	280	11292		49

* Base asphalt cement was not subjected to distillation
** Oil bath temperature

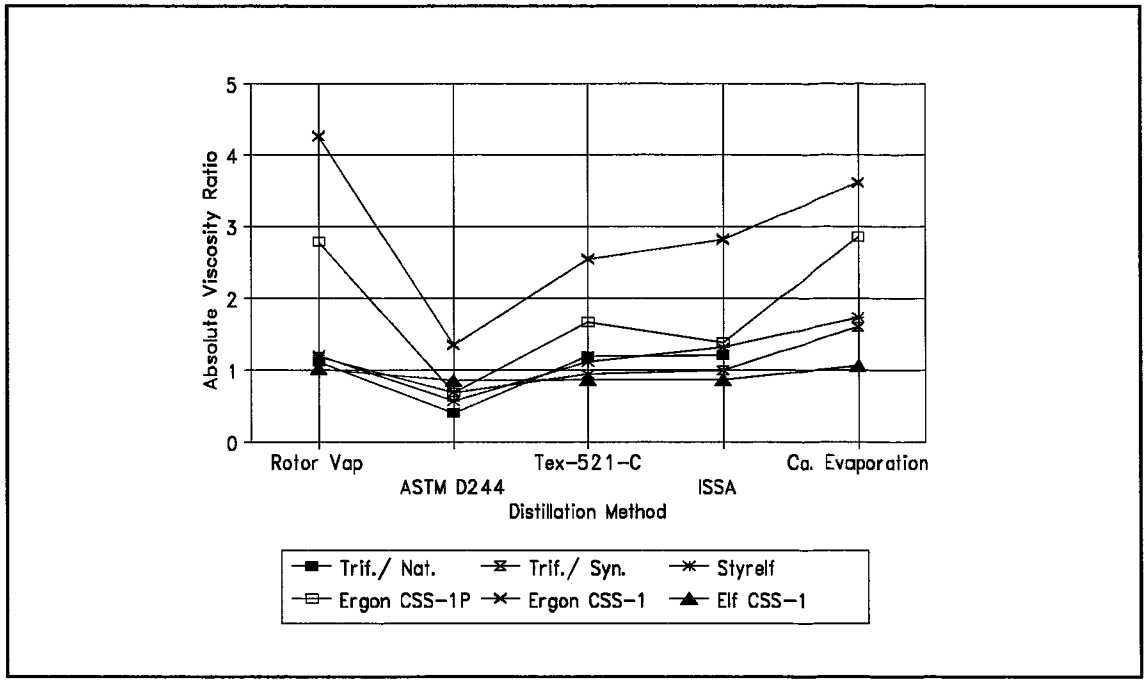

Figure D-1. Absolute Viscosity (60°C) Ratio for the Five Different Distillation Methods Evaluated

at 135°C (275°F) versus distillation method is presented in Figure D-2. Figure D-3 shows the ratios for penetration at 25°C (77°F) versus distillation method.

The residue/base asphalt ratios in Figures D-1 through D-3 indicate that the ASTM D244 procedure results in a modified binder that is softer than the original base asphalt. It is surmised from these changes in rheological properties upon heating to 260°C (500°F) that the polymers were being broken down or depolymerized during the distillation process. In addition, in these samples, the modified base asphalt exhibited a grainy texture, a typical characteristic of the rubber modified asphalt. The residue from the ASTM D244 at 260°C (500°F) distillation method had a much smoother texture. This is further evidence that the polymer was being broken down. These visual observations were most evident on the comilled samples.

The data suggest that, as the maximum temperature for the metal still was successively lowered (as with ASTM D244 at 260°C (500°F), Tex 521-C at 177°C (350°F), and ISSA at 138°C (280°F), the mean value of the residue/base ratios for these three methods indicated a successively harder residue was produced. This was likely due to less breakdown of the polymer at the lower temperatures. Of course, lower temperatures should result in less hardening of an unmodified asphalt. Upon completion of the ISSA procedure, the residues were foamy on the surface, thus indicating that not all of the water was removed by the 138°C (280°F) temperature at atmospheric pressure.

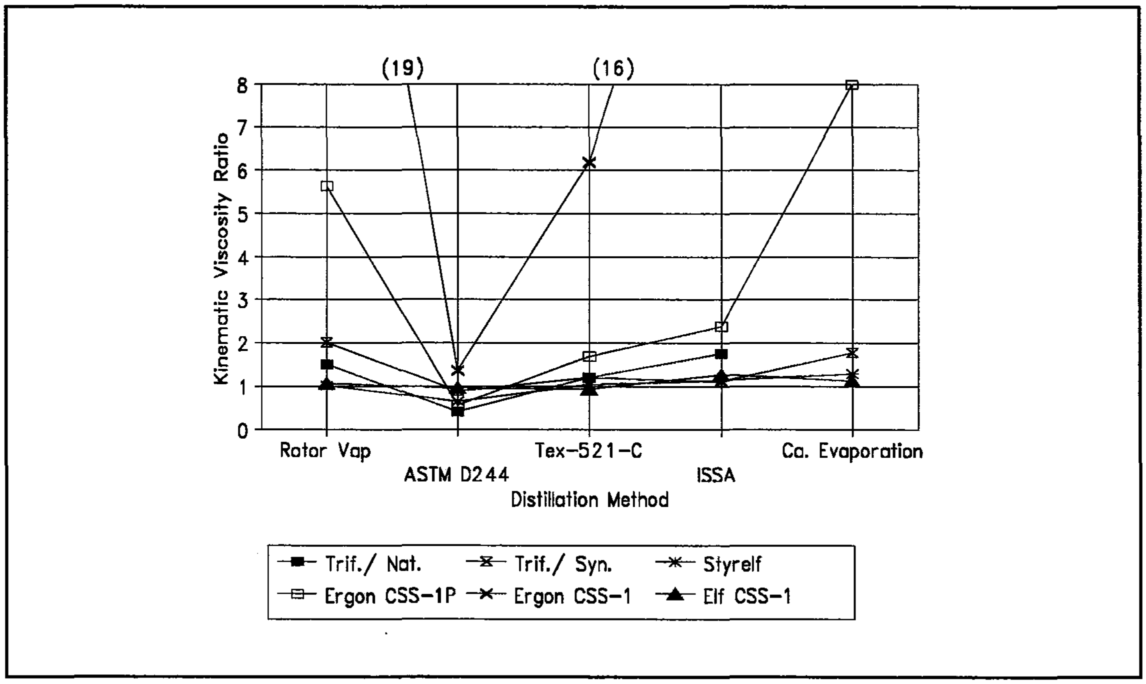

Figure D-2. Kinematic Viscosity (140°C) Ratio for the Five Different Distillation Methods Evaluated

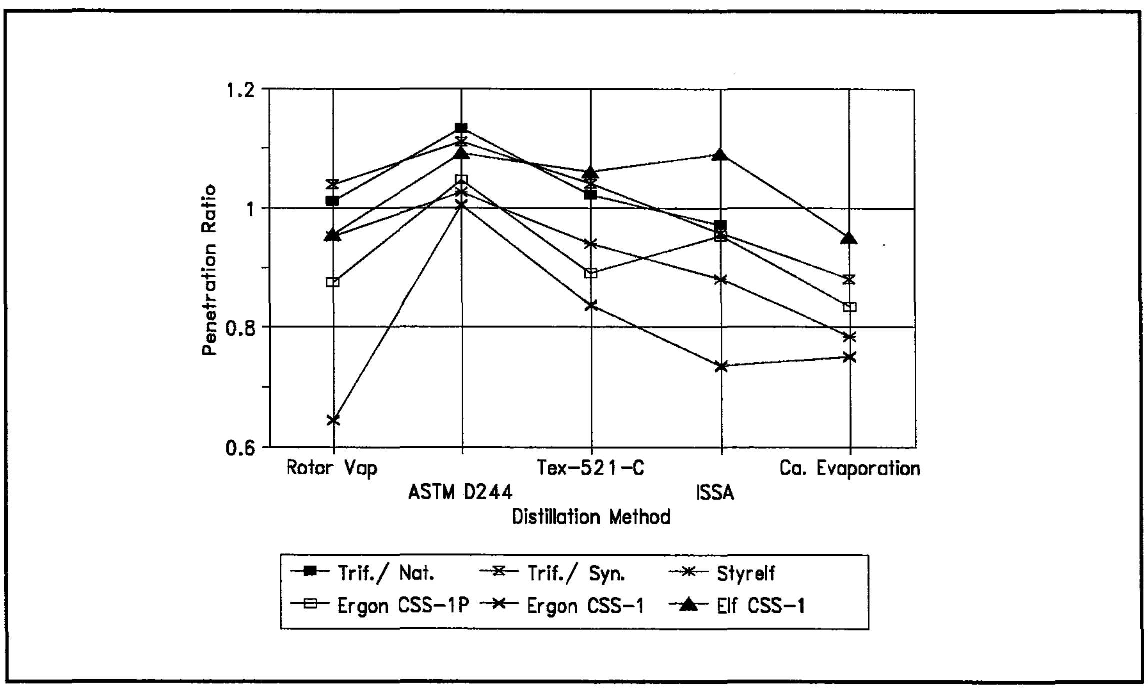

Figure D-3. Penetration Ratio for the Five Different Distillation Methods Evaluated

California test method 331 resulted in significant binder hardening as compared to the other methods and a large amount of data scatter.

The Rotavapor method exhibited a relatively large amount of scatter in the residue/base ratios (Figures D-1 through D-3), particularly with regard to the Ergon products. In fact, the Ergon products almost always showed more hardening than the other binders.

There was no established test procedure for distilling emulsions using the Rotavapor method. It was found that the final temperature of these asphalt residues needed to be at least 138°C (280°F) to facilitate flow inside the rotating flask and removal of the water. That is, near the end of the procedure, the viscosity of the binder had to be low enough to permit diffusion of the water molecules from the liquid asphalt. At temperatures lower than 138°C (280°F), the residues appeared to be too viscous to allow the remaining water to readily escape.

One problem encountered with the Rotavapor method was determining the end point. At first, a time limit for the test was selected to indicate the end point. This was not uniformly effective because each sample behaved differently, i.e., water from some samples was driven of quickly, while others took considerably more time. This is apparently due to the relative viscosity of the different materials; higher viscosity materials require more time for the water vapor to diffuse out. Another attempt at determining the end point of the test was to use a time limit between consecutive water droplets of condensation. This was not effective because the condensation did not uniformly decrease as distillation proceeded but would periodically stop and then start again. Finally, the method selected for determining the end point was the stage when the rotation of the flask could be stopped for two minutes and no bubbling of the residue was observed.

The Rotavapor procedure appeared to work reasonably well for four of the six samples. However, this method resulted in significant hardening in the two Ergon samples as shown in Figures D-1 through D-3.

Distillates (mostly water) from the four asphalt recovery procedures using a still (ASTM D244, Tex 521-C, ISSA, and Rotavapor) were collected and visually examined. The distillates from the metal still, at any of the operating temperatures used, always exhibited a translucent or cloudy appearance. The higher the distillation temperature, the more cloudy the distillate became. Distillate from the 260°C (500°F) still exhibited brown oil floating on top of the cloudy water which clearly indicates that light oils were being distilled from the asphalt. Distillates from the Rotavapor method were completely clear indicating no oils were distilled from the residue.

For two polymer-modified Ergon samples, alcohol was used to break the emulsion. With the asphalt and water thus separated, most of the water-alcohol solution was then decanted. This was done in an attempt to reduce distillation time and thus reduce asphalt hardening and/or polymer damage. One sample each for the Rotavapor and the Tex 521-

C procedures were treated with alcohol. This procedure proved ineffective in consistently reducing binder hardening as shown in Table D-3.

The data indicate that all five distillation methods resulted in unacceptable changes in rheological properties of the polymer-modified asphalts. A wide range of properties may be obtained from a distilled residue and the resulting properties may depend on the source of the emulsion. The data do not permit indisputable conclusions to be stated because two processes apparently occurred to varying degrees during all five distillation procedures. These two processes have opposite effects on the properties of the binder. One process, of course, is asphalt hardening due to heat exposure which has the effect of increasing the binder viscosity. The other process is breakdown or depolymerization of certain polymers due to heat exposure which has the effect of lowering the binder viscosity. The degree to which these two phenomena occur due to the different distillation procedures varied and was not measured separately.

For a polymer-modified asphalt, a realistic value for the residue/base asphalt ratio would be slightly greater than one indicating that some hardening occurred and that no depolymerization occurred. However, without performing other tests such as gel permeation chromatography (GPC), which gives molecular size distribution, it is impossible to ascertain whether or not depolymerization actually occurred.

Two unmodified emulsions were tested and compared with the modified samples (Table D-2). This was done in order to determine whether the distillation methods affected the unmodified emulsions and the polymer modified emulsions in the same way.

The unmodified Ergon sample showed results similar to the modified samples except that the distilled residue was usually slightly softer. The unmodified Ergon sample was supposedly identical to the polymer-modified Ergon samples except that it contained no polymer. Because the results from the unmodified and polymer-modified samples were so similar, there is some question as to whether or not there may have been some polymer in the sample labeled "unmodified." The process used by the manufacturer to produce this sample allows for the possibility of inclusion of some polymer.

The Elf unmodified emulsion showed a different trend than the corresponding modified samples. With this material, all the distillation methods yielded a residue softer than the original base asphalt. The Rotavapor method showed the least amount of change in properties of the distilled residue. The California evaporation method yielded the most hardening of the residue.

Table D-3. Results for Alcohol Treated and Untreated Ergon Samples (CSS-1P) for the Rotavapor and TxDOT 521-C Distillation Methods

Method	Alcohol Treated	Absolute Viscosity @ 60°C (140°F), poises	Kinematic Viscosity @ 135°C (275°F), cSt	Penetration @ 25°C (77°F), 1/10 mm
Rotavapor	yes	23,200	3,399	51
	no	23,300	11,000	49
TxDOT 521-C	yes	14,900	3,890	51
	no	13,900	3,290	50

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on distillation by five different methods of six different types of emulsified asphalt from three sources and comparison of resulting rheological properties with base asphalts (not emulsified) of the same composition, the following conclusions are proffered.

1. Exposure of polymer-modified asphalts to heat as required during binder recovery by distillation produces changes in rheological properties that are uncharacteristic of the polymer-modified base asphalt (i.e., binder in micro-surfacing).

2. The five asphalt recovery methods evaluated yielded residues that exhibited wide variability in properties and/or residues with unrealistically low consistency.

3. None of five the methods evaluated appear suitable for recovering polymer-modified asphalts from emulsions for testing of rheological properties.

4. At temperatures of 138°C (280°F) and above for 1½ hour or more, typical polymers used in micro-surfacing binders appear to be broken down resulting sometimes in a decrease in viscosity of the recovered binder.

5. Most binders at temperatures lower than 138°C (280°F) appear to be too viscous to allow water vapor to readily escape or readily flow around the sides of a rotating distillation flask.

6. Removal of most of the water by breaking of the emulsion using alcohol and decantation prior to distillation was unsuccessful in improving results with the Rotavapor and TxDOT 521-C methods.

Recommendations

Based on the foregoing study of distillation of polymer-modified emulsified asphalts, the following recommendations are made.

1. Specifications should not require that polymer-modified emulsified asphalts be distilled to recover binders to ascertain rheological properties of the residue.

2. The data suggest there is no need to replace the distillation procedure being used by TxDOT (Tex 521-C) with another existing method. The other methods tested did not show any improvement over the TxDOT method.

3. If distillation of emulsions is to be used to obtain a residue for testing, more study is needed to develop a suitable procedure. One aspect that needs to be studied is the effect of temperature on certain polymer additives.

4. Instead of developing micro-surfacing specifications for the polymer-modified asphalt residue, it appears more beneficial to develop end-result specifications for the final micro-surfacing product.

APPENDIX E

DRAFT QUALITY ASSURANCE GUIDELINES

FOR MICRO-SURFACING

QUALITY ASSURANCE GUIDELINES FOR MICRO-SURFACING

GENERAL

The following provides guidance for completing quality assurance tests and checks during the application of micro-surfacing. The goal of the quality assurance tests and checks is to insure that a quality product is delivered by the contractor. These procedures include laboratory tests before and during the treatment application, checks by the inspectors during the treatment application, and some general discussions of problems that may be encountered with recommendations on how to correct them.

A specification is supposed to be a precise statement of requirements to be satisfied by a product, system, or service. Specifications function as the link between the Department and the contractors and producers telling them exactly what is expected of them. Quality assurance testing is used to check that the desired quality product is delivered in accordance with the specification.

Micro-surfacing as a material appears to violate many of the techniques TxDOT inspectors have developed over the years to insure that quality hot mixed asphalt concrete pavements are constructed. These guidelines were developed to give direction for the checks and tests that should insure that a quality product is provided by the contractor.

BEFORE CONSTRUCTION

Checks and tests conducted before construction normally address the acceptability of the materials and mixtures. Sometimes, trial work is required. The before-construction checks and tests are often used as a materials acceptance and mixture verification testing. All acceptance tests must be completed prior to the time work commences.

MATERIALS ACCEPTANCE TESTS

In materials acceptance testing, the basic materials proposed for use by the contractor are tested to ensure they meet the specification requirements. The material may be submitted by the contractor or collected by a TxDOT representative; however, they must be available to TxDOT in adequate time to allow all required tests to be completed prior to commencement of work. Testing may be completed at District or Materials and Test Division laboratories.

Polymer-Modified Emulsified Asphalt Cement

Tests are conducted to ensure that the polymer-modified emulsified asphalt cement meets the specification requirements. All tests shall be conducted in accordance with AASHTO Standard Test Method T-59, unless otherwise required. The emulsion shall be homogeneous, shall not show significant separation of polymer and shall comply with the following requirements:

	Min	Max
Viscosity, Saybolt Furol at 25°C (77°F), Sec.	20	100
Storage stability test, one day, percent	-	1
Particle charge test	Positive	
Sieve test, percent	-	0.1
Distillation		
Oil distillate, by volume of emulsion, percent	-	½
Residue, percent	62	-

The base asphalt cement shall be meet the requirements of an AC-20 as defined by Item 300 of the Standard Specifications for Construction of Highways, Streets and Bridges.

The distillation residue of the modified emulsion shall contain a minimum of 3.0 percent polymer by weight, as determined by Texas Test Method TEX-533-C or the gel permeation chromatography (GPC) test procedure. The FTIR may not give accurate results when the polymer is natural rubber and the GPC should be used for those materials.

Aggregate

The mineral aggregate shall all be generated by crushing operations from a single source and shall be composed of clean, tough, and durable particles of crushed traprock, crushed granite, crushed sandstone or other material approved by the Engineer.

A sand equivalent of 70 or higher is required as determined using Test Method Tex-203-F.

The aggregate shall show a maximum weight loss of 25 percent when subjected to five cycles of conditioning using magnesium sulfate solution in accordance with Test Method Tex-411-A. The test shall be performed on the gradation to be used on the project.

If a polish value is required for the aggregate, it shall be tested in accordance with Test Method Tex-438-A. The polish value test shall be performed on the parent rock.

Grades. When tested by Test Method Tex-200-F, Part II, Washed Sieve Analysis, the gradation requirements shall be as follows:

Grade 1 (Fine Graded Surface Course)	Percent Aggregate By Weight
Retained on 9.50 mm (3/8 in) sieve	0
Retained on 4.75 mm (No. 4) sieve	0-2
Retained on 2.36 mm (No. 8) sieve	10-25
Retained on 1.18 mm (No. 16) sieve	25-50
Retained on 0.60 mm (No. 30) sieve	50-70
Retained on 0.30 mm (No. 50) sieve	65-82
Retained on 0.15 mm (No. 100) sieve	79-90
Retained on 0.075 mm (No. 200) sieve	85-95

Grade 2 (Coarse Graded Surface Course)	Percent Aggregate By Weight
Retained on 12.5 mm (½ in) sieve	0
Retained on 9.50 mm (3/8 in) sieve	0-1
Retained on 4.75 mm (No. 4) sieve	6-14
Retained on 2.36 mm (No. 8) sieve	35-55
Retained on 1.18 mm (No. 16) sieve	54-75
Retained on 0.60 mm (No. 30) sieve	65-85
Retained on 0.30 mm (No. 50) sieve	75-90
Retained on 0.15 mm (No. 100) sieve	82-93
Retained on 0.075 mm (No. 200) sieve	85-95

Mineral Filler

Mineral filler shall be non-air-entrained Portland cement which is free of lumps or foreign matter meeting the requirements of Item 524 of the Texas Standard Specifications for Construction of Highways, Streets and Bridges or, if approved by the engineer, hydrated lime meeting the requirements of Item 264 of the Texas Standard Specifications for Construction of Highways, Streets and Bridges.

Water

The water shall be potable and shall be free of harmful soluble salts.

Other Additives

The contractor shall define what type of additives will be used with the micro-surfacing by chemical composition, brand name and additive designation or other acceptable method.

MIXTURE DESIGN VERIFICATION

In the mixture design verification testing, TxDOT will conduct a series of tests on the basic materials to verify the mixture design submitted by the contractor. The materials must be available to the Department so that this verification can be completed prior to work commencing. The mixture design verification testing may be conducted at district or Materials and Test Division laboratories. Once the mixture design is approved, all mixtures must meet the resulting job mixture formula. The following minimum tests will be conducted to ensure that the mixture design provided by the contractor meets the current specifications.

The Wet Track Abrasion Test performed in accordance with the TxDOT procedure shall have a maximum value of 807 g/m^2 (75 g/ft^2) after six days of soaking.

DURING CONSTRUCTION

The checks and tests conducted during construction normally address whether the materials being placed meet the requirements established in the specifications and approved in the before construction materials and mixture design acceptance checks and tests. Samples are normally collected by TxDOT inspectors from the construction site and from the materials stockpile locations. Actual laboratory testing may be conducted at district or Materials and Test Division laboratories. Any batch of material not meeting these requirements will be rejected, and any work completed using unacceptable material will be replaced.

MATERIALS TESTS

Tests are conducted on samples of the polymer-modified emulsified asphalt cement taken from the storage tank or from the micro-surfacing application machine. One sample will be taken and tested from each tanker load of emulsion or once each week, which ever is the larger number. Samples will be taken in accordance with ASTM D 140-88. The material will be tested in accordance with AASHTO Standard Test Method T-59, unless otherwise designated as described earlier in the section on acceptance tests and shall meet all requirements defined in the earlier section on acceptance tests.

Tests are conducted on the representative aggregate samples taken from the job site stockpile using AASHTO Standard Test Method T-2. One test will be completed for each stockpile established prior to commencement of micro-surfacing application or for every 900,000 kg (1000 tons) of aggregate delivered during treatment application. The amount of mineral filler added to the mix shall be included in determining the total minus 0.075 mm

(No. 200) sieve aggregate fraction. Once the stockpiled material is accepted, only the gradation and sand equivalent tests will be required. Determination of aggregate gradation will be based on sieve analysis of using Tex-200-F, Part II, Washed Sieve Analysis. Sand equivalent tests will be conducted using Test Method Tex-203-F.

The aggregate shall not vary from the design gradation by more than the tolerances which follow. The material passing the No. 200 sieve is further restricted to conform to the limitations for the master grading for the type specified.

Sieve Size	Allowable Tolerance, Percent by Weight or Volume as Applicable
Passing 9.50 mm (3/8 in) sieve	Plus or minus 5
Passing 4.75 mm (No. 4) sieve	Plus or minus 5
Passing 2.36 mm (No. 8) sieve	Plus or minus 5
Passing 1.18 mm (No. 16) sieve	Plus or minus 5
Passing 0.60 mm (No. 30) sieve	Plus or minus 3
Passing 0.30 mm (No. 50) sieve	Plus or minus 3
Passing 0.15 mm (No. 100) sieve	Plus or minus 3
Passing 0.075 mm (No. 200) sieve	Plus or minus 2

Mineral filler shall be checked to see that it is certified to meet the requirements of Item 524 of the Texas Standard Specifications for Construction of Highways, Streets and Bridges if it is non-air-entrained Portland cement or Item 264 of the Texas Standard Specifications for Construction of Highways, Streets and Bridges if it is hydrated lime.

Water shall be from an approved potable water source unless otherwise allowed in the specification.

Additives shall be checked to ensure they match those identified by the contractor in the materials acceptance checks and tests.

DETERMINATION OF MIXTURE COMPOSITION AND TOLERANCES

The contractor shall provide the proportions of all materials included in the mixture based on the readings from the equipment periodically throughout the day and cumulative at the end of the day.

Mixture composition will be verified from samples taken from the mixing unit discharge in a pan or bucket of width such that the complete discharge stream is included in the sample. Mixture samples shall be dried to constant weight at 110°C (230°F) plus or minus 6°C (10°F) prior to determination of asphalt content. The residual asphalt content of the paving mixture shall not vary from the design amount by more than 0.5%. One sample will be taken for every 900,000 kg (1000 tons) of mixture or once each day, which ever occurs first.

The asphalt content may be determined in accordance with Test Method Tex-228-F or ASTM D-2172-88, Test Method B (Reflux Extraction). If ASTM D-2172-88, Test Method B is used, the heat source should be turned off at the usual time and the solvent-soaked aggregate allowed to set overnight. The next morning, reflux should be run again until the filtrate is a straw color. This is to be repeated daily until the filtrate is straw color at the start of the distillation process. This will reasonably assure removal of all asphalt cement and polymer. If the bituminous material recovered during the extraction process is allowed to soak in the solvent overnight, then extracted asphaltic material will not be acceptable for recovery or testing.

LIMITATIONS

Weather Limitations

The material shall be spread only when the atmospheric temperature is at least 10°C (50°F) and rising and the weather is not rainy and there is no forecast of temperatures below 0°C (32°F) within 24 hours after mix placement or rain within 12 hours. Rain on the mixture within fifteen to thirty minutes after placement will not normally damage the mixture; however, if rain falls on the mixture before the emulsion has broken, the emulsion can be washed out of the mixture.

Surface Preparation

The area to be surfaced shall be thoroughly cleaned of all vegetation, animal carcasses, loose aggregate, soil, and other debris. Water will be used to pre-wet the surface ahead of the spreader box. It shall be applied at a rate to dampen the entire surface without any free flowing water ahead of the spreader box.

ACCEPTANCE

Finished Surface

The finished micro-surfacing shall have a uniform texture free from excessive scratch marks, tears or other surface irregularities. Excessive tear marks are considered four marks that or more 12 mm (½ in) wide or wider 150 mm (6 in) or more in length per 11 sq m (120 sq ft) or any marks 25 mm (1 in) wide or wider, 100 mm (4 in) or more in length. The mixture shall adhere fully to the underlying pavement within one hour after application.

Measurements will be made on any section one lane wide by 30 m (100 ft) long selected at random and check for surface characteristics. At least one section will be checked for each four hours of work. Any time that the surface appears to be unacceptable, additional sections can be checked.

The mixture shall provide a uniform skid resistant surface with a skid number of 43 or greater as measured using ASTM E 274 at 64 km/hr (40 mi/hr).

Joints/Seams

The longitudinal and transverse joints shall be neat appearing and uniform. No excessive buildup, uncovered areas or unsightly appearance will be permitted on longitudinal or transverse joints. Longitudinal joints shall be placed on lane lines when possible. Gaps between applications will not be permitted. Joints without gaps will be considered acceptable if no more than a 12 mm (½ in) space exists between the pavement surface and a 1.2 m (4 ft) straight edge placed perpendicular on the longitudinal joint nor 6 mm (1/4 in) for a transverse joint.

Measurements will be made on any section 30 m (100 ft) long. At least one section should be checked for each four hours of work. The same section for used for surface characteristics can be used. Any time that the joints and seams appear to be unacceptable, additional sections can be checked. All transverse joints will be checked.

Edges

The edges of the micro-surfacing shall be uniform and neat appearing along the roadway centerline, lane lines, shoulder or curb lines. The edge shall vary no more than plus or minus 75 mm (3 in) from a 30 m (100 ft) straight line on a straight section or from a 30 m (100 ft) arc of the design curve on a curved section.

Measurements will be made on any section 30 m (100 ft) long. At least one section should be checked for each four hours of work. The same section for used for surface characteristics or joints and seams can be used. Any time that the edges appear to be unacceptable, additional sections can be checked.

Handwork

Areas of hand work shall have a uniform texture that matches the texture and color of the finished surface produced by the spreader box.

Measurements will be made on any section one lane wide by 30 m (100 ft) long selected at random and check for surface characteristics. At least one section will be checked for each four hours of work. Any time that hand work appears to be unacceptable, additional sections can be checked. The same section used for surface characteristics can be used.

Opening to Traffic

The micro-surfacing shall be ready for traffic to be applied within one hour after application. When traffic is applied, the surface shall not be significantly altered. Each time traffic control is moved, the time to opening damage to the surface should be checked.

Ruts

When required on the plans, before the final surface course is placed, preliminary micro-surfacing material shall be required to fill ruts, utility cuts, depressions in the existing surface, etc. Ruts of 13 mm (½ in) or greater depth shall be filled independently with a rut filling spreader box no more than 1.8 m (6 ft) in width. For irregular or shallow rutting less than 13 mm (½ in) in depth, a full-width scratch coat pass may be used as directed by the Engineer. Each individual rut filling, utilizing a rut filling spreader box shall be crowned to compensate for traffic compaction. Ruts that are in excess of 14 mm (3/4 in) depth will require multiple placements with the rut filling spreader box to restore the original cross section. Maximum micro-surfacing thickness applied as rut filling in a single lift shall not exceed 14 mm (3/4 in). Maximum micro-surfacing placed full width of a lane shall not exceed 19 mm (½ in) in any location across the lane. At the end of construction, the transverse profile shall show no rutting in the wheel paths and no more than a 6 mm (1/4 in) height above the desired profile.

Measurements will be made on any section one lane wide by 30 m (100 ft) long selected at random and check for surface characteristics. At least one section will be checked for each four hours of work. Any time that hand work appears to be unacceptable, additional sections can be checked. The same section used for surface characteristics can be used.

POSSIBLE PROBLEMS AND CORRECTIONS

Since micro-surfacing is a new material to many Department inspectors, this section on problems that have been encountered and corrective actions was developed. It is not intended for the inspector to make decisions for the contractor based on the information presented. Rather, the material is provided so that the inspector can determine if the contractor is making reasonable modifications to his work to correct problems. It also gives guidance on how to proceed if the contractor is not able to correct the problem.

Opening to Traffic

The micro-surfacing should be ready for traffic to be applied within one hour after application. When traffic is applied, the surface should not be significantly altered. For this to occur, the emulsion must break, the mixture must gain shear strength, and the mixture must develop bond with the underlying pavement surface. The emulsion should be breaking no more than 30 to 45 seconds after the material is deposited by the spreader box. A small stick can be used to check for breaking of the emulsion. If a stick can be drawn through mixture and the resulting tear repaired by smoothing the mixture with the stick, the emulsion has not broke. When the tear cannot be repaired by smoothing with a stick, the emulsion has broke. The shear strength and bond can be checked in a gross manner by placing your full weight on the sole of your shoe on the mixture. If the sole can be place on the mixture for two seconds without picking up mixture, then the pavement can be opened to straight traffic. If you place your weight on the heel of one shoe on the mixture and twist the heel with only minor surface marks, the mixture can probably be opened to turning traffic without significant damage.

Ambient temperature and moisture have an impact on the rate at which the emulsion will break and strength and bond develop in the mixture. The material shall be spread only when the atmospheric temperature is at least 10°C (50°F) and rising and the weather is not rainy and there is no forecast of temperatures below 0°C (32°F) within 24 hours after mix placement or rain within 12 hours. If it is too cool, the emulsion will not break nor cure quickly enough to allow traffic on the mixture within a reasonable time period. If it rains on the mixture before the emulsion breaks, the mixture can be severely damaged. If it rains on the mixture after the emulsion has broken, there is normally no damage to the mixture.

Cement is used in the mixture as a mineral filler and as a break rate controller. At normal cement rates of 0.25 to 2.0%, cement normally acts as a break accelerator. The mixture design normally establishes a cement content which will produce the break and strength gain needed based on laboratory conditions. As the temperature increases, this break rate may be too fast, and the contractor adds the special additive (generally more of the asphalt emulsifying agent) to reduce the break rate. As the atmospheric conditions change, more or less additive is used to control the break rate. If the temperature decreases and the humidity increases, the mixture may not break and develop strength at the desired rate even with no additive in the mixture. When this occurs, it may be possible to increase the break and strength gain rate by increasing the amount of cement used in the mixture. If the cement is increased, the increase should be no more than 0.5% at a time and the maximum amount of cement should never exceed 3%.

On occasion, changes in water supply have caused the emulsion to break more quickly than expected based on laboratory designs. Water is not generally tested unless problems cannot be resolved otherwise. The water should be clean and potable to avoid problems. If water is suspected to be the cause of a problem, try another water source and see if the problem disappears.

If the desired break and strength gain do not develop adequately to allow the surface to be opened within contract time, the contractor should be required to stop work. Work should not be restarted until the contractor develops a mixture that will meet the requirements and demonstrates that the surface can be opened in the required time with a test strip.

Joints/Seams

Longitudinal joints should be neat appearing and uniform. No excessive buildup, uncovered areas or unsightly appearance should be permitted. Longitudinal joints shall be placed on lane lines when possible. Excessive overlap (greater than 50 mm (2 in) should not be permitted unless the width of the pavement is such that wider overlaps are required to keep the spreader box on the pavement surface. There should be no more than a 50 mm (0.5 in) space between the pavement surface and a 1.2 m (4 ft) straight edge placed on the longitudinal joint perpendicular to the joint. These can generally be adequately controlled if the operator is careful about the steering of the application equipment. Many contractors use equipment with driving controls on both sides of the equipment so that the operator can follow the guidelines. Existing edge markings, string lines, and previously placed micro-surfacing in adjacent lanes are often used as the control. Small gaps and slight overlaps between adjacent lanes can be corrected with squeegees or drag mops by the crew at the back of the equipment during treatment application. When the edge of the pavement is not uniform and the width of the micro-surfacing is equal to or less than the width of the pavement, the operator must follow that edge as closely as possible without allowing the box to travel off the edge of the pavement.

Transverse joints should also appear neat and uniform. No excessive buildup, uncovered areas or unsightly appearance should be permitted. There should be no more than a 6 mm (0.35 in) space between the pavement surface and a 1.2 m (4 ft) straight edge placed on the transverse joint perpendicular to the joint. Some contractors place metal strips on the existing micro-surfacing to start the next pass to insure that a clean joint with no build up is provided. Every joint will provide some roughness and be unsightly; they should minimized as much as possible. The total number of transverse joints, other than those required by bridges, other structures, and repairs, should be minimized and generally should occur no more often than one joint per 1.6 lane km (1 lane mi) based on the total length placed in the project. The contractor must coordinate the material requirements of his application equipment with the delivery capability of his nurse trucks and batch site to ensure that unnecessary stops are not made.

If the desired joints and seams are not provided on occasion, the contractor should be required to repair them with a full width coverage of the affected surface by micro-surfacing material using the standard application equipment. If the desired joints and seams are not provided on a regular basis, the contractor should be required to stop work. Work should not be restarted until the contractor demonstrates that the joints and seams can be properly constructed on a test strip acceptable to the engineer.

Edges

The edges of the micro-surfacing should appear uniform and neat appearing along the roadway centerline, lane lines, shoulder or curb lines. When the micro-surfacing is placed wider than the pavement, and the pavement has no drop-offs greater than 12 mm (0.5 in), the edge should vary no more than plus or minus 100 mm(4 in) from a 30 m (100 ft) straight edge on a straight section or from a 30 m (100 ft) arc of the design curve on a curved section. These can generally be adequately controlled if the operator is careful about the steering of the application equipment. Existing edge markings, string lines, and previously placed micro-surfacing in adjacent lanes are often used as the control. Many contractors use equipment with driving controls on both sides of the equipment so that the operator can follow the guidelines. The edge is considered where the edge of the aggregate in the micro-surfacing mixture ends. Slight runoff of liquids should be expected along the edges. More runoff should be expected on sections with super elevations or high crowns. Excessive runoff indicates excess water in the mixture.

If the desired edges are not provided on occasion, the contractor should be required to repair them with a full width coverage of the affected surface by micro-surfacing material using the standard application equipment. If the desired edges are not provided on a regular basis, the contractor should be required to stop work. Work should not be restarted until the contractor demonstrates that the edges can be properly constructed on a test strip acceptable to the engineer.

Ruts

Ruts of 13 mm (½ in) or greater depth should be filled independently with a rut filling spreader box no more than 1.8 m (6 ft) in width. The rut filling box can be used to crown the filled area; however, this crown should be limited to no more than 6 mm (1/4 in). Ruts in excess of 19 mm (3/4 in) depth generally require multiple placement passes with the rut-filling spreader box to restore the original cross section. If the material is placed too thick, excessive free moisture may be trapped between the micro-surfacing material and the existing pavement reducing the bond between the existing pavement and the micro-surfacing material. Maximum micro-surfacing thickness applied as rut filling in a single lift should normally not exceed 19 mm (3/4 in). For irregular or shallow rutting less than 13 mm (½ in) depth, a full-width scratch coat pass may be used. Maximum micro-surfacing placed full width of a lane should not exceed 25 mm (1 in) in any location across the lane. At the end of construction, the transverse profile should show no rutting in the wheel paths and no more than a 6 mm (1/4 in) height above the desired profile.

If the desired profile is are not provided on occasion, the contractor should be required to repair them with a full width coverage of the affected surface by micro-surfacing material using the standard application equipment. If the profile is not provided on a regular basis, the contractor should be required to stop work. Work should not be restarted until the contractor demonstrates that the profile seams can be properly constructed on a test strip acceptable to the engineer.

Rut filling should generally be considered a temporary maintenance treatment to restore the cross-section profile. It does not repair the cause of rutting but rather repairs the symptom. The "Usage Guidelines" try to provide guidance about when rut filling may be an appropriate maintenance treatment.

Surface Preparation

Vegetation, animal carcasses, loose aggregate, soil, petroleum, and excessive water on the existing surface may reduce or prevent bond between the micro-surfacing and the existing pavement surface. If this occurs, the micro-surfacing will delaminate and leave areas with no surfacing. The original surface should be thoroughly cleaned prior to application of the micro-surfacing. The equipment must be well maintained and operated to prevent leaking oil, hydraulic fluid, or dry aggregate from contaminating the surface.

If the surface is not properly prepared, the contractor should be required to stop work. Work should not be restarted until the contractor demonstrates that the surface has been properly prepared.

Finished Surface

The finished micro-surfacing should have a uniform texture free from excessive scratch marks, tears or other surface irregularities. Proper strike-off equipment, proper application rates and a well trained crew should be able to produce a high quality surface. The type, gage, and size of the squeegee material on the back of the spreader box have an impact on the appearance of the final surface. The primary causes of scratch marks and tears are trying to place the material in too thin of a layer, oversize aggregate in the mixture, not using enough additive during hot weather, and not cleaning the spreader box.

Micro-surfacing can be placed in layers more than twice the thickness of the nominal large aggregate; however, it is not possible to place it thinner than about one and one-half times the nominal maximum aggregate size without creating excessive drag marks. As the surface texture becomes more open, more material is required to meet this minimum thickness because the material must fill the voids in the existing surface as well as provide the needed thickness. As the surface texture changes, the type, gage, and size of the squeegee material on the spreader box may have to be change to developed the desired surface texture.

The aggregate should be handled and stockpiled carefully to insure that oversize material is not allowed to be come mixed with the micro-surfacing aggregate. Current specifications require use of a screen in the aggregate feeding line to catch over size aggregate before it enters the nurse trucks feeding the application equipment.

Some buildup of mixture will naturally occur in the spreader box, but it generally will remain fused during normal operation. When it drys sufficiently, the built up mixture will break loose and fall into the mixture causing drag marks. Proper amounts of additive will reduce the amount of buildup in the spreader box. When dried material drops from the box into the mixture on a regular basis, this indicates that not enough special additive is being used in the mixture.

The spreader box must be cleaned between each use and each time the application equipment stops. If it is not adequately cleaned, the buildup of hardened mixture will develop rapidly which will then break loose and cause drag marks.

An experienced crew watching the application can repair small tears, damaged areas, and drag marks before the emulsion breaks using hand squeegees and drag mops. Some contractors use a double strike-off, and an experienced crew can make the hand repairs between the strike-offs so that they cannot be seen after the second strike-off passes over it. Once the emulsion breaks, the mixture cannot be repaired without leaving an unsightly surface. Excessive repairs will cause the surface to be splotchy and unsightly. After a damaged area has dried, spot patches should not be allowed. All repairs completed after the material has broken should be completed using the application machine and full width coverage with the spreader box. The repairs should be long enough to cover the damaged area and the joints should meet the requirements described above.

If the surface characteristics are not provided on occasion, the contractor should be required to repair them with a full width coverage of the affected surface by micro-surfacing material using the standard application equipment. If the desired surface characteristics are not provided on a regular basis, the contractor should be required to stop work. Work should not be restarted until the contractor demonstrates that the surface can be properly constructed on a test strip acceptable to the engineer.

On occasion, a vehicle will drive across the micro-surfacing before it has gained adequate strength leaving deep tire marks. It may be possible to repair these with micro-surfacing material, but the marks will always show in the surface. It is recommended that they be repaired by placing a second layer of micro-surfacing full width over the damaged area. This will only leave transverse joints which will eventually blend fairly well into the existing surface. The joints must be less unsightly than the repaired tire marks.

APPENDIX F

DRAFT MIXTURE DESIGN VERIFICATION

FOR MICRO-SURFACING

MIXTURE DESIGN VERIFICATION

PURPOSE

The purpose of mixture design verification is to ensure that a set of materials and the mixture design provided by the contractor meets the requirements of the micro-surfacing specifications. Once the mixture design for the selected materials is approved, all mixtures must meet the resulting job mixture formula. The primary difference between a full mixture design process and the mixture design verification, is that in mixture design verification, a full set of tests to identify optimum mixture quantities is not conducted. A single set of tests can be conducted at the optimum values submitted by the contractor to determine if they meet the specified values. If they do not meet the requirements, the Department then rejects the mixture design and requires the contractor to submit a new mixture design. It is the contractor's responsibility to determine what to change to produce an acceptable material.

MIXTURE DESIGN VERIFICATION TESTS

The following tests will be conducted to ensure that the mixture design provided by the contractor meets the current specifications. All tests will be conducted on the aggregate, polymer modified asphalt cement, mineral filler, and additives to be used in the contract being evaluated. Distilled water will be used, unless otherwise directed. All quantities of aggregate, polymer modified emulsified asphalt cement, mineral filler, water, and additives will be based on the optimum quantities identified in the mixture design submitted by the contractor. The average required values described below shall be based on test result on at least three samples for each test.

Mixing Test

The trial mixtures should be checked with the mixing test to determine if they can be mixed at room temperature for at least 120 seconds. This will indicate whether the mixture can be used in standard mixture design tests. In some cases, the mixture design presented by the contractor will have a range of water content. It is recommended that the middle value be used for this analysis. Some mixtures specify a certain amount of special additive to be used in the mixture during the mixture tests. If the mixture cannot be mixed for 120 seconds without breaking, no further tests should be conducted, and a new mixture design should be requested from the contractor.

Wet Track Abrasion Test

Conduct the Wet Track Abrasion Tests (WTAT) in accordance with the Draft Protocol. The Wet Track Abrasion Test run in accordance with ISSA-TB-100 shall have maximum average values of 538 g/m^2 (50 g/ft^2) after one hour of soaking and 807 g/m^2 (75 g/ft^2) after six days of soaking.

APPENDIX G

RECOMMENDED FIELD OBSERVATION CHECKLIST

FOR MICRO-SURFACING

GENERAL

This checklist was prepared for use in collecting and recording information about limitations and workmanship as required in the specifications and further described in the Quality Assurance Guidelines. It was developed to make it simpler to collect such information, and it was field tested in several Districts, first by project staff personnel and later by District personnel.

Information on drag marks should be taken in samples one lane wide by 30 m (100 ft) long. A ruler or tape measure is the only equipment needed for evaluating drag marks.

Micro-Surfacing Field Observation Checklist

Please select appropriate response or enter information and measurements as appropriate.

Project and Location Information

Highway Type (IH, US, SH, FM, etc.) _ _   Highway Number _ _ _ _

Control Section Job Number (CSJ) _ _ _ _ - _ _ _ - _ _ _ _

Texas Reference Marker Number and Offset That This Sheet Describes
Beginning _ _ _ _ . _ _ _   Ending _ _ _ _ . _ _ _

Date of Inspection   Month _ _   Day _ _   Year 19 _ _

Time of Inspection   Beginning _ _ : _ _ am pm   Ending _ _ : _ _ am pm

Inspector's Name _

District Number _ _   Area Office (Residency) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

County _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Weather Conditions

Minimum Temperature _ _ _ (°C)   Maximum Temperature _ _ _ (°C)

Greater than 30% Chance of Rain Forecast   Yes _   No _

Did it Rain During Construction   Yes _   No _

Intensity of Rain	Light _	Moderate _	Heavy _
	(≤ 2.55 mm /hr)	(2.5 - 13 mm/hr)	(≥ 13 mm/hr)
	(≤ 0.1 in/hr)	(0.1 - 0.5 in/hr)	(≥ 0.5 in/hr)

Duration of Rain During Micro-surfacing Construction (minutes) _ _ _

Length of Time After Construction Stopped Until Rain Began (minutes) _ _ _

Comments:

Highway Type _ _
CSJ _ _ _ _ - _ _ _ - _ _ _ _

Highway Number _ _ _ _
Date: Mo. _ _ Day _ _ 1994

Surface Preparation

Surface cleaned of all vegetation, animal carcasses, loose aggregate, soil, and other debris. Surface was

Clean _ Mostly Clean _ Somewhat Dirty _ Dirty _

How was the condition described above distributed along the surface (mark one):

Uniform _ Covers most of Area _ Covers some of Area _

Intermittent _

Was the surface pre-wet ahead of spreader box Yes _ No _

Moisture condition of surface ahead of spreader box.

Dry _ Mostly Dry _ Somewhat Moist _ Moist _

Wet with some pooling _ Wet with standing water _

Comments:

Opening to Traffic

Time from application until crossing traffic could be applied (minutes) _ _ _

Time from application until rolling traffic could be applied (minutes) _ _ _

Comments:

Highway Type _ _
CSJ _ _ _ _ - _ _ _ - _ _ _ _

Highway Number _ _ _ _
Date: Mo. _ _ Day _ _ 1994

Select any section at random and check for surface characteristics. A section is one lane wide by 30 m (100 ft) long. At least one section should be checked for each four hours of work. Any time that the surface appears to be unacceptable, the additional sections should be checked.

Surface Marks

Number of tear marks greater than 12 mm (½ in) wide, deeper than 6 mm (1/4 in), and longer than 50 mm (2 in) in a 3.7 m by 30 m (12 ft by 100 ft) area

Sample 1 _ _ _ Sample 2 _ _ _ Sample 3 _ _ _ Sample 4 _ _ _

Number of tear marks greater than 25 mm (1 in) wide or wider, 100 mm (4 in) or more in length in a 3.7 m by 30 m (12 ft by 100 ft) area

Sample 1 _ _ _ Sample 2 _ _ _ Sample 3 _ _ _ Sample 4 _ _ _

Surface Loss

Area of surface loss in square meters (feet) in a 3.7 m by 30 m (12 ft by 100 ft) area

Sample 1 _ _ _ Sample 2 _ _ _ Sample 3 _ _ _ Sample 4 _ _ _

Hand Worked Areas

Area of surface worked by hand in unacceptable condition in a 3.7 m by 30 m (12 ft by 100 ft) area

Sample 1 _ _ _ Sample 2 _ _ _ Sample 3 _ _ _ Sample 4 _ _ _

Comments

Highway Type _ _ Highway Number _ _ _ _
CSJ _ _ _ _ - _ _ _ - _ _ _ _ Date: Mo. _ _ Day _ _ 1994

Select any section at random and check for joints and seams. A section is 30 m (100 ft) long. At least one section should be checked for each four hours of work. The same section for used for surface characteristics can be used. Any time that the joints and seams appear to be unacceptable, the additional sections should be checked. All transverse joints should be checked.

Joints/Seams

Longitudinal Joints

Were longitudinal joints placed on lane lines Yes _ No _

Maximum distance between surface and 1.2 m (4 ft) straight edge placed with one end on the longitudinal joint and the remainder across the lane in mm (in) {_ _ _)

Location 1 _ _ _ _ Location 2 _ _ _ _ Location 3 _ _ _ _ Location 4 _ _ _ _

Length (m/ft) and width (mm/in) of gaps left between adjacent lanes

Location 1 length _ _ _ _ width _ _ _ _
Location 2 length _ _ _ _ width _ _ _ _
Location 3 length _ _ _ _ width _ _ _ _
Location 4 length _ _ _ _ width _ _ _ _

Transverse Joints

Maximum distance between surface and 1.2 m (4 ft) straight edge placed across transverse joint in mm (inches) {_ _ _}

Location 1 _ _ _ _ Location 2 _ _ _ _ Location 3 _ _ _ _ Location 4 _ _ _ _

Location 5 _ _ _ _ Location 6 _ _ _ _ Location 7 _ _ _ _ Location 8 _ _ _ _

Comments

Highway Type _ _
CSJ _ _ _ _ - _ _ _ - _ _ _ _

Highway Number _ _ _ _
Date: Mo. _ _ Day _ _ 1994

Select any section at random and check edges. A section is 30 m (100 ft) long. At least one section should be checked for each four hours of work. The same section for used for surface characteristics or joints and seams can be used. Any time that the edges appear to be unacceptable, the additional sections should be checked.

Edges

Is the pavement or shoulder surface wider than the micro-surfacing being placed

Yes _ No _

Is there a drop-off from the lane to the shoulder within the limits of the area being covered with micro-surfacing

Yes _ No _

If yes, give maximum drop-off from the lane to the shoulder in mm (in)

Location 1 _ _ _ _ Location 2 _ _ _ _ Location 3 _ _ _ _ Location 4 _ _ _ _

Is there a drop-off from the lane to the shoulder greater than 25 mm (1 in) within 150 mm (6 in) of the outside edge of the micro-surfacing

Yes _ No _

If yes, give maximum drop-off from the lane to the shoulder in mm (in)

Location 1 _ _ _ _ Location 2 _ _ _ _ Location 3 _ _ _ _ Location 4 _ _ _ _

Maximum distance in mm (in) the micro-surfacing edge varies from a 30 m (100 ft) straight edge on a straight section or from a 30 m (100 ft) arc of the design curve on a curved section. (The edge of the micro-surfacing is considered where the edge of the aggregate in the micro-surfacing mixture ends. Stains from slight runoff of liquids should be expected along the edges.)

Location 1 _ _ _ _ Location 2 _ _ _ _ Location 3 _ _ _ _ Location 4 _ _ _ _

Comments

Highway Type _ _
CSJ _ _ _ _ - _ _ _ - _ _ _ _

Highway Number _ _ _ _
Date: Mo. _ _ Day _ _ 1994

Select any section at random and check for rutting. A section is one lane wide by 30 m (100 ft) long. At least one section should be checked for each four hours of work. Any time that the rutting appears to be unacceptable, the additional sections should be checked.

Ruts

Depth to lowest portion of ruts after placing micro-surfacing in mm (in) measured from a 1.2 m (4 ft) straight edge placed across the wheel path of the pavement (if the height of the surface in the wheel path is higher than the desired profile, show as negative value)

Location 1 _ _ _ _ Location 2 _ _ _ _ Location 3 _ _ _ _ Location 4 _ _ _ _

Location 5 _ _ _ _ Location 6 _ _ _ _ Location 7 _ _ _ _ Location 8 _ _ _ _

Comments

APPENDIX H

RECOMMENDED

GUIDELINES FOR MICRO-SURFACING USE

GUIDELINES FOR MICRO-SURFACING USE

INTRODUCTION

Micro-surfacing is a mixture of polymer modified emulsified asphalt cement, well graded crushed mineral aggregate, mineral filler (normally portland cement), and water, often with other additives (normally emulsifying agent). Micro-surfacing is similar to a type II or type III standard slurry seal with a polymer modified binder. The aggregate, mineral filler, polymer modified emulsified asphalt cement and water are mixed in a truck mounted traveling plant. The mixture is deposited into a spreader box mounted behind the truck which spreads the mixture across the pavement surface. No compaction is applied. The mixture is designed to handle traffic within about one hour after placement for normal environmental conditions. The mixture design normally fixes the amount of mineral aggregate, polymer modified emulsified asphalt cement, and mineral filler (cement). The equipment operator changes to amount of water to control the consistency of the mixture. The changes in the amount of moisture in the aggregate and the texture of the existing surface will normally require changes in the amount of water added. The equipment operator changes the amount of additive to control the time at which the emulsion breaks and the time at which traffic can be applied to the finished surface. Changes in temperature, humidity and texture of the existing surface can cause the amount of required additive to be changed.

Micro-surfacing is generally used as a maintenance or surface treatment for an existing pavement with an asphalt concrete surface. As a surface treatment, it provides a skid resistant surface. As a maintenance treatment, micro-surfacing is also used to fill minor ruts. Micro-surfacing has been used on portland cement concrete surfaced pavements and bridge decks; in these cases it is used primarily to develop surface friction.

This document is prepared to provide guidance for appropriate selection and application of micro-surfacing. Analysis procedures are included which, if followed, should provide relatively good assurance that the micro-surfacing will give the desired service. Service life of micro-surfacing applied to pavements in the appropriate condition appears to be 5 to 7 years for relatively high traffic and may be considerably longer for low to moderate traffic. The following sections on usage are separated between the use of the micro-surfacing as a surface treatment and as a maintenance treatment for rut filling.

GENERAL DESCRIPTION

The components of micro-surfacing are very similar to those used in hot mix asphalt concrete. However, they are placed cold allowing much thinner surfaces to be placed. The polymer modified binder and 100% crushed, well-graded fine aggregate make the micro-surfacing more durable than most thin surfaces with conventional binders. Cement or lime is normally used as the mineral filler. Cement acts as an accelerator for the breaking time of the emulsion as well as a mineral filler. A break retarder such as aluminum sulfate may also be used if the material is placed during hot seasons. The emulsion should break after it has been placed on the surface, not in the mixing process. The material should be fluid enough to be spread evenly by the spreader box. The temperature and humidity affect the break, curing time, and consistency of the micro-surfacing. The amount of cement, other additives, and water may have to be changed by the operator as the job progresses to compensate for the weather changes.

Micro-surfacing can generally be opened to rolling traffic within one hour during normal application weather conditions. The climatic conditions affect the curing time. Cool moist conditions require longer curing times before opening to traffic and hot dry conditions lessen the curing time before opening to traffic. If a person's full weight can be placed flatly on the heel and sole of the shoe for about two seconds and no aggregate sticks to the shoe when lifted from the surface, rolling traffic can generally be allowed to use the surface without significant alterations. If a person's full weight is placed flatly on the heel of a shoe on the surface and is twisted about 180° without the large aggregate being displaced, all types of traffic can generally be placed on the surface without a problem. Sharp turns, especially by heavy vehicles, can damage micro-surfacing for some time after application, especially in hot weather.

MICRO-SURFACING AS A SURFACE TREATMENT

Surface treatments are used as preventive and corrective maintenance treatments. Micro-surfacing applied to existing bituminous surfaces reduces deterioration caused by weathering, raveling, and oxidation of the pavement surface. They may also seal small, "non-working" cracks. Micro-surfacing provides a wearing surface with good surface friction, if the appropriate aggregate is used. Some of the corrective capabilities of micro-surfacing include:

- providing or restoring non-skid characteristics,
- reducing entry of air and water into the existing asphalt concrete,
- attaining a uniform appearance,
- increasing visibility of pavement surface at night, and
- possible preservation of the pavement's structural strength.

As a surface treatment, the thickness of the micro-surfacing layer is approximately equal to the maximum size of aggregate used in the mix.

The application of micro-surfacing does not increase the structural capacity of the pavement; however, it helps preserve the structural capacity of the pavement primarily by reducing the environmental damage that would otherwise develop in the original asphalt concrete pavement from the surface down. Decreasing the permeability of the pavement reduces the amount of water entering the asphalt layer and supporting layers from the surface. Most pavement layer materials have reduced stiffnesses with increased moisture levels. Reduction of moisture infiltration reduces this loss of strength and may allow some strength to be regained during hot, dry periods. This preserves the structural capacity of the existing pavement structure so that it can continue to meet its basic objective of supporting wheel loads imposed by traffic.

Water entering the asphalt concrete layers carries dissolved oxygen and trace chemicals which contribute to the oxidative hardening of the asphalt concrete surface. Oxidation leads to weathering, raveling, and surface cracking. Reducing the permeability of the surface by placing a protective layer on the existing surface retards weathering, raveling and age accelerated surface cracking. It may also reduce the rate at which other moisture induced damage such as stripping develops.

Micro-surfacing provides surface friction when skid resistant and polish resistant aggregates are used in the mixture. When applied to portland cement concrete surface, the increase in surface friction is the main benefit provided by micro-surfacing. Micro-surfacing creates a minimum loss of curb height and requires no manhole and other structure adjustments.

Micro-surfacing has been placed on pavements with moderate flushing and bleeding. Some success has been achieved; however, generally two layers are needed to substantially reduce the probability of the underlying excess asphalt from causing flushing in the micro-surfacing. Adequate experience is not available at this time to determine how long micro-surfacing will prevent the excess asphalt from causing flushing in the micro-surfacing. Minor flushing may not create a problem, because it has been reported that the upper layer of asphalt wears from traffic leaving a surface that continues to provide reasonable skid resistance.

Micro-surfacing is more durable than a conventional slurry seal system. Rock loss and windshield breakage are not a problem with micro-surfacing. The material is mixed and placed on the pavement surface with no compaction. Micro-surfacing can be used for any traffic level. However, due to the cost, it is normally used on higher volume pavements where seal coats (aggregate seals and slurry seals) are considered unacceptable.

Micro-surfacing is a thin layer of a relatively stiff material. It will not seal cracks nor will it be able to prevent cracks from reappearing. Most cracks will reflect through the micro-surfacing relatively quickly. If cracking is the major problem on the pavement, then micro-surfacing should not be used. Most cases of loss of micro-surfacing from wheel paths a period of time after application appears to be related to placing micro-surfacing over pavement that is experiencing fatigue or alligator cracking. Sealing this type of crack before application of micro-surfacing will do little to prevent the cracking from damaging the micro-surfacing.

A general concept for using micro-surfacing as a surface treatment would be to use it in place of a conventional seal coat (aggregate seal) when the traffic volume is too high for a seal coat or where vehicles perform too many turning and stopping movements for a conventional seal coat. Areas where micro-surfacing should be considered as an alternate to conventional seal coats include:

- approaches to major intersections,
- urban arterials with an asphalt surface,
- interstate pavements with an asphalt surface, and
- other high traffic asphalt surface pavements.

Micro-surfacing, like other surface treatments, is not a cure-all treatment. It can be used as a preventive and corrective maintenance treatment to protect the present pavement from environmentally caused distress, provide a uniform road surface, reduce surface permeability, and restore skid resistance. Micro-surfacing will provide the longest service and best life extension when applied **before** significant surface observable distress becomes obvious, especially cracking. At this stage micro-surfacing, like other surface treatments, can delay major maintenance or rehabilitation on a structurally adequate pavement for a considerable period and avoid the need to spend a large amount of money for corrective rehabilitation treatments. Micro-surfacing adds no structural strength to a pavement nor does it correct excessive longitudinal roughness problems or seal larger-than-hairline cracks. If properly applied, this maintenance treatment can significantly extend pavement life.

The following guidelines are provided:

1. the pavement should be structurally sound and suitable for future traffic over the expected life of the micro-surfacing;

2. transverse cracks should be sealed and localized areas of fatigue (alligator) cracks should be repaired prior to placing the micro-surfacing; and

3. micro-surfacing can be used on high volume rural highways, urban arterials, and intersections where surface seals are needed but not normally considered feasible.

MICRO-SURFACING AS A RUT FILLER

Micro-surfacing is basically an asphalt concrete placed using a cold process. Because the application is cold and the material is initially relatively fluid, it can be placed in thin layers and can be used to level longitudinal rutting depressions. The polymer modified asphalt cement binder and 100% crushed, dense-graded aggregate generate a mixture stable enough to withstand traffic loads more than one maximum size aggregate thickness. Micro-surfacing has been successfully used to fill ruts up to 50 mm (2 in) deep. When used to fill ruts greater than about 12 mm (½-in) deep, a special spreader box (rut box) is used with the truck mounted mixer. A separate pass of the equipment is made to fill the rut in each wheel path. Generally, a final pass is made with a conventional spreader box to cover the entire lane. Ruts in excess of 27 mm (1 ½ in) deep generally require multiple passes with the special rut filling spreader box to restore the original cross section. A curing period of one day to a week is generally needed between successive layers of micro-surfacing. If the first layer is not adequately cured, the construction equipment will tear it from the original surface during application of the next layer.

Rut filling will only be successful if the rut is caused by mechanical compaction of the pavement structure. Filling ruts corrects the surface profile, but a rut is a symptom of an underlying pavement problem which micro-surfacing cannot repair. If the ruts are caused by an unstable pavement layer material or structurally deficient pavement layer, the source of the rutting problem will generally cause the rutting to return very quickly.

If the pavement surface has been in service for fifteen years and has developed relatively flat rutting 12 to 18 mm (½ to 3/4 in) deep, filling the rut with micro-surfacing may provide the desire transverse profile for a reasonable period. A pavement which has been in service for five years and has 27 mm (1 ½-in) deep dual wheel track ruts in each wheel path generally has an unstable surface layer which will not be corrected by filling the ruts.

If the pavement is structurally inadequate, the micro-surfacing will not provide adequate structural improvement to prevent further deterioration. If the ruts have extensive alligator cracking and shear failure, the pavement can generally be considered structurally inadequate, and filling the ruts will not correct the problem. The structural capacity will need to be increased for any treatment to provide a reasonable period of time.

The following guidelines are provided for using micro-surfacing to fill ruts:

1. the pavement should be structurally sound for the future traffic over the expected life of the micro-surfacing;

2. ruts should be flat, not sharp or showing dual wheel marks;

3. ruts should be indentations only, not an indentation between upward heaves; and

4. ruts should not contain fatigue (alligator) cracking.

RECOMMENDED ANALYSIS

Since micro-surfacing used either as a surface treatment or rut filling does not add substantially to the structural capacity of the pavement, the structural adequacy of the pavement should be determined prior to selecting micro-surfacing as a treatment. This can be accomplished by design and analysis procedures available in the Department. Micro-surfacing as a surface treatment or rut filler should only be placed on pavements considered structurally adequate for projected traffic over the expected life of the micro-surfacing. It is suggested that a seven to ten year period be used in the analysis. If the pavement has rutting and either significant alligator cracking or shear failures, repair methods other than micro-surfacing should be considered.

LAYER THICKNESS GUIDELINES

If rutting is greater than 12 mm (½ in) in depth, a rut filling spreader box should be used to fill the ruts before the final surface is placed. If there are shallow ruts less than 12 mm (½ in) depth, a full-width scratch coat pass should be used to level the surface before the final surface is placed. Ruts in excess of 20 mm (3/4 in) should be filled with multiple placements of micro-surfacing using the rut filling spreader box. The maximum micro-surfacing thickness applied in a single lift should not exceed 20 mm (3/4 in). Each individual rut fill, utilizing a rut filling spreader box should be slightly crowned to compensate for traffic compaction.

Micro-surfacing applied as a surface treatment will vary in thickness and weight of micro-surfacing per unit area when the surface texture of the pavement changes. The basic goal is to place the material with a thickness that is slightly greater than the maximum size of the aggregate in the mixture. When the existing surface is badly raveled or otherwise coarse and open, more material is needed to fill the surface voids. When the surface is nearly smooth or almost flushed, less material will be needed. If too little micro-surfacing is placed on an open surface, individual pieces of aggregate will be caught by the spreader box and pulled along the road surface creating excessive drag marks. This should be expected between wheel paths on "scratch coats," but it is generally considered unacceptable on the final surface. When the surface texture of the existing pavement is non-uniform, the surface of the micro-surfacing will also be non-uniform. A "scratch coat" will be needed prior to application of the final surface to create a uniform surface.

TIME TO TRAFFIC GUIDELINES

Micro-surfacing is normally expected to be able handle rolling traffic in less than one hour after placement without damaging the pavement; stop-and-go traffic, especially heavy vehicles, may require additional curing time. Currently there are no field tests to determine when traffic should be allowed on micro-surfacing which quantify a known property. A very subjective check is shoe test. If a person's full weight can be placed flatly on the heel and sole of the shoe for about two seconds and no aggregate sticks to the shoe when lifted from the surface, rolling traffic can generally be allowed to use the surface without significant effects to the surface. If a person's full weight is placed flatly on the heel of a shoe on the surface and is twisted about 180° without the large aggregate being displaced, all types of traffic can generally be placed on the surface without a problem. Sharp turns, especially by heavy vehicles, can damage micro-surfacing for some time after application, especially in hot weather.

The time it takes for micro-surfacing to be ready for traffic to be applied is a function of the time the emulsion breaks and the mixture cures. As the temperature increases and the humidity decreases, the time it takes the emulsion to break and expel the water decreases. In micro-surfacing, portland cement is normally used as a mineral filler; however, it also affects the rate at which the emulsion breaks. As the amount of cement is increased, the time it takes the emulsion to break and expel the water decreases. In the mixture design process, the amount of cement used in micro-surfacing is selected to control how long it will take for the mixture to reach a selected strength based on torque or other testing at room temperature. This establishes the amount of cement that is used in the field.

Normally, during construction, the temperature is higher than the room temperature at which the amount of cement was selected. So the micro-surfacing would be expected to break more quickly in the field than in the laboratory. To control the breaking and curing time in the field, an additive may be to retard the breaking time. This additive is generally similar to the emulsifying agent used in the emulsified polymerized asphalt cement. If the amount of this additive is increased, the breaking time will increase. If the amount of the additive is decreased, the breaking time will decrease. As the temperature increases during the day and the humidity decreases, the amount of additive is normally increased to maintain the desired breaking time.

In some instances, the conditions in the field may be so cool and moist that the micro-surfacing will not break and cure quickly enough to allow traffic on it within the required time, even when no additive is being added to the mixture. If this occurs, the asphalt supplier may have to reformulate the emulsion so that it will break more quickly in the cool moist weather. For some mixtures, the amount of cement normally can be increased to decrease the breaking time. This increase should be based on the information from the mixture design. If too much cement is added, the emulsified asphalt cement in the micro-surfacing can break in the mixing chamber of the truck or in the spreader box. Trial increases are normally made in 0.5% increments based on dry weight of the aggregate until the required breaking time is achieved without breaking too fast. The special additive may still need to be used to control the breaking time. A 0.5% increase is normally sufficient to reduce the breaking time to allow traffic on the micro-surfacing within the required time for the weather restrictions placed on micro-surfacing in Texas. If greater amounts are required, the emulsion should be formulated since large increases can also affect the film thickness of the asphalt cement coating the aggregate. Generally, no more than 3% cement should be added to the mixture.

WATER PERCENTAGE GUIDELINES

The operator of the micro-surfacing equipment changes the amount of water added to the micro-surfacing to control the consistency of the mixture. If the mixture is too dry, it will not flow across the spreader box and may create an uneven surface thickness. If the mixture is too wet, segregation of the aggregate may occur, and the emulsion may not be evenly distributed.

During the mixture design, an optimum water content is determined for testing. However, in the field, the amount of water needed in the mixture is affected by the amount of moisture in the aggregate, the ambient humidity, the temperature, and the amount of moisture the pavement surface absorbs. When the existing pavement surface changes, the moisture content of the aggregate changes, or the ambient humidity changes, the operator must change the amount of water added to the micro-surfacing mixture to maintain the same consistency.