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MTI MINETA TRANSPORTATION INSTITUTE

Manual for Slurry Surfacing

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CSUTC California State University Transportation Consortium

CALIFORNIA STATE UNIVERSITY Chico

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MANUAL FOR SLURRY SURFACING

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16. Abstract

Slurry surfacing, which includes slurry seals and microsurfacing, is just one type of many maintenance treatments that can preserve pavements and defer the need for and cost of a reconstruction project. Slurry seals, which were developed first, are placing on an existing pavement. They proved to be a promising technique in maintaining road surfaces. Currently, slurry seals are used for a multitude of surfacing projects throughout the world, and are accepted as a cost-effective maintenance treatment.

Microsurfacing, first developed in the 1960s, is an improved version of a slurry seal. Microsurfacing uses a more complex form of slurry surfacing involving special "engineered" polymer-modified Quick Setting (QS) asphalt. Over time, the goals were met with specialized mixes that are able to address more severe distresses with a faster set time. Microsurfacing is now widely used throughout the United States.

Slurry Surfacing, as a pavement preservation treatment, provides an economical means for maintaining and improving the functional condition of an existing pavement. This manual presents the best practices for construction of slurry surfacing which includes guides for trouble shooting problems. Besides project selection, types of slurry surfacing, construction issues, and the design process for slurry surfacing are also covered in this manual.

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EXECUTIVE SUMMARY

This manual is one of several designed to empower local agency staff and contractors, through training, to choose the right treatment at the right time to optimize preventative maintenance funds. Most local agencies defer road maintenance over many years, and there are thousands of miles of public roads that are currently in poor condition. With new state funding available for maintenance and construction projects, proper road preventative maintenance is an issue of paramount importance. Slurry surfacing is just one type of many maintenance treatments that can preserve pavements and defer the need for and cost of a re-construction project.

Slurry seals were first developed in the 1930s, and they proved to be a promising technique in maintaining road surfaces. By the 1960s, with improved emulsions, and continuous flow machines, real interest was shown in using slurry seal across a wide range of applications. Currently, slurry seals are used for public roads, highways, airport runways, parking lots, and a multitude of other surfacing projects throughout the world. Slurry seals have been accepted and incorporated into many maintenance programs as a cost-effective maintenance treatment.

Microsurfacing was first developed in the 1960s in Germany and is an improved version of a slurry seal. Microsurfacing uses a more complex form of slurry surfacing involving special “engineered” polymer-modified Quick Setting (QS) asphalt. Over time, the goals were met with specialized mixes that are able to address more severe distresses. These mixes use polymer-modified emulsions (PME) that contain chemical additives, as well as mineral fillers, such as cement. Microsurfacing is now widely used in the United States, and in California in particular.

Slurry Surfacing as a pavement preservation treatment, which includes slurry seals and microsurfacing, provides an economical means for maintaining and improving the functional condition of an existing pavement. It can be used repeatedly or in conjunction with other preventative treatments that slow deterioration or correct isolated pavement defects.

This manual is one of three manuals being developed by the California Pavement Preservation Center (CP^2 Center) for preventative maintenance. The three manuals are 1) Slurry Surfacing, 2) Chip Seals, and 3) Cape Seals. Besides project selection, and types of slurry surfacing, construction issues and the design process for slurry surfacing are also covered in this manual. By focusing on preventative maintenance treatments for extending the life of local agencies’ aging roads, these manuals will ultimately offer the necessary training and references for agencies to make the best decisions regarding the placement of pavement preservation treatments.

I. INTRODUCTION

BACKGROUND

In 2018, California's legislature passed Senate Bill 1 (SB-1) to raise revenue for transportation infrastructure improvements through state gas taxes. This money is being distributed to all cities and counties throughout the state. The purpose of developing this SB-1 funded manual is to provide training for local agency staff so that they will have the ability to recognize their maintenance needs, and to develop the most cost-effective strategies for preserving their aging hot mix asphalt (HMA) pavements.

Slurry seals were first developed in the mid-1930s in Germany and were first used on the Berlin-Staaken Airport. The consistency of the mixtures made them easy to spread with brooms, squeegees, and spreader boxes. Slurry proved to be a promising technique in maintaining road surfaces, and according to PPRA, the Pavement Preservation and Recycling Alliance, California began using slurry seal in the late 1930s. It wasn't until 1955 that a machine was built specifically for slurry seal. By the 1960s, with improved emulsions and the introduction of continuous flow machines, real interest was shown for using slurry seal in a wide range of applications. Currently, slurry seals are used for public roads, highways, airport runways, parking lots, and a multitude of other surfacing needs throughout the world. The technology has been accepted and incorporated into many maintenance programs as a cost-effective maintenance treatment.

Microsurfacing was also developed in Germany, in the late 1960s through the early 1970s, according to the Pavement Preservation and Recycling Alliance.[1] The goal was to determine a method for applying a thicker application for filling wheel ruts, and to avoid destroying pavement markings. Over time, specialized mixes were developed using polymer modified emulsions that met the goal. Microsurfacing was introduced in the United States in 1980, and it has proved to be a cost effective way to fill surface wheel rutting, and to treat many other road surface problems.

PURPOSE OF SLURRY SURFACING

Most local agencies have deferred road maintenance over many years, and there are thousands of miles of public roads that are currently in poor condition. With new funding being available for maintenance and construction projects through SB-1, the importance of using proper road maintenance strategies is paramount. Slurry surfacing is just one treatment type among many maintenance treatments that will preserve pavements until a re-construction project can be designed and funded.

"Slurry surfacing" is a generic term used to describe the two common types of slurry treatments:

It was stated that slurry surfacing (slurry seals and microsurfacing) maintenance can dramatically extend pavement life by up to eight years per the NCHRP Synthesis 223 (Geoffrey, 1996).[2] Although an untreated asphalt pavement is still adequate after several years of use, pavement deterioration will have already begun. For maximum benefit to

be derived from a slurry seal maintenance program, treatment needs to be started before significant deterioration has occurred as a preventative maintenance treatment.

Slurry surfacing consists of mixtures of asphalt emulsion, graded aggregates, water, and other additives, such as mineral filler and polymers. The mixture is made and placed on a continuous basis using a special slurry surfacing machine. The machine, which is usually truck-mounted, meters the mix components in a predetermined order into a pug mill for uniform mixing. The typical mixing order is aggregate, followed by cement (microsurfacing only), water, additives and the emulsion. Figure 1 illustrates the process and equipment for slurry sealing. The microsurfacing process is similar, but with additives and an auger in the spreader box.

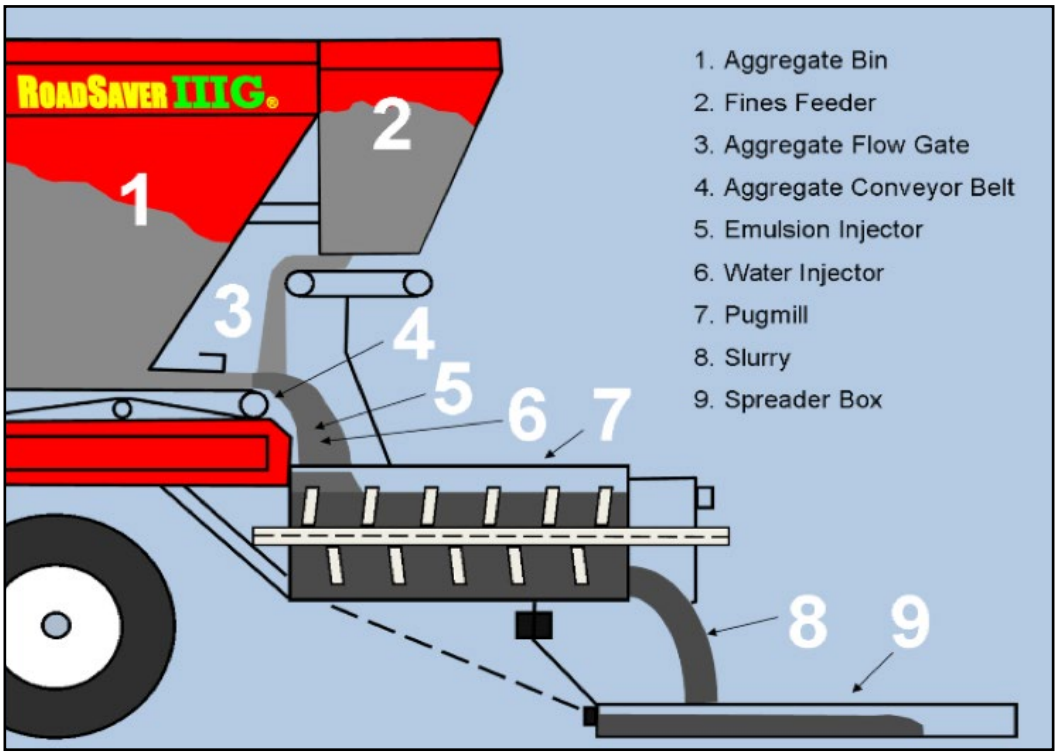

Figure 1. Schematic of a Slurry Surfacing Machine

Note: RoadSaver, 2019.

While conventional slurry seal is widely used as an economical treatment for sealing and extending the service life of both urban and rural roads, microsurfacing had added capabilities due to the use of high-quality materials, including advanced polymers and other additives.

The resulting slurry surfacing mixture is a brownish, thick, free-flowing mix that is spread via a spreader box over the existing road surface. The mixture forms an adhesive bond to the old pavement.

Since the slurry mixture contains a water-based asphalt emulsion, the water evaporates and the emulsion “breaks” and cures on the pavement surface. The asphalt particles coalesce into films, creating a cohesive mixture. The slurry mixture cures, with further loss

of water, into a hard-wearing, black, dense-graded asphalt/aggregate mixture that is tightly bonded to the existing pavement.

Slurry seals use a mixture of QS asphalt emulsions and aggregate as small as 1/8 inch maximum size, and they are spread thin—usually only to the thickness of the maximum aggregate size in the mix. No special additives or mineral fillers are used, and the emulsion may or may not be polymer-modified.

REAS (a proprietary product) is a type of special slurry seal produced at a central mixing plant that uses a more complex form of slurry seal involving twice the asphalt compared to the Rubberized Polymer Modified Emulsions (RPME) emulsions. The RPME slurry contains crumb rubber modifier, chemical additives, and mineral fillers such as cement. The resulting mixture can be spread in a heavier application than a traditional slurry seal. The emulsion for the REAS always uses crumb rubber modifier, and special additives are used to create a “chemical” break that is less dependent on temperature and weather conditions. Since the REAS slurry is mixed off-site at a central mixing plant, a nurse truck is used to supply a specialized slurry paver with the slurry mixture.

PURPOSE OF THE MANUAL

This manual is one of several designed to empower local agency staff, through training, to choose the right treatment at the right time to optimize their maintenance funds. Most local agencies have deferred road maintenance over many years, and thousands of miles of public roads are currently in poor condition. With new funding being available for maintenance and construction projects, the importance of proper road maintenance is paramount. Slurry surfacing is one of several types of maintenance treatments that will preserve pavements until a re-construction project can be designed and funded. Slurry surfacing extends the life of a pavement by preventing moisture intrusion into the base and subgrade. When properly designed and constructed, a slurry surfacing is a cost-effective tool that provides improved life cycle benefits.

As mentioned above, slurry surfacing is a generic term to describe treatments commonly referred to as:

- Slurry seals
- Microsurfacing
- Surface treatments

It has been shown that slurry surfacing provides an improvement in performance and extends pavement life. Although an untreated asphalt pavement may still be adequate after several years of use, pavement deterioration has already begun and the application of a slurry seal needs to be applied as a preventative maintenance measure before significant deterioration has occurred.

Slurry surfacing is a cold mix paving system that has the following benefits for asphalt surfacing:

- Creates a weathertight surface
- Provides color and texture in a single pass
- Fills small cracks and surface voids
- Green technology, using less energy over hot mix applications
- Treatment that is more environmentally friendly, that doesn't create smoke
- Lower-cost treatments using fewer materials
- Thin lift doesn't require grinding at joints or concrete gutters
- Quicker construction
- Stops loss of fines from old surface

Microsurfacing is a more complex form of slurry surfacing involving special "engineered" polymer-modified QS asphalt emulsions, chemical additives, and mineral fillers such as cement. The resulting mixture can be spread at several times the thickness of the largest aggregate, allowing thicker layers to be placed to fill ruts and other surface irregularities. The emulsion used for the microsurfacing is always polymer-modified, and special additives are used to create a "chemical" break that is less dependent on temperature and weather conditions. The application of microsurfacing to correct road defects includes:

- Correction of minor surface profile irregularities
- Wheel path rut filling
- Higher-traffic areas requiring higher durability
- Placing at night or in cooler temperatures
- Shorter closure times for traffic with faster set control additives

ORGANIZATION OF THE MANUAL

This manual is one of three manuals for preventative maintenance training. The three manuals are 1) Slurry Surfacing, 2) Chip Seals, and 3) Cape Seals. Besides “Project Selection”, the “Types of Slurry Surfacing”, and “Design Process for Slurry Surfacing”, and “Construction” are also covered in this manual. A reference list for this manual is also included followed by the appendices, which include:

A. Sample specifications

B. Mix Designs

B-1. Example for Slurry Seal

B-2. Example for microsurfacing

C. ISSA equipment calibration

II. PROJECT SELECTION

WHEN SHOULD SLURRY SURFACING BE USED?

Slurry Seals

Slurry seals with emulsions are primarily used as a preventative treatment to seal the pavement and improve aesthetics and surface texture. Slurry seals should be used to:[3]

- Seal sound and oxidized pavements
- Restore surface texture by providing a new skid-resistant wearing surface
- Improve waterproofing characteristics
- Correct raveling
- Provide a new surface where weight restrictions preclude the use of heavier overlays, i.e., bridge decks
- Provide a new surface where height restrictions are a problem, i.e., under-crossings
- Significant defects on the pavement surface should be repaired prior to slurry surfacing
- Pavement edge deterioration should also be repaired
- Slurry surfacing offers improved aesthetics by offering a new uniform surface appearance for improved striping and other traffic delineation *Three types of slurry seals are generally used, including the following:*
- Type I Slurries are used to treat surface voids and cracks, as well as minor surface defects, primarily for lightly trafficked roads, parking lots, and bicycle paths where a smoother surface is desired.
- Type II Slurries are used to treat moderate surface defects such as surface voids and raveling, and they are typically used on streets and roadways with moderate to heavy traffic.
- Type III Slurries are used to improve friction and skid resistance for heavier traffic loads, i.e., arterial streets and highways.

Microsurfacing

Both slurry seals and microsurfacing offer many of the same basic benefits to a pavement. Microsurfacing offers several additional uses and benefits that are beyond what a slurry seal can offer:

- Correction of surface profile or smoothness
- Filling of wheel path ruts (up to 1.5” in multiple lifts)
- Use in cooler, higher-humidity weather (e.g. night work, coast areas)
- Carrying traffic sooner after placing
- Providing a more durable surface than a slurry seal
- Longer-lasting treatment with heavier traffic

All types of slurry surfacing can be applied to either asphalt (HMA) or Portland Cement Concrete (PCC) pavements and can provide a long-lasting surface treatment for both pavement types. Slurry surfacing can also be applied over chip seals; this application is referred to as a cape seal. Both slurry seals and microsurfacing are “green technologies” that require less energy for the production of the emulsion and for construction. The Pavement Preservation and Recycling Alliance has a “Sustainability” module that includes a *Cost and Green Calculator* so that a comparison can be made between the conventional approach versus the preservation and recycling approach to treatments.[4] This calculator allows the engineer to quickly choose the most cost effective treatment.

WHEN SHOULD SLURRY SURFACING NOT BE USED?

Slurry Seal

Slurry seals should not be used to:[5]

- Correct surface profile
- Fill potholes
- Alleviate cracking
- Correct rutting
- Improve the structural integrity of the existing pavement If a project has the distresses listed above, repairs need to be made prior to slurry sealing. Best practices would be to place a pavement preservation treatment prior to the pavement reaching a Pavement Condition Index (PCI) of less than 80.

Figure 2 shows PCI values from 0–100 and their corresponding pavement condition rating.

Figure 2. StreetSaver Pavement Condition Index Classifications

Note: County of Riverside Department of Transportation, 2014.

Microsurfacing

Microsurfacing should not be used to:

- Fill potholes
- Improve the structural integrity of the existing pavement
- Improve traffic capacity

III. TYPES OF SLURRY SURFACINGS

SLURRY SEALS

Types of Slurry Seals

There are three types of slurry seals, defined by their aggregate gradation:[6]

- Type I slurry uses a fine aggregate gradation (#200 x 1/8”)
- Type II slurry is the most commonly used mixture, with medium aggregate gradation (#200 x 1/4”)
- Type III slurry uses a coarser aggregate gradation (#200 x 3/8”)

Type I, with smaller aggregate, is generally used for parking lots, courts (tennis, basketball), bicycle paths, and light traffic areas. Type II is the most commonly used slurry, and it is used in moderate to heavy traffic areas. It is used to seal and correct raveling issues, protect against pavement oxidation, and improve skid resistance. Moderate to heavy traffic areas would be collector and arterial routes, as well as residential streets. Type II can also be used on other pavement areas which are showing signs of distress. Type III is used for heavy traffic areas, including truck routes, highways, and areas where heavy equipment operates. Type III would be the most effective mixture to increase skid resistance, and to decrease the chance of hydroplaning in wet conditions. Table 1 shows the aggregate gradation for the different types of slurry surfacing between Caltrans, ISSA, and the Greenbook.

Table 1. Slurry Surfacing Aggregate

	Percentage Passing			
Sieve Size	**Type I**	**Type II**	**Type III**	**Stockpile Tolerance from the Mix Design Gradation**
3/8” (9.5 mm)	100	100	100	
No. 4 (4.75 mm)	100	94–100 **90–100	70–90	± 5%
No. 8 (2.36 mm)	90–100	65–90	45–70	± 5%
No. 16 (1.18 mm)	60–90	40–70 **45–70	28–50	± 5%
No. 30 (600 µm)	40–65	25–50 **30–50	19–34	± 5%
No. 50 (330 µm)	**25-42	**18–36	**12–25	
No. 100 (150 µm)	**15–30	**10–24	**7–18	
No. 200 (75 µm)	10–20	5–15	5–15	± 2%

**GREENBOOK, 2018, differences.

Note: Caltrans 2018, and Greenbook 2018.

Types of Emulsions for Slurry Seals

For slurry seals, water-based asphaltic emulsions are usually modified with latex, which is an asphalt emulsion with rubber particles. The latex does not mix with the asphalt. Rather, the latex and the asphalt particles intermingle to form a 3-D structure, as illustrated in Figure 3. The latex used is either neoprene or styrene butadiene styrene (SBR). When modified with latex, slurry seal emulsions are referred to as PMCQS-1h or, more commonly, LMCQS-1h where “LM” stands for “latex-modified”. Slurry seal emulsions may also be unmodified, or they may be modified with polymers, ground tire rubber, fiber, or special additives for quick set times. REAS (Rubberized Emulsion Aggregate Slurry), a proprietary slurry seal, uses CSS-1h and terminally blends it with crumb rubber modifier (CRM) in a batch process to produce a special asphalt binder.

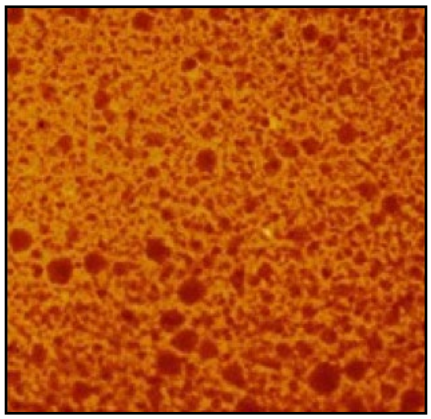

Figure 3. Micrograph of a Latex/Asphalt Cured Film

Note: Holleran, 2002.

Common PM-QS emulsions for slurry surfacing include:

- PMCQS-1h
- PMQS-1h
- Rubberized Polymer-Modified Emulsion (RPME)

MICROSURFACING

Types of Microsurfacing

As with slurry seals, there are three types of microsurfacing. However, Type I is presently not being used by Caltrans. Microsurfacing, with its faster setting emulsion, can be used for leveling, whereas slurry seal cannot be used for leveling. Table 1 presents the aggregate gradation for slurry surfacing. Severe rutting or leveling can also be corrected by using a skin patch of 1/4” hot mix asphalt prior to slurry surfacing. It can also be corrected by digging out the wheel paths and placing hot mix asphalt in the dig out areas prior to applying slurry surfacing.

Types of Emulsions for Microsurfacing

Typically, microsurfacing only uses polymer-modified (PM), quick-set (QS) emulsions. The polymer enhances stone retention, especially in the early life of the treatment. In addition, the added polymer reduces damage from more extreme temperatures and allows the microsurfacing to be placed at lower ambient temperatures than slurry seals. Polymers also improve the asphalt's softening point and flexibility, which enhances the treatment's crack resistance, allowing thicker applications (two to three stones thick) to be placed. Thicker applications allow microsurfacing to be used to fill wheel ruts, as shown in Figure 4. Generally, microsurfacing and slurry seal mixtures with a polymer-modified emulsion do not reduce reflective cracking.

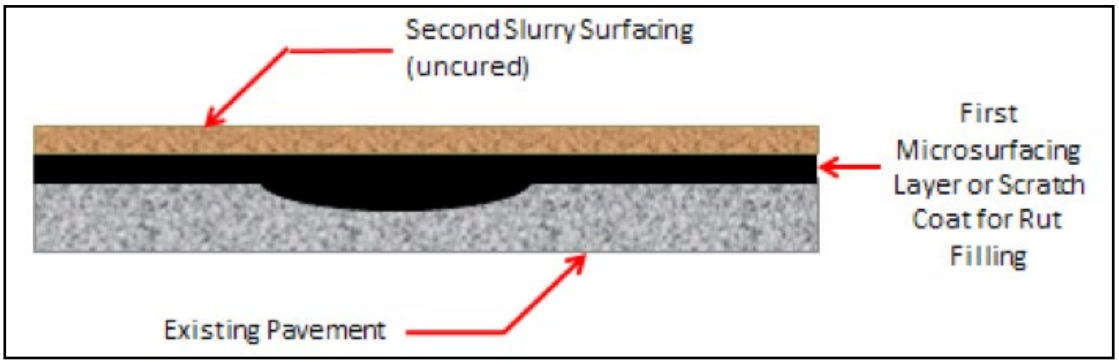

Figure 4. Microsurfacing Used for Rut Filling

Figure 5 shows a project in progress using microsurfacing for rut filling.

Figure 5. Rut Filling During Construction

Common PM-QS emulsions for microsurfacing include:

- PMCQS-1h
- PMQS-1h
- MSE (microsurfacing emulsion)[7]

FACTORS AFFECTING SLURRY SURFACING PERFORMANCE

The primary factors that affect the performance of slurry seals and microsurfacing include:[8]

- Existing pavement/surface conditions
- Surface preparation prior to slurry surfacing
    - Repairing potholes
    - Repairing rutting
    - Crack sealing
- Materials
    - Aggregate type and quality
    - Emulsions (faster set of the finished product with additives)
    - Additives
    - Filler
- Equipment
    - Calibration of equipment
    - Must be in good condition
    - Trained and qualified equipment operators
- Placement/application practices
    - Existing roadway conditions (deterioration and porosity of the roadway)
    - Maintenance efforts and timing of those efforts prior to application
        - Crack seal in cooler weather, may require low expansion crack sealant material

    - Patch or eliminate rutting in warmer weather
    - Don’t place slurry surfacing if there is a possibility of rain
  - Perform a test strip to
    - Confirm what is a good application rate
    - Calibrate all equipment used on test strip and project
- Traffic conditions (present and future volume and percentage of truck traffic)
  - Average Daily Traffic (ADT)
    - Type II is the preferred application for most roads
    - With heavier traffic, use Type III for slurry surfacing
  - Traffic control plan must address cure times (microsurfacing cures faster than slurry seal)
- Weather and environmental conditions
    - Minimum temperature of at least 50°F before starting a slurry surfacing
    - Ambient temperatures over 103°F may cause binder to re-liquefy, and may require delaying opening to traffic, or water cooling
    - High ambient temperatures may be cause to delay slurry surfacing
    - High ambient temperatures may cause material to have a false break
    - Requires a water pollution control plan be approved and implemented before beginning slurry surfacing
    - Rain may cause binder to wash away and pollute waterways when the emulsion is not cured
  - Temperature (50–103°F)
  - Rainfall
    - Don’t perform slurry surfacing if rain is forecast
    - Make sure you have a storm water pollution control plan in place prior to start of construction

        - Use Best Management Practices (BMPs) for storm water pollution prevention plan; Caltrans has several manuals, i.e. Stormwater Quality Handbooks PPDG, Project Planning and Design Guide, which describe BMPs

    - Wind

- Construction Procedures

    - Surface Preparation

        - Crack sealing

        - Pothole repair

        - Repair rutting (if slurry seal, otherwise microsurfacing can address rutting issues)

    - Equipment requirements include calibration and good mechanical condition

    - Stockpile/project staging area requirements

    - Safety and implementation of traffic control plan

        - Pre-job meeting

        - Tailgate safety meetings

    - Application Conditions: The emulsion must break and form continuous films for the slurry seal to be cohesive.

    - Application rates

        - Verify with test strips, and adjust spread rates accordingly

        - Daily quantities must be tracked and compared with ordered spread rates.

    - Workmanship and quality issues include uniform longitudinal and transverse joints, matching edges and shoulders. Poor workmanship with uneven mixes and segregation, smoothness problems, and damage from opening to traffic too soon all need corrective action.

    - Final construction activities including rolling, sweeping, and sanding. Some agencies require rolling; others do not.

    - Post-treatment

- Continue sweeping until rock loss no longer poses a hazard for breaking windshields or other vehicle damage (first four days) and perform final sweeping after two weeks
- Opening to traffic after temporary pavement markings and striping
- Permanent striping and placement of new pavement markings
- Accept project
- Remove construction signs
- Calculate final quantities, and agency to make final payment as specified

IV. DESIGN PROCESS FOR SLURRY SURFACING

SLURRY SEALS

Materials

Materials must be approved, along with the mix design for slurry seals, prior to construction.

Emulsions

According to the 2018 Caltrans Standard Specifications, Section 37-3.02B(3a), the asphaltic emulsion must be either Grade QS1h anionic or Grade CQS1h cationic.

Water must not separate from the asphaltic emulsion before you place the slurry seal. You may use a set-control agent that does not adversely affect the slurry seal.

Per Caltrans Standard Specifications, dated 2018, Section 94-1.021, Quick Setting Asphaltic Emulsion, "Quick-setting asphaltic emulsion must comply with the requirements shown in the following table:

Quick-Setting Asphaltic Emulsion Requirements

		Requirement			
		Anionic		Cationic	
Quality characteristic	Test method	Grade QS1	Grade QS1h	Grade CQS1	Grade CQS1h
Saybolt Furol viscosity, @ 25°C (Saybolt Furol seconds)	AASHTO T 59	15–90	15–90	15–90	15–90
Storage stability test, 1 day (max., %)		1	1	1	1
Sieve test (max., %)		0.30	0.30	0.30	0.30
Particle charge[a]		--	--	positive	positive
Residue by distillation (min., %)		57	57	57	57
Tests on residue from distillation test:					
Penetration, 25°C (dmm)	AASHTO T 49	100–200	40–90	100–200	40–90
Ductility, 25°C, (min., mm)	AASHTO T 51	400	400	400	400
Solubility in trichloroethylene (min., %)	AASHTO T 44	97.5	97.5	97.5	97.5

[a] If the result of the particle charge test is inconclusive, the asphaltic emulsion must be tested for pH under ASTM E70. Grade QS1h asphaltic emulsion must have a minimum pH of 7.3. Grade CQS1h asphaltic emulsion must have a maximum pH of 6.7.

[b] Distillation is defining test if conflict with evaporation.

The Greenbook, dated 2018, allows for only quick-setting emulsions for slurry seals. The quick-set polymer-modified emulsion PMCQS-1h cationic emulsion shall meet the requirements in Table 203-3.4.5(B), using ASTM test methods. PMCQS-1h is specified for slurry seals in section 203-5.4.2.2 of the Greenbook.

Table 203-3.4.5(B): Quick-Set Polymer Modified Emulsion (PMCQS-1h)

		Value	
Property	**Test Method**	**Min.**	**Max.**
Tests on emulsion:			
Saybolt Furol Viscosity @ 25°C, SFS[1]	AASHTO T 59	15	90
Sieve test, %	AASHTO T 59	--	0.30
Storage stability, 1-day, %	AASHTO T 59	--	1
Residue by evaporation, %	AASHTO T 59	60	--
Particle charge	AASHTO T 59	Positive	
Tests or residue by evaporation:			
Penetration, 25°C	AASHTO T 49	40	90
Ductility, 25°C, mm	AASHTO T 51	400	--
Elastic Recovery, %	AASHTO T 301	50	--
Softening Point, °F	AASHTO T 53	135	--

[1] SFS means Saybolt Fural seconds.
[2] PMCQS-1h shall contain a minimum of 2.5 percent by weight of residual asphalt.

Other requirements from the Greenbook include the following:

- Emulsified asphalt shall be composed of a paving asphalt base, and may contain crumb rubber and/or polymer.
- Polymer shall be a neoprene polymer or a styrene and butadiene copolymer.
- Additives, including the asphalt modifier, shall be approved by the Engineer.
- Water shall be potable and compatible the other slurry ingredients.
- Aggregate stockpiled 24 hours prior to beginning work.
- Aggregate shall be rock dust or other mineral aggregates approved by the Engineer, and conforming to Section 200 of the Greenbook.

The 2018 Caltrans Standard Specifications state the following for Polymer Modified Cationic Quick Set Asphaltic Emulsion as shown in the following table from Section 94-1.02J:

Polymer Modified Quick-Setting Asphaltic Emulsion Requirements

Quality characteristic	Test method	Requirement
Saybolt Furol viscosity, @ 25°C (Saybolt Furol seconds)	AASHTO T 59	15–90
Sieve Test (max. %)		0.30
Storage stability after 1 day (max. %)		1
Particle charge[a]		Positive
Residue by distillation or evaporation test (min., %)[b]		60
Tests on residue:		
Penetration, 25°C (dmm)	AASHTO T 49	40–90
Ductility, 25°C, (min., mm)	AASHTO T 51	400
Torsional recovery (min., %)[d]	California Test 332	18
or		
Elastic recovery (min., %)[d]	AASHTO T 301	60

[a] If the result of the particle charge test is inconclusive, the asphaltic emulsion must be tested for pH under ASTM E70. Grade QS1h asphaltic emulsion must have a minimum pH of 7.3. Grade CQS1h asphaltic emulsion must have a minimum pH of 7.3. Grade CQS 1H asphaltic emulsion must have a maximum pH of 6.7.

[b] Distillation is defining test if conflict with evaporation

[c] Distillation temperature of 350°F

[d] Elastic Recovery is defining test if conflict with torsional recovery.

The Greenbook has Table 203-3.4.5 (B), for Quick set Polymer Modified Emulsion (PMCQS-1h), which matches the Caltrans table for polymer-modified asphalt emulsion requirements, except for elastic recovery and softening point.

The Greenbook includes specifications for Rubberized Polymer Modified Emulsions (RPME) in section 203-3.4.4.2. See Table 203-3.4.4.2, shown below, which includes the physical composition of the RPME from the Greenbook:

Table 203-3.4.4.2

Tests	ASTM Test Method	Requirement Min.	Requirement Max.
Viscosity, 77°F (25°C), Brookfield Model RVT # 6 Spindel at 10 RPM (Centipoise) @ 60 sec.	D 2196	4,000	12,000
Residue by Evaporation % (including fillers)	D 6934	50	55
Sieve Test (% retained on the No. 20 (850 µm) sieve	D 6933	--	2.0[1]
Penetration of Residue, 77°F (25°C), 0.1 mm.	D 5	15	30
Solubility of Residue	D 2042	75	--
Weight lbs./gal (g/L) 77°F ± 1°F (25°C ± 5°C)	D 1475	8.33 lbs./gal (1000 g/L)	8.75 lbs./gal (1050 g/L)
Asphalt Content[2]	--	40	--

[1] Sieve test of original emulsion is 0.10 max.

[2] Asphalt Content shall be determined by multiplying Residue by Evaporation by Solubility of Residue.

The Greenbook includes specifications for Microsurfacing Emulsion (MSE) in section 203-3.4.6. When MSE is compared to RPME, PMCRS-2, PMCRS-2h, and PMCQS-1h, it is noted that the residue by evaporation is 62 percent, whereas for the the RPME it is 50 percent; for the PMRS-2 and PMCRS-2h it is 65 percent, and for the the PMCQS-1h value it is 60 percent. Also, the MSE must contain a minimum of three percent polymer solids based on the weight of residual asphalt. Higher residues are indicative of a better-quality product. See Table 203-3.4.6 for MSE requirements shown below.

Table 203-3.4.6

Tests	Test Method	Requirement
Viscosity, 77°F (25°C), SSF	AASHTO T 59	15–90 sec
Sieve Test, max.	AASHTO T 59	0.3%
Settlement, 5 days, max.	AASHTO T 59	5%
Storage Stability, 1 day, max.	AASHTO T 59	1%
Residue by Evaporation, min.	AASHTO T 59	62%
Tests on Residue:		
Penetration of Residue, 77°F (25°C),	AASHTO T 49	40–90
Softening Point, min.	AASHTO T 53	135°F (57°C)
Elastic Recovery, min.	AASHTO T 301	50

The 2018 Caltrans Standard Specifications state the following for microsurfacing emulsion as shown in the following table in Section 94-1.02K:

Microsurfacing Emulsion Requirements

Quality characteristic	Test method	Requirement Grade MSE
Saybolt Furol viscosity, @ 25°C (Saybolt Furol seconds)	AASHTO T 59	15–90
Sieve Test (%)	AASHTO T 59	0.30
Storage stability, 1 day (max. %)	AASHTO T 59	1
Particle charge[a]	AASHTO T 59	Positive
Residue by distillation or evaporation test[b] (min., %)	AASHTO T 59[c]	62
Tests on residue:		
Penetration, 25°C (dmm)	AASHTO T 49	40–90
Softening point, (min. °C	AASHTO T 53	57
Torisional recovery (min., %)[d]	California Test 332	20
or		
Elastic recovery, (min, %)[d]	AASHTO T 301	65

[a] If the result of the particle charge test is inconclusive, the asphaltic emulsion must be tested for pH under ASTM E70. Grade QS1h asphaltic emulsion must have a minimum pH of 7.3. Grade CQS1h asphaltic emulsion must have a minimum pH of 7.3. Grade CQS 1H asphaltic emulsion must have a maximum pH of 6.7.

[b] Distillation is defining test if conflict with evaporation

[c] Distillation temperature of 350°F

[d] Elastic Recovery is defining test if conflict with torsional recovery.

A Certificate of Compliance is required by the Engineer for each shipment of MSE delivered.

Aggregates

Besides gradation requirements, aggregates must meet the following testing requirement per ISSA, GREENBOOK, and Caltrans as shown in Table 2.

Table 2. Aggregate Tests for Slurry Surfacing

	Test Method			
TEST	**AASHTO (ISSA)**	**ASTM (Greenbook)**	**CTM[2] (Caltrans)**	**Specification**
Sand Equivalent Value of Soils and Fine Aggregate	T 176	D 2419	CT 217	45 Minimum 55 Minimum[3]
Soundness of Aggregates by Use of Sodium Sulfate of Magnesium Sulfate	T 104	C 88	CT 214 Not Required	15% Maximum w/ NA_2SO_4 25% Maximum w/ $MgSO_4$
Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[1]	T 96	[3]C 131	CT 211	35% Maximum
Durability	Not Required	Not Required	CT 229	55 Minimum

[1] The abrasion test is run on the parent aggregate.

[2] Caltrans equivalent test is shown as CTM.

[3] Greenbook, for C 131, requires aggregate to be run on plus 4 graded material before final crushing, and D 2419 requires 55 min for Sand Equivalent test.

Per the 2018 Caltrans Standard Specifications, aggregate for slurry seal must have the quality characteristics as specified in the following table:

		Specification by aggregate type		
Aggregate Quality Characteristic	**Test method**	**I**	**II**	**III**
Sand equivalent, min.	California Test 217	45	55	60
Durability index, min.	California Test 229	55	55	55

The 2018 Caltrans Standard Specifications have similar requirements to the ISSA, with two exceptions: 1) AASHTO T 104 or CTM 214, sodium sulfate soundness, is not a requirement. 2) ISSA requires 100 percent crushed aggregate and Caltrans requires only 95 percent. Section 37-3.02B(4) Aggregates for requirements from Caltrans is shown below:

Aggregate Requirements

Quality characteristic	Test method	Requirement
Los Angeles Rattler loss (max., %) At 500 revolutions	California Test 211[a]	35
Percent of crushed particles (min., %)	California Test 205	95
Durability (min.)	California Test 229	55
Sand equivalent (min.)		
Type I	California Test 217	45
Type II		55
Type III		60

[a] California Test 211 must be performed on the source aggregate before crushing. The aggregate supplier must certify that the crushed aggregate being used on the project is manufactured from the source aggregate complying with the LA rattler requirements.

The Greenbook uses ASTM C 131 instead of California Test 211, and both use a 35 percent maximum loss for 500 revolutions.

Additives

There are three types of additives which may be used for various reasons. They are listed as follows:

- Dry additives—aluminum sulfate crystals (retards set), ammonium sulfate, and other inorganic salts are the most common types used. The primary purpose is to control break time. However, too much of this additive may cause early raveling.

- Liquid additives—Liquid aluminum sulfate, amines and other liquid materials are the most common types used. These additives control break, and amines are commonly used with asphalts to improve bonding with aggregates.

- Mineral fillers—Portland cement (can accelerate set time), hydrated lime (can accelerate set time), limestone dust, fly ash, or other approved filler meeting the requirements of ASTM D 242 shall be used if required by the mix design. Mineral fillers may also improve mixture consistency.

These additives may be used to improve the gradation of the aggregate for the mix design, or mineral fillers may be used to enhance the chemical reactions that determine the set properties.

Aggregates

Article 1, Section 37-3.01A(4)(b)(ii) of the 2018 Caltrans Standard Specifications is the sampling frequency and testing criteria for slurry aggregate for quality control. Quality control testing is performed by the contractor and results are shared with the agency.

For aggregate testing, the authorized laboratory must perform sampling and testing at the specified frequency and location for the following quality characteristics:

Aggregate Quality Control

Quality characteristic	Test method	Minimum sampling and testing frequency	Location of sampling
Los Angeles Rattler loss (max., %) At 500 revolutions	California Test 211	1st day of production	See California Test 125
Percent of crushed particles (min., %)	AASHTO T 335	1st day of production	See California Test 125
Sand equivalent (min)	California Test 217	1 per working stockpile per day	See California Test 125
Resistance of fine aggregate to degradation by abrasion in the Micro-Deval Apparatus (% loss by weight)	ASTM D7428	1 per working stockpile per day	See California Test 125
Gradation (% passing by weight)	California Test 202	1 per working stockpile per day	See California Test 125
Moisture content, from field stockpile (%)	AASHTO T 255[a]	1 per working stockpile per day	See California Test 125

[a] Test aggregate moisture at field stockpile every 2 hours if you are unable to maintain the moisture content to within a maximum daily variation of ±0.5 percent."

Note: Caltrans Standard Specifications, 2018.

Mix Design

The performance of a slurry surfacing depends on the quality of the materials and how they interact during cure and after cure. The mix design procedure looks at the various phases of this process, which include:

- Mixing: Will the components mix together and form slurry with desired consistency?
- Breaking and Curing: Will the emulsion break in a controlled way on the aggregate, coat the aggregate, and form good films on the aggregate? Will the emulsion build up cohesion to a level that will resist abrasion due to traffic?
- Performance: Will the slurry surfacing resist traffic-induced stresses?

The steps in slurry design include:

- Pre-screening of Materials
  - Aggregate
  - Emulsion
  - Additives
  - Fillers
- Job Mix Design
- Final Testing

At each stage, mixing, breaking, curing, and performance issues are addressed. An example of a typical Caltrans mix design for a slurry seal is given in Appendix B. For an ISSA mix design, the requirements are listed below.

- Mix designs must be done by a competent laboratory certified by ARML.
- Each of the materials used in the mix design must meet all job specifications.
- Individual materials must be qualified through testing before the laboratory performs the mix design tests.
- Mix design must be submitted to the agency prior to the start of the job.
- Slurry seal consistency (ISSA TB-106). Determines the amount of water to form a workable mixture.
- Trial mix design procedure (ISSA TB-113). Provides insight into the visual appearance of potential mixtures.
- Wet track abrasion test (ISSA TB-100). Measure the wearing qualities of the slurry mixture and determines the minimum asphalt content.
- Excess asphalt using the loaded wheel tester (ISSA TB-109). Measure the resistance of the cured mixture from flushing and determines the maximum asphalt content.
- Wet stripping test for cured slurry mixes (ISSA TB-114). Aids in the selection of a compatible slurry system with a given aggregate.
- Determination of a slurry system compatibility (ISSA TB-115). Evaluates compatibility and available mixing time.
- Classification of emulsified asphalt/aggregate mixtures by modified cohesion tester measurement (ISSA TB-139). Defines the set time and early rolling traffic time.

Mix Design Tests for Microsurfacing Only

- Classification of the aggregate filler-bitumen compatibility by the Schulze-Breuer and Ruck Procedures (ISSA TB-144). Determines the compatibility between aggregate filler of a specific gradations and the asphalt residue.
- Measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes (ISSA TB-144). Measure the amount of compaction of cold mixes under simulated rolling.

Table 3 lists the slurry seal mix design proportion limits recommended by ISSA.

Table 3. Slurry Seal Mix Design Proportion Limits

Residual Asphalt (Type II Slurry)	7.5% to 13.5% by dry mass of aggregate
Mineral Filler	0% to 2% by dry mass of aggregate
Additive	As needed
Water	As required to produce proper mix consistency. Contactor shall set target, min and max water contents in their mix designs and ensure construction conforms to approved mix designs.

Residual asphalt must meet the project mix design. The rates are based on the amount of residual asphalt and normally fall within the following ranges based on the weight of dry aggregate plus any mineral filler. Table 4 lists the normal residual rates for different slurry surfacing types. Mineral filler may vary from 0.0 to 3.0 percent, and other additives are included as needed, and water will be added for proper mix consistency.

Table 4. Residual Asphalt per ISSA

Gradation Designated	Slurry Seal	Microsurfacing
Type I	10%–16%	N/A
Type II	7.5%–13.5%	5.5%–10.5%
Type III	6.5%–12.0%	

ISSA A 143 discusses slurry surfacing mix designs. Table 5 lists the mix design tests recommended by ISSA and the Greenbook.

Table 5. Slurry Seal Mix Design Tests (Greenbook and ISSA)

Quality Characteristic	ISSA Test Method	Requirement
Mix Time @ 77°F (25°C) (per ISSA)	TB 113	Controllable to 180 Second Minimum
Consistency, max. in mm	TB 106	30
Wet Stripping	TB 114	Pass
Compatibility	TB 115	Pass*
Cohesion Test, within 1 hour (min., kg-mm)	TB 139	200
Wet Track Abrasion, max g/m^2	TB 100 ASTM 3910[a]	810 for Caltrans 540 for Lompoc
Excess Asphalt by LWT Sand Adhesion (Per ISSA)	TB 109 (Critical in heavy traffic areas)	50 g/ft^2 (536 g/m^2) Maximum
Extraction	ASTM D 2172[a]	Per the submitted mix design

[a] ASTM testing is recommended by the Greenbook for Wet Track Abrasion and Extraction.

The Greenbook requires that the contractor submit, to the Engineer, the laboratory test results with ASTM D 3910 for the materials to be used. The maximum allowable loss is 50 grams per square foot by Wet Track Abrasion Test (ASTM D 3910). The slurry mixer to be used shall be calibrated by the contractor at their expense.

The Greenbook also allows two days for the contractor to calibrate and test their equipment prior to starting work. The Engineer will be given samples for the Extraction Test (ASTM D 2172), Consistency Test, and Wet Track Abrasion Test (ASTM D 3910) after equipment calibration. When the field samples meet the specified requirements, the Engineer will notify the contractor to begin work. This provision is in Section 203-5.4, Mix Design, of the Greenbook. Section 600 of the Greenbook includes specifications for Rubberized Emulsion Aggregate Slurry (REAS), which is a proprietary emulsion. Its formulation may differ from RPME with a higher asphalt content.

Determination of Application Rates

The project's special provisions should specify an application range for the slurry surfacing. Depending on the type of slurry surfacing, and the condition of the pavement surface, an application rate may vary within the project limits. The application rate should be determined with a test strip and the rate approved by the resident engineer. The typical spread rates for slurry seals are dependent on the sizes of the maximum aggregate, which are listed in Table 6.

Table 6. Application Rates for Slurry Seals

Slurry Seals, Pounds of Dry Aggregate per Square Yard				
Types	**Application Rates* (lbs./yd²)**			
Specifications	**Caltrans**	**ISSA**	**Greenbook**	**Note**
Type I	8–12	Not Shown	8–10	Not recommended for heavy traffic areas
Type II	10–15	10–20	12–15	As directed by the Engineer
Type III	20–25	15–30	20–25	As directed by the Engineer

*Use lower rates for smoother existing surfaces and higher rates for rougher surfaces.

Factors Influencing Application Rates

Several factors can affect the application rate used for a given project. Some of these are included below:

- Aggregate gradation with adherence to Job Mix Formula (JMF) may have varying particle shapes from different crushers or different suppliers
- Aggregates may vary in unit weight, which makes recalibration of placement equipment crucial
- Smoother surfaces may require a thinner application or a minimum application rate
- Application rates may vary with varying surface texture across any given cross-section
- Lift thickness should be 1.5 times the maximum aggregate size.

MICROSURFACING

Materials

Emulsions

According to the 2018 Caltrans Standard Specifications, Section 37-3.02C(3) Microsurfacing Emulsion, the microsurfacing emulsion must be a homogeneous mixture of asphalt, polymer, and emulsifier solution.

Polymer is added to the asphalt or emulsifier solution before emulsification. Polymer solids must be a minimum three percent by weight of the microsurfacing emulsion's residual asphalt. Microsurfacing emulsion must have the values of the properties as specified in the table entitled Microsurfacing Emulsion Requirement from Section 94-1.02K on page 22 of this manual.

Aggregates

According to the 2018 Caltrans Standard Specifications, Section 37-3.02C(2) Aggregate, the aggregate for microsurfacing, excluding mineral filler, must have quality characteristics as specified in the following table.

Microsurfacing Aggregate

Quality characteristic	Test method	Specification
Sand equivalent, min.	California Test 217	65
Durability index, min.	California Test 229	65
Percentage of crushed particles, min.[a]	California Test 205	95%
Los Angeles Rattler Loss at 500 revolutions, max. loss[b]	California Test 211	35%

[a] Crushed particles must have at least 1 fractured face.

[b] California Test 211 must be performed on the aggregate before crushing.

Filler

Per Caltrans Standard Specifications, dated 2018, Section 37-3.02C(4) Mineral Filler, "If Portland Cement is used as mineral filler, it must be any combination of Type I, Type II, or Type III cement."

Mix Design

One can refer to Appendix B-2 Microsurfacing from MTAG, Chapter 9, for an example of a mix design.

According to Caltrans, the microsurfacing mix design, using project source aggregate, an asphaltic emulsion, and set-control agents (if any), must comply with the requirements shown in Table 7.

Table 7. Microsurfacing Mix Design Requirements

Quality characteristics	Test method[a]	Requirement
Wet cohesion	Technical Bulletin 139	
At 30 minutes (set) (min., kg-cm)		12
At 60 minutes (traffic) (min., kg-cm)		20
Excess asphalt (max., g/m^2)	Technical Bulletin 109	540
Wet stripping (min., %)	Technical Bulletin 114	90
Wet track abrasion loss	Technical Bulletin 100	
6-day soak (max., g/m^2)		810
Displacement	Technical Bulletin 147A	
Lateral (max., %)		5
Specific gravity after 1000 cycles of 57 kg (max.)		2.10
Classification compatibility (min., grade points)	Technical Bulletin 144	(AAA, BAA) 11
Mix time at 25°C (min.)	Technical Bulletin 113	Controllable to 120 seconds

[a] Test methods are by the International Slurry Surfacing Association.

Determination of Application Rates

Microsurfacing performs the same functions as slurry seals, essentially, but it has aspects that are not found with slurry seals. Microsurfacing possesses a higher-quality aggregate and are quicker to cure. Microsurfacing is also used in the following applications:[9]

- Correct surface irregularities that are minor
- Correct rutting

Microsurfacing does not improve the structural integrity of a pavement; it is meant to improve the surface of the pavement. It should not be used to treat and/or prevent cracks from forming.[10] Table 8 shows the recommended microsurfacing application rates from Caltrans, ISSA, and the Greenbook.

Table 8. Application Rates for Microsurfacing

Pounds of Dry Aggregate per Square Yard				
Types	**Application Rates* (lbs./yd^2)**			**Higher rates for rougher more irregular surfaces, i.e., rutting**
Specifications	**Caltrans**	**ISSA**	**Greenbook**	**Full Lane Width**
Type II	10–20	10–20	12–15	As directed by the Engineer
Type III[a]	20–32	15–30	20–25	As directed by the Engineer
Type III[b]	30–32	N/A	N/A	As directed by the Engineer

[a] Over asphalt concrete pavement.

[b] Over concrete pavement and concrete bridge decks.

Exact application rates need to be verified in the field by a test strip, and the rate needs to be approved by the Engineer. Application rates may need to be increased or decreased as the condition of the road changes. If a significant change is noted, a new test strip should be evaluated.

V. CONSTRUCTION

PREPARATION AND EQUIPMENT

Prior to constructing the slurry surfacing, the project must have sound pavement. Repair work may include patching, crack sealing, or dig-outs. The road must be swept clean of all debris or pressure washed where organic materials are stuck to surface. Thermoplastic road markings must also be removed. Paint markings require no pre-treatment. Banded rubber crack sealant on the roadway should be removed prior to applying a slurry surface.

Figures 6 through 14 show a typical slurry seal or microsurfacing construction sequence for both suburban and rural areas. Figure 4 show a hot-applied crack sealant as part of the slurry surface preparation. The reason that crack sealant is important is to mitigate reflective cracking. Water intrusion through cracks accelerates the deterioration of asphalt concrete by weakening the base with over saturation. There are many crack sealants available, but hot-applied rubber crack sealant usually gives the longest performance. Routing and cleaning the cracks allows for better penetration and performance of the crack sealant. Using a wand with a spreader head allows for a smoother finish of the sealant so that bumps won't show through the slurry surfacing. Another consideration is to perform the crack sealing in cool, dry weather when the cracks are wider with the cooler temperatures. This also allows for better crack sealant penetration. Crack sealing is an important preparation to use for all slurry surfacing applications, not just parking lots.

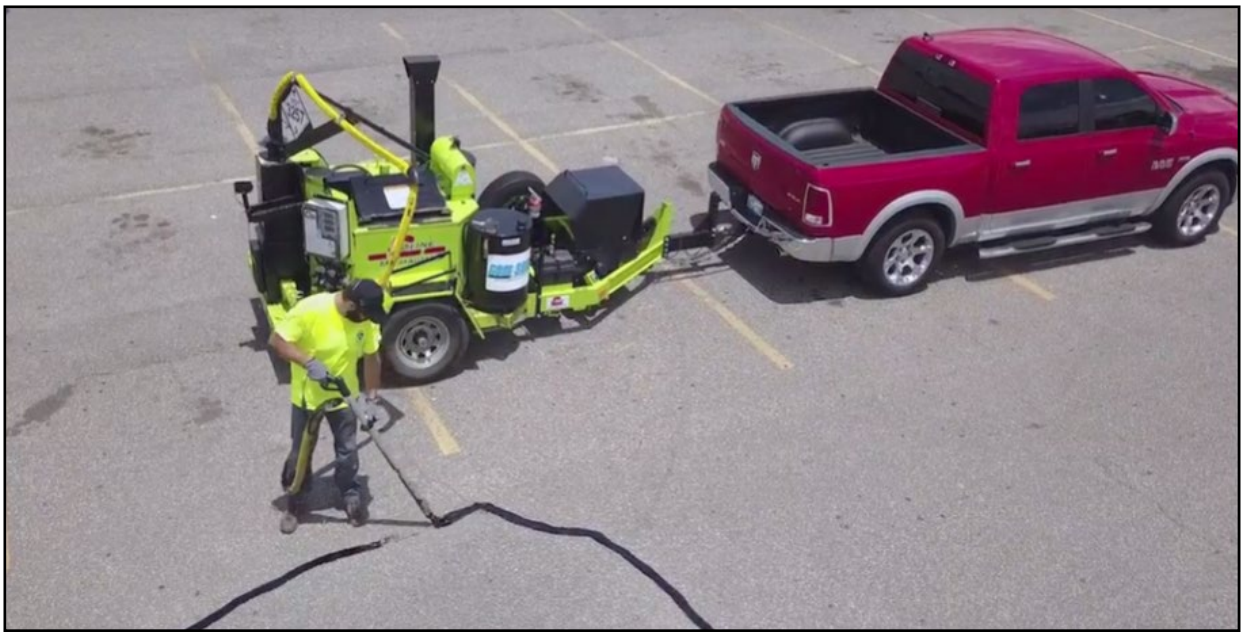

Figure 6. Hot Applied Crack Sealant

Figure 7 shows a thermoplastic stripe being eradicated. This is important for the slurry surfacing to establish a good bond with the existing pavement. If the old thermoplastic markers are not ground off, the old traffic delineation may shadow through the new slurry surfacing. In wet conditions, this may cause confusion to the motorists. There are many different grinders for eradicating thermoplastic.

Figure 7. Eradicate Thermoplastic

Figure 8 shows the existing pavement being swept before application of the slurry surfacing. It is important to remove the dust and dirt to improve the bond, as well as to remove the particulate matter to insure a smooth surface of slurry material. Also, notice in that there are temporary markers placed along the edge and on the center line of the lane. This allows for preservation of the location of the existing striping. The markers have a removable film that gives them a clean bright appearance after the slurry surfacing and allows for an earlier removal of the traffic cones. Some agencies choose to use temporary striping over temporary reflective markers. The temporary striping is quicker to apply after the slurry sets. It is also safer for the laborers, because it minimizes their work time close to live traffic.

Figure 8. Self-Contained Sweeper Removing Dirt and Debris

Figure 9 Shows a rut filling lay down box, a.k.a. wheel path depression box, used to fill ruts of 1/2-inch or more prior to placing microsurfacing. If a rut is deeper than 1/2-inch, a 1/8-inch to 1/4-inch crown should be placed when filling the rut to compensate for additional compaction from traffic. This is a recommendation from ISSA.

Figure 9. Rut Filling Lay Down Box, or Wheel Path Depression Box

Figure 10 shows a filled rut with microsurfacing and the fill being checked with a straight edge for adequacy. The fill should be higher than the adjacent pavement.

Figure 10. Filled Rut (Lt.), and Checking Fill with Straight Edge (Rt.)

Figure 11 shows a screed equipped with an auger applying microsurfacing. The auger-equipped screed is important with this application of slurry surfacing. Microsurfacing has larger aggregate and a thicker consistency which makes it more difficult to achieve good coverage. The auger moves the heavier material to the ends of the screed and allows for a smoother and more uniform finished surface. The canvas or “drag” at the back of the screed is used to achieve a smoother surface texture.

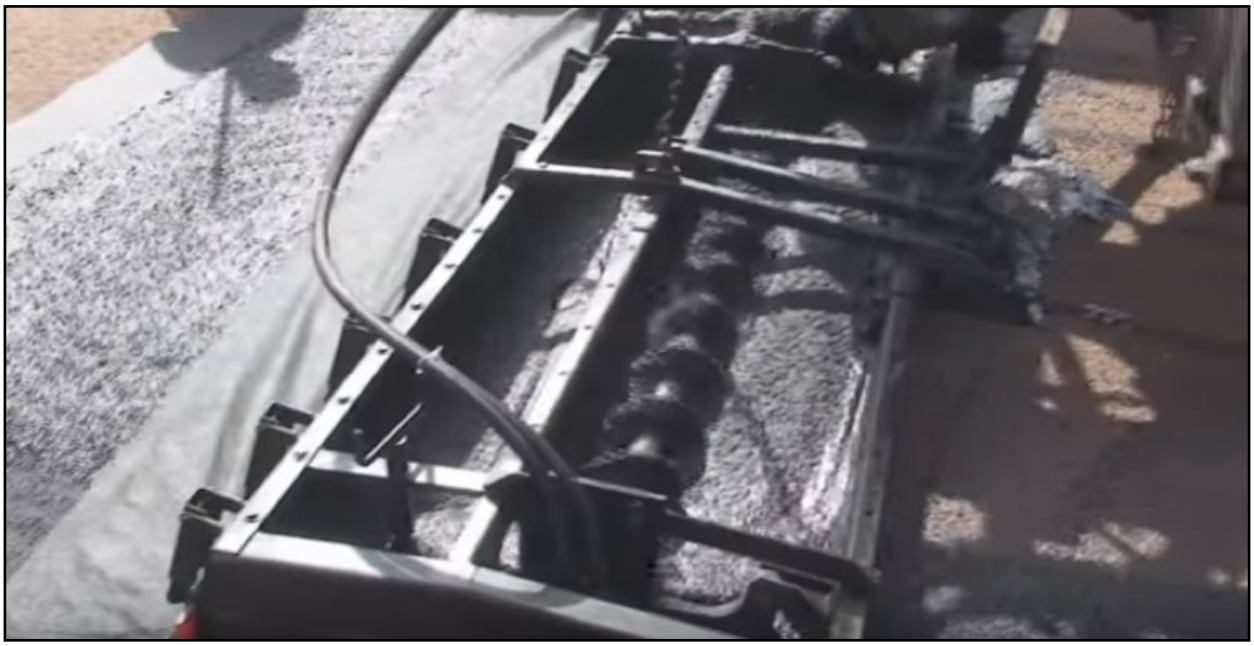

Figure 11. Screed with Auger Performing Microsurfacing

Figure 12 shows microsurfacing being placed with a continuous application machine in a residential area with curbs and gutters. Unlike HMA concrete overlays, the slurry surfacing does not require grinding near the gutter joint. This allows for a cost reduction over a thin HMA concrete overlay as well as a faster construction time. The material is semi-liquid which allows for good joints with minimal racking. With the asphalt slurry mix being at a much lower temperature than hot mix asphalt, there are fewer fumes and no smoke. This technology is greener, using less energy and less material, which allows slurry surfacing to have a lower carbon footprint than hot mix asphalt concrete.

Figure 12. Slurry Surfacing in Residential Area

Figure 13 shows a slurry seal application without the auger in the screed. Slurry seal uses smaller aggregate with the mix having a lower viscosity. The material flows freely to the ends of the screed without an auger.

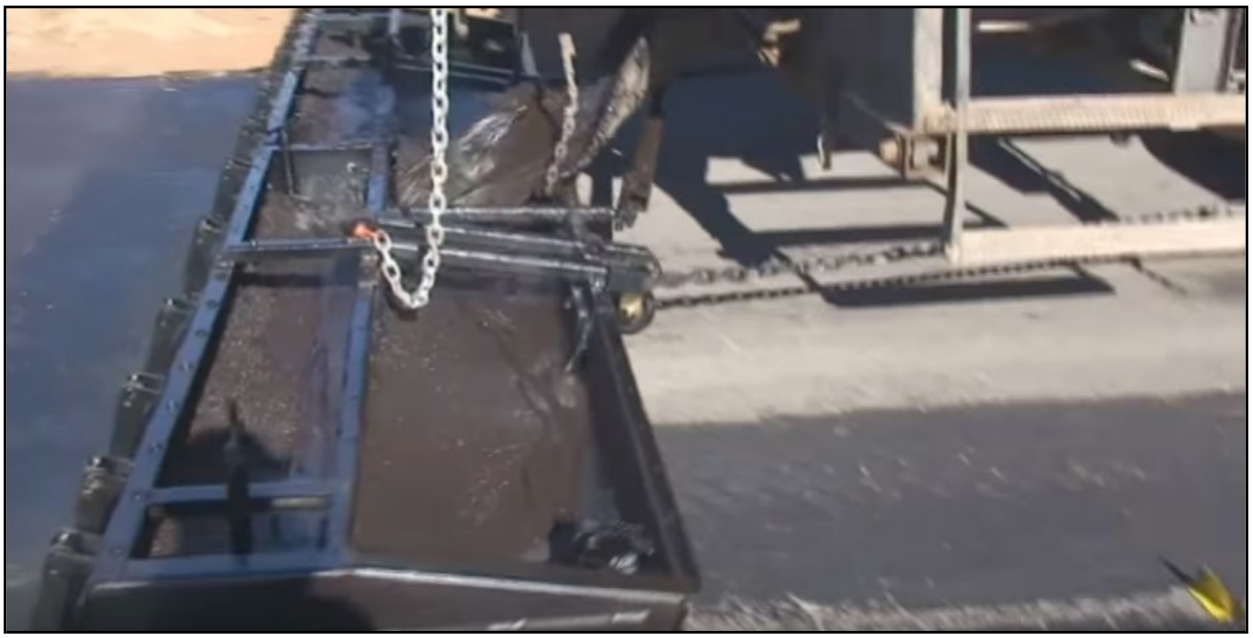

Figure 13. Screed without Auger Performing Slurry Seal

Figure 14 shows a slurry seal being placed on a rural roadway. The slurry gives the roadway a new appearance at minimal cost. Slurry seals may last five to eight years with the lower traffic volumes, and can be applied over concrete surfaces as well as asphalt concrete surfaces.

Figure 14. Slurry Seal on Rural Roadway

Some aggregate loss from slurry seals is normal, and up to 3 percent is considered acceptable. Pneumatic rolling helps decrease aggregate loss by allowing the water to be pressed to the surface, which promotes evaporation and curing. The recommended rolling is one to two passes at low speed with a non-ballasted roller. Rolling also helps seat the aggregate by pressing it onto a flat side, and at the same time smooths the surface for a better ride. Figure 15 show a Caterpillar pneumatic roller, a.k.a. rubber tired roller.

Figure 15. Caterpillar Pneumatic or Rubber Tired Roller

Figure 16 shows the last step of the slurry surfacing construction, with the application of new striping. Striping with a moving lane closure can be performed very quickly with minimum traffic control. A moving lane closure is also a time and cost savings.

Figure 16. Striping with Moving Lane Closure in a Suburban Area

Types of Equipment Used

Both slurry seals and microsurfacing have very similar equipment requirements.

- Slurry or microsurfacing machine as shown in Figure 1
  - As part of machine, screed without auger for slurry seal application, as shown in Figure 11
  - As part of machine, screed with auger for microsurfacing application, as shown in Figure 7
- Crack sealing equipment as shown in Figure 4
- Grinder to remove thermoplastic markers as shown in Figure 5
- Striping equipment for new pavement markings
  - Paint truck
  - Thermoplastic stencils and equipment for hot placement
- Self-contained sweeper truck (may require several) as shown in Figure 6
  - Used to remove debris prior to slurry or microsurfacing application
  - Used to remove loose aggregate after application has set
- Pneumatic tired rollers may be used to seat aggregate in fresh slurry or microsurfacing to aid its setting (see Figure 15).

Calibration of Equipment

Calibration of equipment is very important to ensure that the correct spread rates with the correct material proportions are applied. This is particularly important with continuous mix plants such as those commonly used for slurry surfacing. Equipment calibration needs to be performed prior to applying test strips, and prior to beginning contract work. Calibration of equipment from ISSA Inspector's Manual is included in Appendix C. It is important that the equipment be calibrated on each job with the agency personnel present, or per the agency's standards.[11]

Slurry machines must be calibrated to achieve consistent results using the actual project materials. The calibration process provides data that allow the operator to accurately set the machine for proper proportioning of each material of the mix design. Each machine should be calibrated at least once a year, or per the agency's requirements. Each application machine must have a current calibration sticker prior to starting work on the project. If equipment is changed, the new equipment must also have a current calibration sticker or be calibrated.

All materials used in the application of slurry surfacing should have laboratory testing during the mix design procedure. Testing is to assure that the materials and the mix design as presented by the contractor meet the project's specifications. Also, the materials that are delivered to the job site need to be sampled and tested for quality requirements as specified during construction. Frequency of testing for specific tests should be specified in the specifications.

The specifications may require a quality assurance and quality control plan (QA/QC). Quality control is the responsibility of the contractor and quality assurance is the responsibility of the agency. Should the contractor not meet the specifications for the project, the agency's inspector or resident engineer needs to have the authority to suspend the contractor's operations until the contractor has demonstrated that the problems have been corrected.

CONSTRUCTION PROCESS

How is Slurry Surfacing Constructed?

The first step, after contract award, is to place required construction area signs. In cases of short construction times, the agency may choose to place temporary signs on barricades instead of posts. The signs should be clean and in good condition with good reflectivity. The contract plans should have a sign list and a placement plan. This should be followed during construction, and attention should be paid to intersections. Flagging requirements for intersections should be stated on the plans and in the specifications. Flagging requirements need to be enforced by the engineer with the contractor.

Prior to beginning work, area residents should be notified of the project and any expected traffic delays. The type of work should be included, and the purpose of the work. Sometimes fliers will be placed on their doors noting how the construction may affect access to their properties as well as traffic delays. The notice should state beginning and ending time for

daily work, as well as the start and end dates for the project. The article should also include who the contractor is, and the contractor's and Resident Engineer's contact information. There should also be an article in the local newspaper prior to beginning work which should include the above information. Social media is an additional resource for notifying the residents of the project.

Slurry surfacing requires the removal of raised pavement markers and thermoplastic pavement markings prior to construction. Any newly applied banded crack sealant should be removed. If crack sealing is placed shortly before the slurry surfacing, a non-expansive crack sealant should be used, and it should be struck off at the pavement surface. Banded crack sealant will reflect through the slurry surfacing.

Both slurry seals and microsurfacing have similar surface preparation requirements. Slurry seals are not suitable to repair rutting, whereas microsurfacing can be used to fill ruts. If rutting is an issue, a scratch coat of microsurfacing should be applied prior to applying the surface course.

Both treatments require that potholes be filled, and large cracks be sealed, prior to slurry surfacing. All debris on the pavement surface needs to be swept up prior to construction for either slurry surface application.

The slurry surfacing machine must be calibrated, and a test strip must be run, prior to beginning construction. Test strips may be run outside of the project limits, such as the stockpile or staging areas. The equipment must all be in good working order, and the tires on the pneumatic rollers must be at the proper tire pressure.

The stockpile areas need to have good access to the roadway and must be of sufficient size to store the aggregate for the project. Size is also important for equipment storage, and for both equipment and truck turning radii. The post-construction condition of the staging area needs to be acceptable to the property owner and the agency.

After construction has been completed, the engineer and the contractor need to do a project walk-through and compile a punch list of any corrections that need to be made. The project is not accepted until the punch list items have been completed, and removal of all of the construction signs as well as of the temporary storm water pollution control items.

The main components of the construction process include:

- Safety and Traffic Control
- Equipment Requirements
- Stockpile/Project Staging Area Requirements
- Surface Preparation
- Application Conditions

- Types of Applications
- Quality Issues
- Post Construction Conditions
- Post-Treatments

Weather Limitations

Since slurry surfacing uses an emulsion instead of an asphalt binder, it is susceptible to water damage prior to curing. If the emulsion is washed away by rain, it causes the aggregate to ravel, and the project will fail. The second risk of placing slurry surfacing in the rain is the potential pollution of the waterways when contaminated by the emulsion runoff. Even if rain is not in the forecast, it is still important to have a water pollution control plan in place as a preventative measure. This should be a bid item in the contract, and the plans may show specific water pollution prevention details. Specific items may include sand bags around drainage inlets, or straw waddles placed perpendicular to flow lines in ditches. There are many ways to prevent water pollution, and it is imperative to have an engineer-approved water pollution prevention plan in place prior to beginning slurry surfacing. Waterways, such as rivers, creeks, and lakes, must be protected from pollution.

Specifications must delay slurry surfacing work when there is rain in the forecast. The pavement also needs to dry out thoroughly after rain so that water is not under fresh slurry surfacing in the voids of the existing pavement, which may cause the underlying asphalt pavement to strip.

Some projects specify the following temperatures for slurry surfacing placement. Only place slurry surfacing when the ambient and pavement surface temperature is 50°F (10°C) minimum and rising. The forecasted high temperature must be at least 65^{o}F within 24 hours after placement, and it shall not be placed if rain is falling or is imminent, or if there is the possibility that the finished product will freeze within 24 hours.

Workmanship Issues

Good workmanship enhances a project's appearance as well as improving its longevity. Concrete surfaces from the slurry surfacing at joints between gutters and around manholes and utility boxes need to be protected. This may require taping Kraft paper on top of manholes and utility boxes. Drainage inlets also need to be protected from slurry surfacing by placing sand bags around the inlet and placing mesh or plastic sheeting over the grates. These steps should be required as part of the water pollution prevention plan.

What to Look For?

The following items need to be monitored carefully:

i. Uniformity

Poorly-designed slurry mixtures or mixtures with low emulsion content or too high a water content may separate once mixing in the box has ceased. This leads to a black and flush looking surface with poor texture. Separated mixes may lead to “false slurry” where the emulsion breaks onto the fine material on the surface. In such instances, delamination may occur, resulting in premature failure. These types of mixes can be recognized as non-uniform mixes that appear to set very slowly. Figure 17 illustrates delamination resulting from a false slurry set. Even if the mix is of good quality, and if it was applied properly, excess raveling can occur if it is opened to traffic before it is properly set, as shown in Figure 17.

Figure 17. Delamination from Poor Mix

Slurry sealed edges and shoulders can be rough and look poor. The edge of the spreader box should be outside the line of the pavement, and edge boxes should be used when shoulders are covered. Figure 18 illustrates high-quality edge and hand-work. The edge stripe and the edge of slurry should be an even distance apart through the run.

Figure 18. Example of High-Quality Edges

ii. Good Joints

Transverse joints are a disadvantage when working with batch systems rather than continuous mix equipment. Every time a truck is emptied, a transverse joint occurs. Figure 19 illustrates poor-quality and high-quality transverse joints. The joints must be butted to avoid these bumps, and handwork should be kept to a minimum. Starting transverse joints on roofing felt can alleviate many quality problems with joints as shown in Figure 20.

Figure 19. Poor Quality Joint (Lt.), Good Quality Joint (Rt.)

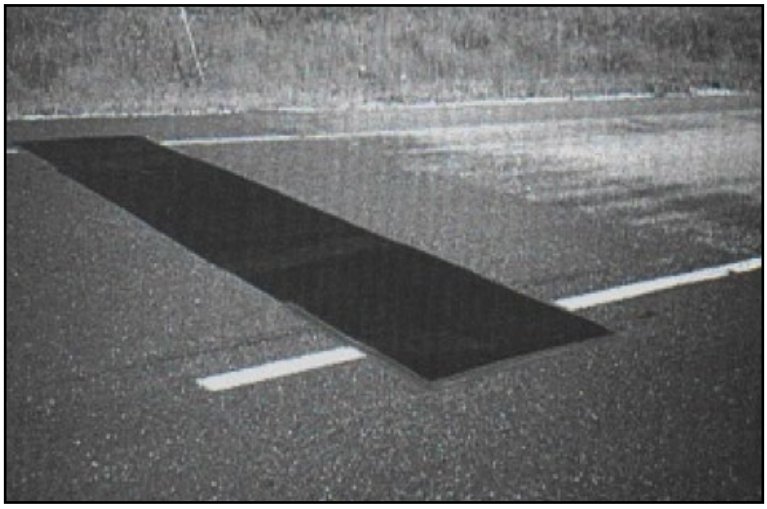

Figure 20. Use Roofing Felt for Clean Joint

Expectations

Slurry surfacing is a preventative maintenance tool, and it is expected that the pavement will last longer when the proper treatment is applied at the right time. It is expected that slurry seals will increase the service life of HMA pavement from 3 to 5 years. Microsurfacing may increase the service life of HMA pavement from 5 to 7 years.[12] This should save the agency thousands of dollars while delaying the need for rehabilitation or reconstruction of a section of road. With the shorter construction times needed for slurry surfacing, the user-delay costs are also minimized.

SAFETY

As with all construction projects, safety is the Number One concern for pedestrians, motorists, contractors' personnel, and local agency inspectors. A personal injury accident or a fatality cannot be reversed. Slurry surfacing projects have some issues which are unique for this project type. As the design and construction engineer, you should be aware of many items regarding safety.

Traffic Control

Lane closures are always required for slurry surfacing work, since traffic must be kept off of fresh slurry surfacing until at least an initial break and cure has taken place. Since these are water-based materials, the time required to cure will depend on climate factors such as air temperature, relative humidity, and wind speed. It is desirable to have the temperatures higher than 80^{o}F and lower than 105^{o}F because the pavement temperature may be nearly 150^{o}F. If the ambient temperature reaches 105^{o}F, a PME may re-liquefy and may need to be water-cooled. Microsurfacing typically requires a shorter cure period (1 to 2 hours) than conventional slurry seals. Slurry seals will require at least 2 hours and warmer air temperatures. If there are shady areas and cooler temperatures, cure time must be extended since these areas will take longer to cure. Since curing time can vary depending on the weather conditions, it is important that the contractor maintain the detours or traffic control until the slurry surfacing is cured. Cure time may take 8 to 10 hours after placement. During this time, traffic must be restricted from the new slurry surface. If a new slurry surface is open to traffic too soon, raveling and scuffing from turning movements may occur.

For urban area projects, the first item that should be considered is detouring traffic. In a downtown situation, it is usually easy to close a street and move traffic over a block. Also, businesses and residences should be notified of street closures ahead of construction. Business owners will often ask that the construction be done on a weekend or at night so that their normal business is not disrupted. If that is not possible, customers may have to walk by the construction zone. It is important for pedestrian safety to cordon off the work areas from the sidewalks and for flaggers to direct pedestrians who may want to cross the street. Decisions must be made ahead of construction for leaving certain intersections open to traffic, as well as how the access to businesses and residences will be managed during construction. Construction signing for detours must be included in the approved traffic control plans. Some agencies require that the traffic control plans (TCP) be approved by a professional engineer.

If it is a rural two-lane road project, only one direction will be constructed at a time, with traffic control using a pilot car with flaggers to alternately allow traffic to be piloted in one direction at a time. After the slurry surface is cured, traffic must be switched over to the lane with the new slurry surface, and the opposing lane will be constructed. There are traffic control standards that must be adhered to during the construction and curing process.

Safety During Construction

It is important to be familiar with the equipment traffic patterns on the project and know what the “NO ZONES’ are. Figure 21 shows where the “NO ZONES” are. Drive through the project in the traffic queue if there is one-way controlled traffic. Observe the flow of equipment, i.e., the slurry truck direction and speed. Also, observe the haul trucks for the aggregate and the asphalt emulsion. The haul trucks supplying the slurry paving truck may back up at very high speeds, and must have backup alarms. The Resident Engineer is usually in charge of enforcing the safety items on the project. All the equipment must be equipped with backup alarms.

The haul truck and the slurry paving truck drivers have limited vision when backing up. With the limited vision, be sure to make contact with the truck driver before walking behind the truck. The drivers will not be able to see who or what is behind their vehicles.

Many observations can be made from the vehicle, so don’t be standing in the construction zone unless sampling or performing tests. Assign an observer to watch traffic when the tester is unable to, and be sure to perform testing or sampling in a lane closure.

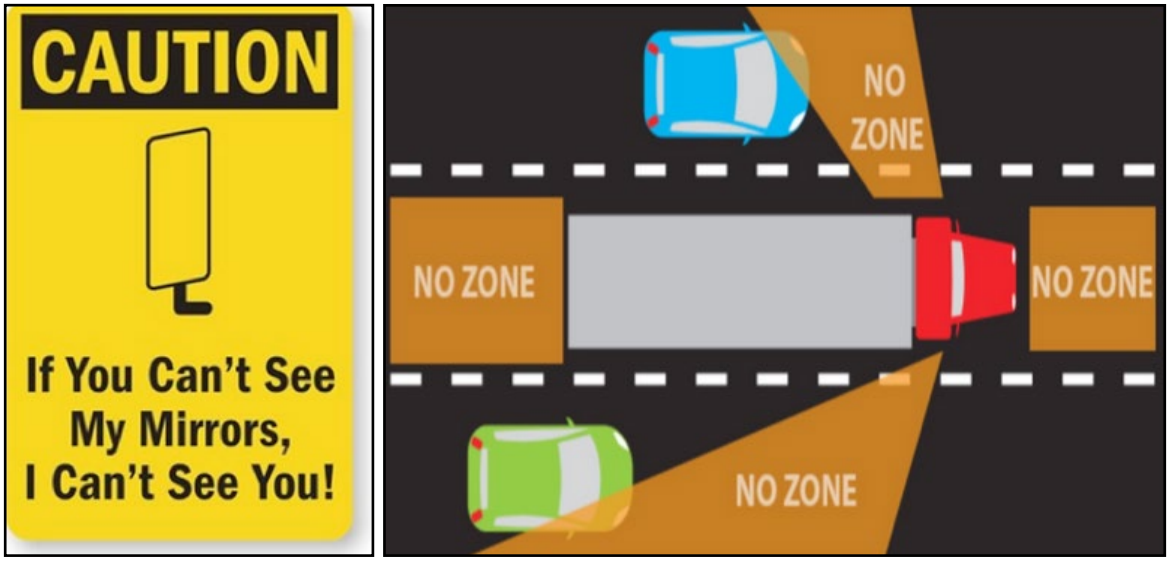

Figure 21. Mirrors and the No Zone

All construction personnel must wear safety vests, hard hats, and safety glasses in active construction zones. All construction personnel must also wear long pants, and suitable shoes or boots. No sandals or shorts are allowed for construction personnel. If work takes place in an area with high levels of noise, earplugs should be worn by the worker. Gloves must be worn by workers performing hand labor or handling hot materials. Workers handling hot materials must also wear face shields.

VI. QUALITY ASSURANCE

Quality assurance establishes the core elements required to achieve quality materials and workmanship for construction projects. Figure 22 shows the core elements of a quality assurance.[13]

Figure 22. Core Elements of a Quality Assurance Program

All materials used in the application of slurry surfacing should be tested during the mix design process. Also, the materials that are delivered to the job site need to be sampled and tested for quality requirements. Frequency of testing for specific tests should be given in the specifications. The specifications may require a quality assurance and quality control plan (QA/QC). Quality control is the responsibility of the contractor, and quality assurance is the responsibility of the agency. Should the contractor not meet the specifications for the project, the agency's inspector or resident engineer needs to have the authority to suspend the contractor's operations until the contractor has demonstrated that the problems have been corrected.

CONTRACTOR QUALITY CONTROL PLAN

Based on 2018 Caltrans Standard Specifications, the following are specified:

37-3.01A(3) Submittals for Mix Design

“At least 15 days before starting placement of a slurry seal or microsurfacing, submit:’

1. Samples for:

    1.1. Asphaltic emulsion slurry seal, two 1-quart wide mouth plastic containers with screw top lid of asphaltic emulsion

    1.2. Polymer modified asphaltic emulsion slurry seal, two 1-quart wide mouth plastic containers with screw top lid of polymer modified asphaltic emulsion

    1.3. Microsurfacing, two 1-quart wide mouth plastic containers with screw top lid of microsurfacing emulsion

2. Asphaltic emulsion, polymer modified asphaltic emulsion, or microsurfacing emulsion data as follows:

    2.1. Supplier and Type/Grade of asphaltic emulsion

    2.2. Type of modifier polymer for polymer modified asphaltic emulsion or microsurfacing emulsion

    2.3. Copy of the specified test results for asphaltic emulsion, polymer modified asphaltic emulsion, or microsurfacing emulsion

3. 50 pounds of aggregate

4. Aggregate test results for the followings:

    4.1. Gradation

    4.2. Los Angeles Rattler

    4.3. Percent of crushed particles

    4.4. Sand equivalent

    4.5. Durability

“At least 10 days before starting placement of a slurry seal or microsurfacing, submit a laboratory report of test results and the proposed mix design from an authorized laboratory. The authorized laboratory must sign the laboratory report and mix design.’

“The report must include:

1. Test results used in the mix design compared with specification requirements

2. Proportions based on the dry weight of aggregate, including ranges, for:

    2.1. Aggregate

    2.2. Water

    2.3. Additives

    2.4. Mineral filler

    2.5. Slurry seal emulsion or microsurfacing emulsion residual asphalt content

3. Recommended changes to the proportions based on heating the mixture to 100 degrees F and mixing for 60 seconds, if atmospheric temperatures during application will be 90 degrees F or above, for:

    3.1. Water

    3.2. Additives

    3.3. Mineral filler

4. Quantitative moisture effects on the aggregate’s unit weight determined under ASTM C29M

“If the mix design consists of the same materials covered by a previous laboratory report, you may submit the previous laboratory report that must include material testing data performed within the previous 12 months for authorization.

If you change any of the materials in the mix design, submit a new mix design and laboratory report at least 10 days before starting slurry seal or microsurfacing work.’

CONTRACTOR QUALITY CONTROL DOCUMENTATION

Based on Caltrans standard specifications, dated 2018, Section 37-3.01A(3)), the following are specified:

“Submit a certificate of compliance as specified for asphaltic emulsion in Section 94-1.01C with each shipment of asphaltic emulsion, polymer modified asphaltic emulsion or microsurfacing emulsion. Submit quality control test results for the quality characteristics within the reporting times allowance after sampling shown in the following table:

Quality Control Test Reporting Requirements

Quality characteristic	Maximum reporting time allowance
Los Angeles Rattler loss (max, %)	2 business days
Percent of crushed particles (min, %)	2 business days
Durability (min)	2 business days
Resistance of fine aggregate to degradation by abrasion in the Micro-Deval Apparatus (% loss by weight)	2 business days
Gradation (% passing by weight)	48 hours
Sand equivalent (min)	48 hours
Moisture content (%)	48 hours

Within 3 days after taking asphaltic emulsion, polymer modified asphaltic emulsion or microsurfacing emulsion quality control samples, submit the authorized laboratory's test results."

SAMPLING AND TESTS TO RUN INCLUDING FREQUENCY

Both contractor and agency need to have a sampling control plan prior to beginning work. See example below in Table 9:

Table 9. Example Sampling Control Plan

Project Location	
Product	**Producer's Emulsion**
Where	On site/Sampling Port
When	15 minutes after starting application
How much	Four 1/2 gallon plastic jugs
Who	Consultant Tester
Testing	Agency and/or Consultant Tester
	CT 351 for Residual Asphalt, or as specified
Product	**Aggregate, Producer**
Where	Stockpile, or from equipment
When	Various times, once daily or per 500 tons
How much	1-Bag, 20 pound ±
Who	Operator or Agency Inspector or Agency Tester
Testing	Sieve Analysis by Agency or Consultant Lab for all aggregate specified characteristics
Tests	Sieve Analysis of Fine and Coarse Aggregates (AASHTO T27, ASTM C136, CT 202, and as specified)
Mineral Fillers	**Verify once per day**
	Same as mix design
Water	**Beginning of project**
	Same pH range as emulsion, and check again if water source changes.
Product	**Slurry Surfacing Mix, Producer**
Road Mixer, Continuous Flow	Field Mix Verification (Agency) Extraction Test (ASTM D6307)
	Consistency Tests
Prior to start of work	Modified Wet Track Abrasion Tests (ASTM D3910)

A consultant tester may be employed by either the contractor or the agency. Usually, the person sampling the product will take two samples, giving one to the agency and one to the contractor as a split sample. This is a good strategy in case these is a discrepancy on the test results. Even though there is testing of the product before construction, there needs to be assurance that the product being delivered is verified to be of the same quality as the product that was submitted to the agency prior to construction.

Acceptable mix tolerances for the slurry mixture are:

- Dry weight of aggregate (after residual asphalt content is determined) ± 1.0 percent by weight of dry aggregate
- Slurry consistency (per ISSA TB 106) ± 0.2 inches from the JMF
- Rate of application ± 2 percent per yd^2 with uniform surface texture

AGENCY INSPECTION AND DOCUMENTATION

The agency has the responsibility to document the quality of the products being used and the construction processes used on their project. The engineer is responsible for keeping daily diaries to document the construction process, and there is usually an Assistant Resident Engineer on the job. Depending on the size of the project, there may also be an agency tester on the project responsible for the materials sampling. The agency tester may be a consultant tester or an agency employee. The tester should be certified in any and all of the tests that are being run, including sampling the products.

The materials test results are compared to the specified tests to make sure that the materials are within the specified limits of each test specified and performed. Some out of specification products may be accepted to be left in place on the project with a deduction. This is at the contractor's discretion. If the materials are too far outside of the specified limits, the engineer should order that the material be removed and replaced at the contractor's expense.

INDEPENDENT ASSURANCE

When the various ingredients are combined in proper proportions, they produce mixes that ultimately make up the new surface on the pavement. Obviously, high-quality materials, good mixing and construction practices, and good quality control/quality assurance will help maximize the smoothness, uniformity, skid resistance, and appearance of the slurry surfacing. Quality control is critical during the construction process to achieve a uniform surface finish. The contractor is responsible for quality control, and the agency is responsible for quality assurance. If there is a difference in the testing results between the contractor and the agency, it may be necessary to go to dispute resolution. Independent assurance mediates the dispute resolution process, monitors both laboratories during their retesting of the materials.

Samples that have been maintained during the project in case of dispute resolution are run as split samples, similar to a round robin, between the two laboratories whose results are in dispute. The independent assurance is to determine why there was a difference in the test results, and to get the laboratories to produce consistent testing results between the laboratories. This is done so the dispute can be settled in a fair and equitable process between the contractor and the agency.

Besides the appearance of the project, the materials need to be tested during construction. If two tests in a row fail, the work should be suspended until the contractor remedies the problem. If no problem can be identified, then re-testing needs to follow. Independent assurance process may be used when the re-testing is being done between the two laboratories.

VII. MEASUREMENT AND PAYMENT

BY WEIGHT

If the contractor is paid by weight, the quality of the item may be improved by a heavier placement than if the item is paid for by area. The units by weight need to be included in the bid items for the project.

37-3.04 PAYMENT (Caltrans, Specifications 2018)

> "The payment quantity for slurry seal is the weight determined by combining the weights of the aggregate and asphaltic emulsion. The payment quantity for slurry seal does not include the weights of the added water and set-control additives."
>
> "The payment quantity for microsurfacing is the weight determined by combining the weights of the aggregate and microsurfacing emulsion. The payment quantity for microsurfacing does not include the weights of added water and set-control additives."

BY SQUARE YARD

Measurement and payment by the square yard is not the preferred standard. Both Caltrans Standard Specifications, dated 2018, and the Greenbook, dated 2018, specify payment by the ton. The Greenbook, also specifies that no payment will be made for rejected test strips, or for their removal. This payment clause is stated in section 302-3.11, "Payment".

If the area to receive slurry surfacing has many obstacles and requires a lot of handwork, the agency may choose to pay by the square yard.

Measurement for payment for area (square meter) from Ontario Provincial Standard Specification, section 337.09, is discussed below.

Actual Measurement (Slurry Seal)

Measurement of the slurry seal placed shall be by area in square yards with no deductions for appurtenances.

Plan Quantity Measurement

When measurement is by Plan Quantity, such measurement shall be based on the units shown in the total quantities as shown on the plans, usually by the square yard or as shown in the bid item. The unit price shall include all work associated with the slurry surfacing placement. This total includes cleaning of the pavement prior to beginning work, calibration of the truck-mounted mixing unit, and furnishing and placing the slurry surfacing material, plus any incidentals needed to complete the work in place.

BASIS OF PAYMENT

337.10.01 Slurry Seal

Actual Measurement (Microsurfacing)

Payment at the contract price for the above items shall be full compensation for all labor, equipment, and material to perform the work.

Repair, removal, disposal, and replacement of any damaged or defective slurry seal or microsurfacing shall be at no extra cost to the agency.

The accepted trial area within the contract construction area shall be paid for at the unit price for slurry seal or microsurfacing. All costs associated with removal and disposal of unacceptable trial areas within the contract construction area shall be borne by the contractor at no extra cost to the agency.

The contractor may furnish the following warranty after completion of the work and prior to final payment if a warranty is specified as shown in the example below:

> "The Contractor hereby warrants that all workmanship and all materials furnished under the contract comply fully with requirements of the slurry surfacing specifications. If at any time within two years from the date of filing of the Notice of Completion, any unfaithful or defective work should appear which in the opinion of the agency is due to inferior materials or workmanship, the Contractor warrants doing whatever is necessary to remedy the defects immediately without cost to the agency. The agency will notify the Contractor in writing of the defects and the repairs to be made, and the Contractor will begin repairs within a mutually agreed time frame."

A warranty may be for only one year, and a list of deficiencies should be given to the contractor after nine months. The contractor shall be required to complete this work before the one year warranty period expires.

VIII. TROUBLESHOOTING GUIDE

Table 10 is from MTAG, Chapter 8 and Chapter 9, dated 2008. This is a very useful guide for determining what may be wrong during field construction of slurry surfacing. Table 11 lists some solutions to potential problems for slurry surfacing.

Table 10. Troubleshooting Guide for Slurry Surfacing

CAUSE	PROBLEM										
	BROWN	WHITISH	WILL NOT SET	POOR COATING	DELAYED OPENING TO TRAFFIC	BREAKS IN BOX	RAVELS	FLUSHES	DELAMINATION	SEGREGATION	SCUFFING
Emulsion											
Emulsion Unstable				●		●			●		
Emulsion too Stable	●		●		●		●				
Emulsion too Hot						●					
Too Little Emulsion	●			●			●				
Too Much Emulsion								●			
Mix											
Too Many Fines				●		●	●				
Too Much Cement		●				●					
Too Little Cement			●		●		●			●	●
Too Little Additive				●		●	●				●
Too Much Additive		●	●		●		●				
Too Much Water	●		●		●		●	●		●	●
Too Little Water		●			●	●	●		●		
Aggregate/Emulsion not Compatible			●	●	●		●		●	●	●
Weather Conditions											
Too Hot	●			●		●	●	●			
Too Cold			●		●		●		●		
Rain	●		●	●	●		●	●	●		
High Humidity		●	●								
Surface After Treatment											
Fatty (Oily)			●					●			
Dusty or Dirty Aggregate							●		●		
Aggregate not Pre-Wetted							●		●		

Table 11. Common Problems and Related Solutions (MTAG 2008)

PROBLEM	SOLUTION
UNEVEN SURFACE – WASH BOARDING	• Ensure the spreader box is correctly set up. • Ensure the viscosity of the mix is not too high. • Make adjustments so that the mix does not break too fast. • Wait until the ambient temperature is lower. • Use water sprays on the front of the spreader.
POOR JOINTS	• Reduce the amount of water at start up. • Use water spray if runners of spreader box are running on fresh micro-surfacing.
EXCESSIVE RAVEL	• Add cement and reduce additive so that the mix breaks and cures faster. • Check aggregate to ensure the clay fines are not too high. • Control traffic longer and at low speeds. • Wait until fully cured before allowing traffic. • Wait until mix is properly set before brooming or opening to traffic.

APPENDIX A: SAMPLE SPECIFICATIONS

A sample specification for slurry seal can be found at the following website:

https://www.csuchico.edu/cp2c/_assets/documents/specs/appendix-a-1-slurry-seal-sample-spec-1-20-2019.pdf.

A sample specification for Microsurfacing can be found at the following website:

https://www.csuchico.edu/cp2c/_assets/documents/specs/appendix-a-2-microsurfacing-sample-spec-1-20-2019.pdf.

APPENDIX B: SAMPLE MIX DESIGNS

A sample mix design for slurry seal and microsurfacing can be found in the Caltrans MTAG at the CP2 Center's website: 2008.

https://www.csuchico.edu/cp2c/_assets/documents/appendix/appendix-b-sample-slurry-surfacing-mix-design-1-20-2019.pdf.

The table below lists the Technical Bulletins for recommended microsurfacing mix design tests from Caltrans (2018).

Micro-surfacing Mix Design Tests

Property	International Slurry Surfacing Association test method	Specification
Wet cohesion @30 minute (set), min kg-cm @ 60 minute (traffic), Min kg-cm	Technical Bulletin 139	 12 20
Excess asphalt, max, g/m^2	Technical Bulletin 139	540
Wet stripping, min, %	Technical Bulletin 114	90
Wet track abrasion loss 6-day soak, max, g/m^2	Technical Bulletin 110	810
Displacement Lateral, max, % Specific gravity after 1000 cycles of 57 kg max	Technical Bulletin 147A	5 2.10
Classification compatibility, min, grade points	Technical Bulletin 144	(AAA, BAA) 11
Mix time @ 25° C	Technical Bulletin 113	Controllable to 120 seconds

APPENDIX C: ISSA EQUIPMENT CALIBRATION PROCEDURE

The ISSA equipment calibration procedure can be found at the following website and should be referred to prior to the calibration process of the equipment:

http://www.csuchico.edu/cp2c/_assets/documents/appendix/appendix-c-slurry-surfacing-calibration-1-20-20191.pdf.

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TERMINOLOGY

Terminology

- **Cape Seal:** This treatment type can be combined with a chip seal, slurry seal, microsurfacing seal and asphalt rubber. Cape seals typically increase the durability and produce a smooth surface.

- **Chip Seal:** A bituminous binder is applied, followed by aggregate application and rolling to embed the aggregate into the binder.

- **Corrective Maintenance:** This maintenance type is conducted in response to defects that affect operations of a facility and integrity of pavement sections. This form of maintenance is also known as reactionary maintenance and can be conducted throughout the lifespan of a pavement. It is typically used to fix localized defects and return a pavement to an acceptable service quality. Maintenance activities include patching of potholes and replacement of concrete slabs.

- **Distresses:** Deterioration resulting from factors including the environment, construction and design practices, material selection, load on pavement. There are two distinct categories of distresses: functional and structural.

    - **Functional distress:** Deterioration affecting the pavement's ability to serve its function of being a safe, smooth, and quiet surface for comfort while driving. Using preservation treatments, minor functional problems can be addresses as long as there are no structural problems.

    - **Structural distress:** Deterioration resulting from excess weight and loading, lack of thickness and support for the pavement structure. Considerable deterioration does not allow for the distresses to be addressed using preservation treatments.

- **High-traffic-volume Roadway:** Rural roadways have an ADT greater than 5,000 vehicles per day and urban roadways have an ADT greater than 10,000 vehicles per day.

- **Major Rehabilitation:** To extend the service of a pavement and/or improve load-carrying capabilities through structural enhancement.

- **Microsurfacing:** This treatment type relates to slurry seals; however, the main variation between the two is the quality of the materials. With this treatment, the polymer and asphalt residual content is greater than that of slurry seals, and the aggregate quality is better. In addition, the cost is greater than slurry seals; however, the cure time is shorter than for slurry seals.

- **Minor Rehabilitation:** The distresses addressed are non-structural enhancements to improve the lifespan, slow surface cracking, and restore the pavement to serve its function. The distresses could be a result of environmental factors. These are typically referred to as pavement preservation techniques occurring midway in a pavement's lifespan when the quality of the roadway begins to diminish.

- **Pavement Condition Index (PCI):** This index is most commonly used by the Metropolitan Transportation Commission (MTC) as a value ranging from 1–100 directly related to the condition of the pavement.

- **Pavement Preservation:** The practice of utilizing a cost-effective system that allows for the tracking and recording to extend and enhance the quality and life of a pavement. In addition, preservation would serve as a way to improve safety and provide good ride quality. The system primarily focuses on preventive maintenance as a cost-effective way to treat roadways and improve the quality of the road.

- **Performance Curve:** Diagram that displays the relationship between time and a variable, such as the Pavement Condition Index (PCI) of road sections. The performance curves would detail the life and condition of a roadway before and after treatment application.

- **Preventive Maintenance:** Cost-effective strategy for treatment to roadway system accounting for ways to preserve the roadway and prevent deterioration in addition to improving or maintaining the condition of the roadway. This is typically performed early, before significant structural deterioration can appear. Some activities include joint sealing, crack sealing and filling, as well as utilizing chip seals and slurry seals.

- **Reconstruction:** After failure of the pavement structure to perform its function, removal and replacement of an existing pavement structure is needed. This may involve recycled or new materials to replace the old pavement structure.

- **Routine Maintenance:** Maintenance performed routinely to preserve the roadways condition or to return the roadway to a proper level of service. Some maintenance activities include crack filling and/or sealing, as well as maintaining the drainage system, all of which are performed throughout a pavement's life.

- **Slurry Seal:** A thin surface treatment in a thickness equivalent to the largest aggregate size. This treatment returns the roadways surface texture to an acceptable quality as well as improve water proofing. The cure time needed before allowing traffic to re-enter is 24 hours.

- **Slurry Surfacing:** A generic term to describe the two common types of slurry treatments, which are slurry seal and microsurfacing. Both treatment types are preventative maintenance surface treatments that can add years to pavement life at a low cost.

- **Surface Type:** Surface type is the upper most layer and is dependent on the type of material used whether it be HMA or Portland cement. The surface type also depends on the functional class (arterial, collector, residential).

- **Treatment Category:** Treatments with application times and objectives alike. For instance, one group of treatments is meant to hinder and prevent deterioration; however, other treatments would include maintenance, rehabilitation, and construction of roadways

- **Treatment Type:** A certain treatment used to treat specific distresses on a roadway. These treatments would include chip seals, slurry seals, microsurfacing, HMA overlays, and diamond grinding. For some situations, treatment combinations are required to ensure quality performance of the roadway.

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AAPT	Association of Asphalt Paving Technologists
ADT	Average Daily Traffic
AEMA	Asphalt Emulsion Manufacturers Association
AGC	Associated General Contractors
AI	Asphalt Institute
APWA	American Public Works Association
AR	Asphalt Rubber
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BMPs	Best Management Practices
Caltrans	California Department of Transportation
CalRecycle	California Department of Resources Recycling and Recovery
CCPIC	City and County Pavement Improvement Center
CP2C	California Pavement Preservation Center
DOT	Department of Transportation
FHWA	Federal Highway Administration
HMA	Hot Mixed Asphalt
IRI	International Roughness Index
ISSA	International Slurry Surfacing Association
JMF	Job Mix Formula from Mix Design
LCCA	Life Cycle Cost Analysis
LCC	Life Cycle Cost
MSA	Maintenance Superintendents Association
MTAG	Maintenance Technical Advisory Guide
MTC	Metropolitan Transportation Committee
MTI	Mineta Transportation Institute
NDOT	Nevada Department of Transportation
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PME	Polymer Modified Emulsion
PMS	Pavement Management System
SWPPP	Storm Water Pollution Prevention Plan
TCV	Total Cracking Value
TDA	Tire-Derived Aggregate
TRB	Transportation Research Board
UNR	University of Nevada, Reno
WPCV	Wheel Path Cracking Value
WSDOT	Washington State Department of Transportation

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PEER REVIEW

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