CHAPTER 8 SLURRY SEALS

8.1 OVERVIEW

This chapter provides an overview of the types of slurry seals presently used in California, including materials and specifications, mix design, project selection, details regarding construction, a troubleshooting guide to assist the Engineer if problems arise during the placement of these mixtures, and a listing of suggested field considerations when placing a slurry surfacing.

8.1.1 General Description

Slurry seals are a mixture of asphalt emulsion, graded aggregates, mineral filler, water and other additives. The mixture is made and placed on a continuous basis using a travel paver (Slurry Surfacing Machine). The travel paver meters the mix components in a predetermined order into a pug mill. The typical mixing order is aggregate followed by cement, water, the additive and the emulsion. Figure 8-1 illustrates the process of slurry surfacing.

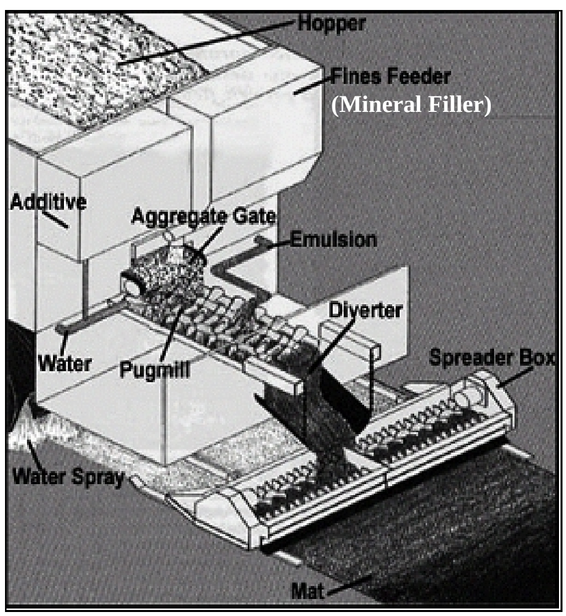


Figure 8-1 Schematic of a Slurry Surfacing Machine (Holleran, 2001)

The resulting slurry material is a free flowing composite material that is spread via a spreader box over the existing road surface. The consistency of the slurry material allows it to spread over the pavement, wetting it, and forming an adhesive bond to the pavement.

The slurry mixture contains asphalt emulsion that breaks onto the pavement surface through heterogeneous or homogenous flocculation. The asphalt particles coalesce into films, creating a cohesive mixture. The mixture then cures, by loss of water, into a hardwearing, dense-graded asphalt/aggregate mixture that is bonded to the existing pavement.

A slurry surfacing does not add any structural capacity to an existing pavement; they are applied as a maintenance treatment to improve the functional characteristics of the pavement surface. The types of slurry surfacing and the pavement characteristics they improve are discussed next.

8.1.2 Purpose of a Slurry Seal

A slurry seal is a thin surface treatment that is laid in a thickness equal to the largest stone in the grading of its component aggregate. It may include either a conventional or polymer modified emulsion, and the slurry seal may be slow or quick setting. The emulsion is usually cationic in nature, but may be anionic. Slow set systems break mostly by evaporation; quick set systems have emulsifiers that react chemically with the aggregate surfaces. These quick set emulsions maintain a degree of chemical break. For both systems, breaking and curing times are strongly influenced by the environmental conditions at the time of application; at high temperatures the emulsion in quick set systems breaks and cures very quickly such that the surface treatment can be opened to traffic within a few hours; slow set systems typically require a longer time to break and cure. In cooler conditions, the times before opening to traffic are longer for both systems. For this reason, slurry seals should not be applied at night.

A slurry seal is used to:

- Seal sound and oxidize pavements
- Restore surface texture by providing a skid-resistant wearing surface
- Improve waterproofing characteristics
- Correct raveling
- Provide a new surface where weight restrictions preclude the use of heavier overlays (e.g., bridge decks), and
- Provide a new surface where height restrictions are a problem (e.g., overcrossings).

A slurry seal should not be used to:

- Correct surface profile
- Fill potholes, and
- Alleviate cracking (with or without polymer modification)

8.2 MATERIALS

The main materials used in slurry surfacing are:

- Asphalt Emulsion

- Water
- Aggregate
- Mineral Filler
- Additives

8.2.1 Asphalt Emulsion

Asphalt emulsions are defined in Chapter 2 of this advisory guide as dispersions of asphalt in water stabilized by a chemical system. In the case of slurry surfacing, the emulsion may be cationic or anionic; however, cationic emulsions are the most common. Caltrans Standard Specifications Section 94 (Caltrans, 2006) provides specifications for the main emulsion types. Emulsions used in slurry seals are either slow setting (SS) or quick setting (QS). Common slow and quick setting emulsions include:

- CSS1h (Cationic Slow Set)
- CQS1h (Cationic Quick Set)
- SS1h (Anionic Slow Set)
- QS1h (Anionic Quick Set)

These emulsions are specially formulated for compatibility with the aggregate and to meet the appropriate mix design parameters. These emulsions are defined in Chapter 2 of this guide, Section 94 of the Standard Specifications (Caltrans, 2006), and in the ISSA Slurry Surfacing Workshop (Holleran, 2002) identified at the end of this chapter.

Emulsion specifications are based on standard emulsion characteristics, such as stability, binder content, and viscosity. In some quick set slurry systems polymer is added to the emulsion. The polymer enhances stone retention, especially in the early life of the treatment. The added polymer also reduces thermal susceptibility. Polymers also improve softening point and flexibility, which enhance the treatment's crack resistance.

Emulsions are usually modified with latex, which is an emulsion of rubber particles. The latex does not mix with the asphalt; rather, the latex and the asphalt particles intermingle to form a sort of 3-D structure, as illustrated in Figure 8-2. The latex used is either neoprene or styrene butadiene styrene (SBR) for slurry seal. When modified with latex, slurry seal emulsions are referred to PMCQS1h (Polymer Modified Cationic Quick Set) or, more commonly, LMCQS-1h (Latex Modified Cationic Quick Set, Holleran, 2001).

Latex may separate from the emulsion due to the differences in density. If separation occurs, the latex must be remixed into the emulsion by circulation in the tanker before the modified emulsion is transferred to the slurry machine for application (Holleran, 2002).

Basic emulsion requirements are shown in Table 8-1. Key requirements include the binder content and residual properties. The viscosity is of importance as is the storage stability to ensure that the emulsion can be used effectively in the field.

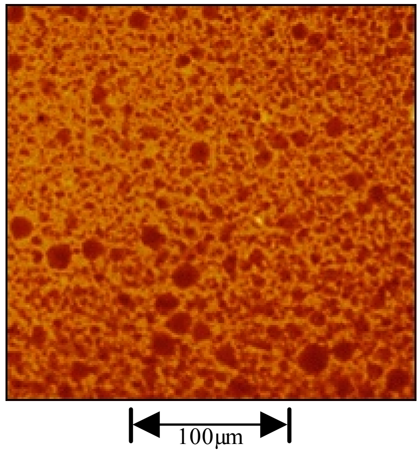


Figure 8-2 Micrograph of a Latex/Asphalt Cured Film (Holleran, 2002)

Table 8-1 Typical Emulsion Properties for Quick Setting Asphalt Emulsions (Caltrans, 2006)

Tests on Emulsion	Typical Specification	Method
Viscosity, SSF @ 50°C, sec	15 – 90	AASHTO T 59
Settlement, 5 days, %	< 5	ASTM D 244
Storage Stability, 1 day, %	< 1	AASHTO T 59
Sieve Test, %	< 0.30	AASHTO T 59
Demulsibility, %	> 40	
Particle Charge	Positive	
Ash Content, %	< 0.2	ASTM D 3723
Residue by Evaporation, %	> 65	California Test 331
Tests on Residue from Evaporation Test	**Typical Specification**	**Method**
Penetration, 25°C	< 90	AASHTO T 49
Ductility, 25°C, mm	> 400	AASHTO T 51
Torsional Recovery, %	> 18 (LMCQS-1h)	California Test 332
Polymer Content, % (by weight)	> 2.5 (LMCQS-1h)	California Test 401

8.2.2 Aggregates

The aggregate's key physical characteristics for suitable incorporation into a slurry surfacing mix are defined by:

- **Geology:** This determines the aggregate's compatibility with the emulsion along with its adhesive and cohesive properties.

- **Shape:** The aggregates must have fractured faces in order to form the required interlocking matrix (Holleran, 2001). Rounded aggregates result in poor mix strength.
- **Texture:** Rough surfaces form bonds more easily with emulsions.
- **Age and Reactivity:** Freshly crushed aggregates have a higher surface charge than aged (weathered) aggregates. Surface charge plays a primary role in reaction rates.
- **Cleanliness:** Deleterious materials such as clay, dust, or silt can cause poor cohesion and adversely affect reaction rates.
- **Soundness and Abrasion Resistance:** These features play a particularly important role in areas that experience freeze-thaw cycles or are very wet.

Caltrans Standard Specifications, Section 37-2, specifies three aggregate grading sizes for slurry seals: Type I, II and III (Caltrans, 2006). The gradation for each type is listed in Table 8-2.

Table 8-2 Caltrans Slurry Surfacing Aggregate Gradings (Caltrans, 2006)

SIEVE SIZE	PERCENTAGE PASSING		
	TYPE I	TYPE II	TYPE III
3/8 in (9.5mm)	-	100	100
No. 4 (4.75 mm)	100	94-100	70-90
No. 8 (2.36 mm)	90-100	65-90	45-70
No. 16 (1.18 mm)	60-90	40-70	28-50
No. 30 (600-µm)	40-65	25-50	19-34
No. 200 (75-µm)	10-20	5-15	5-15

The primary difference among these gradations is the aggregate top size. This indicates the amount of residual asphalt required by the mixture and the purpose to which the slurry is most suited. The Type I slurries are the finest and are used for lightly trafficked roads or parking lots. Type II slurries are coarser and are suggested for raveling and oxidation on roadways with moderate to heavy traffic volumes. Type III slurries have the coarsest grading and are appropriate for filling minor surface irregularities, correcting raveling and oxidation, and restoring surface friction. Type III slurries are typically used on arterial streets and highways.

The role of fines (i.e., aggregate particles No. 200 [75 µm] and finer) in a slurry surfacing mix is to form a mortar with the residual asphalt to cement the larger stones in place. The fines content is essential for creating a cohesive hardwearing mix. Generally, the fines content should be at the mid-point of the grading envelope. The general aggregate quality requirements are listed in Table 8-3.

Table 8-3 General Aggregate Properties (Caltrans, 2006) and Aggregate Requirements (Schilling, 2002)

TEST	SLURRY SEAL TYPE			TEST # AND PURPOSE
	I	II	III	
Sand Equivalent (min)	45	55	60	CT 217 Clay Content
Durability Index (min)	55	55	55	CT 229 Resistance to wet/dry exposure

8.2.3 Mineral Filler and Additives

According to ISSA, the mineral filler can be Portland cement, hydrated lime, limestone dust, fly ash or other approved filler meeting the requirements of ASTM D242, and is considered part of the dry aggregate. The Caltrans specification does not provide any details on the mineral filler.

In most slurry surfacing, cement is used as a mixing aid allowing the mixing time to be extended and creating a creamy consistency that is easy to spread. Additionally, hydroxyl ions counteract the emulsifier ions, resulting in a mix that breaks faster with a shorter curing time. Cement is also a fine material and, as such, absorbs water from the emulsion, causing it to break faster after placement. Fine materials, as previously discussed, also promote cohesion of the mixture by forming a mortar with the residual asphalt.

Additives other than cement vary and are features of particular systems. They act as retardants to the reaction with emulsions, either as a prophylactic, slowing the emulsifier's access to the aggregate surface, or by preferentially reacting with the emulsifier in the system. Additives include emulsifier solutions, aluminum sulfate, aluminum chloride, and borax. Generally, increasing the concentration of an additive slows the breaking and curing times. This is useful when temperatures increase during the day.

8.3 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:

- Prescreening of Materials

- Job Mix Design
- Final Testing

At each stage, mixing, breaking, curing, and performance issues are addressed.

8.3.1 Prescreening

Prescreening involves testing the physical properties of the raw materials. The emulsion type is selected based on job requirements and is checked against the requirements laid out in the specifications (Standard Specifications, Section 94). The aggregate is checked against specifications (Tables 8-2 and 8-3) and a simple mixing test is performed to assess compatibility with the emulsion. When both of these steps are satisfied, the job mix formula can be developed. During the overall process the materials may be changed at any time until satisfactory results are obtained.

8.3.2 Job Mix Design

Mix designs for slurry seals are generally done by private laboratories and follow the ISSA mix design procedure. The following sections discuss some of the design considerations for slurry seals

Mixing Proportions

The International Slurry Surfacing Association (ISSA) test method TB 102 (detailed in Technical Bulletin 102) is used to determine the approximate proportions of the slurry mix components (ISSA, 1991). In this test, a matrix of mix recipes are made up and the manual mixing time is recorded for each mixture. A minimum time is required to ensure that the mixture will be able to mix without breaking in the slurry machine. At this stage, phenomena such as foaming and coating are visually assessed. Also at this stage, the water content and additive content can be determined to produce a quality mixture. Figure 8-3 illustrates a good slurry mixture consistency.

Figure 8-3 Good Mixture Consistency

The mixing time must be at least 180 seconds for a slurry seal at 77°F (25°C). The process may be repeated at elevated or reduced temperatures to simulate expected field conditions at the time of application. The best mix is chosen, based on good coating of mixing times in excess of the minimum required through the entire range of expected application temperatures. This is a subjective test; the result is highly dependent on the operator

Cohesion Build-up

Once the emulsion content is determined, three mixes are then made, one at the selected emulsion percentage from above, one at -2% of the selected emulsion content and one at +2% of the selected emulsion content. This allows a bracketing of the desired mix proportions. The ISSA test method detailed in TB 139 (ISSA, 1991) is used to determine the cohesion build-up in a slurry mixture. This test may be performed at the expected field temperatures to provide the most accurate estimate of the treatment's characteristics. Table 8-4 lists mix requirements for slurry surfacing.

Abrasion Resistance (Wet Track Abrasion Test – WTAT)

Mixes are made at three emulsion contents, optimum, optimum +2%, and -2% of optimum. These mixes are then cured in circular molds for 16 hours at 140°F (60°C). The samples are then soaked for either 1 hour or 6 days, depending on the abrasion test (TB 100) (ISSA, 1991) and the material. Slurry design requires a 1-hour soaking. After soaking, a standard rubber hose is orbitally ground over the surface of the sample (while still submerged) for a set period of time. The wear loss is then calculated. The test equipment is shown in Figure 8-4, while the abrasion resistance requirements are listed in Table 8-4.

a) Mixer Equipped with sample Mold and Rubber Hose Attachment

b) Orbital Grinding of Sample Using Rubber Hose Attachment

Figure 8-4 Wet Track Abrasion Test Apparatus and Test in Progress

Table 8-4 Typical Mix Requirements (Caltrans, 2006)

PROPERTY	TEST	SLURRY SEAL REQUIREMENTS
Slurry Seal Consistency, in (mm)	TB 106	1.2 (30) max
Wet Stripping	TB 114	Pass
Compatibility	TB 115	Pass[a]
Cohesion Test [b], kg-mm within 1hour	TB 139	200 min.
Wet Track Abrasion, g/m^2	TB 100	800 max.

[a] Mixing test must pass at the maximum expected air temperature at the project site during application

[b] Using project source aggregate and asphalt emulsion and set-control agents if used

The results of the abrasion test are plotted along with the specification requirements. This allows selection of the minimum binder content of the mixture.

Upper Binder Limit

The upper binder limit is determined using the Loaded Wheel Test, as described in TB 109 (ISSA, 1991). In this test, the slurry seal specimen is compacted by means of a loaded rubber tired reciprocating wheel as illustrated in Figure 8-5. After 1000 loading cycles, the specimen is removed from the machine, washed and dried to constant weight. Then, the specimen is mounted again on the machine and hot sand is added on the surface. After another 100 cycles of compaction, the increase in weight of the specimen due to sand adhesion is noted. This provides a measure of the free asphalt on the surface of the sample. The more prone the mix is to flushing or bleeding under traffic loading the larger the amount of sand retained on the specimen. Figure 8-5 illustrates the test apparatus along with a series of tested samples.

a) Testing Apparatus b) Tested Samples Showing Retained Sand

Figure 8-5 Loaded Wheel Test and Excess Asphalt Test Apparatus and Test Samples

Optimum Binder

The optimum percentage emulsion or binder content is found by plotting the results obtained from the Wet Track Test (TB 100) and the Loaded Wheel Test (TB 109) (ISSA, 1991). Figure 8-6 illustrates a typical plot of test results. The optimum binder content is chosen close to the intersection of the two plotted lines. The optimum binder content should be selected by an experienced designer based on field knowledge and experience. This is a weakness in the current design process.

8.3.3 Final Testing

Once the job mix components have been selected, the mix is tested to determine its properties and ensure compliance with the specifications listed in Table 8-4. If the mix conforms to the specifications, the emulsion content and aggregate grading is reported as the job mix formula.

Field adjustments may be made to the job mix formula to accommodate climatic variables during application. As a result of the mix design process, adjustments are limited to the amount of additives (cement and retardant) and water content required to ensure a good homogeneous mix at the time of application.

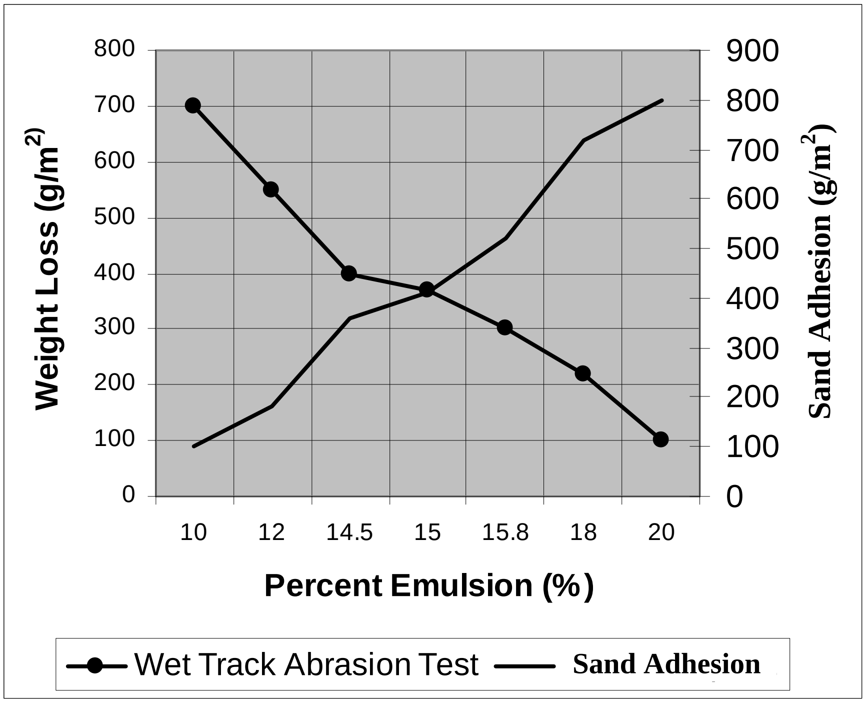


Figure 8-6 Determining Optimum Binder Content

8.3.4 A Modern, Rational Mix Design for Slurry Surfacing Systems

Recognizing the need for more rational design methods for slurry seal and micro-surfacing, the Federal Highway Administration (FHWA) enlisted the California Department of Transportation (Caltrans) to form a pooled fund study with the overall objective of developing a rational mix design method for slurry seal and microsurfacing. The improved mix design procedures, guidelines, and specifications will address the performance needs of the owners and users, the design and application needs of the suppliers, and improve the reproducibility of the test methods used for the mix designs. The pooled fund study project involves 13 State Departments of Transportation, was started din 2003 and is expected to end in 2008.

8.4 PROJECT SELECTION

8.4.1 Distress and Application Considerations

Slurry surfacing may be used for a range of applications, but job selection is critical and often pretreatments such as pothole patching, crack sealing, and dig outs are required. Table 8-5 lists general job selection criteria for slurry surfacing treatments and typical application rates.

The main use of slurry surfacing materials is for pavement preservation as a part of a program of periodic surfacing before distresses appear. The main criteria for project selection are:

- Sound and well drained bases, surfaces, and shoulders
- Free of distresses, including potholes and cracking

Table 8-5 Job Selection Criteria

APPLICATIONS	AGGREGATE TYPE		
	I	II	III
Void Filling	●	●	
Wearing Course (AADT) < 100	●	●	
Wearing Course (AADT) 100 – 1,000		●	●
Wearing Course (AADT) 1,000 – 20,000			●
Minor Shape Correction (0.4-0.8 in [10-20mm])			●
Application Rates in pounds of dry aggregate per square yard	8 - 12	10 - 15	20 - 25

Distress modes that can be addressed using slurry surfacing include:

- Raveling: Loose surfaces or surfaces losing aggregate may be resurfaced using slurry seals
- Oxidized pavement with hairline cracks: These surfaces may be resurfaced using slurry seals
- Friction Loss: Skid resistance can be restored by application of slurry seals

Distress modes that cannot be addressed using slurry surfacing include:

- Rutting
- Cracking (including reflection cracking)
- Base Failures (of any kind)
- HMA Layers that exhibit plastic shear deformation

Slurry surfacing will not alleviate the cause of these distresses. As a result, the distresses will continue to form despite the application of a slurry surfacing.

8.4.2 Performance of Slurry Seals

According to a California study, slurry seals have been estimated to last around 3 to 5 years (Van Kirk, 2004). Longer service lives (up to 15 years) have been observed when the seals are placed as true preventive maintenance treatments on suitable roads.

Traffic is not a limiting factor. The main failure mechanism is wear. Over time, the slurry surfacing oxidizes and abrades under traffic. Premature failure occurs from placement on highly deflecting surfaces, cracked surfaces, pavements with base failures, and on dirty or poorly prepared surfaces (resulting in delamination).

8.5 CONSTRUCTION

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

Section 8.6.2, “Suggested Field Considerations”, at the end of this chapter, provides a series of tables to guide project personnel through the important aspects of applying a slurry surfacing.

8.5.1 Safety and Traffic Control

Traffic control is required both for the safety of the traveling public and the employees performing the work. Traffic control should be in place before work forces and equipment enter onto the roadway or into the work zone. Traffic control includes construction signs, construction cones and/or barricades, flag personnel, and pilot cars to direct traffic clear of the maintenance operation. For detailed Traffic Control requirements, please refer to the Caltrans project specifications and the Caltrans Code of Safe Operating Practice (Caltrans, 1999).

Traffic control is required to ensure that the slurry surfacing has had adequate time to cure prior to reopening to traffic. The curing time for the slurry surfacing material will vary depending on the pavement surface conditions and the weather conditions at the time of application. It is recommended that the public is informed of the pavement maintenance activities that will take place in their neighborhood and that it is very important not to drive on the new surface for as long as the traffic signs are present. Very often drivers assume that the slurry surfacing is drivable despite of the warning signs and cause damage to the fresh placed treatment. Door knob cards are recommended to notify the residents and provide information on how to accommodate the construction activities. Additional traffic control considerations are listed in the Field Considerations section (8.6.2) of this chapter.

8.5.2 Equipment Requirements

Equipment requirements for slurry machines are covered in Caltrans Standard Specifications Section 37 (Caltrans, 2006). Calibration requirements are discussed in California test method CT 109. Modern equipment, as shown in Figure 8-7, can be used to place slurry seal.

A slurry seal spreader box is a drag box, as shown in Figure 8-8. The drag box is pulled behind the paver by means of chains. This box may or may not have augers; for quick set systems augers should be used. The slurry seal should be easy to work and spread, and not cause any hang-up in the box.

The design mix is proportioned by weight while the slurry surfacing machines deliver materials by volume. Due to this different nature of the measurements, it is essential that calibration be done with the actual job materials. No machine should be allowed to work on a Caltrans job without a proper calibration.

Figure 8-7 Slurry Surfacing Machine

Figure 8-8 Slurry Seal Box with Augers

8.5.3 Stockpile / Project Staging Area Requirements

The stockpile and project staging area must meet some basic requirements. These requirements include:

- A clean, well-drained pad for aggregate piles
- A front-end loader for loading machines or Flow Boy-type vehicles in continuous operation
- A salt-free water supply
- An emulsion tanker
- An additive tanker

The stockpile and staging area should be as close as possible to the job site. Figure 8-9 illustrates a typical stockpile and staging area.

Figure 8-9 A Typical Stockpile and Project Staging Area

Operations should be scheduled to run as smoothly as possible and provide good traffic flow through the work zone. Aggregates that are below optimum moisture content specified in the mix recipes should be remixed using the front-end loader to avoid segregation. In some cases aggregates that are separating in the stockpile or during loading may need to be sprayed with water to avoid fines loss.

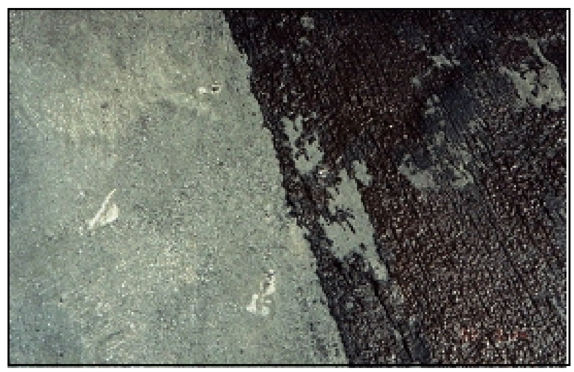
8.5.4 Surface Preparation

The main objective of surface preparation is to provide a clean and sound surface on which the microsurfacing is applied. The first step of surface preparation is to restore the pavement's structural integrity and functional performance characteristics through crack sealing and patching (see Chapters 4 and 5 of this guide for more information on these procedures).

Immediately before the slurry surfacing is applied, the road must be swept clean of all debris including clay and hard-to-remove materials (such as organic matter). High power pressure washing may be required. If left on the road, these types of contaminants will cause delamination of the treatment in these areas. Thermoplastic road markings must also be removed prior to placing a slurry surface, or at least abraded to produce a rough surface. Paint markings require no pretreatment. Rubber crack sealant on the roadway should be removed prior to applying a slurry surface.

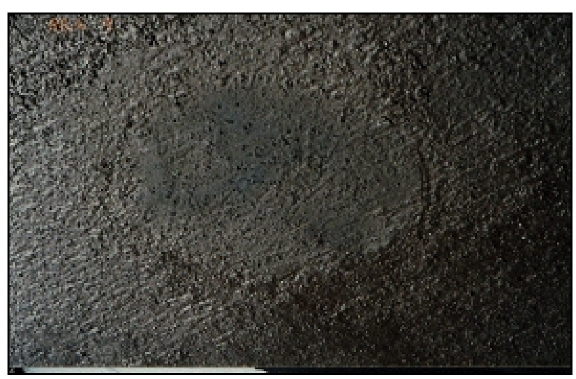
Utility inlets should be covered with heavy paper or roofing felt adhered to the surface of the inlet. The paper is removed once the slurry surfacing has sufficiently cured. In addition to covering the inlets, all starts, stops, and handwork on turnouts should be done on roofing felt to ensure sharp, uniform joints and edges. Figure 8-10 illustrates the various surface preparation steps along with illustrations of delamination resulting from poor surface preparation.

a) Sweeping



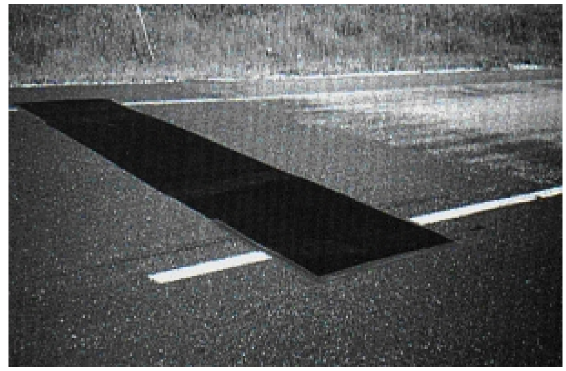
b) Dirty surfaces Result in Poor Adhesion (Delamination)

c) Cover Utilities with Kraft Paper



d) Slurry Covers Inlet and Paper Cover

e) Peel Off Paper Covering Once Treatment has Cured



f) Starting Transverse Joints on Roofing Felt Produces Clean Joints

Figure 8-10 Surface Preparation Methods

8.5.5 Application Conditions

The application conditions required are addressed in detail in the Caltrans Standard Specifications Section 37 (Caltrans, 2006). The basic requirement for success is that the emulsion must be able to break and form continuous films, as it is the only way a slurry mixture can become cohesive. As a result, humidity, wind conditions, air and pavement surface temperature are important and need to be considered. Modifications to additives should be made according to the changing environment during application. In any case, application of a slurry seal is generally not suitable for night work. This is due to the lower evaporation rate at night, which results in longer breaking and curing times.

For a conventional slurry seal project, air temperature should be a minimum of 50°F (10°C) and rising. Humidity should be 60% or less and a slight breeze is advantageous. Work should not be started if rain is imminent. Slurry seals will typically resist rain induced damage after as little as one hour but typically require at least three hours to cure to a fully waterproof state. Additionally, breaking time for a slurry is affected by ambient temperature. Work should not be started if freezing temperatures are anticipated within 24 hours of construction. Aggregate and emulsion temperature are also affecting the breaking time. An example is given in Figure 8-11.

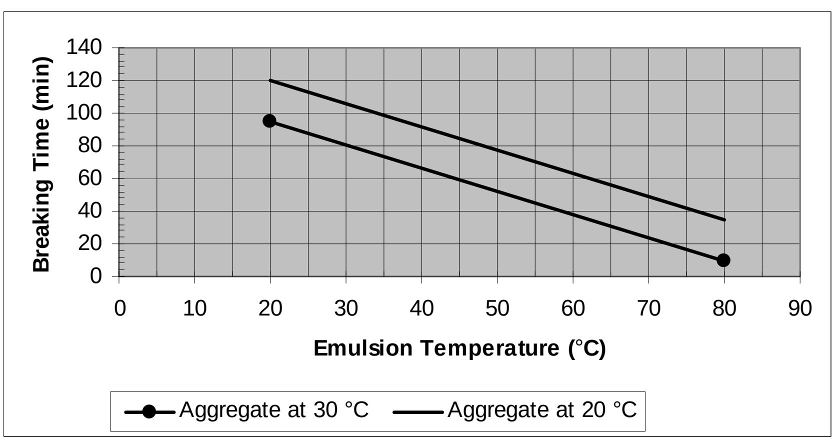


Figure 8-11 Effect of Temperature on Break Rate

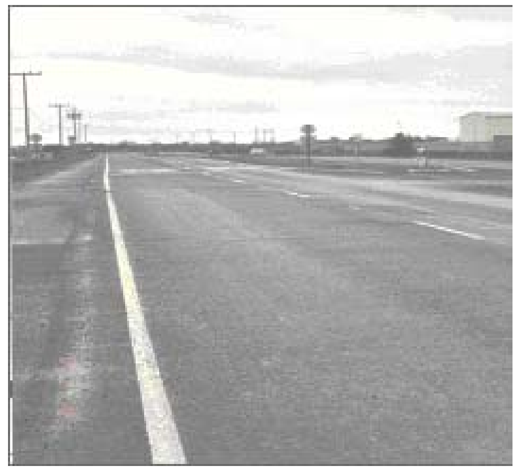
8.5.6 Quality Issues

Quality control is critical during the constriction process to achieve a uniform surface finish. The main areas of concern are discussed below.

Longitudinal Joints

Longitudinal joints may be overlapped or butt jointed. They should be straight or curve with the traffic lane. Overlaps should not be in the wheel paths and should not exceed 3 in (75 mm) in width. Figure 8-12 illustrates high quality and poor quality longitudinal joints.

a) High Quality Longitudinal Joint



b) Poor Quality Longitudinal Joints

Figure 8-12 Longitudinal Joints

Transverse Joints

Transverse joints are inevitable when working with batch systems; every time a truck is emptied a transverse joint is required. Transitions at these joints must be smooth to avoid creating a bump in the surface. The joints must be butted to avoid these bumps and handwork should be kept to a minimum. The main difficulty in obtaining a smooth joint occurs as the slurry machine starts up at the joint. Some contractors tend to over wet (add too much water) to the mix at start-ups. This leads to poor texture and scarring at the joints. Starting transverse joints on roofing felt can eliminate these problems. Figure 8-13 illustrates high quality and low quality transverse joints.

a) High Quality Transverse Joint b) Low Quality Transverse Joint

Figure 8-13 Transverse Joints

Edges and Shoulders

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 8-14 illustrates high quality and poor quality edge and handwork.

a) High Quality Edges and Shoulder b) Poor Quality Edges and Shoulder

Figure 8-14 Edges and Shoulders

Uneven Mixes and Segregation

Poorly designed slurry mixtures or mixtures with low cement 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 a "false slurry" where the emulsion breaks onto the fine material. In such instances delamination may occur, resulting in premature failure. These types of mixes can be recognized as non-uniform mixes that appear to be setting very slowly. Figure 8-15 illustrates segregation and delamination resulting from a false slurry.

a) Segregation

b) Delamination from a False Slurry

Figure 8-15 Poor Mixes

Smoothness Problems

Slurry mixtures follow the existing road surface profile and thus do not have the ability to significantly change the pavement's smoothness. However, when using stiffer mixes the spreader box may, if incorrectly set up, chatter or bump as the material is spread and produce a washboard effect. The chattering may be addressed by making the mixture slower to set, adjusting the rubbers on the box, or adding weight to the back of the spreader box. Figure 8-16 illustrates the washboard effect.

Figure 8-16 Wash Boarding Effect

Damage Caused by Premature Reopening to Traffic

The slurry seal must build sufficient cohesion to resist abrasion due to traffic. Early stone shedding is normal, but should not exceed 3%. If a mixture is reopened to traffic too early it will ravel off quickly, particularly in high stress areas. It is important that the mixture has formed adequate cohesion before it is opened. Choosing the right time to reopen a surface to traffic is based largely on experience. However, a general rule of thumb for a slurry seal is that it can be opened when it has turned black. Figure 8-17 illustrates raveling caused by premature opening to traffic.

Figure 8-17 Traffic Damage Caused by Early Trafficking

8.5.7 Post Construction Conditions

Emulsion systems do not lose all water in the first hours after placement; the total water loss process can take up to several weeks. During this period the surface will be water resistant; however, if the water freezes, it can cause rupture of the binder film and subsequent raveling. For this reason, projects should not be started without a 2-week window when freezing weather will not occur.

Asphalt emulsion based systems cannot re-emulsify; however, if not fully cured, these systems can be tender enough to re-disperse under the effects of traffic loading and excessive water, especially ponding water. In this process, broken aggregates or asphalt particles that have not fully coalesced into films are dispersed in water, which disintegrates the emulsion. Thus, while light rain 3 hours after placing a slurry seal is acceptable, heavy rain coupled with heavy traffic will likely lead to surface damage, especially in high shear areas. Figure 8-18 illustrates damage caused by a combination of heavy rain and high shear (e.g., turning movement).

Figure 8-18 Damage Due to Post Application Heavy Rain with Shear

8.5.8 Post-Treatments

Rolling

Slurry seals will lose stone until the surface voids have been closed off, but it is acceptable for approximately 3% of surface stone to be lost. To limit the amount of loss, rolling with pneumatic rollers may be incorporated. For rut filling applications, rolling is almost always recommended. The roller should be light (6-7 tones maximum) and non-ballasted. One to two passes at a slow speed are recommended. This allows the water to be pressed to the surface, promoting evaporation and curing. Larger stones will be punched into the new surface, reducing early raveling. Figure 8-19 illustrates a typical roller operation.

Figure 8-19 Rolling a Slurry Surfacing

Sweeping

On heavily trafficked roads or where opening has lead to excessive stone loss, sweeping is essential. A suction broom is the best type of sweeper to use. Sweeping should be done just prior to opening to traffic and at periods determined by the level of stone loss. Figure 8-20 illustrates a suction broom.

Figure 8-20 Sweeping with a Suction Broom

Sanding

Sanding may be used to reduce the time that cross streets or intersections are closed. Sanding is the application of a fine layer of dry, washed sand that is broadcast over the slurry surface to prevent pickup. Sanding may also be used on wet spots. Sanding should not be done until the slurry can withstand walking traffic. Figure 8-21 illustrates the use of sanding at a cross street.

Figure 8-21 Sanding at a Cross Street

8.6 TROUBLESHOOTING AND FIELD CONSIDERATIONS

8.6.1 Troubleshooting Guide

This section provides information to assist the maintenance personnel in troubleshooting problems with slurry seals along with "dos and don'ts" that address common problems that may be encountered during the course of a project. The troubleshooting guide presented in Table 8-6 associates common problems to their potential causes. For example, an unstable emulsion, too little water in the mix, incompatibility between the emulsion and the aggregate, and so on, may cause a slurry surface to delaminate.

Table 8-6 Trouble Shooting Slurry Seal Job Problems

CAUSE	PROBLEM									
	BROWN	WHITISH	WON'T SET	POOR COATING	DELAYED OPENING TO TRAFFIC	BREAKS IN BOX	RAVELS	FLUSHES	DELAMINATION	SEGREGATION
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			•	•	•		•		•	•
CONDITIONS										
Too hot	•			•		•	•	•		
Too cold			•		•		•		•	
Rain	•		•	•	•		•	•	•	
High humidity		•	•							
SURFACE										
Fatty (Oily)			•					•		

In addition to the troubleshooting guide, Table 8-7 lists some commonly encountered problems and their recommended solutions.

Table 8-7 Common Problems and Related Solutions

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 material.
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.

8.6.2 Field Considerations

The following tables are guides to the important aspects of performing a slurry surfacing project. The tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The field supervisor should be acquainted with its contents.

The intention of the table is not to form a report but to bring attention to important aspects and components of the slurry surfacing project process. Some information is product specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	• Is the project a good candidate for slurry surfacing? • What is the depth and extent of any rutting? • How much and what type of cracking exists? • Is crack sealing needed? • How much bleeding or flushing exists? • Is the pavement raveling? • What is the traffic level? • Is the base sound and well drained? • Review project for bid/plan quantities.
DOCUMENT REVIEW	• Bid Specifications • Mix Design Information • Special Provisions • Construction Manual • Traffic Control Plan (TCP)
MATERIALS CHECKS	• Has a full mix design and compatibility test been completed? • Is the binder from an approved source (if required)? • Has the binder been sampled and submitted for testing? • Does the aggregate meet all specifications? • Is the aggregate clean and free of deleterious materials? • Is the aggregate dry? • Is the emulsion temperature within application temperature specifications?

PRE-SEAL INSPECTION RESPONSIBILITIES	
SURFACE PREPARATION	• Is the surface clean and dry? • Have all pavement distresses been repaired? • Has the existing surface been inspected for drainage problems?
EQUIPMENT INSPECTION CONSIDERATIONS	
BROOM	• Are the bristles the proper length? • Can the broom be adjusted vertically to avoid excess pressure?
SLURRY SEAL EQUIPMENT	• Has each machine been calibrated with the project's aggregate and emulsion? • Who carried out calibration and what documentation has been provided? • Is the machine fully functional? • Has the machine been calibrated for this project's aggregate and certified. Is the spreader rubber clean and not worn? • Is the texture rubber clean and set at the right angle? • Are all paddles in the pug mill intact? • Is the spreader box clean?
ROLLERS (IF USED)	• Do the roller tire pressures comply with the manufacturer's specification? • What type roller will be used on the project (pneumatic-tired roller recommended)? • Do the roller tire size, rating, and pressures comply with manufacturer's recommendations? • Is the pressure in all tires the same? • Do all tires have a smooth surface?
STOCKPILE	• Is the stockpile site well drained and clean? • Does the Contractor have all of the equipment required at the stockpile site (loaders, tankers, and so on)?

EQUIPMENT INSPECTION CONSIDERATIONS	
EQUIPMENT FOR CONTINUOUS RUN OPERATIONS	• Is all equipment free of leaks? • Are "Flow Boys" or other nurse units clean and functional? • Are there enough units to allow continuous running with minimal stops for cleaning box rubbers?
SITE CONSIDERATIONS	
WEATHER REQUIREMENTS	• Have air and surface temperatures been checked at the coolest location on the project? • Do air and surface temperatures meet agency requirements? • Are adverse weather conditions expected? High temperatures, humidity, and wind will affect how long the emulsion takes to break. • The application of the slurry surfacing does not begin if rain is likely? • Are freezing temperatures expected within 24 hours of the completion of any application runs?
TRAFFIC CONTROL	• Do the signs and devices used match the traffic control plan? • Does the work zone comply with Caltrans requirements? • Flaggers do not hold the traffic for extended periods of time? • Unsafe conditions, if any, are reported to a supervisor (contractor or agency)? • The pilot car leads traffic slowly, 24 mph (40 kph) or less? • Signs are removed or covered when they no longer apply?
APPLICATION CONSIDERATIONS	
DETERMINING APPLICATION RATES	• Have agency guidelines and requirements been followed? • Have rut filling and leveling course application rates been calculated or estimated separately? • Has a full mix design been done? • Is more material applied to dried-out and porous surfaces? • Is more material applied on roads with low traffic volumes? • Is less material applied to smooth, non-porous, and asphalt-rich surfaces? • Has moisture content been adjusted in the application rate?

PROJECT INSPECTION RESPONSIBILITIES	
SLURRY SURFACING APPLICATION	• Has a test strip been done and is it satisfactory? • Have field tests been carried out and are the results within specification? • Are enough trucks on hand to keep a steady supply of material for the slurry machine? • Does the application start and stop with neat, straight edges? Will an edge box be used? • Does the application start and stop on building paper or roofing felt? • Are drag marks present due to oversize aggregate or dirty rubbers? • Are rubbers cleaned regularly and at the end of each day? • Does the machine take a straight, even line with minimal numbers of passes to cover the pavement? • Is the mix even and consistent? • Are fines migrating to the surface? • Is the application stopped as soon as any problems are detected? • Does the application appear uniform? • Does the surface have an even and uniform texture? • Is the application rate checked based on amounts of aggregate and emulsion used? • What is the time between spreading, foot traffic, and opening to vehicular traffic?
ROLLING	• Does rolling wait until the mat is stable? Roller is 5-6 tonnes (Caltrans, 1999b) maximum. • Is the entire surface rolled only once? • Do the rollers travel slowly, 5 mph (8-9 kph) maximum?
TRUCK OPERATION	• Are trucks staggered across the fresh seal coat to avoid driving over the same area? • Do trucks travel slowly on the fresh seal? • Are stops and turns made gradually? • Do truck operators avoid driving over the new slurry? • Do truck operators stagger their wheel paths when backing into the paving unit?
LONGITUDINAL JOINTS	• Is the meet line overlapped a maximum of 3 in (75 mm)? • Do the spreader box runners avoid running on fresh mat? • Are the meet lines made at the center of the road, center of a lane, or edge of a lane not in the wheel paths?

PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	• Do all applications begin and end on building paper or roofing felt? • Mixture is not too wet at start up? • Is the building paper or roofing felt disposed of properly?
BROOMING	• Does brooming begin after the slurry surfacing can carry traffic? • Does brooming dislodge the slurry surfacing? • Is the surface raveling? Follow-up brooming should be done if raveling is high or if traffic is high.
OPENING THE SLURRY SURFACING TO TRAFFIC	• Does the traffic travel slowly — 24 mph (40 kph) or less—over the fresh slurry surfacing? • Are reduced speed limit signs used when pilot cars are not used? • After brooming, have pavement markings been placed before opening to traffic? • Have all construction-related signs been removed when opening to normal traffic?
CLEAN UP	• Have all loose aggregate from brooming been removed from traveled way prior to opening to traffic? • Have all binder spills been cleaned up?

8.7 REFERENCES

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