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Surface Rehabilitation Techniques

State of the Practice Design, Construction, and Performance of Micro-surfacing

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16. Abstract

This document is a comprehensive overview of the terminology, design, construction, application, and performance of micro-surfacing paving technology. This technology consists of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and field control additives as needed. Micro-surfacing is primarily used to improve surface friction and to fill wheel ruts. When properly designed and constructed, it has shown good performance for 4 to 7 years. Since micro-surfacing is applied in a thin layer, 10 to 13 mm, its use should be limited to structurally sound pavements.

The one unresolved engineering issue concerning this technology is the lack of standard mixture design test procedures. Although the current testing procedures have resulted in micro-surfacing systems that have generally provided good performance, there is a need to validate and standardize the existing test procedures and adjust design standards to better reflect the effect of various material combinations. Standardized mixture design procedures and State acceptance criteria will further enhance the acceptance of this technology by the highway community.

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EXECUTIVE SUMMARY

Micro-surfacing is a thin surface paving system composed of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and field control additives as needed. It is applied as a thin 10 to 13 mm surface treatment mainly to improve friction characteristics of the pavement. Its other major use is to fill wheel ruts on both moderate and high volume roads. Micro-surfacing has also been used to address pavement distresses such as flushing, raveling, and oxidation.

Micro-surfacing developed in Europe in the mid 1970's, was first introduced in the United States in 1980 in Kansas. Since then it has been used on moderate and high volume roads in various States. When properly designed and constructed, micro-surfacing has shown promising results with 4 to 7 years of service life. Because micro-surfacing can bond well with the existing surface, can be feathered without edge raveling, and can generally be opened to traffic within one hour of placement, it is particularly suitable for high volume roads and urban areas.

Considering the potential of micro-surfacing, its use has been somewhat constrained due to several factors. These include a lack of experienced contractors, a lack of quality aggregate in many parts of country, inability of contractors (in some instances) to obtain required aggregate gradation because of low demand, reluctance of users to apply newer technologies, and scattered or incomplete information on this technology. From an engineering point of view, the micro-surfacing design procedures have not yet been standardized. The slurry and micro-surfacing industry is aware of this, and is currently taking steps to further improve and standardize mixture design test procedures and adjust design standards to better reflect the effect of wide variations in material components.

Technologies such as micro-surfacing may offer cost-effective solutions and improved overall pavement performance. This paper is a comprehensive overview of the terminology, design, construction, cost, and performance of micro-surfacing. The compilation of information will assist the managers and designers by providing an additional option when selecting the type of surface rehabilitation technique to meet both the budget and project performance criteria.

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MICRO-SURFACING

(A Surface Rehabilitation Technique)

INTRODUCTION

A. BACKGROUND

The performance of a pavement depends on its structural and functional condition. While structural condition depends on the load-carrying capacity of the pavement and subgrade, functional condition describes how "good" the road is in enabling a user to move from point A to point B under safe and comfortable conditions and at acceptable speed and cost. Preventive maintenance and surface rehabilitation techniques that can preserve and improve these functional conditions offer relatively low initial cost solutions and improved overall pavement performance. These techniques should be considered by managers and engineers when selecting a strategy to meet both the budget needs and project performance criteria.

Generally, no or minimal structural improvement is developed in a pavement section through the application of preventive maintenance/surface rehabilitation techniques. Accordingly, these techniques should be considered for only those pavements that possess the necessary remaining strength to support the design vehicular loads. Nearly all highway agencies use some type of surface rehabilitation technique to maintain and extend the service life of their pavements.

One promising new technology, micro-surfacing, has been used in the United States as a surface rehabilitation technique for asphalt pavements since 1980. Micro-surfacing is a paving system composed of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and field control additives as needed. When properly designed and applied, it has shown good results in improving surface friction characteristics and filling wheel ruts and minor surface irregularities on both low and high volume roads. Micro-surfacing has also been used as a surface seal and to address distresses such as flushing, oxidation, and raveling. Performance results have been mixed but are generally encouraging for these applications as well. Micro-surfacing use on portland cement concrete (PCC) pavements and bridge decks has been relatively limited but is usually satisfactory.

B. OBJECTIVE

Selecting the most economical and effective surface rehabilitation strategy for a given project requires a thorough understanding of the limitations, performance, and associated costs of each viable rehabilitation strategy. Unfortunately, the information on research and actual applications is often scattered, and evaluations are incomplete. Therefore, necessary information is not readily available to the managers and engineers faced with selecting the most appropriate surface rehabilitation technique. This is particularly true for micro-surfacing, for which, even after 10 years of use, few engineers and inspectors fully understand the various aspects of the system, the materials requirement, and the mixture design.

The objective of this paper is to synthesize information on the usage, design, construction, performance, cost, and limitations of micro-surfacing. It is intended to summarize the experiences of several States and to communicate the information to the highway agencies for their use when considering micro-surfacing as a rehabilitation technique for their pavements. A detailed literature review was conducted along with field reviews of numerous existing and ongoing projects in a number of user States. These projects were selected to represent various climates and pavement conditions and moderate to heavy traffic volume roadways. Discussions were held with the representatives of user agencies and the industry to gather information on usage, performance, and the cost of micro-surfacing. In addition, visits were made to the industry materials laboratories and equipment manufacturing facilities to gather information on mixture design and equipment operation.

C. DEFINITIONS

High Volume Roads

For the purpose of this paper, high volume roads are defined as freeways and arterials that carry more than 5,000 vehicles per day per lane. Roads with heavy truck traffic (more than 500,000, 80 kN equivalent single axle loads per year) are also considered as high volume roads. Low volume roads are defined as local and collector roads that have an average daily traffic (ADT) of fewer than 500 per lane.

Maintenance and Surface Rehabilitation Techniques

Maintenance and surface rehabilitation techniques as discussed in this paper are broadly defined as work accomplished to the pavement surface to preserve or extend the pavement's serviceability until major rehabilitation or complete reconstruction can be performed. These techniques may be classified according to their purpose or function as either corrective or preventive.

- **Corrective techniques** are used to repair pavement surface deficiencies as they develop. They may include both temporary and permanent repairs. Rut filling and improving surface friction are usually considered corrective maintenance.

- **Preventive techniques** are intended to keep the pavement above some minimum acceptable level at all times and are used as a means of preventing or retarding further pavement deterioration to a level that would require corrective techniques or reconstruction. Surface sealing is considered a form of preventive maintenance.

Breaking, Setting, and Curing of Emulsion

An asphalt emulsion is a suspension of asphalt cement in water with an emulsifying agent. The separation of asphalt cement from the water on contact with a foreign substance, such as aggregate or a pavement, is called "**breaking**" [1]. The time until the asphalt droplets separate from the water phase is commonly referred to as "breaking time." For example, an unmodified rapid-set emulsion will generally break within one to five minutes [1], whereas a medium-setting emulsion may take 30 minutes or longer to break. Modified emulsions for micro-surfacing are normally designed to break within 2 to 4 minutes. The purpose of the breaking process is to coat the aggregate particles in the mixture. Mineral filler and a field additive (emulsifier) are used to control the breaking of micro-surfacing emulsion. The breaking process can be recognized by a change of mixture color from brown to black.

Setting time, in the context of micro-surfacing, refers to the time at which clear water is expelled from the mixture upon application of pressure. At this time, the mixture is water resistant and cannot be remixed. Micro-surfacing is designed to set in about 20 minutes.

Curing process is the complete removal of water from the emulsified mixture due to evaporation, chemical expulsion, pressure, or by aggregate absorption. Although it may take 7-14 days before micro-surfacing is completely cured, most of the water (90-97 percent) in the mixture is displaced within the first 24 hours.

Aggregate Coating

Aggregate coating is a process that begins and continues progressively as the mixture breaks, sets, and cures. At the end of the curing process, the aggregate coating with asphalt cement is complete.

Traffic Time

Traffic time, in the context of micro-surfacing, refers to the time after which traffic can be allowed on the newly placed surface without damaging it. The micro-surfacing applications, placed up to 13 mm thick, are designed to accept rolling traffic within one hour after placement.

D. DESCRIPTION, USAGE, AND HISTORY

Micro-surfacing is a mixture composed of polymer-modified asphalt emulsion (quick-setting type), 100 percent crushed mineral aggregate, mineral filler, water, and field control additive as needed [2]. Mineral filler is generally Type 1 portland cement; however, most non air-entrained types can be used. Hydrated lime has also been used in a few systems. Field control additive is used to adjust the break time during the field application.

Micro-surfacing is basically a type of slurry seal with a polymer-modified binder and often higher quality aggregates. Although slurry seals can be placed only 1½ times as thick as the largest size aggregate in the mix (due to high asphalt content), micro-surfacing can be placed in relatively thick layers due to the increased stability of the mixture. Compared to hot-mix asphalt (HMA), which is workable when hot and hardens upon cooling, micro-surfacing is mixed and applied at ambient temperatures using emulsions. The emulsion breaks and hardens through an electro-chemical process and by the loss of water from the system. Micro-surfacing is also called a cold mixed system.

The most common uses of micro-surfacing are **surface texturing/sealing** and **rut filling** on asphalt concrete pavements. Some States have used micro-surfacing for other purposes as well. These include:

- Correcting raveling/flushing
- Leveling course
- Interlayer
- Crack sealing/filling
- Void filling
- Pothole patching (small and shallow type)

Although micro-surfacing is primarily used on asphalt pavements, some States have used it on PCC pavements and bridge decks for the restoration of skid-resistant characteristics. At least one State has used micro-surfacing for filling ruts on PCC pavements.

History of Micro-surfacing

Micro-surfacing was first developed in Europe, where it is generically known as micro asphalt concrete [3]. In the mid 1970's, Screg Route, a French company, designed its Seal-Gum, a micro asphalt concrete that was subsequently improved by the German firm Raschig. Raschig marketed its product in the United States under the trade name "Ralumac" during the early 1980's. Later in the 1980's, the Spanish firm Elsamex developed and marketed its micro asphalt concrete in the United States under the name Macroseal. Today several other proprietary and generic systems are available in the United States.

Micro-surfacing in the United States

Micro-surfacing was first introduced in the United States in 1980 in Kansas. Since then, many other States and local agencies have used this treatment to address certain pavement conditions on their moderate to heavy volume roads. Major user States are Kansas, Ohio, Oklahoma, Pennsylvania, Tennessee, Texas, and Virginia. Micro-surfacing has also been applied on several kilometers of heavily travelled turnpikes in New Jersey and Pennsylvania and other freeways in various other States.

Micro-surfacing Systems

The major differences among the various micro-surfacing systems are due to the types of emulsifiers and polymers used. Although micro-surfacing can be designed with either anionic or cationic types, all of the emulsion used to date for micro-surfacing in the United States have been cationic. Most of the micro-surfacing systems are known by the generic name (i.e., micro-surfacing), however, some of the systems are commonly known by the trade name of the emulsions. For example, the micro-surfacing system that uses Ralumac emulsion is named as Ralumac. Some of the other trade name systems are: Polymac; Macroseal; and Durapave.

MIXTURE DESIGN PRACTICES

As discussed in this paper, design refers to materials characterization and mixture design. Since micro-surfacing, like other thin surface treatments, is intended for functional improvements, no structural design is performed. Under current practice, the contractor is required to submit a mixture design to meet a State highway agency (SHA) materials and mixture specification. The mixture design that is normally developed by an emulsion producer establishes amounts for polymer-modified emulsion, aggregate, and mineral filler and includes a recommended range for the amount of water and additive. The contractor is responsible for selecting the desired amount of water and additive based on field conditions. The mixture design information in this paper is based on ISSA design documents and other publications, visits to materials laboratories, review of State specifications, and discussion with user agencies and industry.

The micro-surfacing design process consists of the following steps:

A. Selection and testing of mixture components to verify whether they meet the materials specification.

B. Mixture testing to determine (a) mixing and application characteristics of the two major constituents (i.e., emulsion and aggregate), effects of water content, and effects of filler and additives and (b) optimum asphalt cement content.

C. Performance related tests on mixture samples to ensure good long-term performance.

A. COMPONENT SELECTION AND TESTING

The first step in designing a micro-surfacing mixture is the selection and testing of the mixture components (primarily aggregate and polymer-modified emulsion). Most of the mixture component tests are standard American Association of State Highway and Transportation Officials (AASHTO) and American Society of Testing Materials (ASTM) tests.

1. Aggregates

Aggregates (excluding mineral filler) constitute about 82 to 90 percent by weight of the micro-surfacing, depending on the aggregate gradation and application, and have a strong influence on the micro-surfacing performance. For best results, the aggregates should be 100 percent crushed, clean, strong, and durable particles free of absorbed chemicals, clays, and other materials that could affect bonding, mixing, and placement. Preferably the crushed aggregate should be angular and not have too many flat or elongated particles. Aggregate gradations and other mixture components required by different States normally follow International Slurry Surfacing Association (ISSA) recommendations with minor variations (see table 1).

Selection

Aggregates for micro-surfacing should be of high quality. Current State specifications generally

TABLE 1. COMPOSITION OF MICRO-SURFACING SYSTEMS

STATE TYPE	ISSA II	ISSA III	PA B	OK II	OH —	TX GR–2	TN —	VA C	AZ III
SIEVE SIZE	% PASSING								
mm									
9.5	100	100	95–100	99–100	100	99–100	100	100	90–100
4.75	90–100	70–90	65–85	80–94	85–100	86–94	64–100	70–95	55–75
2.36	65–90	45–70	46–65		50–80	45–65	40–75	45–70	45–55
2.00				40–60					
1.18	45–70	28–50	28–45		40–65	25–46	25–60	32–54	25–40
0.60	30–50	19–34	19–34		25–45	15–35	16–39	23–38	19–34
0.40				12–30					
0.30	18–30	12–25	10–23		13–25	10–25	8–29	16–29	10–20
0.22				8–20					
0.15	10–21	7–18				7–18	5–20	9–20	7–18
0.075	5–15	5–15	4–10	5–15	5–15	5–15	2–14	5–15	5–15
Residual Asphalt*	5.5–9.5	5.5–9.5	5.5–7.5	6–9	6–8	6–9	5–9	5–7.5	6–11.5
Mineral Filler*	0–3	0–3	0.5–2.5	1.5–3.0	0.5–2.5	0.5–3.0	0.5–3.0	0.25–3.0	0.1–1.0
Polymer modifier**	3 min.	3 min.	as req.	3 min.	as req.	as req.	as req.	2.8 min.	5 min.
Application Rate, kg/m^2	5.4–10.6	8.1–16.2	13.3–21.3	13.3	11.7–16.2	13.3	10.6–16.2	10.6–18.7	
Water and Additive ***									

* % by dry weight of dry aggregate
** % solids by weight of residual asphalt
*** as needed

Notes:

1. Some States (e.g., Tennessee) routinely apply two layers of micro-surfacing.
2. PA uses 3 gradations (A, B, RF). A is a finer type, and RF is coarser and used for filling deep ruts. Only natural rubber is specified as a modifier.
3. OK uses 3 gradation types, I, II, III. Type III is normally used for filling deep ruts.
4. OH and Tennessee specify only one gradation.
5. TX specifies two gradations: Grades 1, 2.
6. VA specifies two gradations: Types B, C. Type C is also used for rut filling with slightly reduced binder content (4.5–6.5%)
7. NC gradations/application rates and mixture composition are similar to Virginia, except that polymer content must be a minimum of 3%.

identify the type of aggregates that can be used for micro-surfacing. The contractor, on the advice of the mixture design laboratory, selects the approved aggregate type and source most suitable for the operation, notifies the mixture laboratory of its selection, and if needed, provides an aggregate sample for laboratory use. Although good quality aggregate is available in many parts of the country, the contractors in other locations face difficulty in obtaining good quality aggregate within reasonable haul distances. Another problem is the reluctance of aggregate producers to supply micro-surfacing gradations because of relatively low quantities involved in these projects. Different types of aggregates have been used successfully in micro-surfacing in several States. These include:

State	Rock Type
Ohio	limestone, furnace slag, silicate
Pennsylvania	limestone, silicate
Virginia	granite, diabase, silicate, basalt
Tennessee	granite, slag
Oklahoma	flint, granite, sandstone
Texas	granite, sandstone, basalt (traprock), rhyolite
Kansas	flint, limestone
Nebraska	flint, granite, crushed gravel, quartzite
Colorado	granite, silicate gravel, basalt, diabase

Testing

User agencies perform several basic tests on aggregate sources and stockpiles to determine their suitability for surface courses. Additional tests are performed by design laboratories to determine the aggregate characteristics considered important for the design, construction, and performance of micro-surfacing mixtures. Table 2 shows some of the aggregate tests required for micro-surfacing. Additional discussion on these aggregate tests along with their importance to micro-surfacing is included in Appendix A.

It is very important for the quality control of micro-surfacing that continual testing of the aggregate source be accomplished, since the source composition and chemistry can quickly change in many pits and quarries. Many of the common aggregate tests for HMA and slurry seal are applicable to micro-surfacing as well. Generally, user agencies requirements for micro-surfacing mixtures are higher than for slurry seals.

2. Mineral Filler

Mineral filler serves two major purposes: (a) to minimize aggregate segregation and (b) to speed up or slow down the rate at which the system breaks and sets. For most aggregates, mineral filler shortens the break time. Portland cement and hydrated lime have been used as mineral filler for micro-surfacing. Mineral filler typically increases the stiffness of the asphalt residue. For most aggregates, mineral filler is required for the mixture to set properly. Mineral filler, particularly portland cement, may also be used to improve gradation, but the cost may be prohibitive. Normally up to 3 percent of portland cement (or 1/4 to 3/4 percent of hydrated lime) by dry weight of aggregate is specified.

Mineral filler is normally accepted by the mixture design laboratories on the basis of manufacturer's certification and no additional quality tests are performed. Most laboratories stock the mineral filler they use in their design. Sometimes a sample of mineral filler is provided by the contractor if it is from a source unfamiliar to the design laboratory. Sieve analysis of mineral filler is performed under AASHTO T37 (ASTM D546) test.

TABLE 2. COMMONLY USED AGGREGATE TESTS FOR MICRO-SURFACING

Test	Standard			Significance of the Test	Commonly Used Values for Micro-surfacing
	ASTM	AASHTO	ISSA		
Soundness	C88	T104		Durability, Resistance to weathering disintegration	15-20% max. weight loss
LA Abrasion	C131	T96		Hardness, Resistance to abrasion under traffic	30% max. weight loss
Particle Shape and Texture	D3398 D4791			Workability, strength, and skid resistance	100 % crushed; good texture
Gradation	C136	T27		Calculation of AC content, maintain proper void content, affects surface texture, workability	ISSA Type II, III
Sand Equivalent	D2419	T176		Determine the amount of clay or plastic fines	60 min
Unit Weight	C29	T19		Determine change in unit weight of aggregate with change in moisture content	
Specific Gravity	C 127 C 128	T84		Determination of AC content	
Methylene Blue			TB 145	Determines fines reactivity	15 max*

* This value represents the maximum amount of methylene blue commonly allowed for the test. Only few laboratories run this test.

3. Emulsion

Polymer-modified cationic asphalt emulsions are currently used for micro-surfacing mixtures in the United States. The residual asphalt content of micro-surfacing generally varies from 5.5 to 9.5 percent of the dry weight of aggregate (see table 1, page 6).

Properties of an asphalt emulsion greatly depend on the chemical known as the **emulsifier**. The emulsifier determines whether the emulsion will be classified as anionic, cationic, or nonionic. The emulsifier keeps the asphalt droplets in stable suspension and permits breaking (i.e., a reversion to asphalt cement) at the proper time. As the amount of emulsifier is increased, the break time is generally increased.

Many emulsifiers are available in the market. Each emulsifier must be appraised for compatibility with the selected asphalt cement. Most cationic emulsifiers are fatty amines (e.g., diamines, imidazolines, amidoamines)[1]. The amines are converted into soap by reacting with acid, usually hydrochloric. Other types of emulsifiers (i.e., fatty quaternary ammonium salts) used to produce cationic emulsions do not require the addition of acid to make them water soluble. Each emulsifier manufacturer has its own procedure for using its emulsifier in asphalt emulsion production. In most cases, the emulsifying agent is mixed with water before introduction into the colloid mill. Current specifications do not specify any tests for emulsifier.

For micro-surfacing, emulsion suppliers purchase asphalt cement that meets the SHA specifications. The asphalt cement producers typically perform tests on asphalt cement to determine its characteristics such as ductility, viscosity, penetration, and thin-film oven loss in order to certify conformance with State specifications for a specific grade of asphalt (e.g., AC-10, AC-20).

Testing

Emulsion producers perform several standard tests on emulsions and asphalt residue to (1) determine their suitability for use in micro-surfacing and (2) ensure conformance with State specifications. Some of the commonly used tests are [2,4]:

Tests on Emulsion

- Viscosity, Saybolt Furol @ 25 °C, sec AASHTO T50 (ASTM D244)
- Settlement Test AASHTO T59 (ASTM D244)
- Sieve Test AASHTO T59 (ASTM D244)
- Particle Charge AASHTO T59 (ASTM D244)
- Residual Asphalt Content AASHTO T50 (ASTM D244)
- pH Test (ISSA)

Tests on Evaporation Residue

- Absolute Viscosity, 60 °C, poises ASTM 2171

- Penetration, 100 gm @ 5 sec. 25 °C, AASHTO T49 (ASTM D2397)
- Softening Point AASHTO T49 (ASTM D36)
- Ductility, 25 °C, 5 cm/min. cm (ASTM D113)
- Polymer Content in Asphalt Residue

Table 3 shows emulsion and asphalt residue tests required by some of the States. A discussion on these tests is included in Appendix A. There is a good possibility that several of the currently used tests such as viscosity, softening point, penetration may be replaced by Strategic Highway Research Program (SHRP) binder specifications.

TABLE 3. TESTS ON EMULSION AND RESIDUE

STATE	VA	AZ	TX	OK
TESTS ON EMULSION				
Viscosity @ 25 °C, sec.	15–50	20–100	20–100	
Storage Stability, 24 hrs, %	0.1 max.	.01*–1	0-1	0-1
Sieve, %		.01–0.1	0-0.1	0-0.1
Particle Charge	positive	positive	positive	positive
Residue, %	57 min.	60–61.5*	62 min.	62 min.
TESTS ON RESIDUE				
Absolute Viscosity, 60 °C, poises	8,000 min.	6,621*–8,000		8,000
Penetration, 100 gm, 5 sec.		40–100	55–90	40–90
Softening Point, °C	59 min.	60-69 *	57 min.	57 min.
Ductility, 25 °C, 5 cm/minute.		40–119	70	70
Solubility in Trichloroethylene, %	97.5		97	97

*** Typical values**

4. Water

Water is the mixing medium for the micro-surfacing mixtures. It is the main factor determining mixture consistency. It is introduced in three ways: as moisture already in the aggregate, as mixing water, and as one of the two major constituents of the emulsion. All potable water can generally be used for micro-surfacing. Normally, water quality is not as much an issue as is quantity.

Depending on the weather condition and aggregate absorption rate, good micro-surfacing mixtures can be placed over a limited range of *total moisture content*, typically 4 to 12 percent of the weight of the dry aggregate. Lower amounts of mixing water are used during cold weather, and higher amounts are used during hot weather. Mixtures containing lower moisture may be too stiff to spread, and there will be poor adhesion to the existing pavement. On the other hand, mixtures containing more than 12 percent water may become too fluid and segregate, as evidenced by the settling of the aggregate and floating of the asphalt.

Water is not submitted to the laboratory for mix design testing. However, if the water is excessively high in minerals (a possibility in remote places), it may cause mixing and setting difficulties. Current State specifications do not put any limit on the amount of water that can be added in the field.

5. Polymer

The addition of polymers typically increases the stiffness of the asphalt and improves its temperature susceptibility. Increased stiffness improves the rutting resistance of the mixture in hot climates and allows the use of a relatively softer base asphalt cement, which in turn, provides better low temperature performance. Polymer-modified binders also show improved adhesion and cohesion properties. Polymers can be added into the emulsifier solution, or they can be blended with the base asphalt cement at the refinery or at the emulsion plant before emulsification. The former method is preferred by some emulsion producers as some degradation in certain lattices can occur with heat.

An amount of 3 to 4 percent polymer solids (present in distillation residue) by the weight of asphalt residue is typically specified for micro-surfacing mixtures. Generally, an increase in polymer amount (up to a limit) will increase the mixture stiffness. Laboratory tests indicate that mixture stiffness is also sensitive to the amount of asphalt emulsion. Some laboratory studies indicate that the addition of polymers will usually result in maximum stiffness at an asphalt emulsion content of about 10 to 12 percent [5].

The polymers used in micro-surfacing are the same as used for other asphalt mixes. Natural rubber latex is used most often, but other polymers, including styrene-butadiene rubber (SBR), styrene-butadiene-styrene (SBS), and ethylene-vinyl-acetate (EVA), have also been used. Some asphalt cements do not modify as well as others. Similarly, certain polymers work better than others. Current performance data does not identify the best type of polymer(s) for micro-surfacing. The amount and suitability of polymers is currently determined by viscosity and softening point tests on the asphalt cements. If a polymer does not contribute to improving the performance characteristics of the mixture, this will quickly become apparent in asphalt residue and mixture testing.

6. Field Control Additive

Although an additive may be used to either accelerate or retard the break time of micro-surfacing mixtures, the additive is commonly used to retard the break time. Current State specifications do not specify the type or amount of additive that can be added in the field. Generally, the emulsifier used in emulsion manufacturing is used as an additive because of its compatibility with other mixture components. The amount of additive ranges from 0 to 2 percent by the volume of emulsion. The common practice is to keep the quantity of additives low. On cooler days, none or only a minimum amount of additive is needed. The mixture design includes recommendation on the amount and use of additive. Additive costs range from $2.60 to $5.20 per liter.

B. MIXTURE TESTING

As in any surface mix, good quality materials are important for the proper performance of micro-surfacing mixtures. However, **good quality materials alone may not ensure a satisfactory micro-surfacing mixture, since some good quality materials may be incompatible when mixed together. This is the reason that mixture tests are so important in evaluating micro-surfacing.**

Mixture testing is performed to determine (1) the mixing and application characteristics of the constituents and (2) optimum asphalt cement content. Most of the following tests are ISSA tests and are described in ISSA Design Technical Bullettins (TB) [6].

1. Mixing and Application Characteristics

Since micro-surfacing is a mixture of various materials, any change in a single component may change the performance of the system. Accordingly, a number of laboratory specimens are prepared and subjected to empirical testing. This involves the preparation of trial mixes with variations in the content of asphalt emulsion, water, mineral filler, and additives as desired to determine the effects of changes on mixing, breaking, and setting characteristics in order to ensure good control of the system in the field. Mixing tests are conducted to determine: (1) if the primary components, emulsion and aggregate, are compatible (i.e., there is good adhesion between them); (2) if a mineral filler or field control additive is needed, and if so, in what concentration; and, (3) the range of water concentration over which homogeneous mixtures can be obtained.

After mixture consistency is determined by initial testing, trial mixes are prepared to determine the optimum filler content and the effects of mineral filler on wet cohesion value. These mixes are prepared with constant asphalt emulsion contents and 0.25 or 1 percent incremental changes in hydrated lime or portland cement, respectively. Once the desirable mineral filler content has been determined, trial mixes are again prepared at constant mineral filler content with incremental variations in asphalt emulsion content.

Another test run by some laboratories during this stage is the pH test. This test measures the pH of the water that is exuded from the sample patty using a litmus paper. A pH change of 2 to 10, from finished emulsion to mixture immediately on setting, is considered desirable for micro-surfacing mixtures. This test is both a laboratory test and a field test and insures that a chemical reaction is taking place and mixture breaking and setting can occur in desired time period. Acceptable samples are subjected to a cohesion test that is primarily used to classify the mixture in terms of how quickly it develops adequate cohesion to be opened to traffic. The cohesion test may also be used to optimize the optimum filler content.

Cohesion test (ISSA· TB-139)

The Cohesion test is used to classify the micro-surfacing systems by set time and traffic time. The cohesion tester (photo 1) is a power steering simulator that measures the torque required to tear apart a 6 or 8 mm thick x 60 mm in diameter specimen under the action of a 32 mm diameter rubber foot loaded to 200 kPa. Torque measurements are made at suitable time intervals such as 20, 30, 60, 90, 150, 210, and 270 minutes after casting.

A system is defined as "quick-set" if it develops a torque value of 1.2 N·m within 20 to 30 minutes. Similarly, a "quick traffic system" is defined as the mixture that develops 1.96 N·m torque within 60 minutes. A torque of 1.2 N·m is considered the cohesion value at which the mixture is set, water resistant and cannot be remixed. At 1.96 N·m, sufficient cohesion has developed to allow rolling traffic. ISSA uses five systems to classify various slurry seals and micro-surfacing systems (see fig. 1). All micro-surfacing mixtures are designed as quick set, quick traffic systems.

Cohesion test results have been used by some laboratories to optimize mineral filler by the use of the "Benedict Curve" (see fig. 2), in which the effect of an incremental addition of mineral filler versus cohesion is plotted. The optimum filler content is the value that gives the highest cohesion value. The shape of the curve will show the sensitivity of the system to changes in mineral filler. This should help in determining the range of mineral filler that will give acceptable laboratory results.

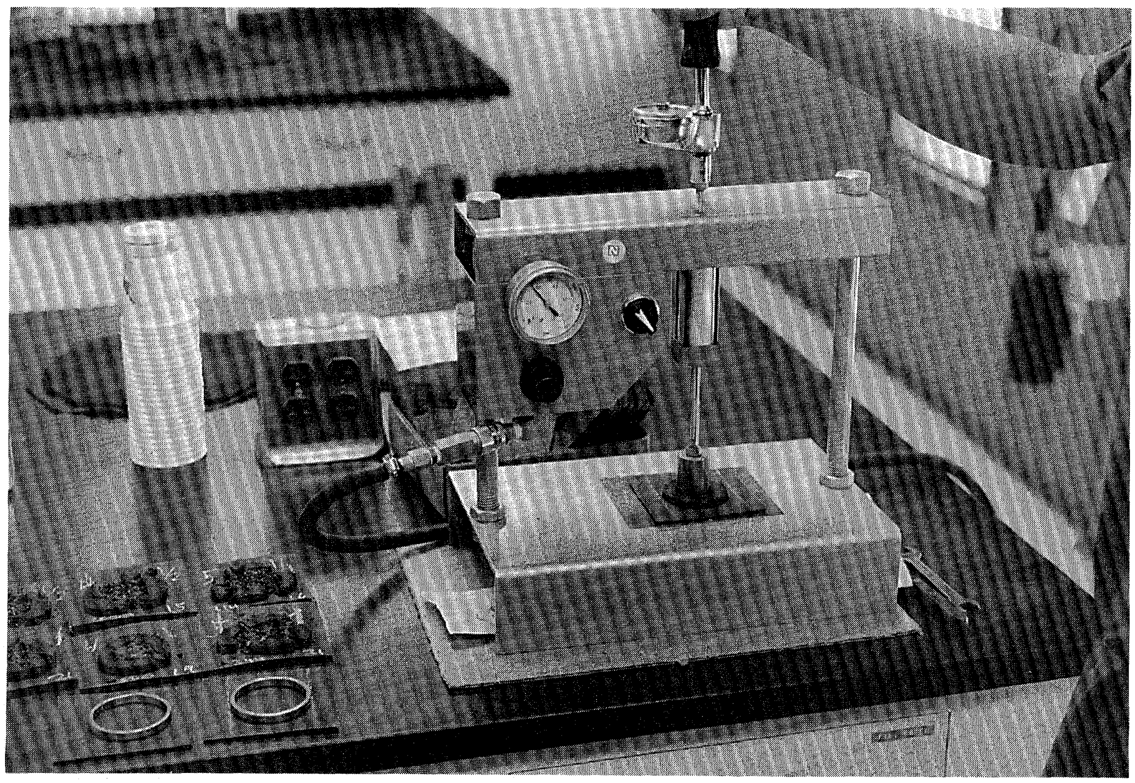

Photo 1 The modified ASTM D39-10-80a Cohesion Tester. The tester is used for classification of slurry and micro-surfacing systems and to optimize the optimum filler content.

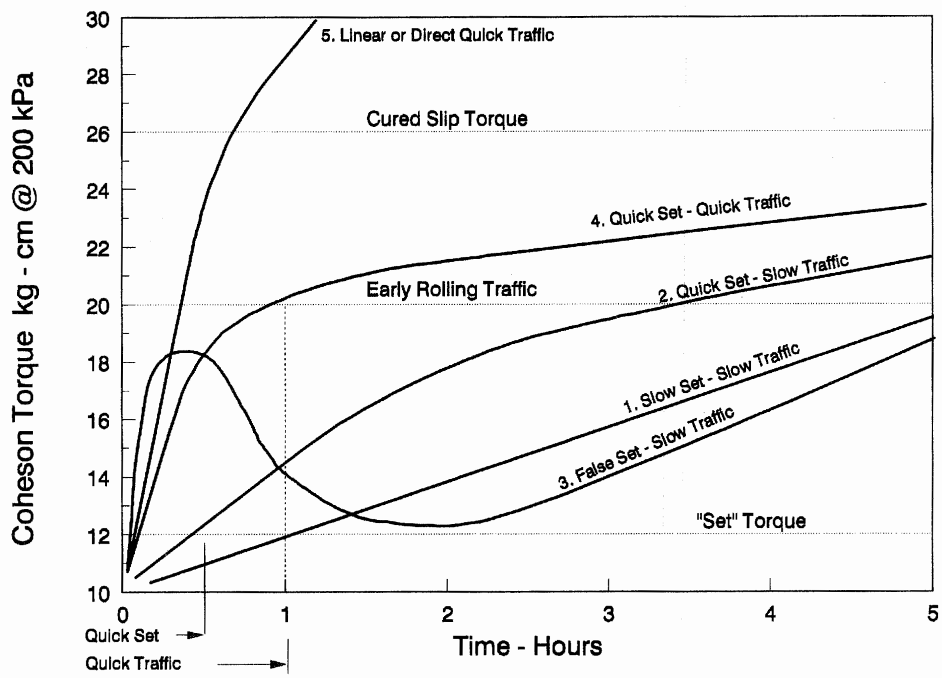

Fig. 1 Classification of mix systems by cohesion test curves. [6]

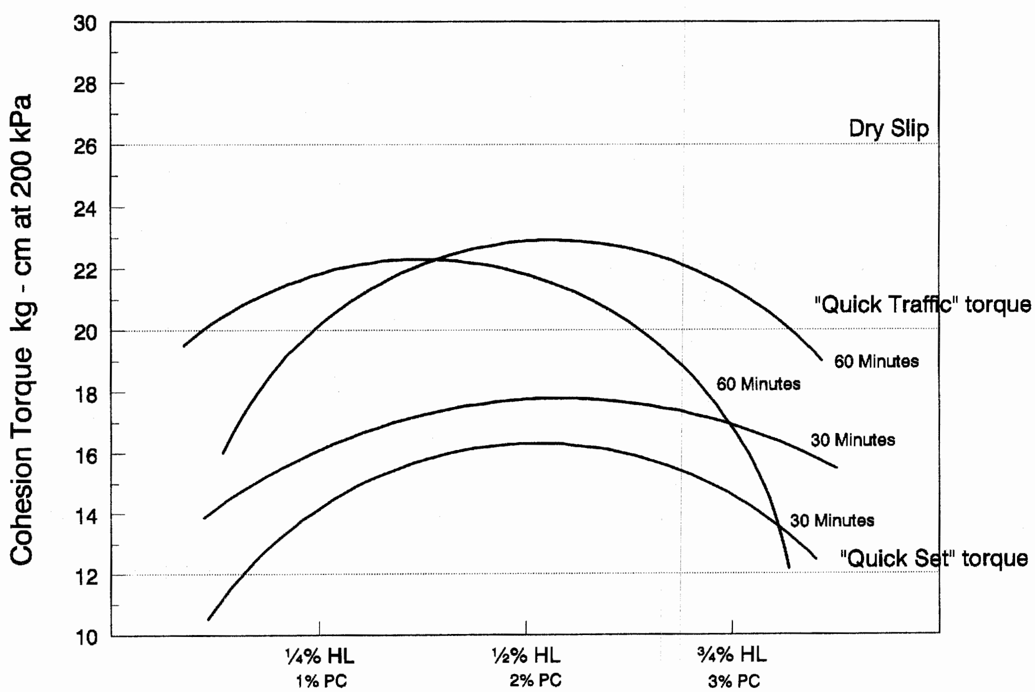

Fig. 2 Mineral filler content optimization "Benedict Curve."

Initial Compatibility (Aggregate/Binder Adhesion) Test

As the final step under the mix-testing phase, some laboratories perform a quick compatibility check. Two tests are used for this purpose: Wet Stripping Test (ISSA TB 114) and the Boiling Test (ISSA TB 149). The Wet Stripping Test is performed on 60 °C cured cohesion specimens that are boiled in water for 3 minutes to determine the asphalt adhesion to the aggregate. A coating retention of 90 percent or greater is considered satisfactory, with 75 to 90 percent being marginal and less than 75 percent unsatisfactory. The Boiling Test is similar to the Wet Stripping Test. Both tests are used as an early compatibility indicator test.

Another test used for determining compatibility under wet conditions is the Schulze-Breuer and Ruck Test (ISSA TB 144). This test, however, is normally used as a final check for performance and is discussed below under long-term performance related tests.

2. Determination of Optimum Asphalt Content

Design laboratories typically use two types of tests to determine asphalt cement content. Some laboratories use ISSA test procedures, and others use a modified Marshall procedure. A few States also specify requirements for Hveem stability.

ISSA Procedure

Under ISSA procedures, the optimum asphalt content is determined by graphically combining the results of a wet track abrasion test (WTAT) and a loaded wheel test (LWT). Fig. 3 (a, b, and c) shows how the optimum asphalt content along with an acceptable range can be determined by graphically combining WTAT and LWT data. The minimum and maximum asphalt content should be within the specification master range. The ISSA recommends that residual asphalt content be within a range of 5.5 to 9.5 percent. The WTAT and LWT are discussed below (see also reference 6).

Wet Track Abrasion Test ISSA TB 100 - This test determines the abrasion resistance of micro-surfacing mixture relative to asphalt content and is one of two ISSA tests used for determining optimum asphalt content. This test simulates wet abrasive conditions such as vehicle cornering and braking. A cured sample 6 mm thick x 280 mm in diameter that has been soaked for periods of either 1-hour or 6 days is immersed in a 25 °C water pan and is wet abraded by a rotating weighted (2.3 kg) rubber hose for 5 minutes (photo 2). The abraded specimen is dried to 60 °C and weighed. Maximum allowed weight losses for one-hour and 6-day soaks are 0.54 kg/m^2 and 0.8 kg/m^2, respectively. Asphalt contents that result in these weight losses are considered the minimum asphalt contents.

The WTAT on a 6 days soaked sample is generally not required. However, due to the increased severity of the 6-days soak, it is preferred by some laboratories and user agencies for predicting the performance of the system.

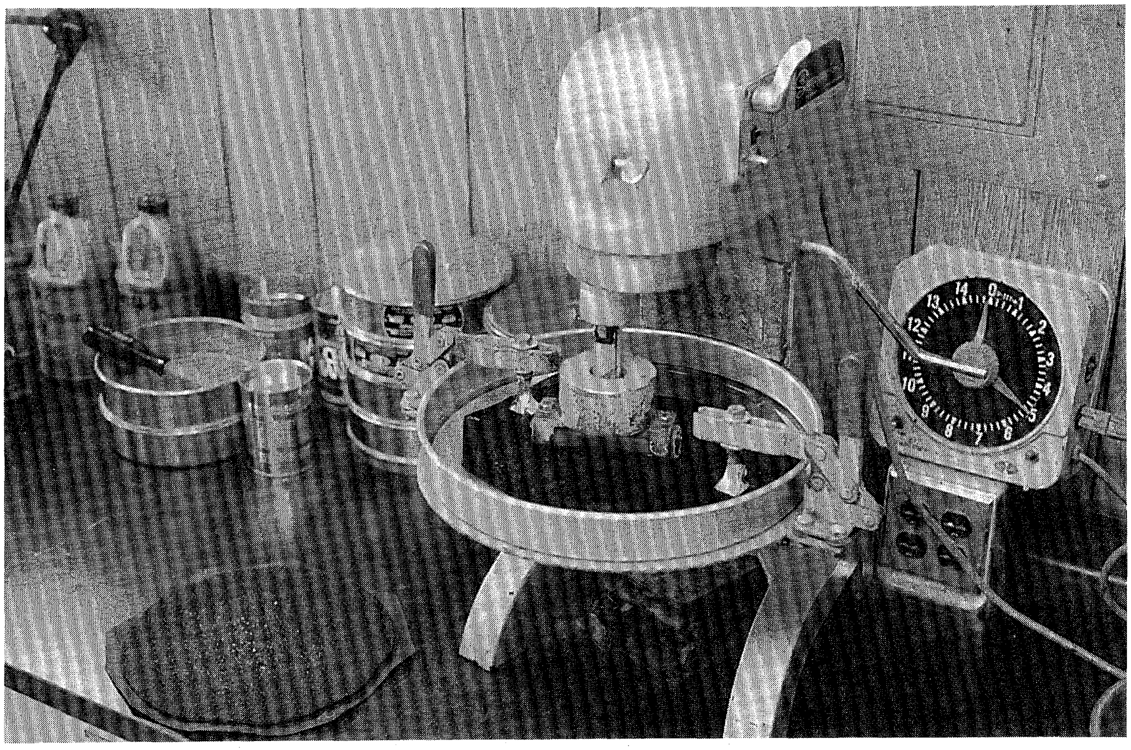

Photo 2. A Hobart wet track testing machine. The round slurry specimen is abraded under water by a rubber hose attached to the bottom of the shaft.

The Loaded Wheel Test ISSA TB 109 - This test is used to determine the maximum asphalt content to avoid asphalt flushing in slurry and micro-surfacing systems. This is accomplished by specifying and measuring fine sand that adheres to the sample subjected to simulated wheel loadings. The ISSA recommends a maximum sand adhesion value of 0.54 kg/m^2 for heavy traffic loadings. If the sand adhesion is below this maximum value mixture bleeding should not occur.

In this test a 50 mm wide x 375 mm long specimen of desired thickness (generally 25% thicker than the coarsest particle) is fastened to the mounting plate and is compacted with 1000, 57 kg cycles at 25 °C. At the end of compaction the specimen is washed, dried to 60 °C, and weighed. A measured quantity of sand is then placed on the sample, and the loaded wheel test is repeated for a specified (usually 100) number of cycles. The specimen is then removed and weighed. The increase in weight due to sand adhesion is noted. Photo 3 shows a loaded wheel tester.

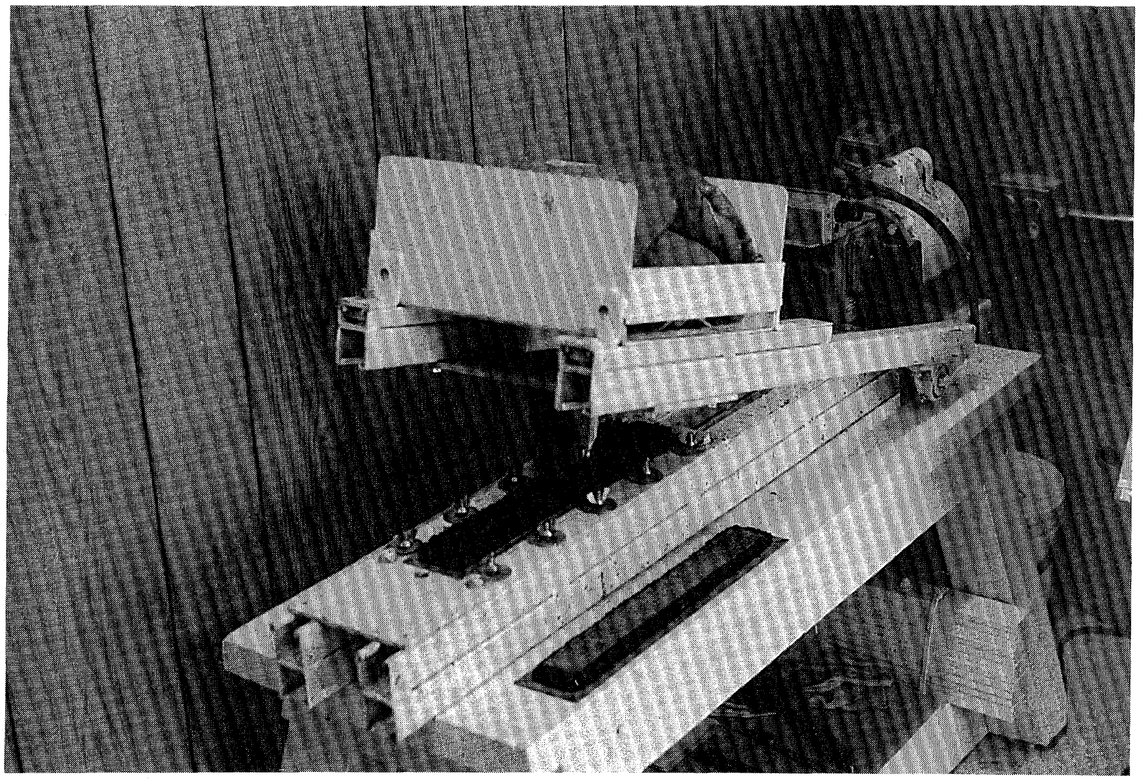

Photo 3. The Loaded Wheel Tester. In this test, the loaded wheel is placed on the specimen which is fastened on a mounting plate. The compaction is achieved by a to-and-from motion of the loaded wheel for a specified number of cycles.

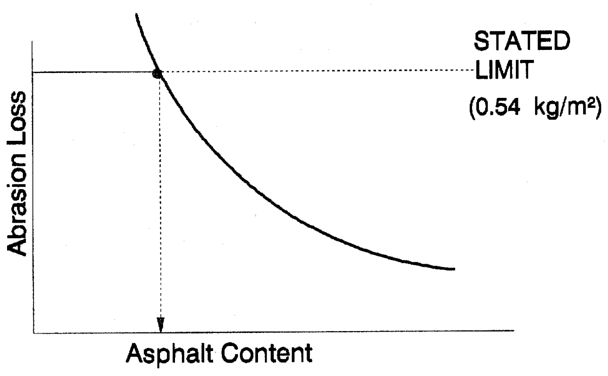

Fig. 3a Minimum asphalt content by wet track adrasion test.

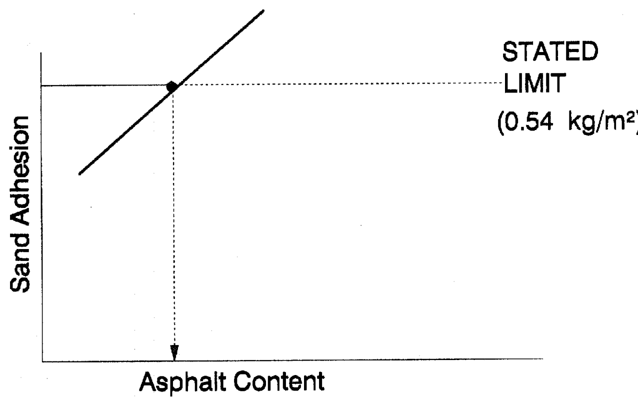

Fig. 3b Maximum asphalt content by loaded wheel test.

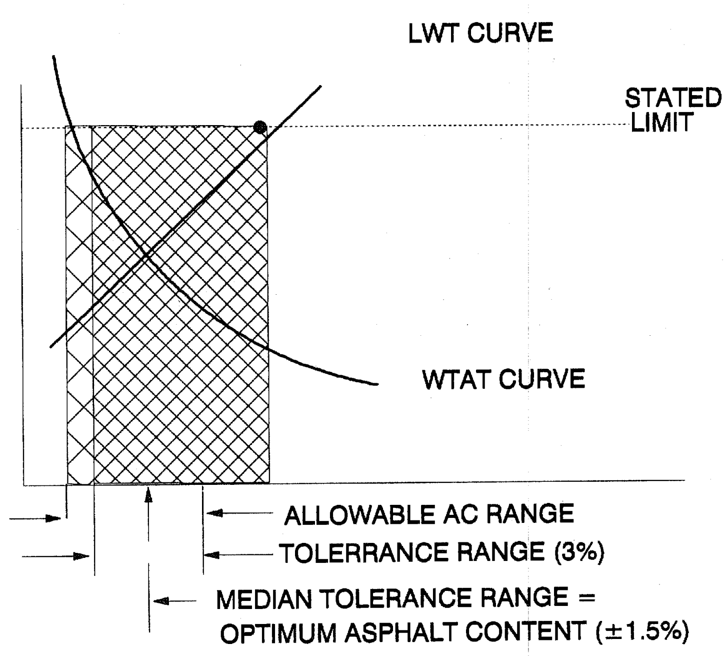

Fig. 3c Determination of optimum asphalt content. Combined WTAT and LWT curves. [6]

ISSA Design Limitations and Recommendations

Laboratory tests have shown that the accuracy and reproducibility of the results can be affected by many factors. Micro-surfacing is a water-sensitive system. A 1 to 2 percent change in water content can have a significant effect on laboratory results and quality of application. The mix design should enable the operator to mix the ingredients with minimum amounts of water and control additive. Sample preparation has considerable influence on the laboratory results. Aggregate segregation can result if extreme care is not exercised when preparing the samples.

Torque values are measured in the laboratory under specific conditions (there has been no correlation established with pavement performance in the field). The mixing and wet cohesion test should be performed at various moisture contents, relative humidities, and temperatures to simulate the expected field conditions. In addition, it has been reported that some aggregates that met ISSA torque standards for 60 minutes have failed to meet the torque values for 30 minutes. Some laboratories also use a subjective analysis to determine torque. The sample is examined after the torque is applied, and should it fail, the torque value is determined from a visual examination of the condition of the sample. However, this analyses would appear to negate the objectivity of the cohesion test. This indicates an area where the industry should reexamine their procedures for cohesion test and consider the effect of various aggregates on test results.

WTAT was correlated to field performance for only 6 mm thickness and 0/4 gradations. Accordingly, values of 0.54 kg/m^2 or 0.8 kg/m^2 may not be appropriate for other thicknesses and aggregate gradations. Further tests are needed to verify or establish new values. Also, some limestones meet the WTAT standard for one-hour soak period, but fail to meet maximum abrasion loss when a sample with a 6-day soak is tested. While WTAT on a 6-day soak specimen is generally used for information only, the Industry may wish to review and adjust their current design standards.

The reproducibility of the loaded wheel test is questionable. The arm that moves the wheel does not stay horizontal, but rather moves up and down during the test. This changes the pressure on the sample. The arm should be modified to stay horizontal. At the present time, the weights used to apply pressure are bags of lead shot. These bags may shift during the test and can affect the applied pressure. The bags should be replaced by plates that can be attached to the machine.

Sample preparation has been shown to affect the LWT results by a factor of as much as two. The test specimen can flush if water levels are not carefully controlled. This condition will effect the sand adhesion. Current laboratory procedures for sample preparation should be improved so that samples can be more consistently molded. For some aggregates, LWT has shown to permit excessive amounts of binder resulting in unacceptable mixtures. This is true particularly for applications in high shear areas such as intersections. Performance data indicates that mixtures produced with these aggregates using a lower binder content (than would have been permitted by LWT) have performed well in extending the pavement service life.

The specific gravity specification is very subjective due to sampling procedure. The entire LWT specimen is weighed wet and dry to obtain specific gravity. After compaction the same test is repeated. The problem is only 50 to 60 percent of the specimen is compacted. Variations in the specific gravities of samples can also skew LWT results. Industry should evaluate the existing LWT procedures and standards by conducting additional tests with different aggregates.

Marshall Stability and Flow Procedure *(Modified ASTM D1559, AASHTO T245)*

The second commonly used method for determining/confirming optimum asphalt content is through the use of hot mix asphalt mixture criteria. Since these are cold polymer-modified emulsion systems, the stability and flow test procedures have been modified to allow for air and low temperature drying (at least 3 days of air curing, 18-20 hours of drying in an oven at 60 °C before compaction at 135 °C). The mixes are usually compacted with 50 blows per side.

Under this procedure several test specimens are prepared for combinations of aggregate and asphalt content. The asphalt contents are selected to provide voids in total mix (VTM) of about 4.5 to 5.5 percent. The compacted test specimens are tested for the bulk specific gravity (ASTM D2726 or AASHTO T166), stability, and flow values. Finally, the optimum asphalt cement content is determined using results from these tests. For the thin micro-surfacing surface applications, the stability is not considered a primary factor in determining the optimum asphalt cement content. For some aggregates, flow values may require asphalt cement content to be determined for a higher VTM. Several States require modified Marshall procedures to determine optimum asphalt cement content [7].

Marshall Design Limitations

The applicability of this HMA test for micro-surfacing is questionable. The Marshall series uses large specimens of varying asphalt contents which are dried, reheated to 135 °C, and compacted to low void content. Micro-surfacing mixtures neither reach these temperatures nor do they compact to low design voids. Field observation has noted air voids of 10 to 15 percent after 1 to 2 years of placement. There is a need to correlate the voids measured during the design using the hot mix method with the actual field voids. One materials laboratory that has developed a cold Marshall test procedure to estimate field voids, is currently correlating the field voids with the voids obtained by the modified HMA procedure.

The HMA samples are prepared by compacting in a mold. The question whether the micro-surfacing samples should be compacted or screeded into the sample mold remains to be answered. Also, for reliable results, the sample has to be cured in a uniformly distributed film throughout the thickness of the lift.

C. LONG-TERM PERFORMANCE RELATED TESTS

The final step in the mixture design procedure for micro-surfacing is field simulation tests. These tests are ISSA tests and are not included under an AASHTO or ASTM listing of standard tests. These tests provide the industry a measure of mixture's future field performance.

Multilayer Loaded Wheel Test (LWT) ISSA TB 147B

The LWT is used to study compaction rates of multilayered asphalt specimens. Specimens using 0 to 5 mm or 0 to 8 mm aggregate are cast into test strips of 13 or 19 mm thick x 50 mm wide x 380 mm long. These samples are air cured for 24 hours and then dried at 60 °C for 18 to 20 hours. The samples are then cooled at room temperature for 2 hours. Finally these samples are measured and compacted with 1,000, 57 kg LWT cycles at an ambient temperature of 21 °C. At the end of the test, the percentages of vertical displacement (rut depth), lateral displacements, and compacted densities are determined. Either a standard loaded wheel device or a three track machine can be used for this test (see photo 4).

Acceptable micro-surfacing mixtures have shown to reach close to a steady state of specific gravity while unacceptable mixtures continue to increase in specific gravity. Recommended limit for compacted specific gravity is 2.10. A graph consisting of specific gravity versus number of cycles by LWT can be developed for this purpose. The test is useful in determination of maximum layer thickness for rut filling applications and to predict the amount of "crowning" required to allow for initial traffic consolidation. Although limits of 10 to 12 percent vertical and 5 percent lateral displacements are recommended by some design laboratories, several other laboratories report difficulty in meeting the standard for vertical compaction.

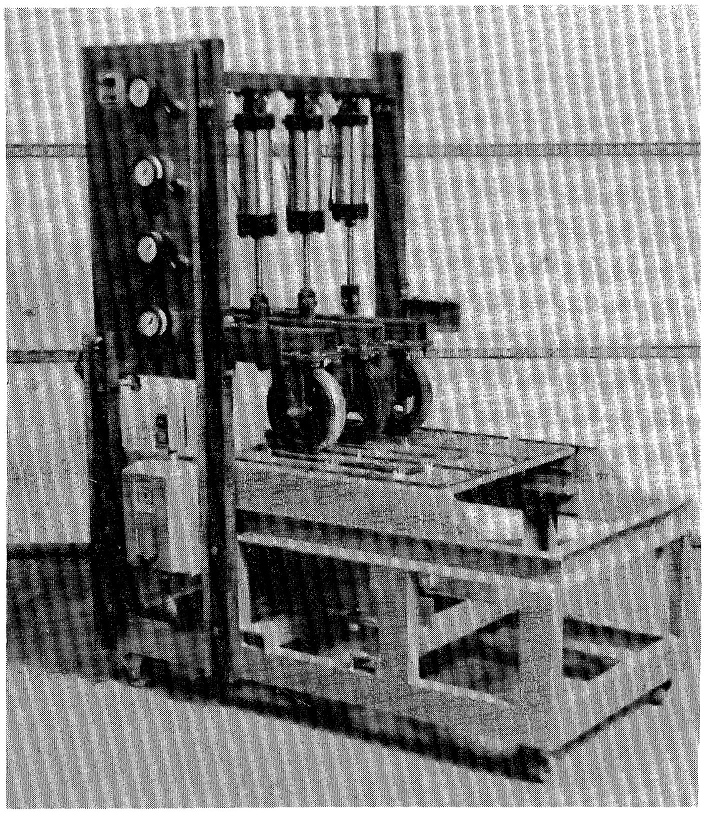

Photo 4. A three-track machine for the determination of vertical and lateral displacements and compacted densities.

Schulze-Breuer and Ruck Test ISSA TB 144

The Schulze-Breuer and Ruck (S-B) test is run as a final check on the compatibility (i.e., bonding) between 0/2 mm (0/#10) aggregate and asphalt residue. This test has been used for many years in Germany to check the material compatibility for "Gussasphalt." In this test, the aggregate is mixed with 8.2 percent asphalt cement and pressed into a 40 gram specimen, about 30 mm in diameter x 30 mm thick, and then soaked for 6 days. After the 6 days, the pill is weighed for absorption and then wet tumbled in the S-B machine's shuttle cylinders for 3,600 cycles at 20 RPM (see photo 5). At the end of this process the specimen is weighed for abrasion loss. The abraded sample is then immersed in boiling water for 30 minutes, weighed and recorded as a percentage of the original saturated specimen. This percentage is the high temperature cohesion value or simply, "integrity." Finally, after air drying for 24 hours, the remaining specimen is examined for the percentage of aggregate filler particles that are completely coated with asphalt. This percentage of coating is recorded as adhesion.

Each of the mixture's properties (i.e., absorption, abrasion loss, integrity, and adhesion) is assigned a rating to identify the best asphalt for the given aggregate source. ISSA recommends a minimum total of 11 points for an acceptable system [6].

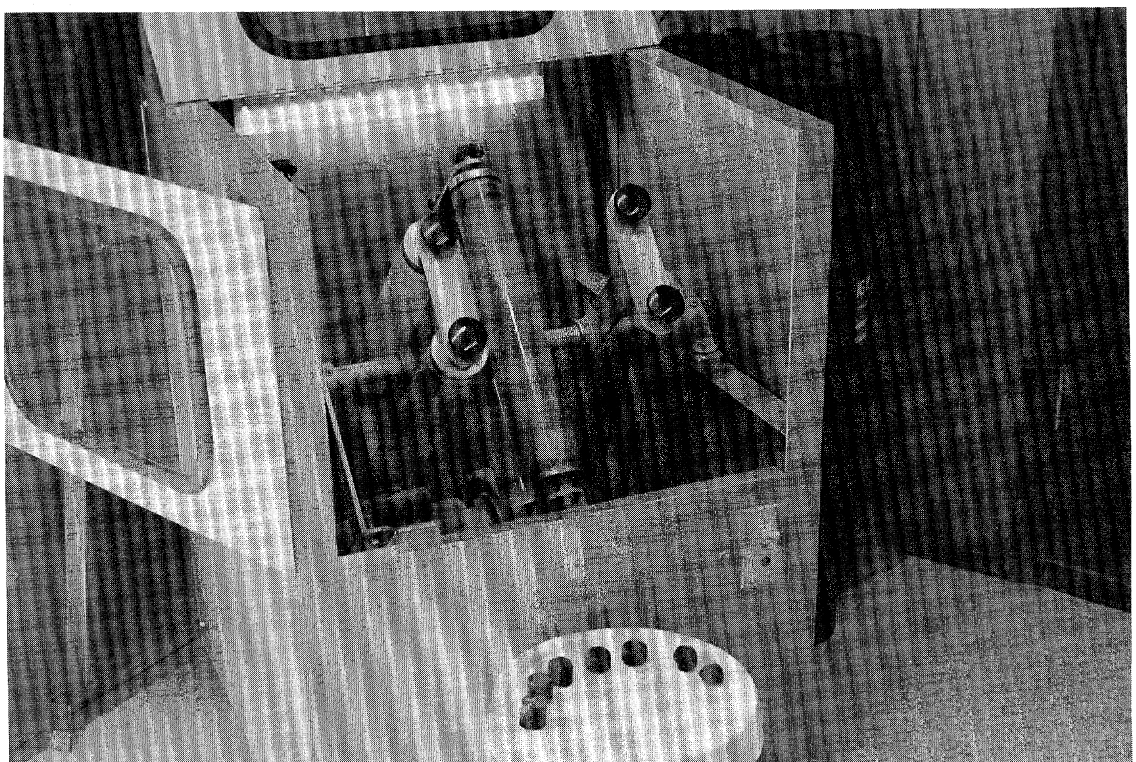

Photo 5. Micro-surfacing samples are wet tumbled in the Schulze-Breuer machine's shuttle cylinders for about 3 hours. This test determines the abrasion, absorption, adhesion, and integrity of the mixture.

General Design Issues

The main purpose of all the design tests at this time is to determine the compatibility of the various materials. Although more work is needed to validate and standardize ISSA mixture design test procedures, field experience indicates that micro-surfacing has generally performed well for the intended purposes when a mixture has passed the various ISSA test requirements. Besides design, competent quality control is essential to achieve the satisfactory end results and the long- term success of the system. Table 4 provides mixture testing requirements by some of the States.

Loaded wheel, wet track abrasion, and wet cohesion tests were originally developed for slurry seals. Although LWT and WTAT are also applicable to micro-surfacing, their validity as long-term performance tests for micro-surfacing is not fully assured. The ISSA nonetheless believes that these tests are a fair indicator of the field performance of micro-surfacing systems and are useful to help identify the risk factors for micro-surfacing systems.

At this time, some of the mixing and long-term performance related tests are not well defined. *Also, not all of the tests are used by every laboratory.* The industry is trying to correct these problems by agreeing to a uniform set of tests that can be repeated, accepted, and used by all its members. The industry is also looking into working with ASTM/AASHTO to get its tests standardized. FHWA will be working with SHAs and the industry toward this end. Despite many differences in design approach, the success of a great number of projects lends credence to the industry's overall design efforts.

Micro-surfacing Laboratories and Laboratory Testing Equipment Manufacturers

There are approximately 11 laboratories in the United States and Canada that design micro-surfacing mixtures. In addition, seven companies in the United States are known to manufacture one or more types of the laboratory testing equipment used for designing and evaluating micro-surfacing materials and mixtures. The names and addresses of these companies can be obtained from ISSA.

TABLE 4. STATE SPECIFICATIONS FOR MIXTURE TESTING

STATE	AZ	PA	VA	CO	TX	TN	OH
TEST							
Cohesion, N·m							
@ 30 min.	1.2					1.4	
@ 60 min.	2.0					2.3	
Adhesion %, min.	90						
LOADED WHEEL							
Sand Adhesion, kg/m^2	0.54					0.54	
compaction (mm)							
WET TRACK ABRASION kg/m^2							
one day							
six days	0.8					0.8	
SCHULZE-BREUER							
Total grade points							
Abrasion loss, %				9			
Adhesion							
Integrity							
water absorption, %				9			
Methylene Blue (MB), max. (mg of MB/gm of aggregate)			15				
MARSHALL							
1. Stability		1,800	1,800	1,800			1,800
2. Flow		6–16	6–16	6–16			6–16
3. Voids, %				4–6			
Hveem Stability, min.				35	35*		

Note: Several other States (OK, NB, KS, ND) specify requirements for component materials, but do not specify any requirements for mixture.

* Hveem is generally required when application thickness exceeds twice the maximum aggregate size. Texas is evaluating variations of ISSA mixture design tests for inclusion in its specification.

CONSTRUCTION

Several micro-surfacing projects were reviewed in several States during the 1991-1992 construction seasons to observe the construction and performance of micro-surfacing. The States visited were: Texas, North Carolina, Tennessee, West Virginia, Virginia, Ohio, Oklahoma, Kansas, Arizona, Massachusetts, Pennsylvania, and Wisconsin. In addition, several reports documenting user agencies' construction and performance experience with micro-surfacing were reviewed. The following summarizes the findings and recommendations.

A. WEATHER CONDITIONS

Micro-surfacing should not be placed if either the pavement or air temperature is below 10 °C, if it is raining, or if there is a forecast of ambient temperature below 0 °C within 24 hours of placement [2]. Some projects have failed when placed in cold and/or wet conditions. If placed in cold weather, micro-surfacing may ravel and crack. If placed in very hot, dry weather, the surface can break too fast, causing water retention and slowing interior curing. Hot weather requires a formulation change for longer mixing times to enable the micro-surfacing to be properly applied.

B. EQUIPMENT

Mixing Machine

For high volume roads, a self-propelled, front feed, continuous loading and mixing machine is used to place micro-surfacing (see photo 6). These machines are capable of receiving materials from nurse trucks while continuing to mix and apply the mixture. Opposite-side driver stations on the front are provided on these machines to optimize longitudinal alignment during placement. The machines allow the operator (at the rear of the machine) full control of the speed during placement. Speed control is important when filling wheel ruts of variable depth because it allows the operator to adjust the material supply by simply adjusting the speed. The driver in the front of the machine is responsible only for steering the machine during placement.

The self-propelled, continuous machines have a self-contained aggregate storage space, a mineral filler bin, and separate tanks for water, emulsion, and additive. Aggregate is received by a front hopper, delivered to a storage area, and then fed to the mixer on a conveyor belt that is driven by a non slip roller at the forward end. At any given conveyor speed, the rate at which aggregate is delivered to the mixer can be controlled by varying the vertical position of a metering gate directly above the roller. In most machines, emulsion is delivered under pressure to the mixer by a positive-displacement gear pump that includes a counting device. The water is supplied under pressure by a centrifugal-type pump to the mixer, to the spray bar to moisten the road surface ahead of the mixer, and to a hand hose that is used to clean the mixer and the spreader box. Liquid additives are stored in tanks sized from 95 to 950 L (depending on the concentration) and are delivered by either positive displacement or centrifugal pumps [8].

Self-propelled machines are designed for working speeds of 1.0 to 4.0 km/h and are capable of applying up to 450 metric tons of micro-surfacing per day. In addition to self-propelled, continuous loading machines, several highway agencies permit truck mounted units for micro-surfacing projects on lower type and/or lower volume facilities. A fully loaded truck mounted unit can generally produce between 0.4 and 0.5 lane kilometer of finished product.

Photo 6. A typical self-propelled micro-surfacing paving machine.

Proportioning Devices

The machines are equipped with the individual volume or weight controls for proportioning each material being fed into the mixer. Amounts of emulsion, aggregate, and mineral filler are generally fixed before placement, and only the amount of water and additive needs to be changed during placement to achieve proper consistency, and control mixing and breaking time.

Calibration — Calibration of metering devices is essential to obtain desired proportioning of component materials. Common practice is to calibrate the machine at least every 12 months to compensate for wear. Metering devices should also be calibrated and verified if the material source changes.

Most of State specifications currently require calibration. However, requirements for calibration and compliance vary from State to State. A few agencies require calibration to be witnessed by State personnel while many others accept contractor certification. To ensure proper material proportioning, calibration should be spot checked or verified prior to start of each project or at least once each week during steady operation using metering controls and revolution counters on the machine.

Mixer

The mixers for micro-surfacing machines are about 1 to 1.3 m long and are fitted with multibladed twin shafts to allow a thorough blending of materials into a homogeneous mixture. The materials are mixed for about 5 to 10 seconds at a mixer speed of about 300 RPM. Mixing time depends on the characteristics of the emulsion-water-aggregate system. Excessive mixing time may result in stripping of the asphalt from the aggregate. Micro-surfacing mixers are powered with 90 horsepower engines, compared to conventional slurry seal machines, which require mixer engines of about 30 hp [9].

Mineral filler is added to the aggregate just before it enters the mixer. Water and additives are combined and added to the aggregate as it falls into the mixer. These ingredients are mixed before the emulsion is introduced, usually at about the one-third point of the mixer [8]. The discharge of the mixture into the spreader box is controlled by the amount of aggregate flowing into the mixer. The mixture should be discharged into the moving spreader box at a rate sufficient to always maintain an ample supply across the full width of the strike-off. The mixer should be cleaned each time the paving operation stops if material build-up begins to occur.

Spreading Equipment

Spreader box

For texturing/sealing and scratch (leveling) applications, micro-surfacing is placed by a full-width box equipped with hydraulically powered augers to mix (for 10 to 15 seconds), and spread the mixture throughout the box for a uniform application. The width of the spreader box can be adjusted from 2.4 to 4.2 m. The box is attached to the rear of the micro-surfacing machine. Seals are provided at the side, front, and rear elements of the box. The purpose of the side and front seals is to retain the mixture within the box. The rear seal acts as a strike-off (screed) and is usually made of a rubber material. Steel strike-offs are used for scratch courses and are also preferred by some agencies for texturing on irregular surfaces. Photo 7 shows a schematic of production and spreading of micro-surfacing mixture.

To improve surface texture, many contractors now use a secondary rubber strike-off that is attached to the rear of the spreader box.

Rut box

For rut filling, a specially designed rut box is used. Rut boxes usually come in two sizes, 1.5

and 1.8 m and have two V-shaped chambers with the point of the V toward the rear of the box. The box is fitted with two shafts with multiple blades to continuously agitate the material. The box is designed to push the larger size aggregate to the deeper or center parts of the rut. Rut boxes have one or two metal leveling plates and a rubber strike-off. Ruts up to 38 mm can be filled with one pass (though it is not recommended). Rut boxes are adjusted to leave a slight crown in the surface to compensate for the initial compaction by the traffic.

Each wheel path area is individually filled (i.e., each lane will require 2 passes of the rut box) to restore the road profile. Currently, equipment that can simultaneously fill ruts in both wheel paths is not available.

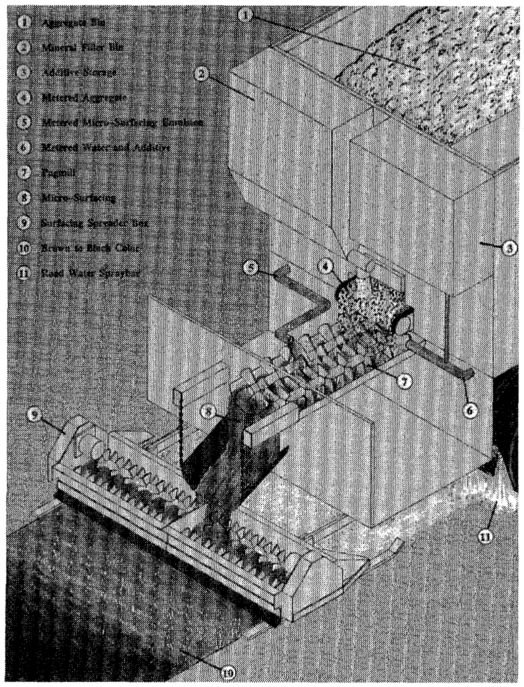

Photo 7. Schematic of micro-surfacing process. (Source: ISSA)

Equipment Manufacturer and Cost

In the United States, continuous and truck mounted machines are made by a number of companies. Truck-mounted machines cost from $140,000 to $150,000 (including the cost of truck), and continuous machines cost from $300,000 to $400,000. Full width spreader boxes cost from $10,000 to $18,000 and rut boxes cost from $8,000 to $12,000. The information on equipment manufacturers can be obtained from ISSA.

C. PREPARATION OF SURFACE

Treatment of Pavement Cracks/Joints

All pavement joints and cracks that are 6 mm or wider should be repaired and sealed before the application of micro-surfacing. To ensure proper curing of repair work all surface cracks, joints, and potholes should be repaired 1 to 6 months before micro-surfacing is applied.

Crack/joint sealant should not be allowed to build on the surface; otherwise, the sealant could be torn by screeds during the application of micro-surfacing, leaving drag or tear marks. Sealant accumulation on pavement surface is particularly troublesome during warmer weather and when steel screeds are used. It is desirable to keep crack sealant below or flush with the surface. Also, any old sealant should be scraped off the surface prior to micro-surfacing application.

Tack Coat

A tack coat is not required unless the pavement surface is extremely dry, raveled, or made of concrete. If needed, a diluted emulsion tack coat should precede the application of micro-surfacing. ISSA recommends the tack coat should consist of one part asphalt emulsion and three parts water and should be applied at a rate of 0.16 to 0.32 L/m^2. The tack coat should be allowed to cure before application of micro-surfacing; otherwise, the residue could accumulate on the machine, subsequently falling off in clumps. A minimum curing period of 1/2 to 2 hours is normally required under favorable conditions.

Water Fogging

During hot weather, the pavement is usually prewetted to control a premature breaking of the emulsion and to improve bonding with the existing surface. Prewetting should leave the surface damp, but with no free water in front of the spreader box.

D. APPLICATION

Construction Crew

Much of the success of the construction of micro-surfacing depends on the knowledge and skill of the crew that operates the machine as a traveling cold mix plant. User agencies have indicated that the quality of work improved as more experience was acquired by the contractor staff. The basic application crew consists of an operator/supervisor, a driver, and 3 to 5 laborers. During placement, the driver is primarily responsible for steering the machine and ensuring that it remains on its intended course. The operator at the back of the machine controls the speed and lay-down operation. The operator is also responsible for adjusting the quantity of water and additive. Laborers are needed to perform the necessary hand work, to place and move traffic control devices, and to assist in loading and cleaning operations

Mixture Consistency and Application Rates

When the micro-surfacing mixture is deposited in the spreader box, it should be of desirable stability and consistency. If the mix is too stiff, it may prematurely set in the spreader box or will drag under the strike-off. If it is too fluid, the mixture may segregate or run into channels, and binder-rich fines can migrate to the surface, resulting in uneven surface friction. Some of these irregularities were noted on some projects. Slightly drier mixtures generally perform better than wetter mixtures.

During the mixture design, an optimum water content is determined for field application. In the field, the amount of water needed in the mixture is affected by the amount of moisture in the aggregate, the ambient humidity, wind, and temperature, and the amount of moisture that the pavement surface absorbs. As conditions change, the operator must change the amount of water to maintain a uniform consistency. Field adjustments should remain within the design range. During the spreading operation, the spreader box should be adjusted to provide an application rate that will completely fill the surface voids and provide a uniform surfacing.

The application rates for texturing seals on high volume roads range from 8 to 20 kg/m^2 depending on the unit weight (gradation) of aggregate, pavement condition, and average surfacing thickness that is selected based on traffic volumes. Generally, 8 to 16 kg/m^2 is used for layer thicknesses of 6 to 13 mm for a single application. The application rate for scratch course varies depending on the surface irregularities. For wheel ruts, the application rate varies according to the rut depth. Aggregate gradations and application rates used by different States are shown in Table 1 (page 6).

Micro-surfacing surface courses are usually applied in thicknesses of 10 to 15 mm. The basic goal is usually to place the material with a thickness that is at least 1 1/4 times the maximum nominal size of the aggregate in the mixture. When the existing surface is raveled or otherwise coarse and open, more material is needed to fill the surface voids. If too little micro-surfacing is applied 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. When the surface is smooth or flushed, less material is needed. A single application of micro-surfacing can be sufficient to achieve desired goals when applied over pavement surfaces with a good profile. However, if the pavement surface is irregular or wheel ruts are between 6 and 13 mm deep, two layers of micro-surfacing should be used. The first layer should be used as a "scratch course" to improve the transverse profile, and the second should be the final texturing course.

Break & Set Time

Predicting and controlling the breaking process is essential for proper micro-surfacing applications. Temperature and humidity affect the breaking, curing, and consistency of micro-surfacing. As the temperature increases and the humidity decreases, the time it takes the emulsion to break and expel the water decreases. Aggregate type, surface area, and the chemistry and absorption characteristics of the aggregate have an influence on the breaking time and amount of asphalt deposited on the aggregate.

Additive — During placement, an additive is used to control the break-set time of emulsion. The mix design includes a recommended range for additive type and amount, and the operator decides on the usage and amount of additive based on field conditions. The amount of additive used varies depending on the ambient conditions. During hot weather, additive is used to increase the break time. If the breaking time cannot be controlled using additive, an emulsion reformulation may be needed. During cold weather, an additive may not be needed at all. Generally, a lower additive quantity will result in a better product.

Mineral Filler — The amount of mineral filler is determined during the design, and the contractor is generally not required to change the design amount during the construction operation. However, during very cold conditions, the micro-surfacing may not break or cure quickly enough to allow traffic on it within the required time, even when no additive is added to the mixture. Under these circumstances, the best course of action is to reformulate the emulsion.

If immediate action is required during cold field conditions, the amount of mineral filler may need to be increased to accelerate the breaking time. The operator should be careful when increasing the amount of mineral filler, since too much filler can result in a premature breaking of emulsion in the mixing chamber or spreader box. An increment of 0.5 percent over design value (up to a maximum of 3 percent for cement) should normally be sufficient to achieve desired results. At normal rates of 0.5 to 2.0 percent, cement normally acts as a break accelerator for most aggregates.

Emulsion Handling and Application Temperature

Emulsion handling will affect the performance of the final product. Excessive pumping of the emulsion may result in a lowering of emulsion viscosity or separation of ingredients. It has been reported that emulsions arriving at the job too hot (at 65 to 82 °C), may break too fast or not mix well, resulting in drags and streaks. Therefore, emulsion may need to be stored for a period to bring down its temperature before being used. Also, emulsions should be gently agitated before use to insure consistency of polymer, temperature, and asphalt residue.

Oklahoma has reported drag marks and streaks resulting from use of fresh (hot) emulsion [10]. Some other States have reported similar problems. For best result, the emulsion temperature should be between 27 and 49°C during application.

Traffic Time

Micro-surfacing is designed so that the system can sustain rolling traffic after one hour of application. 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. There was a general consensus among the users that well-designed and-placed micro-surfacing cures fast and can be subjected to traffic within one hour without any detrimental affects such as rutting or raveling. During field reviews a few projects were observed that had experienced raveling/debonding and/or rutting immediately after the construction. Inadequate design and/or construction quality control appeared to be the main reasons for these irregularities.

On some projects tearing was reported to have occurred in areas of turning movements even after one hour. Use of a relatively dry mixture followed by dusting with sand have shown to address the tearing of mixture in these areas. Traffic control plans which consider such situations are essential for successful completion of the project. Currently there are no field tests to determine exactly when traffic should be allowed on the pavement after application. The ISSA is currently working on development of a field cohesion tester.

Test Strip

Micro-surfacing is a quick-set system. It is quite possible that a mixture, designed under laboratory conditions, may not work well under field conditions. The result may be either excessively quick break/set of the mix or an overly slow break/set. To ensure proper proportioning and placement of micro-surfacing in the field, it is **highly desirable to construct a test strip** prior to actual placement.

Currently, only Ohio, Oklahoma, and Pennsylvania DOTs require the use of a test strip to demonstrate the workability of the mixture under field conditions.

Maintenance and Protection of Traffic

During the field reviews, several micro-surfacing projects were noticed as being placed without formal traffic control plans. The maintenance and protection of traffic for micro-surfacing projects is as important as for other types of construction and should receive the same attention. The traffic control plans should be developed following recommendations in the Manual on Uniform Traffic Control Devices (MUTCD) or applicable State requirements, as appropriate.

E. CONSTRUCTION QUALITY

1. Texturing/Sealing

One of the most common uses of micro-surfacing is surface texturing/sealing. Micro-surfacing should result in a smooth, skid-resistant surface. To achieve this, the finished surface should be free from excessive scratch marks, tears, rippling, and other surface irregularities. In addition, good quality longitudinal and transverse joints and edgelines enhance ride quality and road appearance.

Although State specifications do not adequately define or set limits on items affecting the finished surface, the majority of micro-surfacing projects reviewed in several different States exhibited generally good workmanship. Surface irregularities, noticed on some projects, appeared to be mainly due to poor workmanship by lesser experienced contractors. Some surface deficiencies and their causes are described in following paragraphs.

Rippling

Ripples, also known as corrugations, are transverse undulations (i.e., alternate valleys and crests) at regular intervals in the surface of the pavement.

Transverse Rippling — Various amounts of transverse rippling were observed on several micro-surfacing projects. Too thin an application and/or inadequate mixture quantity is thought to contribute to transverse rippling. Speed of spread may also have an effect on the texture. Engineers in Texas have observed that faster spreading speeds tend to result in rippling in the completed surface.

Use of a rubber strike off usually results in better texturing than steel strike off. Several contractors now use a secondary rubber strike off, which reduces rippling and improves texture. Texas DOT now requires use of a secondary strike off on its micro-surfacing projects. Some contractors use a different technique, which involves use of a drag mop. The drag mop has worked well for finer slurry seals by providing a uniform texture. Its use on micro-surfacing projects, however, is questionable. One problem is mixture adherence to the mop which increases its weight and leaves depressions. Larger particles also tend to catch in the drag mop material and cause drag marks.

In order to control transverse rippling on a project, an agency may specify limits on the extent and depth (such as 5 mm) of rippling. A 3 m straight edge may be used to measure the rippling.

Longitudinal Streaking — Longitudinal rippling was also observed on some projects. Dirty or worn screeds and drag mops (where used) were usually the cause. Longitudinal rippling should be kept to a minimum. Construction criterion for transverse rippling may also be used for longitudinal rippling.

Tear/Drag Marks

Reasons for tear marks include (1) worn and/or unclean strike off, (2) oversized aggregates, (3) insufficient material, (4) tearing of crack sealant where steel strike-offs are used, and (5) premature breaking of mixture. These conditions must be avoided in order to obtain a mark-free surface. Sometimes during the paving operation, material will begin to accumulate on the screed. Left alone, this material can result in drag marks behind the spreader box or can fall off in chunks. The operator should watch for any buildup so that material can be removed before the problems occur. To avoid drag marks the aggregate should be screened just prior to use in micro-surfacing projects. Most of the State specifications require that the aggregate be passed over a scalping screen prior to use in the mixing machine.

Another reason for drag marks is a lower application rate. Lower application rates should be avoided by ensuring that layer thickness is at least 1 1/4 times (preferably 1 1/2 times) the largest size aggregate. Also, to prevent tearing, cracks should be filled flush or slightly below the surface. **To ensure a good finished surface, it is desirble to specify a criterion that would limit the number and extent (i.e., width and length) of drag marks within a specified pavement surface area.**

Surface Cross Section

Minor surface irregularities in the existing pavement can be corrected during the texturing application with a full-width spreader box fitted with a steel strike off. The rubber strike off is not as effective for pavement profiling since it conforms to the existing surface irregularities and results in spread of the same amount of mix across the pavement regardless of existing profile. **The finished surface should be checked with a 3 m straight edge to determine acceptable surface cross section.**

Texture Consistency

On normal cross-slope sections, a wetter than normal texture sometimes appears in the middle or on one side of the paving lane. Excessively fluid mixture is usually responsible for the inconsistency. On other projects, particularly on superelevated sections, a wetter discharge was noticed on the lower side of the pavement surface. These inconsistencies generally resulted from (1) unsatisfactory mixing and distribution of the material throughout the spreader box, and (2) a wetter than normal mixture.

As mentioned earlier, use of overly wet mixture should be discouraged. The emulsions should be formulated to allow contractors to apply a relatively dry, consistent mix during all roadway conditions. Modern spreader boxes allow contractors to control the speed and direction of augers. This feature is important when working on superelevated sections and curves. A spreader box that cannot distribute the material evenly throughout the box should not be permitted. The industry is considering further design improvements for spreader boxes. One possible design would replace spreader pedal augers with spiral-ribbed augers in order to improve distribution of mixture throughout the spreader box. Another method would segment the box with diversion chutes and gates (plates) to attain more uniform distribution of the mixture over its full width.

Joint Construction

Current State specifications prohibit excessive overlap, uncovered areas, and unsightly appearance for either transverse or longitudinal joints. However, these parameters are not always well defined or well enforced. In addition, the number of transverse joints allowed per section, or maximum permissible overlap in case of longitudinal joints, is usually not specified. This has resulted in less-than-satisfactory joint construction on some projects.

In the case of transverse joints, humps and patch-like appearances were sometimes noted. Since micro-surfacing is a fast-breaking material, every time a stop is made, the spreader box must be lifted and cleaned of mix which has set in the box. Lifting and repositioning the box could leave a hump of excess material and may result in patches or bumps at transverse joints.

Similarly, longitudinal joints could be a problem due to excessive overlap that can leave a ridge. Most of the specifications do not indicate the type of longitudinal joint (i.e., butt or lap type) that can be used for micro-surfacing projects. Butt joints will improve this condition but these are generally difficult to construct because of thin, wetter application.

To ensure good joint construction, State specifications should be strengthened by inclusion of measurable criteria such as "place longitudinal joints on lane lines using butt joints or lap joints with less than 50 mm overlap on adjacent passes and no more than 6 mm overlap thickness as measured with a 3 m straight edge. If applicable, place overlapping pass on the uphill side to prevent any ponding of water. Restrict transverse joints to five per 6500 m of paving lane. Construct transverse joints with no more than 3 mm difference in elevation across the joint as measured with a 3 m straight edge. Use paper strip or metal flashing when constructing transverse joints. Construct transverse joints to appear neat and uniform."

Edges

Most of the current specifications do not address construction of edge lines. Field reviews found that the quality of edge line construction varied by the contractor. Some contractors used a string line while others simply tried to follow existing edges by sight.

To ensure consistent results, States should specify criteria to control uniformity of edge lines. For example a criterion such as "place edges to appear neat and uniform along the existing travel lanes, shoulders, and curb lines. Place edges to no more than ± 50 mm horizontal variance in any 30 m," may be used.

2. Rut Filling

Rut filling by micro-surfacing will be more successful (provide a longer term solution) if the rut is caused by wear or mechanical compaction of the pavement structure and/or if the existing pavement is stable. Wheel consolidations are generally limited to 6 to 13 mm in depth depending on the surface thickness.

If the rut is caused by subgrade or an unstable pavement layer, micro-surfacing will correct the surface profile for a shorter period depending on the cause and severity of the rut. Many asphalt pavements rut due to an unstable surface layer. Plastic flow in the surface layer may be recognized by dual wheel track ruts in each wheel path or by indentations between upward heaves. If micro-surfacing has to be used as a temporary measure, any elevated deformations present due to plastic flow should be milled prior to rut filling. Also, micro-surfacing should not be used if ruts are accompanied by alligator cracking, which indicates structurally inadequate pavement. When rut depths are due to reasons other than traffic consolidation, an analysis of the pavement structure should be performed to determine the cause of rutting. Generally, if the pavement has been in service for 10 years and has developed only 10 to 20 mm deep ruts, the pavement could be considered stable.

When filling ruts, particularly of varying depths, an adequate supply of material must be maintained in the rut box. This is accomplished by controlling the speed of the machine. Deeper ruts would need more material, requiring a slower speed. For this reason, selfexperience in this type of application. This State uses polymer-modified emulsion tack coat at a rate of 0.22 to 0.44 L/m² prior to application of micro-surfacing. Tennessee also recommends using a tack coat on all other surfaces to achieve a better bond and to seal the underlying pavement.

Use over Flushed Pavement Surface

Micro-surfacing has been used by some States, particularly Texas [12], to correct/minimize flushing on chip seals and asphalt concrete pavements. Micro-surfacing use on flushed pavements should be limited to sites where flushing is of a low to moderate severity; otherwise flushing may reappear.

When used on flushed pavements, two applications of micro-surfacing may be considered. The first application may consist of considerably reduced binder content and the second of a slightly reduced to normal binder content.

Use on Oxidized and Uneven Surfaces

If the surface appears too oxidized or uneven, it may be desirable to place a leveling course of micro-surfacing or hot mix asphalt (HMA). Alternatively, milling or heater scarification may be used to address oxidation and correct surface unevenness. A Kansas DOT district routinely carries out the heater scarification before application of micro-surfacing.

Use On Fabrics

Micro-surfacing use directly on paving fabrics has not proven effective. Incidences of raveling within a few months have been reported. Oklahoma DOT, which has undertaken research in this area, reports that micro-surfacing placed on a fabric may result in immediate local failures [10].

F. MISCELLANEOUS DESIGN AND CONSTRUCTION ISSUES

Noise Levels

Micro-surfacing is usually slightly noisier than dense asphalt concrete pavements. The noise may be due to aggregate gradation, shape and type, or overall coarseness of the surface due to mixture consistency or rate of application (forward speed).

During the field reviews, a few applications (new and 2-3 years old) were observed to have objectionable noise levels. Actual noise levels, however, were not measured by instruments on any of the sites. While excessive noise levels were noticed on only a few projects, the industry needs to look at the aggregate composition and overall mixture design and construction practices in order to strike a balance between providing skid resistant and smooth riding surfaces on a more consistent basis. User agencies may consider developing some guidelines on pavement noise levels.

Flushing

The factors that may cause micro-surfacing courses to flush include early opening to traffic, excessive binder and water in the mixture, and hot weather. In addition, finer mixtures should not be used on high volume roads. During field reviews, it was also noticed that when deep ruts (more than 30 mm) were filled in one rut pass, the pavement had flushed after a short period. As noted previously, ruts over 25 mm should be filled in multiple passes to avoid flushing.

Raveling

Micro-surfacing applications can ravel due to one or a combination of the following factors: (1) deficient asphalt content; (2) insufficient amount of fine aggregate matrix to hold the coarse aggregate particles together; (3) too thin application; (4) low quality asphalt cement; (5) insufficient water; and (6) cold conditions during and within 24 hours after application. Field reviews and discussion with representatives of user agencies indicate that instances of micro-surfacing raveling have generally been limited. Some of the special situations where micro-surfacing may ravel are discussed in "Section E."

Stripping

Stripping can be defined as the weakening or eventual loss of the adhesive bond, usually in the presence of moisture, between the aggregate surface and the asphalt cement in HMA pavements or mixtures.

Generally, micro-surfacing exhibits good resistance to stripping. With the exception of a few poorly designed applications, delaminations or pot holes observed on micro-surfacing projects were usually a result of stripping or spalling of the underlying pavement.

G. SPECIFICATIONS

States use method specifications for micro-surfacing projects. As far as mixture design is concerned, these specifications set requirements for two of the component materials, aggregate and emulsion. No requirements are set for other materials such as water, mineral filler, and additive. The amount of mineral filler is generally controlled by gradation. Amount and usage of water and additive are left up to the contractor. Only a few States specify any requirements for mixture design. Where specified, the tests follow either ISSA guidelines for micro-surfacing or Marshall test procedures for hot mix asphalt. Current ISSA mixture design procedures are not ASTM or AASHTO standard tests and their repeatability is not well established. Similarly, Marshall test procedures may not be appropriate for cold mixtures.

Construction specifications address types of equipment and placement operation in general terms. **Most of the quality control is left up to the contractor and representatives from the mixture design laboratory or the emulsion supplier**. The success of micro-surfacing application and eventual performance is therefore affected by experience level of the contractor who is not only responsible for placement operation but also for the quantity adjustment of some of the mixture components.

Materials control by the State is usually limited to sampling and testing of the aggregate and the mixture for ensuring conformance with the specification. Extraction tests are run on the mixture samples to check the percentage of asphalt cement and aggregate. The results of extraction tests, however, may not be accurate in every instance due to polymer in the emulsion. In some instances, extraction of asphalt cement from mixture was found to be considerably less (up to 1 1/2 percent) than the asphalt cement originally placed in the mixture. A recent study by ISSA identifies the Troxler (nuclear gauge, ASTM D4125) and Soxhlet (modified Texas 215F) as more appropriate methods for determining binder content for micro-surfacing systems.

Comments

Attainment of a quality product and long term performance is dependent on quality material, good design, and quality construction. **While improvement in the design area will take a larger, coordinated effort and some time, improvement in the construction area can be effected immediately.** One way to ensure quality product is to strengthen existing construction criteria through use of end result specifications. End result specifications cover those items that can be identified and are present at the end of construction. These items generally do not change over time.

One more approach to ensure a quality product and long term performance is through the use of warranty specifications. A warranty clause may include items covered under both end result and performance specifications. Performance specifications address items that can change over time. FHWA is currently working with the industry and several States to develop guidelines for a warranty clause. Once completed, the warranty clause will be field tested in several States under FHWA Special Experimental Project No. 14. Examples of items that can be covered under each type of specification include:

<u>End Result Items</u>

- finished surface
- longitudinal and transverse joints
- edges
- time at which surface can be opened to traffic
- cross-section
- surface friction

<u>Performance Items</u>

- flushing
- raveling and debonding
- surface friction
- rutting
- noise levels

Example construction criteria for some of the items are discussed previously in this paper. **These criteria should not be construed as recommended values, but rather as suggestions.** Each State highway agency is encouraged to develop its own end result criteria that are appropriate for the variables encountered in that State. When developing criteria, it is important that all requirements be enforceable. Requirements that are difficult to enforce should not be used because the compliance cannot be measured in the field. To verify the applicability of the specifications, the agency may develop an experimental work plan to determine which requirement is enforceable.

PERFORMANCE

Performance of micro-surfacing depends on many factors such as climatic conditions, traffic volumes, existing pavement conditions, quality of materials, mixture design, and construction quality. Performance of micro-surfacing for its two major uses, filling of wheel ruts and providing a texturing coarse with improved surface friction characteristics, is summarized below. Also discussed is micro-surfacing performance when used in other applications. It should be noted, however, that sufficient information on "other applications" is not yet available and more long-term performance information is needed. The performance information in this paper is based on extensive field reviews, review of State performance reports and other literature, and discussions with user agencies and industry.

A. RUTTING

Rutting is caused by the progressive movement of materials under repeated loads either in the asphalt pavement layers or the underlying base. This can occur either through consolidation or through plastic flow. The ability of micro-surfacing to be tapered to a thin edge and laid in various thickness makes it well suited for filling wheel ruts. When properly designed and constructed, and **used on structurally sound pavements**, micro-surfacing has generally performed well in resisting wheel ruts for 4 to 7 years under various climatic and traffic conditions. Reconsolidation during this period has generally been limited to 10 mm, especially when the original ruts were 20 mm or less.

The Kansas DOT, which has placed over 1,300 lane-km of micro-surfacing on several heavily trafficked pavements over the last 8 years, has obtained good performance from micro-surfacing. Kansas is obtaining up to 5 years of service before recurrence of substantial 15 mm or more rutting.

The Pennsylvania DOT has used micro-surfacing as a rut filler on both asphalt and PCC pavements since 1982. Pennsylvania has developed several reports on evaluation of micro-surfacing projects [11,13]. In Pennsylvania micro-surfacing (Ralumac) has performed well in resisting rerutting relative to other thin alternatives. Several rut filling projects were monitored for a period of 3 to 5 years. Results indicated that micro-surfacing resisted reformation of ruts, particularly in areas where rut depths were less than 20 mm. For example, ruts of 25 to 50 mm rerutted 6 to 13 mm after 3 years and to 16 mm after 5 years. This compared to less than 3 mm for areas where original rut was 20 mm or less.

A current study by Pennsylvania DOT indicates that micro-surfacing placed between 1989 and 1991 to fill 13 mm ruts on PCC pavement or bridge decks has to date resisted recurrence of significant mechanical wear and abrasion. A 1993 field review of several micro-surfacing projects in Pennsylvania supports the State's findings.

The Texas DOT, a major user of micro-surfacing since 1988 (though the first micro-surfacing project was constructed in 1984), has used micro-surfacing to fill wheel ruts. Although most of the Texas projects are 5 years or younger, reasonably good results have been observed under a wide variety of climatic and traffic conditions, and the acceptance of micro-surfacing is growing among Texas DOT districts.

A 1984 rut-filling project in Texas resisted significant rerutting for more than 6 years [14]. A field review of several 3-year old projects in 1991 revealed no significant wheel consolidation, and it appeared that several more years of good performance was possible from those projects. A recent Texas report [12] rates micro-surfacing rut-filling performance as 3.84 on a scale of 0 to 5, with 5 being the best rating.

The North Carolina DOT has placed micro-surfacing projects on Interstate and other high volume roads since 1988. Projects were constructed to fill rut depths ranging from 10 to over 25 mm. A field review of several projects in 1992 revealed that micro-surfacing is performing well in resisting rerutting.

The Tennessee DOT has been using micro-surfacing to fill ruts on high volume roads since 1989. Though long-term performance data are not yet available, reasonably good results have been obtained for texturing and rut-filling projects. Tennessee expects 5 or more years of service life from micro-surfacing. A field review of several projects in 1992 supported the State's expectations.

Oklahoma DOT completed its first micro-surfacing project in 1983. Since then over 1,930 lane-km have been treated with micro-surfacing under varying traffic conditions. With few exceptions, micro-surfacing has provided a performance life of 5 to 7 years. Oklahoma recommends micro-surfacing for rut filling and restoring pavement cross-section profile [10].

The Ohio DOT has constructed over 600 micro-surfacing projects since 1987 (a few other projects were constructed between 1984 and 1986) to fill ruts and provide improved surface friction. Many projects were constructed on asphalt surfaces over concrete base. While a few projects have performed unsatisfactorily due to construction and design problems, the majority have performed well. Micro-surfacing projects in Ohio have generally performed well for 4 to 7 years, depending on the traffic, existing pavement condition, and design/construction quality. A field review of various projects confirmed the State's experience.

A 1989 Arkansas report on a 1985 micro-surfacing project indicates no significant re-formation of rutting after 4 years of placement [15].

Two micro-surfacing projects placed in 1989 on a heavily travelled interstate in Wisconsin were field reviewed in 1992. The projects did not exhibit reformation of significant ruts (i.e., original ruts of 10 to 20 mm rerutted to only 5 mm after 3 years).

B. SKID RESISTANCE

Pavement friction characteristics depend on both micro-texture and macro-texture. Micro-texture refers to the detailed surface characteristics of the aggregate contained in the material. A suitable micro-texture establishes effective areas of contact between the tire and aggregate on the road surface. Macrotexture refers to the general coarseness of the surface material that promotes bulk drainage of water across the surface to provide proper interaction with the tire. Several user agencies consider a skid number equal to or greater than 40, measured at 65 km/hr, provides adequate surface characteristics for normal conditions of wet-weather driving.

User States' experience with respect to skid resistance has been very positive. While actual skid numbers depend on the aggregate type and gradation used, initial numbers ranging from the mid 40's to the high 50's have been fairly common for micro-surfacing projects. Long-term skid resistance results collected by various States indicate good performance all through the service life of micro-surfacing.

Oklahoma has found that micro-surfacing provides adequate surface friction for at least 4 years under traffic volumes up to 70,000 ADT [10].

Pennsylvania indicates good long-term skid resistance performance for micro-surfacing placed over both asphalt and concrete pavements. Skid data collected for up to 5.5 years on several high volume roads showed that average friction numbers varied from 40 to 50. On several projects, friction numbers were observed to actually increase with age [11].

Experience of Ohio, Virginia, West Virginia, Tennessee, Texas and other user States has been very positive in this regard. With respect to skid resistance, Texas rates micro-surfacing as 4.52 on a scale of 0 to 5 with 5 being the best rating [12].

C. RAVELING/DEBONDING

Raveling is separation of aggregate from the mix. Micro-surfacing has been used to address raveling by a number of States with good results. A project placed in Ohio to address raveling of existing wearing surface on an interstate performed well for over 5 years [16]. Several other projects in Ohio have performed similarly.

Tennessee has used slurry seals and micro-surfacing to cover raveled OGFC pavements since 1989. These projects are generally exhibiting good performance.

A project constructed in Oklahoma over a badly raveled and rutted OGFC section in 1990 was evaluated after 3 years. No raveling and minimal rutting (less than 10 mm) were observed on this project.

D. CRACK SEALING/FILLING

Cracking can be characterized into two broad groups: load-related and nonload-related. The principal class of load-related cracking is fatigue cracking and of nonload-related cracking is low-temperature cracking. The cracking can also be described according to its geometry, such as longitudinal, transverse, alligator or map, and block, or by the mechanism that caused the cracking, such as slippage, shrinkage, and reflection.

Micro-surfacing, like other thin treatments and overlays, offers no long term resistance to development of reflective cracks. During reviews of completed projects in several States, it was observed, however, that micro-surfacing can delay the development of reflective cracks when the cracks are generally inactive (cracks that exhibit no or minimal horizontal or vertical movements such as closely spaced random or block cracking or longitudinal cracking).

Oklahoma reports that micro-surfacing placed on several projects resisted reflection cracking for up to 4 years when 100 percent of cracks reflected through [17]. Review of several projects in Ohio indicated that most of the cracks reflected through the micro-surfacing within the first three years. These cracks, however, were relatively narrow and there was no deterioration at these cracks.

A few studies have shown that increasing the layer thickness of micro-surfacing will not have any positive effect on micro-surfacing's ability to delay reflective cracking. A research project in Oklahoma revealed that increasing the micro-surfacing thickness, from 13 to 28 mm, will have no positive effect in terms of reducing reflective cracking [17]. Pennsylvania has also evaluated the effect of application rate and thickness on the crack retardation. Their evaluations did not show any benefit in increasing the application rate or layer thickness over the normal State practices [13].

Oklahoma has also experienced good performance when micro-surfacing was used in filling wide cracks and depressions in pavements.

Tennessee, which has nearly 3 years of substantial experience with micro-surfacing, reports that reflective cracking in micro-surfaced sections is usually less than in sections with thin HMA overlays.

E. FLUSHING

Some States use micro-surfacing to address flushing on asphalt pavements. Texas, which frequently applies micro-surfacing to address light to moderate flushing, rates its performance with respect to flushing as 3.74 on a scale of 0 to 5 [12].

F. INTERLAYER

Pennsylvania and Oklahoma have used micro-surfacing as an interlayer, and both have obtained good performance. The use of micro-surfacing has not prevented joints or cracks from reflecting through the HMA layer. However, interlayers have been observed to retard formation of cracks [10].

COST

Micro-surfacing costs vary depending on many factors including location, availability of quality materials and contractor, application rates, maintenance of traffic, and other bid items. The number and size of projects in each State also affect the application cost in that State. Currently several methods are used for measurement and payment of micro-surfacing. Measurement methods include (1) measurement of quantity of aggregate and polymer-modified emulsion; (2) measurement of quantity of composite mixture; and (3) measurement of surface area. Payment is made under either contract unit price of component materials and composite mixture, or contract unit price per square yard. Table 5 gives measurement methods and basis of payment for micro-surfacing projects in several States.

Micro-surfacing is approximately two to three times the cost of hot mix asphalt concrete on a weight basis. Since its unit cost is higher, the cost-effectiveness of micro-surfacing is dependent on the concept that thinner applications can be utilized. Thinner applications also reduce adjustments to curbs, shoulders, drainage inlets, bridge expansion dams, and guardrail. When used for filling wheel ruts, micro-surfacing cost-effectiveness depends on negating the need for usually used combined milling and overlay operations. When compared with other surface treatments such as slurry seals and chip seals, engineering judgment and performance experience together with life cycle cost analyses need to be considered in selecting an appropriate technique.

While there are few formal studies examining the cost effectiveness of micro-surfacing, user States generally believe that micro-surfacing is a prudent and cost-effective technique for texturing and filling wheel ruts on high volume roads.

TABLE 5 MEASUREMENT METHODS AND UNIT COST OF MICRO-SURFACING

STATE	MEASUREMENT/PAYMENT BASIS					TYPICAL UNIT COSTS ($)	
	AGGREGATE (TON)	MODIFIED EMULSION TON/GAL.	FILLER	MIXTURE (TON)	SURFACE AREA (SQ. YD)	BASED ON WEIGHT Mg (TON)	BASED ON SURFACE AREA m^2 (yd^2)
NC	√	√				99–110 (90–100)	1.13–1.25 (0.94–1.05)
OH					√		1.44–1.68 (1.20–1.4)
PA	√	√		√		126–149 (115–135)	1.80–2.40 (1.50–2.0)
VA				√		99–112 (90–102)	
TN	√	√				83–100 (75–90)	
TX				√		88–94 (80–85)	
OK	√	√				88–94 (80–85)	
KS	√	√	√			92–97 (83–88)	

Notes:

- Above unit costs pertain to applications on high volume roads in rural areas. The cost includes maintenance of traffic, mobilization, and other minor incidental work. Pavement striping is generally paid separately. Applications in urban areas cost more depending on the traffic maintenance requirements.
- For payment purposes, Pennsylvania uses quantity method for rut filling and surface area method for texturing course.
- Ohio average application rate is 11.9 to 16.3 kg/m².
- Average application rates for texturing course in TX, OK, and KS are approximately 11.9 to 13.5 Kg/m².
- Application rates in NC range from 9.7 to 19 kg/m². North Carolina uses surface area method if contracts are awarded by central office.
- Tennessee uses a tack coat prior to micro-surfacing application on all projects. This increases the overall cost by 1 to 3%.

SUMMARY AND ISSUES

As more and more pavements reach their terminal serviceability, highway agencies are becoming increasingly concerned with finding appropriate surface rehabilitation techniques that help extend pavement service life in the most cost-effective manner. One promising product, micro-surfacing, has been used in the United States as a surface rehabilitation/maintenance technique since 1980. When properly designed and applied, micro-surfacing has performed well in improving surface friction characteristics and filling wheel ruts under varying traffic and climatic conditions.

Several States routinely use micro-surfacing technology, but there are many others that are either not familiar with this product or have constructed only a few projects. One reason is scattered information on the design, construction, and performance of micro-surfacing. While the performance of micro-surfacing has been documented by some States, many other users have not adequately evaluated/documented this technology. Increased availability of performance data is expected to eventually improve the acceptance of this technology by the highway community.

There is one principal engineering issue related to the use of micro-surfacing which needs to be addressed. This issue concerns current mixture design procedures. Currently, mixture design laboratories use two procedures to determine the optimum asphalt content. Some laboratories use ISSA procedures while others use a modified Marshall method. There is a lack of consensus among the various designers as to the repeatability and/or applicability of several of the procedures. While performance to date has been generally positive, it does not lessen the need for repeatable mixture design procedures. There is also a need for reviewing the current mixture standards since they were developed using relatively few material combinations. The industry is aware of this issue and is taking steps to standardize and adjust its design test procedures and standards.

Additionally, to improve the acceptance of micro-surfacing training of both owner agencies and contractors is warranted. Initial unsatisfactory applications, mostly by inexperienced contractors, have discouraged many first time users in the past.

Another area of major concern is the lack of effective specifications and construction acceptance procedures. This concern can be addressed at the highway agency level. Development of appropriate construction inspection techniques or use of end result specifications can ensure a quality product and should be considered by the user highway agencies. Each highway agency that has not used micro-surfacing should develop an experimental work plan to evaluate the proper application of this technology appropriate for the variables encountered in that State. While the experiences of user States are valuable sources of information, other States experience may not be an appropriate for local materials and field conditions.

There is one other factor that is affecting the use of this technology. This involves lack of quality aggregate sources and/or availability of the proper gradation within reasonable haul distances. For example, the first micro-surfacing project in Texas was completed in 1984 using aggregate from a Missouri source. While that project performed well, additional projects were not constructed until aggregate sources within Texas were found about 4 years later. Progress in locating suitable aggregate sources could enhance micro-surfacing usage. Another problem is the reluctance of aggregate producers to supply micro-surfacing gradations because of the small market. As the demand for micro-surfacing increases, this problem should subside.

Finally, the technology should continue to develop. Use of different aggregate gradations and construction procedures to optimize surface friction while reducing noise levels should be examined. Use of fibers and gap-graded aggregate gradations in micro-surfacing mixture is beginning to emerge. This area needs additional research and field performance evaluation.

APPENDIX A — Aggregate and Emulsion Testing

Tests on Aggregate

Soundness Test AASHTO T104 (ASTM C88)

This test determines the ability of aggregate to resist weathering disintegration. Among other damage, weathering can reduce the frictional characteristics of a road surface. Approximately 90% of the United States is classified as regions of severe weather, thus subjecting micro-surfacing to freeze-thaw damage. This test is generally performed by SHAs. A maximum of 15 to 20 percent change in aggregate gradation is permitted for micro-surfacing.

This test involves submerging the aggregate in a solution of sodium or magnesium sulfate for 18 hours at a constant temperature. The sample is then removed from the solution, dried to constant weight at 105 - 115 °C, and cooled to room temperature. The cycle is typically repeated for 5 times, after which the sample is washed to remove the salt and is dried. The loss in weight for each size fraction is determined by sieving, and the average percent loss for entire sample is computed.

Los Angeles Abrasion Test AASHTO T96 (ASTM C131)

This test determines the wear and abrasion resistance of coarse size aggregate. Aggregate must be hard enough to resist abrasion and degradation during construction and under traffic. This test is typically carried out by SHAs. For micro-surfacing a maximum abrasion of 30% is permitted.

LA abrasion test is a rigorous pounding of the material in a steel circular cylinder being rotated in such a manner that the aggregate falls and is crushed by steel balls. After tumbling, the fines are weighed and the percentage of material worn away is determined.

Gradation AASHTO T27 (ASTM C136)

This test determines the size of the aggregate by separation through a variety of sieve sizes. The real purpose in establishing and controlling aggregate is to provide and maintain a proper void content in the aggregate. Gradation is important in calculation of theoretical asphalt content. Gradation plays a role in surface texture of micro-surfacing.

Although a complete dry sieve analysis (sometimes a washed test) is performed by the industry materials laboratories, the SHA also conducts gradation tests on the material from the stockpile as part of its compliance program. Two types of gradations with 100% passing 9.5 mm are recommended by ISSA for use in micro-surfacing.

The gradation is determined by doing an analysis with a set of different size sieves in progressively smaller size. Gradation is usually expressed in terms of a percentage passing or a percentage retained on the various sieves.

Sand Equivalent Test AASHTO T176 (ASTM D2419)

This test is used to determine the amount of clay and dust in the fine aggregate. Low sand equivalents may cause excessive asphalt emulsion consumption as well as mixing and setting difficulties. The test is routinely carried out by industry laboratories. A minimum sand equivalent value of 60 is generally required by user agencies.

This test is run on -4.75 mm material. Although cement is considered part of the aggregate gradation, it should not be included in the aggregate sample tested for sand equivalency in order to obtain more representative results. ASTM notes two procedures to run the test. Under one procedure aggregate sample is tested without drying in oven and under the second procedure the sample is first dried at 105°C. For cold mixtures such as micro-surfacing, the first procedure should be used.

Methylene Blue Test ISSA TB 145 (No AASHTO designation)

This test is performed by some laboratories to measure the amount of clays and other organic matter in the aggregate. Clays affect the surface reactivity of the aggregate. This test is run on the 0.075 mm fraction without mineral filler. The test indicates aggregate reactivity and aids in determining additive requirements during the field application. Though no end point (saturation) values of methylene blue are mentioned in ISSA Technical Bullettons (TB), standards have been set by some users which call for rejection of aggregate if the end point exceeds a certain value. While the test is used as an indicator of aggregate reactivity there is no consensus on rejection of aggregate if higher MB value are encountered.

This test is run on the 0.075 mm fraction without mineral filler. In this test the aggregate fines are swirled in a distilled water solution and then mixed with methylene blue dye solution. The amount of methylene blue required to saturate the fines is determined. A high value is normally associated with high reactivity and low sand value.

Specific Gravity AASHTO T84 (ASTM C128)

This test determines aggregate weight in relationship to water. The SG is used in determination of theoretical asphalt content.

Unit Weight Test AASHTO T19 (ASTM C29)

Unit weight of the aggregate sample is determined at various moisture contents in order to determine change in unit weight with changes in moisture content. Unit weight of the aggregate decreases as the moisture content increases (the "bulking effect"). This change in unit weight of aggregate can cause calibration problems since the emulsion is fed at a constant rate (the bulk effect will cause the asphalt content to increase).

Some other commonly used aggregate tests are: Resistance to polishing (ASTM D3319, E303, E660, D3042); Durability (ASTM D3744); Resistance to stripping (ASTM D1664, D1075; AASHTO T283, T182); Asphalt absorption (ASTM D2041, D4469); Cleanliness (ASTM C117 & D422, C123, C142, D2419, D4318).

Tests on Emulsion

Viscosity, Saybolt Furol @ 77°F, sec AASHTO T50 (ASTM D244)

Viscosity is defined as a fluid's resistance to flow. This test determines the pumpability of the asphalt emulsion. Test results are reported in Saybolt Furol seconds. A viscosity range of 20-100 is normally specified, with typical values ranging between 20 and 30.

Settlement Test AASHTO T59 (ASTM D244)

This test is performed to determine the storage stability of the emulsion. It detects the tendency of asphalt globules to settle during storage. Under this test samples are taken from the top and bottom parts. The residue weights are then checked for difference between the asphalt cement of the two samples. This provides a measure of settlement. Generally small asphalt particles will result in a more stable emulsion. Emulsion upon standing undisturbed for a period of 24 hours should show no white, milky colored substance on its surface, but be a homogeneous brown color throughout.

When the asphalt emulsion is to be used promptly, most agencies will accept Storage Stability Test (24 hour, % AASHTO T59 (ASTM D244)). Specifications normally allow .01% to 1% difference in asphalt residue weights.

Some States (e.g., Virginia, Pennsylvania) do not require these tests under their asphalt acceptance program. For micro-surfacing emulsions that contain components with different specific gravities some settling usually occurs. Perhaps, what is important is not the settlement itself but, when agitated, will the suspension be uniform and will the emulsion have the same properties as when originally produced. Tests may be performed to verify and compare properties of emulsion originally produced and after sitting in storage tanks for a few days, and the results can be used for acceptance determination.

Sieve Test AASHTO T59 (ASTM D244)

This test complements the storage stability test and has a somewhat similar purpose. It is used to find the amount of asphalt in the form of rather large globules that may not have been detected in the storage stability test and could affect the pumpability. A maximum value of 0.1% and typical value of 0.01 to 0.05% are used.

Particle Charge AASHTO T59 (ASTM D244)

This test is used to identify the emulsion type. For micro-surfacing, emulsions with positive charge (i.e., cationic) are normally used. Anionic emulsions, however, may also be used.

Residual Asphalt Content AASHTO T50 (ASTM D244)

This test determines quantity of polymer-modified asphalt in emulsion. This information is used to determine design asphalt content based on design emulsion requirements. A minimum residue of 60-62% is normally specified. (Note: this test may have to be modified by using lower temperatures because the higher temperatures may degrade some of the polymers.)

pH Test (not a standard test)

This test is used by some laboratories as an indicator of emulsion reactivity with aggregate. By finding the proper emulsifier and by optimizing the emulsifier dosage and pH value, asphalt emulsions can be adjusted to the aggregate so that the system will mix and set to the desired specification. Emulsifier solution pH is different than finished emulsion pH, which in turn is different and lower than pH of mixture. The pH of the modified emulsion generally ranges from 0.8 to 2.0.

<u>Tests on Evaporation Residue</u>

Absolute Viscosity, 60°C, poises ASTM 2171
Kinematic Viscosity, 135°C, poises ASTM 2170

Viscosity of asphalt cement can be defined simply as its resistance to flow. Asphalt cement viscosity at 60°C has influence on the performance of HMAs and micro-surfacing systems during hot summer days when the pavement temperatures are near 60°C. Low viscosity binders can induce flushing and/or rutting. The viscosity grading of asphalt cements is based on measurements at 60°C. Another measure of viscosity, the kinematic viscosity, is measured at a temperature that approximates the mixing and laydown temperatures used in the HMA construction.

The viscosity test is used for specification compliance and degree of modification in polymer enhanced systems. Minimum absolute viscosity of 8000 poises is specified for modified emulsions to be used in micro-surfacing mixtures.

A capillary tube viscometer is mounted in a constant temperature water or oil bath, which is maintained at 60°C. The viscometer tube is charged with asphalt cement through the larger side until the level of asphalt cement reaches the filling line. After the equilibrium temperature of 60°C is reached, a partial vacuum is applied to the small side of the viscometer tube to cause the asphalt cement to flow. After the asphalt cement starts to flow, the time (seconds) required for it to flow between two timing marks is measured. The measured time is multiplied by a calibration factor to obtain the value for viscosity in poises.

Penetration, 100 gm @ 5 sec. 25 °C AASHTO T49 (ASTM D2397)

This test indicates hardness of asphalt cement and is used as an indicator of asphalt suitability for climatic conditions. It ensures that asphalts of an undesirably low or high penetration are excluded from use. In this test an asphalt cement sample brought to the standard temperature (25°C) is placed under a standard needle. The needle is loaded with a 100 gm weight and is allowed to penetrate the asphalt cement sample for 5 seconds. The depth of penetration is measured in units of 0.1 mm and is reported as penetration units. For example if the needle penetrates 5 mm, the penetration of asphalt cement is 50.

Specification values for asphalt cement used in micro-surfacing range from 40 to 100 with 50 to 90 as typical. Penetration values on the modified residue are usually 25-30 less than values of the base asphalt cement. Climatic conditions should be considered when selecting a range. It is good practice to use harder (low penetration) asphalt in areas with moderate to hot climates and softer asphalt in areas where winters are severe.

Softening Point AASHTO T49 (ASTM D36)

This test is used to estimate the micro-surfacing resistance to wheel rutting at warm temperatures. The softening point test can be defined as the temperature at which an asphalt cement cannot support the weight of a steel ball and starts flowing. A minimum softening point (temperature) of 57°C is normally specified for micro-surfacing.

The softening point test uses a small specimen of asphalt cast into a nickel sized brass collar which is suspended in a beaker filled with water. A small steel ball is placed on the sample when the asphalt is cool. The bath is then warmed at a controlled rate of 5°C/minute. When the asphalt cement softens, the ball and asphalt cement specimen sink toward the bottom of the beaker. The temperature is recorded at the instant when the softened asphalt cement touches the bottom plate.

Ductility, 25 °C, 5 cm/min. cm ASTM D113

The ductility of asphalt cement is considered to be related to pavement performance. Some in the industry question the importance of this test to determine field performance. Ductility measures the degree of elongation of the residue on a longitudinal axis. A pavement, however, is subject to flexing, which is an up and down motion rather than being pulled apart solely on a longitudinal axis. Specification values range from 40 to 120. Higher values are preferable.

Under this test the asphalt cement sample is brought to temperature in a water bath maintained at a temperature of 25 °C. The two ends of the sample are separated at the rate of 5 cm/minute until rupture. The ductility of asphalt cement is measured by the distance to which it will elongate before breaking when two ends of a briquette specimen are pulled apart at a specified speed and temperature.

Polymer Content in Asphalt Residue

A few States use analytical methods to determine polymer content in the emulsion.

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