

*Disclaimer*

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## CHAPTER 2 MATERIALS

### 2.1 OVERVIEW

Materials play an important role in the efficient and effective use of maintenance treatments. Most materials used in maintenance treatments are covered in the Standard Specifications, SP's or SSP's that can be found on the Caltrans web site [2025 Standard Plans, Standard Specifications, and Contract Item Codes](#). The specifications are referenced for specific treatments in this MTAG, Chapters 4 through 14. This section discusses the main materials used and provides a general explanation of their composition, manufacturing, storing and handling techniques, and addresses special application requirements. In some cases, the materials themselves are derived from a mixture of raw materials or may be derived from Recycled Asphalt Pavement (RAP). This section will also address some issues related to specific materials included in this Chapter.

The two main materials comprising flexible pavement maintenance treatments are binder and aggregate. Asphalt binders in use in California include:

- Asphalt Binders
- Asphalt Emulsions (both conventional and polymer modified)
- Modified Asphalts
- Asphalt Rubber

Aggregates in use in California cover a range of geological types. The general requirements, gradings, and physical properties are covered in various sections of the Standard Specifications (Caltrans, 2025).

### 2.2 ASPHALT BINDERS

#### 2.2.1 Paving Asphalt (Asphalt Cement) Constituent

Conventional paving asphalt is a complex hydrocarbon mixture which consists primarily of the residue from crude oil refining. The properties of the asphalt produced depend on its chemical composition, crude source and type, and the processing/refining method used (Kirk, 1978). Asphalt properties are highly temperature dependent. At temperatures above the softening point, i.e. when hot, asphalt liquefies and acts as a lubricant. At temperatures

below the softening point, asphalt becomes semi- solid and acts like a glue. Below its freezing point, asphalt becomes a brittle solid. Caltrans requirements for asphalt binders are described in the Caltrans 2025 Standard Specifications, Section 92.

### 2.2.2 Paving Asphalt Manufacture

Several processes are used to manufacture asphalt including:

- 1. Steam Distillation:** Fraction distillation begins with the desalting and de-waxing of the crude oil. The crude is then heated to approximately 572°F (300°C) (Kirk, 1978). A furnace then heats the crude to 752°F (400°C) and the heated crude is continuously delivered to the flash zone of the atmospheric tower. The material is separated (by its boiling point) with the most volatile (lightest) components rising to the top and the less volatile escaping on the sides of the tower. The residue in the tower is stripped using steam to remove volatiles. For some heavy crudes, this residue may be suitable asphalt. In California, most asphalt cements used are steam distilled. See Figure 2-1 for a schematic of a typical distillation column.

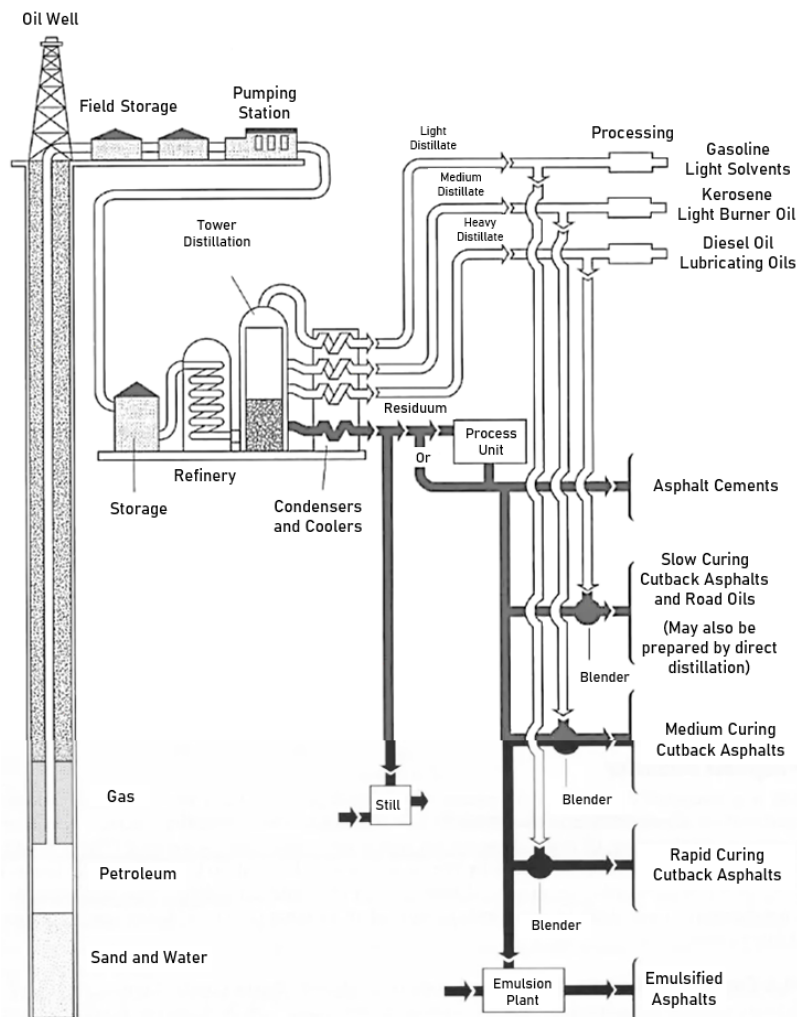


Figure 2-1 Typical Distillation Process (MS-22, Asphalt Institute)

2. **Straight Run/Blending:** Vacuum tower residue may be suitable as paving asphalt or it may require blending with other feed stocks, fluxes from the vacuum tower, or from other parts of the process such as solvent de-asphalting.
3. **Solvent Refining:** Solvent refining of the asphalt rich fraction uses a short chain hydrocarbon (propane usually) to precipitate out the insoluble asphalt fractions.

### 2.2.3 Asphalt Specifications

Specifications drive production of asphalts that will perform well in the field. In the past, asphalt specifications were based on measurements of consistency at various temperatures which provided little information about expected performance. For many years, California operated under similar specifications for “Aged Residue” (AR) of asphalt which evolved to partial use of Performance based asphalts. In 2006, Caltrans adopted the Performance Graded (PG) system for asphalt binders, which is based on fundamental engineering properties of the asphalt over the entire range of expected service temperatures. In the PG system, the property requirements remain the same for all asphalt binders; what varies are the high and low temperature values at which these requirements are met. The PG grading for asphalt binders is used by FHWA for the Superpave HMA mix designs.

In the PG system, asphalt is specified by results of the following tests:

- Dynamic Shear Rheometer (DSR)
- Rotational Viscometer (RV)
- Binder Conditioning
  - Rolling Thin Film Oven (RTFO)
  - Pressure Aging Vessel (PAV)
- Fracture Related and Fracture Testing
  - Ductility Meter
  - Bending Beam Rheometer (BBR)
- Quality Control Testing
  - Asphalt Binder Tester (ABT)
- Aging Characteristics
- Purity and Safety

Table 2-1 lists the testing equipment and purposes in the PG grading system.

**Table 2-1 Superpave Asphalt Binder Testing Equipment and Purposes (FHWA, 08/01/2022)**

Equipment	Purpose	Performance Parameter
Dynamic Shear Rheometer (DSR)	Measure binder properties/stiffness at high and intermediate temperatures	Dynamic Shear Rheometer, DSR
Rotational Viscometer (RV)	Measure binder properties at high construction temperature	Handling & pumping
Rolling Thin Film Oven (RTFO)	Simulate binder aging during HMA production & construction	Resistance to aging during and immediately after construction
Pressure Aging Vessel (PAV)	Simulate binder aging during HMA life	Resistance to aging over the length of pavement service life
Ductility Meter (DDA-3)	Determines strain tolerance of binders at intermediate temperatures with the Double Edge Notch Test (DENT)	Low-temperature (thermal) cracking of asphalt binders
Bending Beam Rheometer (BBR)	Measure binder properties at low service temperatures	Resistance to thermal cracking
Asphalt Binder Cracking Device (ABCD)	Used to determine low temperature thermal cracking for asphalt binders	Resistance to thermal cracking
Asphalt Binder Tester (ABT)	To quickly and accurately assure asphalt binders meet the specified grade for highway construction	Maximum creep deflection and percent recovery values are determined using the ABT

The following paragraphs and figures provide additional testing details.

- Dynamic Shear Rheometer (DSR):** is used to measure the properties of the asphalt binder at high and intermediate pavement service temperature. The asphalt binder is tested in the DSR in its original (unaged), oven aged (Rolling Thin Film Oven (RTFO) residue), and long-term aged conditions after conditioning by the Pressure Aging Vessel (PAV). The original and RTFO-aged binders are tested at the maximum pavement design temperature to determine the asphalt susceptibility for rutting. PAV aged residue is tested at the intermediate design temperature to determine the asphalt binder’s ability to resist fatigue cracking. The DSR is also used to perform the Multiple Stress Creep Recovery (MSCR) procedure. This is the latest improvement to the Superpave Performance Graded (PG) Asphalt Binder specification. This new test is listed as AASHTO TP 70, and AASHTO MP 19, which provides the user with a new high temperature binder specification. The MSCR test can provide information for both performance and formulation of the binder.

- See photos in Figure 2-2 of a Dynamic Shear Rheometer (DSR), and Figure 2-3 of a Rotational Viscometer (RV).



**Figure 2-2 Dynamic Shear Rheometer (DSR), (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview)**



**Figure 2-3 Rotational Viscometer (RV) (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview)**

- **Ductility Meter and Bending Beam Rheometer (BBR):** is used to test asphalt binder at low pavement service temperatures to determine the binder's resistance to thermal cracking. The BBR measures the stiffness  $S(t)$  and  $m$ -

value.  $S(t)$  is a measure of the thermal stresses developed in the HMA, as a result of thermal contraction. The slope of the stiffness curve,  $m$ , is a measure of the rate of stress relaxation. Figure 2-4 shows a photo of a Ductility Meter (DDA-3), and Figure 2-5 shows a photo of a Bending Beam Rheometer (BBR).



**Figure 2-4 Ductility Meter (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview)**



**Figure 2-5 Bending Beam Rheometer (BBR) (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview)**

- **Aging Characteristics:** Aging in asphalt is associated with oxidation and hardening of asphalt. During processing and while in service in the HMA pavement, asphalt loses its volatile fractions. The loss of this volatile material can lead to hardening. Aging is one cause of asphalt failure as the material becomes brittle, shrinks, and cracks. Short-term aging is simulated by exposure to air in a Rolling Thin Film Oven (RTFO). Long term aging during service life is simulated using a Pressure Aging Vessel (PAV) (AASHTO R-28). Figure 2-6 shows a photo of a RTFO, and Figure 2-7 shows a photo of a PAV.



**Figure 2-6 Rolling Thin Film Oven (RTFO) (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview)**



**Figure 2-7 Pressure Aging Vessel (PAV) (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview)**

- **Quality Control Testing:** The Asphalt Binder Tester (ABT) was developed by Laser Technology, Inc. (LTI) to produce accurate field testing to assure that the correct asphalt grade is being delivered to HMA plants. “Additional data generated from the creep and recovery curve is used in predicting the PG of asphalt binder that is tested. The prediction of PG allows DOTs to rapidly determine compliance to PG during the paving season.” Figure 2-8 shows a photo of an ABT. This quality control test, using the ABT, is not commonly used by Caltrans. No AASHTO test method is listed for the ABT and its usage by FHWA.



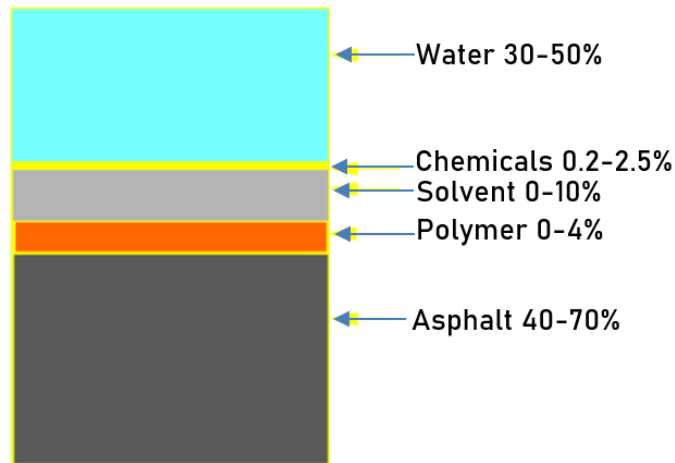
**Figure 2-8 Asphalt Binder Tester (ABT), (FHWA Research, Asphalt Binder and Mixtures Laboratory Overview, Last Updated August 1, 2022)**

The Caltrans asphalt binder gradings and requirements are included in Caltrans Standard Specifications, Section 92, Asphalt Binders, dated 2025. See table entitled, “PG Asphalt Binders”, and “PG Modified Asphalt Binders”, for their allowable gradings and testing requirements.

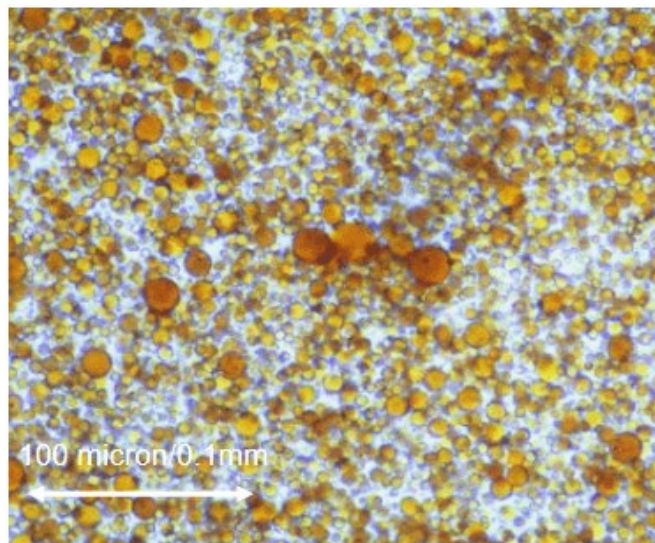
## 2.3 ASPHALT EMULSIONS

### 2.3.1 Emulsion Constituent

Figure 2-9 shows the percentages of the material components of asphalt emulsion. An asphalt emulsion is asphalt cement dispersed in water using an emulsifier, chemicals, solvent, and a polymer for polymer modified emulsions. The emulsifier keeps the asphalt droplets in a stable suspension and controls the breaking time. The emulsion does not have a long shelf life and is susceptible to separation. Emulsions are commonly used as a tack coat prior to HMA paving and are also used in pavement preservation treatments such as seal coats and Cold in Place Recycling (CIR). Figure 2-10 shows a photomicrograph of an asphalt emulsion.



**Figure 2-9 Components of an Asphalt Emulsion, Delmar Salomon, Pavement Preservation Systems LLC, and Alan James, AkzoNobel Surface Chemistry, TRB Webinar, Asphalt Emulsions: Chemistry, Manufacturing, and Applications (April 22, 2011)**



**Figure 2-10 Photomicrograph of an Asphalt Emulsion (SlideShare, Asphalt Emulsions 101.1, 2018, AEMA)**

In an emulsion, the particle sizes range from  $3.94 \times 10^{-5}$  to  $3.94 \times 10^{-3}$  inches (1 to 100  $\mu\text{m}$ ) in diameter. An emulsion lies between these two extremes and is defined by the size of the particles involved. This allows the particles (once chemically stabilized) to form a stable dispersion. When the particle size is less than one micron, the material is termed as a colloid. Such systems may be stable without the use of extra chemical stabilizers as they are usually self-stabilizing (e.g., clay in water).

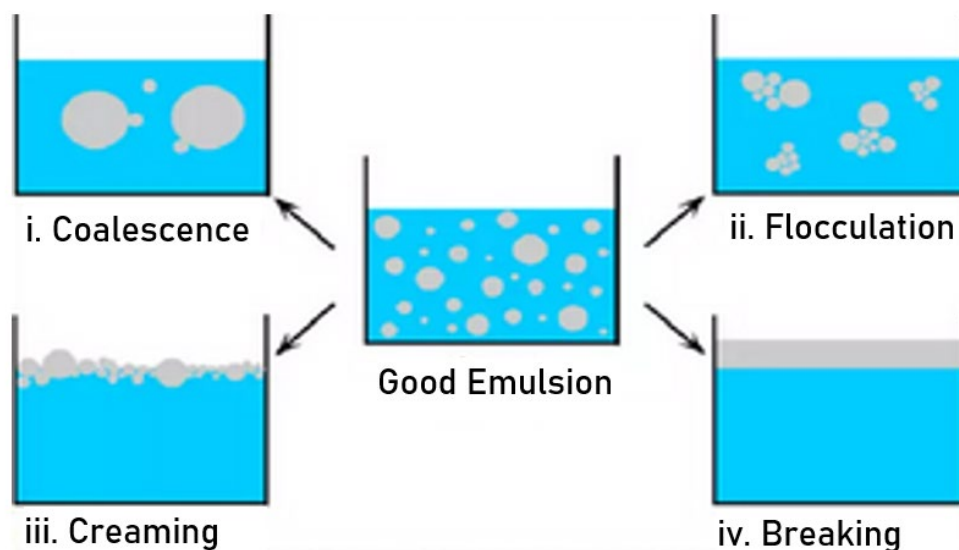
Emulsions form an asphalt binder with low enough viscosity for easy spray bar application. The dispersion in water gives the asphalt many of the properties of water such as low viscosity, lower temperature requirements for both application and storage, and less sensitivity to application on damp surfaces. Emulsions do not require high heat or solvents and are more environmentally friendly than hot applied asphalt products.

### 2.3.2 Emulsion Production

Asphalt is semi-solid at ordinary temperatures 50 to 140°F (10 to 60°C). To make an emulsion, the asphalt must be sheared into small droplets and coated/ reacted with a chemical stabilizer or emulsifier. Figure 2-11 shows the differences between a good emulsion and those with poor characteristics. Figure 2-12 shows the cross section of a typical colloid mill, one of the devices that is used to shear the particles to the proper sizes. Figure 2-13 is an example of the grinding plates inside a colloid mill.

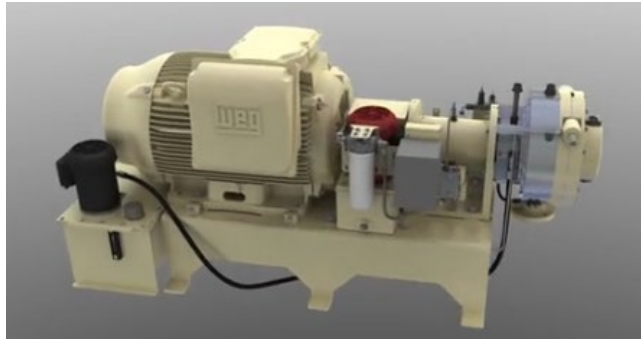
There are other methods of shearing the asphalt to produce an emulsion. These include homogenizers, pressure reducers and pumps. The colloid mill is the equipment most commonly used to produce asphalt emulsions. The chemical emulsifier solution (also known as the soap solution) is combined with the asphalt and introduced into a gap between a high-speed rotor and a stator (or other rotor rotating at a lower speed). The resulting shear breaks the asphalt particles down to the required size. The geometry of the sheared particles has a big effect on the particle size distribution, which in turn affects the properties of the emulsion (Holleran, 2002).

A stable emulsion has droplets that are evenly suspended and have a narrow size range. Unstable emulsions allow the droplet to agglomerate or stick together. Figure 2-11 shows an example of different emulsion states.

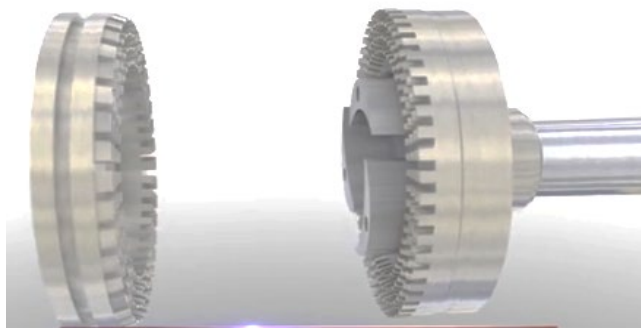


**Figure 2-11 Unstable Emulsion States (Pharmaceuticals Dispersion Theory- Suspension and Emulsion, Sachin Aryal, March 2, 2020)**

Figure 2-12 shows a colloidal mill which can provide a stable emulsion, and Figure 2-13 shows the emulsifier plates for the same unit.

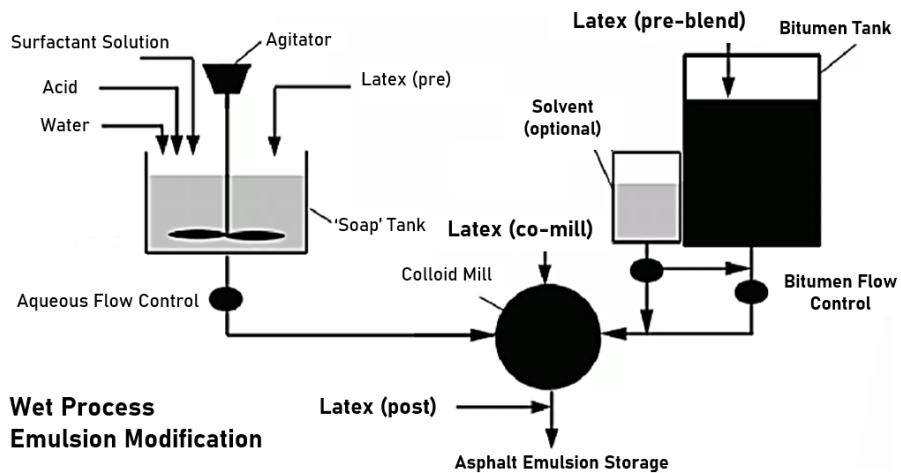


**Figure 2-12 Colloidal Mill to Provide Stable Emulsion (Heatec, 2024)**



**Figure 2-13 Emulsifier Plates Inside a Colloid Mill (Heatec 2024)**

In an emulsion plant, several operations must be carried out. Figure 2-14 shows the key elements of an emulsion plant.



**Figure 2-14 Schematic of Asphalt Emulsion Production (Polymer Modified Asphalt Emulsions Composition, Use, and Specifications for Surface Treatments, Publication No. FHWA-CFL/TD-12-04, January 2012)**

The asphalt must be stored correctly and at the right temperature. For normal operation (non-polymer binder emulsification), the storage temperature will range from 275 to 284°F (135 to 140°C). For polymer-modified binders, the storage temperature will range from 320 to 338°F (160 to 170°C). If higher temperatures are required, the colloid mill must be operated under back pressure, about 29 to 43 psi (2 to 3 bar) and a heat exchanger on the mill outlet is required to ensure that the emulsion is cooled to below boiling temperatures before the back pressure is reduced to atmospheric pressure. If the backpressure and heat exchange operations are not properly carried out, the emulsion will boil and be destroyed.

The soap solution (emulsifier solution) preparation is required because the emulsifiers usually need to be reacted with a base or acid to create the surface-active or emulsifying form (salt). This may be done in a continuous fashion or in a batch fashion. As the reactions are between an acid and an alkaline emulsifier (cationic systems) or an alkaline chemical and an acid emulsifier (anionic systems), the pH of the soap solution and the pH of the resulting emulsion are key factors in the quality of the emulsion.

In many cases, additives for emulsion stability or modification are introduced. The most common method of modifying an emulsion is through the addition of rubber latex (synthetic or natural). The latex is either introduced via the soap solution or directly injected into the mill via the soap line. This method has the advantage that no heat exchanger or pressure operation is required.

### 2.3.3 Emulsifiers and Types of Emulsion

Emulsifiers in their neutralized state may have a negative charge (anionic), a positive charge (cationic), or no charge (nonionic) (Holleran, 1999). The exact chemistry and type of emulsifier determines the application of the finished emulsion. Other factors that determine physical and application characteristics include pH of the emulsion, the binder content, the particle size and distribution, and the compatibility with the aggregate sources. Anionic emulsifiers are based on fatty acids while cationic emulsifiers are based on various types of amines. Cationic emulsifiers are used for slow set, rapid, quick sets and micro surfacing of various types of amines depending on the application. See Table 2-2 for the differences of charges between cationic and anionic emulsions. Caltrans Standard Specification, 2025, only list characteristics for cationic and anionic emulsions. Cationic emulsion is the most commonly specified.

**Table 2-2 Asphaltic Emulsion**

	<b>Asphaltic Emulsion</b>	
Cationic	Low pH, (+) positive charge pH 6.7 max.	Acidic
Anionic	High Ph, (-) negative charge pH 7.3 min.	Basic

### 2.3.4 Anionic Emulsions versus Cationic Emulsions

Caltrans uses anionic and cationic emulsions for various applications. The choice between

anionic and cationic is made based on the application requirements and the characteristics of the aggregate to be used in the mix. Generally, anionic emulsions of the slow set variety are more compatible with soils and easier to dilute with water. Thus, they are normally chosen for soil stabilization and fog seals. Anionic emulsions break by flocculation and coalescence. In this process, as water evaporates from the emulsion and the particles come into close contact, they stick together. These particles then “floc” or coalesce into larger particles. This process continues until the particles begin to form films and a reaction occurs (French Society, 2000). Thus, anionic emulsions are suitable for use with calcareous aggregates such as limestone, not typically used with setaceous.

Figure 2-15 illustrates material compatibility in general terms along with the associated breaking process. Cationic emulsions may be formulated for all application types and aggregates. These emulsions are most useful for rapid setting chip seals, slurry emulsions and micro surfacing emulsions. This is due to a cationic emulsion’s specific reaction with all compatible aggregates that creates a stronger adhesive bond. For the same reason, cationic emulsions are also less susceptible to cooler conditions and dampness than anionic emulsions.

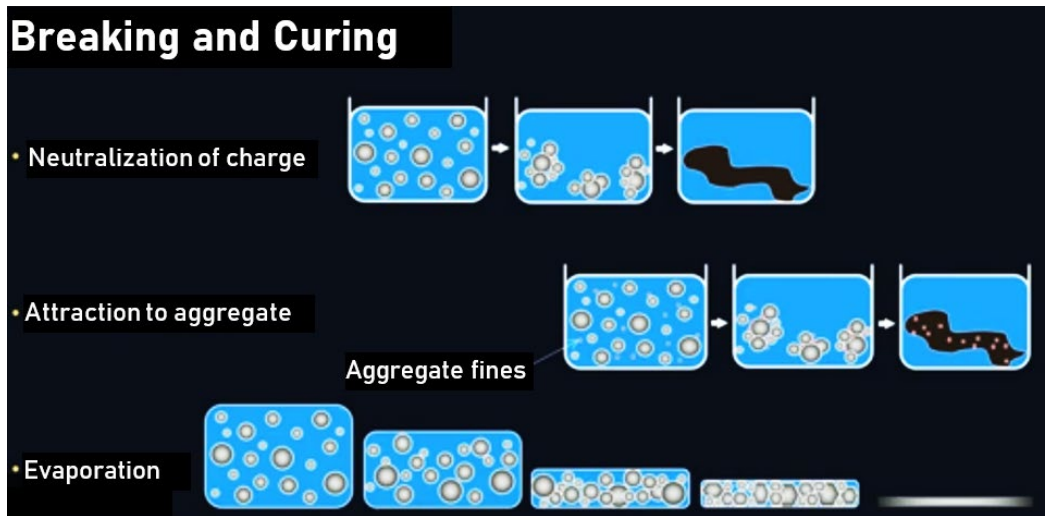


Figure 2-15 Breaking and Curing of Emulsion, “Asphalt Emulsions 101.01”, (AEMA)

The curing process is the same for both types of emulsion, except the reaction mechanism for cationic emulsion pushes water away from the aggregate surface. Thus, cationic emulsions tend to cure faster. The decreased curing time for cationic emulsions has implications in the application and handling of these emulsions. These implications will be discussed in the sections on specifications for storing and handling.

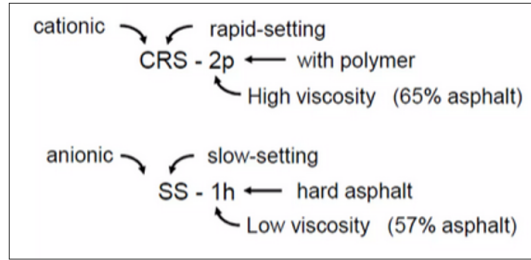
### 2.3.5 Specifications and Testing

- 1. Caltrans Specifications:** Caltrans uses several common emulsion types. These are described in detail in Caltrans Standard Specifications, 2025, Section 94 and are briefly described below:

- **Anionic Emulsions, Slow Set (SS).** There are subcategories that describe the base asphalt (“h” equals hard or 80/100-penetration grade or if there is no ‘h’ designation, it refers to the use of a softer grade - 120-150 pen grade). SS grades are only designated as SS-1 or SS-1h and are 57% minimum binder content. See Caltrans Standard Specifications, 2025, Section 94, Asphaltic Emulsion for the emulsion requirements for slow-setting anionic asphaltic emulsion in the table entitled “Slow-Setting Anionic Asphaltic Emulsion Requirements”. This table lists Grade SS-1, and SS-1h.
- **Cationic Emulsions, Slow Set (SS).** There are subcategories that describe the base asphalt (“h” equals hard or 80/100-penetration grade or if there is no ‘h’ designation, it refers to the use of a softer grade - 120-150 pen grade). SS grades are only designated as CSS-1 or CSS-1h and are 57% minimum binder content. See Caltrans Standard Specifications, 2025, Section 94, Asphaltic Emulsion for the emulsion requirements for slow-setting anionic asphaltic emulsion in the table entitled “Slow-Setting Cationic Asphaltic Emulsion Requirements”. This table lists Grade CSS-1, and CSS-1h.
- **Cationic Emulsions, Rapid Set (CRS).** There are subcategories that describe the base asphalt (“h” equals hard or 80/100-penetration grade. If there is no ‘h’ designation, it refers to the use of a softer grade). Numbers describe the binder content of the emulsion (1 for lower and 2 for the higher level). In cationic emulsions, these binder content designations are different for different grades; CRS-1 is 60% minimum binder content, and CRS-2 65% minimum. Caltrans Standard Specifications, 2025, Section 94, Asphaltic Emulsion for the emulsion requirements for rapid-setting cationic asphaltic emulsion must meet the requirements shown in the table entitled “Rapid-Setting Cationic Asphaltic Emulsion Requirements”. This table includes CRS-1, CRS-2, CRS-1h, and CRS-2h.
- **Cationic Emulsified Recycling Agent.** This must be cationic and is used as a recycling agent. For cold-in-place recycling. This material must meet the requirements shown in the table Entitled, “Cationic Emulsified Recycling Agent Requirements” in section 94-1.02E, “Cationic Emulsified Recycling Agent”. This table does not show a grade for the recycling agent but does show a requirement of a minimum of 63% residual asphalt.
- **Bonded Wearing Course Asphaltic Emulsions:** This must be a cationic emulsion with a minimum residual of 63% and must meet the requirements shown in the Section 94-1.02G, “Bonded Wearing Course Asphaltic Emulsions”, in the table entitled “Bonded Wearing Course Asphaltic Emulsion Requirements”. Currently, there is only one bonded wearing course asphaltic emulsion shown in the Caltrans Standard Specifications, 2025.
- **Rapid-Setting Polymer-Modified Rejuvenating Asphaltic Emulsions:** There is no specific grade, but it must be cationic. This is a rapid set and must have the letter P at the start of the designation. For example, PMCRS-2h is a polymer modified cationic rapid set emulsion with the hard binder. All the emulsion binder contents for this class of emulsions are 65% minimum. These

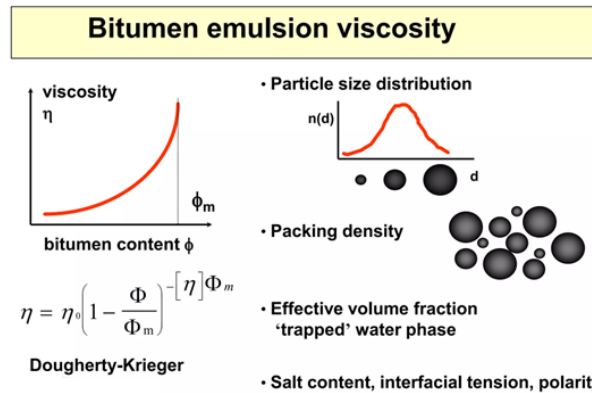
emulsion types are further discussed in Chapter 7, Chip Seals, and must comply with the requirements shown in section 94-1.02H, in the table entitled, “Rapid-Setting Polymer-Modified Rejuvenating Asphaltic Emulsion Requirements”, of the Caltrans Standard Specifications, 2025.

- **Quick-Setting Asphaltic Emulsions:** These may be anionic or cationic (QS or CQS) and have minimum binder contents of 57%. Quick-setting asphaltic emulsions must comply with the requirement shown in Section 94-1.02I, “Quick-Setting Asphaltic Emulsions”, in the table entitled “Quick-Setting Asphaltic Emulsion Requirements”, in the Caltrans Standard Specifications, 2025. The table includes the following grades of emulsion: QS-1, QS-1h, CQS-1, and CQS-1h. This is further discussed in Chapter 8, Slurry Seals of this MTAG.
  - **Quick-Setting Polymer-Modified Cationic Asphaltic Emulsions:** This must be a cationic emulsion with a minimum residual of 60% and must meet the requirements shown in the table entitled “Quick-Setting Polymer-Modified Cationic Asphaltic Emulsions Requirements”, per Section 94-1.02J, Caltrans Standard Specifications, 2025. Caution must be used in applying this type of emulsion for a seal coat of any type over a polymer modified HMA. These asphalts age more slowly, and may cause the polymer modified HMA to rut. Severe rutting may require HMA replacement, which may be costly.
  - **Micro Surfacing Emulsions:** This must be a cationic emulsion with a minimum residual of 62% and must meet the requirements shown in the table entitled “Micro Surfacing Emulsion Requirements”, per section 94-1.02K, “Micro Surfacing Emulsions”, Caltrans Standard Specifications, 2025. This MSE grade is the only grade approved by Caltrans for micro surfacing.
- 2. What Specifications Mean:** The test methods listed in the specifications (Caltrans Standard Specifications, 2025) are designed to provide an indication of the stability, physical characteristics, and performance of the emulsion. This section presents a general overview of tests contained in the specifications.
- Binder content is measured by distillation or evaporation. This is important because application rates are based on residual binder.
  - Viscosity indicates the application properties (whether the emulsion can be pumped and sprayed) and whether it will remain where it is applied without running off. The viscosity of an emulsion is a function of the binder content within the emulsion, as illustrated in Figure 2-16.
  - Viscosity is also influenced by the asphalt binder properties, emulsifier properties, and environmental conditions, such as temperature.



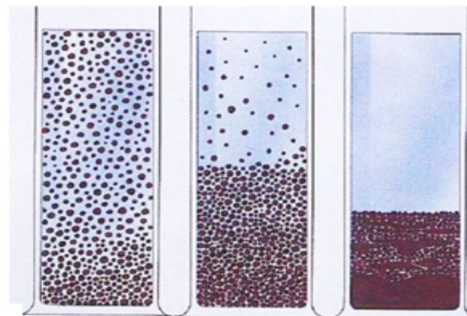
**Figure 2-16 Asphalt Emulsion Classification (Sallie Houston, Nov. 7, 2019)**

- Figure 2-17 shows that viscosity increases as bitumen increases.



**Figure 2-17 Relative Viscosity Vs Oil Content (Shell Global Solutions, "An introduction to emulsion technology.ppt", April 21, 2023)**

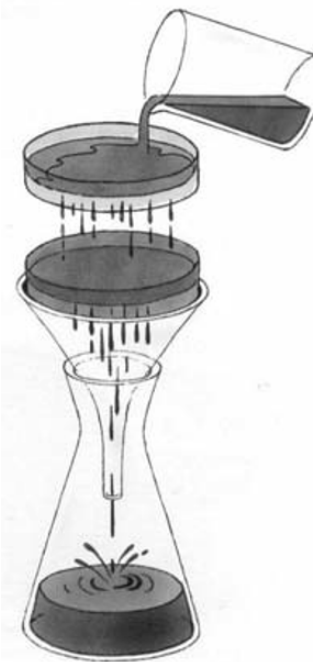
- Settlement and storage stability are determined by the same test but performed over different periods of time. They determine if an emulsion can be stored without "breaking" in the storage container. If settlement occurs during the test (shown in Figure 2-18), and is not re-dispersed, this indicates the emulsion may flocculate and coalesce ("break") during storage. ASTM D6930-19 is the Standard Test Method for Settlement and Storage Stability of Emulsified Asphalts.



**Figure 2-18 Sedimentation and Storage Stability, (Shell Global Solutions, "An introduction to emulsion technology.ppt", April 21, 2023)**

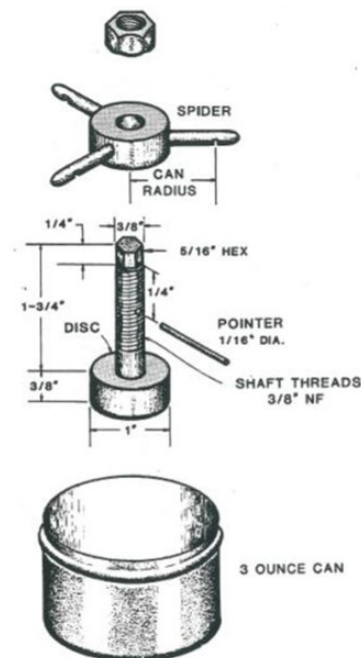
- Demulsability is the measure of emulsion's resistance to breaking and shows whether the emulsion is rapid or slow setting.
- The coating test refers to mixing characteristics with soil or aggregate.
- The cement-mixing test is a stability test for mixing emulsions with soils or aggregates.
- The sieve test may reveal foreign matter in the emulsion that might cause problems such as clogging nozzles during spraying or clogging in-line sieves during pumping operations. It is also an indication of stability.

Figure 2-19 shows a sieve test which is used in AASHTO T-59. Tests on residual binder are carried out to check the base asphalt and the polymer. Penetration and ductility are conducted on the residue of both conventional and polymer modified emulsions. Torsional recovery and infrared testing are used to examine polymer content. Torsional recovery is carried out using the equipment shown in Figure 2-20. The recovery from a torsional load is measured and related to polymer content (the test method used is CT 332).



**Figure 2-19 Sieve Test**

(Note: Normally only 1 sieve is used in the AASHTO T-59 Standard Method of Test for Emulsified Asphalt (Latest revision 2022))



**Figure 2-20 Torsional Recovery Test Equipment, CT 332 (AASHTO T59-16), July 6, 2022**

## 2.4 PERFORMANCE GRADE ASPHALT BINDERS

### 2.4.1 Performance Grade Asphalt Binders (PG Asphalt Binders)

Performance grade asphalt binders have become the industry standard throughout the United States and comprise the neat asphalt grades used in California. Asphalt binder suppliers must comply with the Caltrans Certification Program for Suppliers of Asphalt per Section 92-1.01D(2), “Certification”, in Caltrans Standard Specifications, 2025, for asphalt to be used on State projects. The PG binder grades include PG 58-22, PG 58-16, PG 64-10, PG 64-16, PG 64-28 and PG 70-10, with the requirement for each shown in the table entitled “PG Asphalt Binders” in Section 92-1.02B, “Performance Grade Asphalt Binders”.

PG asphalt binders have a wide range of uses:

- Bond breakers between concrete and treated concrete aggregate base
- Binder for chip seals
- Slurry seals when emulsified
- Seal coats
- Tack coats
- Base binder for asphalt rubber for RHMA and asphalt rubber chip seals
- Base binder for polymer modified asphalt binder, and for terminal blend binder
- Cape seals
- Stress Absorbing Membranes Interlayer (SAMI)

## 2.5 MODIFIED BINDERS

### 2.5.1 Polymers and Modified Binders

Polymers are long chain molecules that are used to enhance the performances of asphalt cement and asphalt concrete pavement, particularly at high or low temperatures. Depending on the basic polymer units or monomers used, a wide range of properties can be achieved. Polymers are conveniently described as having glassy (stiffness) or rubbery (elastomeric) properties. Examples of polymers commonly used in asphalt mixtures include:

- Styrene Butadiene Copolymer (radial and linear) (SBS)
- Polyethylene (PE)
- Styrene Butadiene Rubber (SBR)
- Polybutadiene (PB)
- Ethylene Vinyl Acetate (EVA)
- Ethylene Methyl Acrylate (EMA)
- Atactic Polypropylene (PP)
- Epoxies and Urethanes
- Tire Rubber (Crumb)

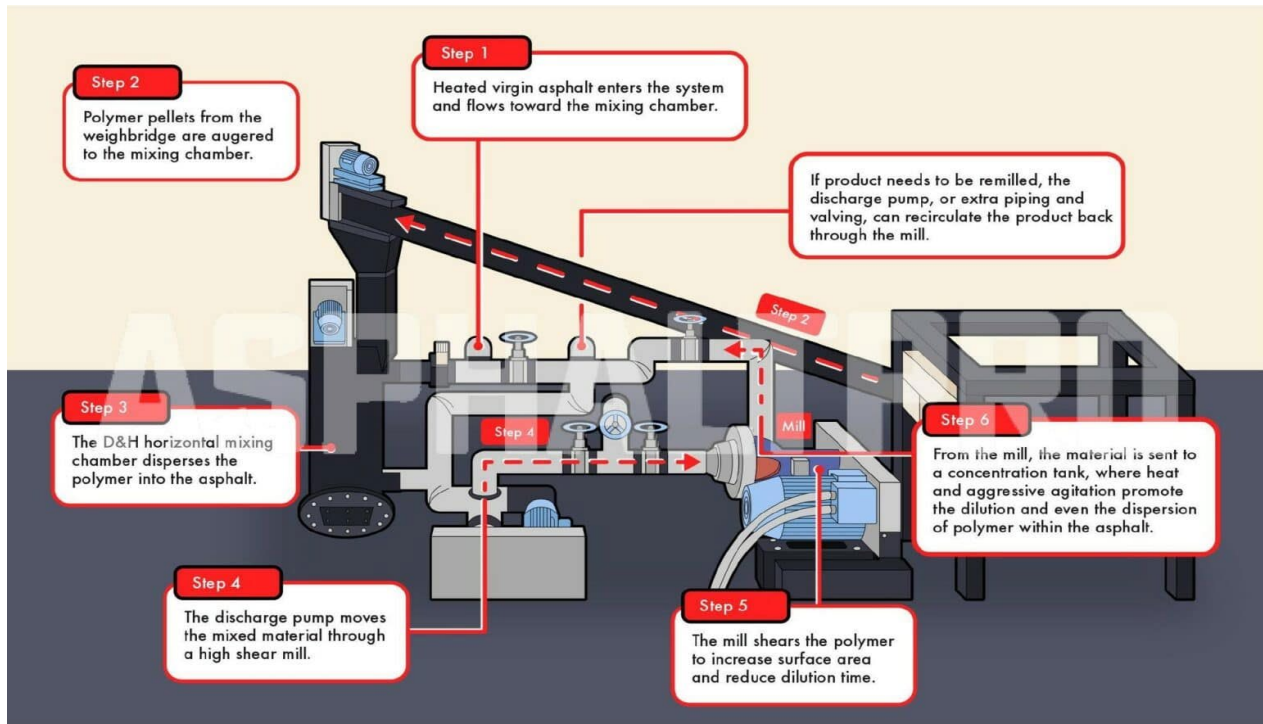
### 2.5.2 Polymer Modified Binder Manufacture

Many types of manufacturing configurations exist to make polymer-modified asphalts. Manufacturing may be done at high or low shear, on site, or in a refinery. The main stages of manufacturing require the following procedures:

- Metering of Polymer, Asphalt, and Additives
- Wetting of the Polymer by the Asphalt/Additive Blend
- Dispersion of the Polymer
- Allowance for any Interaction (Reaction) of the Polymer with the Asphalt
- Storage and Transportation

Polymer modified binder may be produced at a plant, and it may be called Terminal Blend. Asphalt rubber may be considered a polymer, and it is generally blended with an asphalt binder at a site near the project. This is an example of a terminal blend asphalt rubber binder. A Terminal Blend may include both a crumb rubber and polymer as listed in section 2.5.1 above.

Most of these are mechanical issues and are achieved by relatively simple techniques. Figure 2-21 illustrates a blending plant for polymer modified asphalt binder.



**Figure 2-21 Polymer Modified Asphalt Blending Plant (D&H Equipment’s PMA Blending Plant, Courtesy Asphalt Pro Staff, 2024)**

The most important steps in the manufacturing process are dispersion and reaction. This determines the structure (i.e., morphology) of the final binder and hence its properties. These steps also determine the level of polymer required to achieve the desired results.



## 2.6 ASPHALT RUBBER

### 2.6.1 Asphalt Rubber Binder (ARB)

Asphalt rubber binder is no longer specified in the Standard Special Provisions but are in the Caltrans 2025 Standard Specifications. The applicable sections are Section 37, and 39-2.03A(3)(a), “General” through 39-2.03C, “Construction” for Rubberized Hot Mix Asphalt-Gap Graded (RHMA-G). Most RHMA used by Caltrans is Gap-Graded, unless it is being used in preventative maintenance projects.

Scrap rubber, crumb rubber, and reclaimed rubber are all terms describing recycled rubber. The largest recycled rubber source is automobile and truck tires and is referred to as crumb rubber modifier (CRM). This rubber is not a pure polymer but a blend. Most car tires in the USA are made of mainly Styrene Butadiene Rubber (SBR) or polyisoprene and carbon black. Other polymers are included in some blends, and tires are not uniformly formulated or compounded. Truck tires generally contain a higher percentage of natural rubber than car tires (up to 30% of the combined polymer content).

The variations in CRM may affect the properties. However, in asphalt rubber binders, the particle size of the added CRM is relatively large compared to a polymer modified system. Asphalt rubber binder is typically produced in the field; near to the job site for chip seal applications or at the hot plant site for hot mix applications.

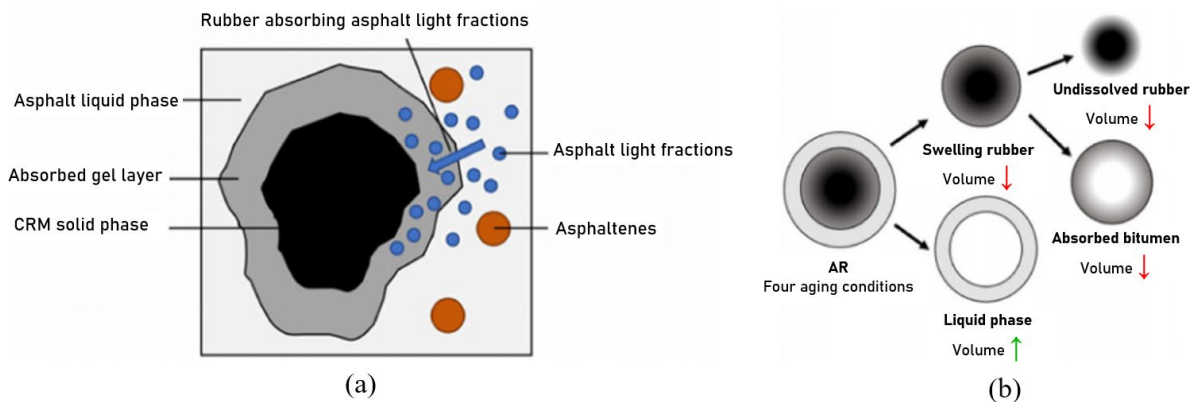
The asphalt rubber specification requires that the supplier submit a Job Mix Formula (JMF) per Caltrans 2025 Standard Specifications. The JMF must meet specific physical property requirements. Two rubber types are specified, one is tire rubber and the other is a high natural rubber recycled material. The required rubber properties are controlled by the specifications (Caltrans 2025 Standard Specifications). Mixing temperatures are important and should be kept between 375 and 440°F (190 and 226°C). CRM Grading is important in determining the rate of digestion and the binder’s final properties. These materials are mixed into asphalt that has been modified with 2-6% extender oil (high aromatic hydrocarbon).

The asphalt rubber binder has an extended fatigue life, superior rut resistance, and provides better stone retention and crack retardance in chip seals when compared to other binders. In California, asphalt rubber gap-graded overlays thicknesses may be reduced up to 50% thickness of conventional overlays and still provide the same resistance to reflective cracking, however half thickness does not apply to structural requirements. Caltrans uses asphalt rubber binders in gap graded and open graded mixes, as well as preventative maintenance treatments that include chip seals, and cape seals. They are also used as Stress Absorbing Membrane Interlayers (SAMIs) as a reflective crack preventative treatment. Caltrans does not currently use ARB in dense graded mixtures.

### 2.6.2 Asphalt Rubber Production

To produce asphalt rubber binder, the asphalt cement is heated to approximately 375 to 440°F (190 to 226°C) then CRM is added via a hopper system into a pre-wet tank. The

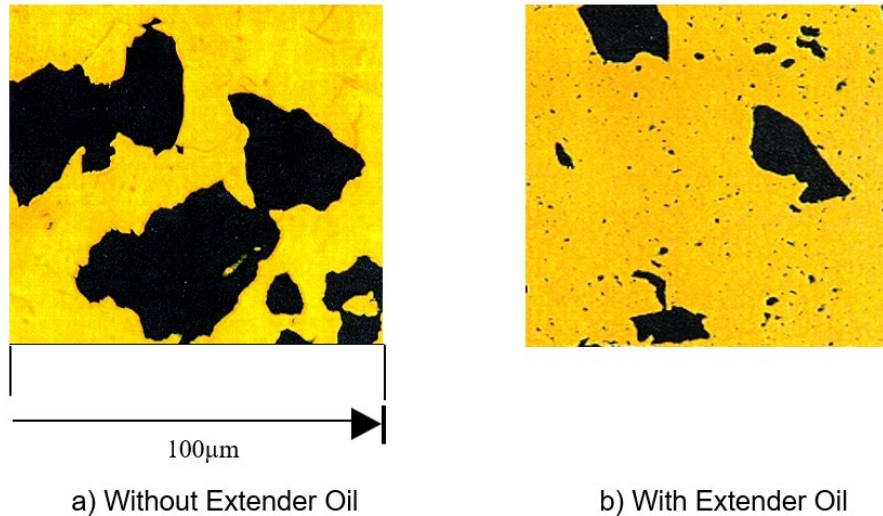
asphalt contacts and wets the CRM particles. This mix is then transferred into a reaction vessel where it “reacts” with the lighter fractions in the asphalt oils that swell the outer areas of the particles. The asphalt and the rubber particles interact to form a gel coated particle. This reaction is similar to the process of swelling that occurs in polymer asphalt systems. The reaction is shown in Figure 2-23.



**Figure 2-23 (a) Schematic of Multiphase Structure within CRM (Li et al, 2021), (b) Volume Evolution of Phases within CRM during Thermal Aging (DN Li et al, 2022)**  
**Aging evolution and sustainability implications of crumb rubberized asphalt binder: A state-of-the-art, January 2024, Journal of Cleaner Production.**  
[https://www.researchgate.net/publication/376484940\\_Aging\\_evolution\\_and\\_sustainability\\_implications\\_of\\_crumb\\_rubberized\\_asphalt\\_binder\\_A\\_state-of-the-art](https://www.researchgate.net/publication/376484940_Aging_evolution_and_sustainability_implications_of_crumb_rubberized_asphalt_binder_A_state-of-the-art)

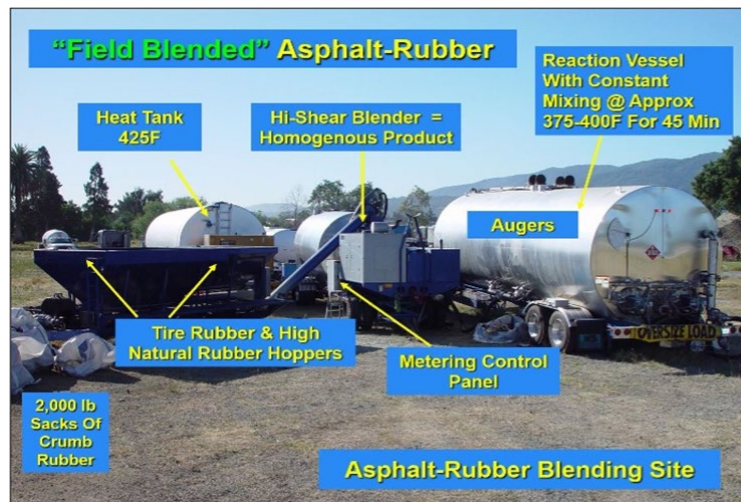
How well this model reflects the actual reaction, and the relative effect of particle sizing is not clear, but, based on polymer and asphalt chemistry, it seems adequate. It also explains why a significant change in properties occurs over time, since this type of system is not thermodynamically stable.

Further, the increase in viscosity early in the interaction is due to the continuation of this solvation process (Holleran, 1998b) & (Australian Institute, 1993). See Figure 2-24 for an illustration of ARB with and without extender oil. This can be shown by examining micrographs of asphalt rubber digested with and without extender oil (relative sizing is important; all micrographs are to the same scale, and the largest particles are  $3.94 \times 10^{-3}$  inches [100 $\mu$ m]). The amount of extender oil, interaction time and temperature affect digestion. However, the intent is not to achieve full digestion which causes viscosity to drop below acceptable limits for the binders.



**Figure 2-24 Micrographs: Asphalt Rubber Extender Oil Effects (Holleran, 2001)**

Figure 2-25 shows a typical field blending plant for ARB.



**Figure 2-25 Typical Asphalt Rubber Field Blending Plant, CP2 Center, Asphalt Rubber Chip Plant, SR 139**

### 2.6.3 Caltrans Specification Requirements for Asphalt Rubber Binder (ARB)

PG 58-22 is specified as the base asphalt cement for use in asphalt rubber binders for the high mountain and high desert climate areas where resistance to cold temperature cracking is critical to long term performance. A stiffer grade, PG 64-16, is specified for use in asphalt rubber in the rest of California (coastal, valley, low or southern mountains, low desert). The base asphalt cement shall not be polymer modified. Warm Mix Additive (WMA) may be used when producing RHMA-G.

“The combined asphalt binder and asphalt modifier must be  $80.0 \pm 2.0$  percent by weight of the asphalt rubber binder.” Per 39-2.03B(3)(a) of the Caltrans 2025 Standard Specifications, the table entitled “Asphalt Modifier for Asphalt Rubber Binder” shows the requirements for the asphalt modifier for ARB.

The CRM must include  $25.0 \pm 2.0$  percent by mass of high natural rubber CRM and  $75.0 \pm 2.0$  percent scrap tire CRM. No changes have been recommended to the types of CRM or relative proportions thereof. The scrap tire CRM consists primarily of No. 10 to No. 30 sized particles (2 mm to 600  $\mu\text{m}$  sieve sizes). The high natural rubber CRM is somewhat finer, mostly No. 16 to No. 50 (1.18 mm to 300  $\mu\text{m}$  sieve sizes).

The extender oil dosage for chip seals will remain at 2.5-6% by weight of the asphalt rubber binder. However, the minimum extender oil content for use in ARB mixes may be reduced to 1% to minimize potential for flushing and bleeding for hot climate, high traffic index (TI) locations. To lower the extender oil dosage would require a contract change order.

Extender oils and high natural CRM are used to enhance the asphalt rubber interaction. Extender oils added to asphalt rubber interact with rubber by supplying light fractions (aromatics, small molecules) that swell the rubber particles and help disperse them in the asphalt. High natural CRM has also been found to aid chip retention in chip seal applications, even at concentrations as low as 3% of the asphalt rubber binder mass. Use of high natural CRM appears to improve the bond between cover aggregate and the asphalt rubber membrane.

Just mixing proportions of arbitrarily selected asphalt, CRM and extender oil components within the specified ranges will not necessarily yield a binder that complies with the physical property requirements in the Caltrans 2025 Standard Specifications, section 37-2.04, “Asphalt Rubber Binder Chip Seals”. Properties of asphalt rubber binders depend directly on the composition, compatibility, and relative proportions of the component materials, as well as on the interaction temperature and duration. There are many combinations of suitable materials within the recipe proportions that simply do not provide an appropriate or even usable asphalt rubber binder. Thus, binder design and testing procedures are essential to develop a satisfactory JMF.

## **2.7 AGGREGATES**

### *2.7.1 Aggregate Properties*

Aggregates are the major building material for pavements. The aggregate’s role is to form the structural matrix in an asphalt concrete mix (hot or cold); which bears the traffic loads; as such their properties are critical to the success of a mix (Roberts, et. al, 1996). Local sources are generally used but other materials such as expanded clay (light weight aggregate) or slag may be used if they meet the required specification. In areas where local materials are not suitable for use in the HMA, aggregate may be imported. Major aggregate types in California include the following (Roberts, et. al, 1996):

- **Igneous rocks:** Volcanic rocks formed from molten rock. Examples are granite and basalt.
- **Sedimentary rocks:** Rocks formed by layers of material that is then compressed. Examples include limestone, sandstone, and chert.
- **Gravel:** Formed from the breakdown of any natural rock. Usually found in rivers or waterways. River-bed gravel is an example.
- **Sands:** These are formed from the deterioration of any natural rock. These often contain clay or silt and should be washed.
- **Slag:** This is a by-product of metallurgical processing, from tin, steel, or copper processing. Slag is generally hard but absorbent (typically vesicular).
- **Reclaimed asphalt pavement (RAP):** This product is being more commonly used for various applications. It is also being used in HMA, pavement preservation, and partial depth recycling (PDR), and full-depth recycling (FDR).

There are two major categories of aggregate properties in pavement applications. These are the chemical and physical properties:

**Chemical Properties:** These identify the changes an aggregate may go through due to chemical action. Some aggregates contain substances that are soluble in water, are subject to dissolving, oxidizing, hydrating or carbonating. The main chemical property that affects asphalt applications is the affinity for the aggregate to bond with the asphalt. Asphalt must wet the surface of the aggregate and adhere to it. Failure to do so may produce stripping, where the bond between the aggregate and binder is lost. Stripping is caused by the aggregate having a higher affinity for water than the asphalt. Stripping causes disintegration or raveling of the HMA, or loss of aggregate in other treatments such as slurry or chip seal. No reliable indicators exist for determination of stripping potential based on chemistry of the aggregate alone and most tests are based on testing the mixture (AASHTO T283) (CT 371) (CT 302) (CT389).

In geographical areas where aggregates are known strippers, low tensile strength (TSR) results from testing require that the aggregate for HMA mixes be treated. Lime slurry margination of the aggregate reduces the chance of the HMA of stripping and usually produces a more durable mix with a longer life span. Dry lime treatment is also allowed in the Caltrans 2025 Standard Specifications. Another alternative for mixes with low TSR numbers is to incorporate a liquid anti-strip into the binder with the HMA production.

**Physical Properties:** The most important aggregate properties are listed below:

- **Grading or Particle Size Distribution:** Grading requirements are discussed in the chapters that deal with individual treatments. Caltrans specified grading requirements for HMA are included in the Caltrans 2025 Standard Specifications, Section 39. Grading is important as it determines the mixture characteristics with respect to its physical properties. For example, in HMA this includes fatigue resistance and load bearing, as well as air voids, and surface

texture. In open graded asphalt concrete mixtures, it will determine porosity, while in chip seals and slurry surfacing it will determine surface texture, and durability. The individual grading requirements are further discussed in the chapters on specific treatments 4-14. CT 202 and CT 105 measure grading. The latter test method is used if there is a difference in specific gravity of 0.2 or more between the coarse and fine portions of the aggregate or between blends of different aggregates.

- **Cleanness or Presence of Deleterious Materials:** Dirty aggregates may cause adhesion problems in chip seal and HMA and cohesion problems in slurry surfacing. Lumps of clay may disintegrate under freeze thaw conditions or cause pockmarks in a HMA pavement. Specific testing and requirements are discussed in the chapters concerned with treatments. The Sand Equivalent test (CT 217) is used to measure this property for HMA aggregates passing the No. 4 sieve. The Cleanness Value of coarse aggregate is tested by using CT 227.
- **Hardness or Abrasion Resistance:** Aggregates transmit the wheel loads to the subgrade. They must be resistant to crushing and wear to maintain this function. They must also resist crushing and degradation during stockpiling. A polished or worn aggregate will reduce skid resistance. The LA abrasion test (CT 211) is used to measure hardness and abrasion resistance of aggregate. CT 360 is used to measure the ability of compacted bituminous mixture to resist surface abrasion.
- **Durability or Soundness:** Aggregates must be resistant to breakdown due to the cyclic action of wetting and drying and freeze and thaw cycles. CT 214, also known as the sodium sulfate soundness test, can be used to determine aggregate soundness. This test is more commonly used to test concrete aggregate, but it is also very useful in identifying aggregate for HMA that is susceptible to breakdown under loading in wet conditions.
- **Particle Shape and Surface Texture:** Aggregate particles for use in most treatments should be cubical rather than flat or elongated. This creates more interlock and internal friction in generating higher deformation resistance. In chip seals, it creates greater seal texture depth and skid resistance. The surface texture and the shape are a determinant to workability in mixes and may affect compaction. A rough fractured particle has a higher surface area and forms tougher adhesive bonds. Caltrans measures fractured faces (CT 205) and Fine Aggregate Angularity (FAA) (AASHTO T 304).
- **Absorption Characteristics:** Most aggregates absorb asphalt to some extent; reducing the effective volumetric percentage of the binder mixtures or the effective application rate in chip seals. An overly absorptive aggregate can result in a dry HMA and cause raveling of the pavement, or rock loss in chip seals. CT 206 is currently used as a test for specific gravity and absorption of coarse aggregate. CT 206 test method is patterned after AASHTO T85. CT 303 is no longer used because of the volatiles from using kerosene.

Special aggregate requirements for specific treatments are considered in the relevant chapters.

### 2.7.2 Aggregate Production

Aggregates may be produced from quarry operations by first blasting (if necessary) and then using a series of crushers and screens to create the desired stone sizes. Several methods of crushing may be used; including jaw crushers (usually the primary crusher), impact crushers (these produce cubical aggregates and are generally used later in the process), attrition mills, hammer mills and gyratory cone crushers. The crushing operation combination must be chosen so that the aggregate meets the required specifications, particularly for gradation. Aggregates may also be mined from gravel deposits in or near rivers or streams, may be processed by the same or similar equipment as quarry produced aggregate.

### 2.7.3 Reclaimed Asphalt Pavement (RAP)

“The [Federal Highway Administration \(FHWA\)](#) supports and promotes the use of recycled highway materials in pavement construction to preserve the natural environment, reduce waste, and provide a cost-effective material for constructing highways. The primary objective is to encourage the use of recycled materials in the construction of highways to the maximum economical and practical extent possible with equal or improved performance. As part of the [FHWA recycled materials policy](#), the FHWA actively promotes asphalt pavement recycling and technology.”  
<https://www.fhwa.dot.gov/pavement/recycling/rap/>.

RAP may be a very cost-effective alternative to virgin aggregate as the sources for good aggregates become scarce. If the aggregate performed well in its initial use, and the aggregate met the specifications, it is reasonable for RAP to be incorporated into a new product. RAP can be an environmentally responsible choice, not only can it be used in HMA, it can also be used in chip seals, slurry seals, micro surfacing, or Cold In-Place Recycling.

In mix designs, the amount of binder can be reduced because RAP already contains binder. Binder from RAP (Binder Replacement) is expressed as a percentage of the total binder in the mix. This is stated in the Caltrans 2025 Standard Specifications, 2025, section 39-2.01A(2). Since the binder in the RAP is aged, the new product requires that the binder grade be adjusted. This practice is called a “Bump Down Grade” and needs to be verified in JMF. This is where the RAP with an aged binder is mixed with a binder with a softer grade. Table 2-3 gives the PG Grade “Bump Down” requirements for HMA mixes that contain 16-25% RAP.

**Table 2-3 PG Grade Bump Down Requirements for Mixes Containing 16-25% RAP**

Specified PG Grade	Bump Down Grade
70-10	64-16
64-10	58-16 or 58-22
64-16	58-22
64-28	58-34M
64-28M	58-34M

The maximum amount of RAP in pavement is 25% for Caltrans; however, this is subject to change as its performance is monitored over time. Some contractors are using higher percentages of RAP for their non-State contracts. Caltrans currently has a non-Standard Special Provision (nSSP) for using up to 40% RAP.

## 2.8 STORAGE AND HANDLING

The key aspects of storing and handling any product include safety and quality, so that the material remains within specifications for its intended use.

This section covers storage and handling of:

- Conventional Asphalt Binder
- Modified Asphalts Binders (including asphalt rubber, and polymer modified)
- Asphalt Emulsions
- Aggregates

### 2.8.1 Asphalt Binders

When handled properly, asphalts binders may be reheated or maintained at elevated temperatures without adverse effects. If asphalt binder is heated above its recommended temperature limits in storage, handling, or application, it may harden and no longer meet its specified grading requirements.

#### Avoiding Problems during Storage

The main methods of avoiding potential storage problems are to ensure that equipment is properly designed, in good working condition, and established correct procedures are followed. All asphalt tanks should be designed and built in accordance with a recognized standard (e.g., API 650). General design considerations include tank shape, tank foundations, tank thickness, and tank access. Best management practices require a secondary containment around all tanks. Vertical tanks yield the highest asphalt to tank volume ratio of all tank configurations. Vertical tanks with a cone shaped roof are preferred, although temporary storage in horizontal tanks is acceptable. The operational tank design considerations relate to:

- **Minimizing the risk of overheating:** The tank requires accurate thermal sensors. They should be positioned in the region of the heaters and uniformly distributed throughout the tank. The probes should be in thermal wells and removable for cleaning and calibration. Heating may be accomplished via heat transfer (oil or steam), electric coils, or direct fire. As asphalt is a good insulator (i.e. not a good conductor of heat), the heating rate must be controlled to prevent localized overheating, particularly when direct-fired systems are used. The heating rate should be limited to 77°F (25°C) per hour (Asphalt Institute MS-22, 1998).
- **Minimizing oxidation and loss of volatiles:** Contact with air must be minimized to decrease oxidation and loss of volatiles. This may be accomplished by designing pressure-tested, fully enclosed tanks. To avoid air entrainment, all circulation lines should re-enter the tank under the liquid level. When filling a tank, it should be filled from the bottom and the asphalt should not be allowed to freefall as this can result air entrapment. Venting is an essential safety precaution and cannot be eliminated.
- **Maintaining asphalt homogeneity:** To maintain asphalt binder homogeneity and avoid temperature variation, the binder should be mixed on an intermittent basis. This mixing may be done through circulation or with side mixers under the liquid level. Vortex mixing entrains air and its use should be avoided. When adding fresh asphalt to a tank, circulation is necessary to stabilize temperature and combine the existing material with the fresh material for a homogeneous asphalt mixture.
- **Minimizing heat loss:** To conserve energy, all tanks should be insulated with fiberglass or rock wool insulation. This insulation should be at least 2 in (50 mm) thick and sheathed in aluminum or galvanized steel at least 0.03 in (0.7mm) thick. Additionally, lines should be insulated and heat traced with electric tape, steam or oil.

#### **Safety hazards can arise from:**

- **High Temperatures:** Since asphalt binder must be stored at high temperatures, safety issues involving worker burns, along with the material's contact with water, which causes rapid expansion resulting in foaming and explosive boil over, must be addressed. Burns may be avoided by workers always using the correct safety apparel. Additionally, ensure that all lines and surfaces are thoroughly insulated.
- **Due to the potentially hazardous side effects** of water contacting high temperature asphalt, steps need to be taken to avoid this interaction. As water is slightly lighter than asphalt, it will move to the top of tanks. However, during transport, cold water may migrate to the bottom of a tank. Water entrapment in tanks can be avoided by using watertight cone topped tanks, ensuring that tanks are watertight, and hatches are sealed. Water finding gel should be used to check tanks before filling. If water is present, the asphalt should be heated through the range from 198 to 257°F (92 to 125°C) at a rate of 18 to 27°F (10

to 15°C) per hour. Silicone antifoaming agent at 0.1% can also be added. Pipes and any additives that are to be blended with the asphalt need to be checked for water.

- **Flammable or explosive atmospheres:** Asphalts normally have flash points exceeding 482°F (250°C). However, flammable atmospheres may form if contamination by light products (e.g., products created from cleaning or flushing lines) is disturbed. Ignition sources may include sparks or static electricity. With this as a potential hazard, proper grounding is important along with the use of shielded electric motors.
- **Presence of toxic materials:** Fumes can be generated when asphalt is heated. These fumes contain particulate asphalt, hydrocarbon vapor, and sulfide gases. These fumes are highly toxic and tends to build up in headspace. Proper storage tank venting is required to disperse the fumes.

## Recommended Storage and Handling Temperatures and Times

Asphalt and modified asphalt are stored and handled in similar ways. An exception is asphalt rubber, which is used shortly after production. Allowable storage times are product specific and are calculated and specified for the rate of property change, which occurs during storage. For example, conventional asphalt can be stored for several months, and asphalt rubber is typically formulated overnight (holdovers) and storage times are limited. Refer to 39-2.03B(3)(e)(ii) in the Caltrans 2025 Standard Specifications, for Asphalt Rubber Binder (ARB) production and storage requirements.

### 2.8.2 Asphalt Emulsions

Asphalt emulsions are a convenient way of handling asphalt, but emulsions may be subject to settlement or breaking prematurely. Thus, storage and handling are important issues. Over time emulsions will become coarser and undergo property changes. To prevent emulsion degradation, timely use is required. Storage and handling asphalt emulsion are discussed below.

## Handling

Handling emulsions is not difficult. By following the rules below, potential problems can be avoided.

- **Pumping:** Pumps are a way of doing work to improve an emulsion. Pumps usually compress or shear the material they pump. This results in a compressed emulsion. If compression is too severe or occurs too often, the emulsion will become coarser by the mechanism of flocculation and coalescence and may revert to straight asphalt. Pumps should be selected carefully. Diaphragm pumps are gentle but require high maintenance and should only be used if essential. Centrifugal pumps are acceptable if the peripheral speed is less than 300 rpm. Positive displacement pumps may be

used, but usually 2-3 thousandths of a clearance is needed. Always get expert advice on the appropriate pump to use.

- **Temperature:** When asphalt materials get cold, they shrink. In an emulsion, the asphalt droplets get closer together. The material can flocculate and may coalesce; this may also cause the emulsion to settle out faster than desirable. If the material is pumped when cold, the droplets are more compressed due to temperature related shrinkage. As a result, a pump that was not too tight in January may be far too tight in July. If the emulsion freezes, the droplets become frozen and are in contact, then the emulsion will revert to bitumen upon thawing. For most emulsions, this happens if the emulsion gets below 40°F (4°C). When the emulsion materials get hot, they expand. However, when water gets hot, its evaporation rate increases enormously. If the water evaporates, the droplets get closer together and can result in an emulsion reverting to asphalt by the action of flocculation and coalescence. If any part of the emulsion gets hotter than 203°F (95°C) localized boiling may occur. If this happens, the droplets fuse back into asphalt. This fusing process raises several important aspects surrounding the heating process including the following:
  - When heating emulsions do it slowly and heat according to specifications.
  - Use agitation while heating.
  - Warm pumps before use.
  - On bulk tanks in cold areas, the use of electrical heating is recommended.
  - Do not apply direct heat to emulsions with fire or a blowtorch.

## Transport Handling

Emulsions are generally stable enough to transport. However, a common problem arises when air mixes with the emulsion. Air can cause the emulsion to break in the bubbles of air; CRS emulsions are particularly prone to break in this way. These larger particles can “seed” the emulsion causing settlement. Problems also arise when transport tanks are not clean. Mixing cationic and anionic emulsions can lead to breaking of the emulsion.

## Storage

The points made for storing asphalt relate equally to the storage of an emulsion. When an emulsion is stored, it has a finite lifetime. This lifetime is determined by the formulation, handling, and storage of the emulsion.

Asphalt is slightly heavier than water. Thus, the asphalt moves to the bottom of the storage container. This movement is referred to as settling. Settlement can cause the particles to stick together (flocculate and coalesce). Over time, the emulsion will eventually turn back into bitumen. This settlement may be controlled to some extent by formulation. If the emulsion particles are fine, they will settle more slowly allowing for a longer storage life. Flocculation and coalescence can also occur as the result of electrical attraction between particles. If an emulsion is electrically unstable, it will flocculate and coalesce. This

process may not take the emulsion entirely back to bitumen, but the large particles formed as a result of this process, will settle faster.

Prevent settling by mixing an emulsion prior to the start of flocculation or coalescence. Once an emulsion has coarsened, remixing will not separate the larger particles again. If it has coarsened too much, pumping may break the emulsion. This degradation can be prevented by using the emulsion within the producers recommended time frame.

## Tankage

While vertical tanks are preferred for plant storage, mobile storage is done with a road tanker. The road tanker increases the surface area of the emulsion exposed to air and can promote skinning. However, if properly handled, this will not become an issue for fieldwork.

Specific guides for tankage include:

- Bulk tanks should be circulated at regular intervals. Circulation should be done slowly.
- The frequency of circulation will depend on the weather and how long the emulsion has been in storage.
- Most emulsions only require circulation once a week in summer and once every five days during the winter.
- Circulation should be performed in the middle of the day, not first thing in the morning due to the colder temperatures.
- The time of circulation is based on the size of the tank; a 1,320 gal. (5000 L) tank should be circulated for 15 minutes while a 2,640 gal. (10,000 L) tank requires 20 minutes.
- Pumps must be flushed after use, but never into the emulsion tank.
- Lines and pumps should be able to be warmed before use.
- Lines should not be left part full of emulsion.

## Cleaning Procedures

For emulsions, cleanliness is very important. A sloppy operation will produce problems. When an emulsion is in contact with air, it can begin to break. When a cationic emulsion is in contact with metal, it can begin to break. Thus, if a pump is not properly cleaned after use, it will clog. If lines are left part full of emulsion, they will clog. The higher the performance of the emulsion, the more critical cleaning is. Cleaning should be done before storage of equipment, and it should be done thoroughly. Specific guidelines include:

- Flush equipment, including hoses thoroughly with WATER.
- Flush equipment and hoses with kerosene, NOT diesel, distillate or other solvent. These materials may dissolve asphalt, but they are also incompatible with the emulsion and may cause the emulsion to break rather than flush it away. NEVER FLUSH INTO THE EMULSION TANK.
- Finish with a second flush with water.
- If a pump or line is already clogged with bitumen, gentle heat may be applied at the blockage. Do not apply heat to the lines, as this will break the emulsion.
- Soak pumps with kerosene for an hour or more.

- Flush again with water after blockage is removed.

Table 2-4 shows the mixing, spraying and storage temperatures for various grades of emulsions and ARB. Table 2-5 shows the recommended usages of various grades of emulsions per the Caltrans 2025 Standard Specifications.

**Table 2-4 Mixing, Spraying and Storage Temperatures of Emulsions and ARB for Chip Seals and Micro surfacing**

Product	Mixing Temperature °F	Spraying Temperature °F	Storage Temperature °F
SS-1	50-158	75-130	50-185
SS-1h	50-158	75-130	50-185
CRS-1	N/A	75-130	50-185
CRS-2	N/A	110-185	50-185
CRS-1h	N/A	75-130	50-185
CRS-2h	N/A	110-185	50-185
CSS-1	50-158	75-130	50-185
CSS-1h	50-158	75-130	50-185
PMCRS	N/A	110-185	50-185
PMCRS-2	N/A	110-185	50-185
PMCRS-2h	N/A	110-185	50-185
PMCQS-1h	N/A	75-130	50-185
QS-1	50-104	75-130	50-185
QS-1h	50-104	75-130	50-185
CQS-1	50-104	75-130	50-185
CQS-1h	50-104	75-130	50-185
ARB (not emulsion) Chip Seals	375-440	385-415	375-415
MSE Micro surfacing	50-104	N/A	50-185

\* Many temp. recommendations ref.,

<https://www.mdt.mt.gov/publications/docs/brochures/research/toolbox/aema/docs/c3store.pdf>, Section 3 Storing, Handling and Sampling.

**Table 2-5 Recommended Usage for Various Grades of Emulsions**

<b>Application</b>	<b>Cationic Material</b>	<b>Anionic Material</b>
Fog Seals/Flush Coats	You determine grade, section 37-4.02B & 37-4.03	You determine grade, section 37-4.02B & 37-4.03
Tack Coat	You determine grade, section 37-3.03B(6)	You determine grade, section 37-3.03B(6)
Prime Coat	You determine grade, section 37-3.03B(6)	You determine grade, section 37-3.03B(6)
Partial Depth Recycling	Add later	Add Later
Chip Seal	CRS-2 or CRS-2h, section 37-2.02B(2), section 37-2.03A(4)(b)(iii)	None specified
Chip Seal (Polymer Modified)	PMCRS or PMCRS-2h	None specified
Slurry	Quick-Setting Asphaltic Emulsion or Quick-Setting Polymer Modified Cationic Emulsion	Quick-Setting Asphaltic Emulsion or Quick-Setting Polymer Modified Cationic Emulsion
Parking Area	See Parking Area Seal Acceptance Criteria, section 37-5.01D(3)	See Parking Area Seal Acceptance Criteria, section 37-5.01D(3)
Micro surfacing	Must be MSE Grade, section 37-3.03B(2)	Must be MSE Grade, section 37-3.03B(2)
Bonded Wearing Coarse	Refer to Section 94-1.02G, cationic	Refer to Section 94-1.02G, cationic
Crack Seal	See Crack Treatment Acceptance Criteria, section 37-6.01D(3)	See Crack Treatment Acceptance Criteria, section 37-6.01D(3)
Cold Mix	Not specified as to grade	Not specified as to grade

*\*Emulsion grades may not be the Specified Grades per Caltrans Standard Specifications (2025).*

Rust, dirt, grass, or other foreign material should be kept out of the emulsion. Cationic emulsions can break by reacting with foreign materials.

The main transport requirements are to ensure that correct pumping procedure is used. Pumps should be warmed in cool climates. Clean tanks or a switch-load process should be followed. Switch loading is a process when materials are transported in tanks that last carried a compatible material and therefore do not require the tank to be cleaned between material switching.

Table 2-6 provides acceptable switch loading combinations. Always pump into clean tanks and always transport full containers. Emulsions are chemical systems. To avoid contamination, they should never be mixed with other types of emulsions or with other chemicals.

**Table 2-6 Acceptable Switch Load Combinations (Asphalt Institute MS-4, 2007)**

Last Product in Tank	Asphalt Cement	Cationic Emulsion	Anionic Emulsion
Asphalt Cement	OK to Load	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Cationic Emulsion	Empty to No Measurable Quantity	OK to Load	Empty to No Measurable Quantity
Anionic Emulsion	Empty to No Measurable Quantity	Empty to No Measurable Quantity	OK to Load
Crude Petroleum and Residual Fuel Oils	Empty to No Measurable Quantity	Empty to No Measurable Quantity	Empty to No Measurable Quantity
Any Product Not Listed Above	Tank Must be Cleaned	Tank Must be Cleaned	Tank Must be Cleaned

### 2.8.3 Aggregates

Aggregates must be handled and stored in a manner that avoids contamination and minimizes degradation. (Asphalt Institute MS-22 3<sup>rd</sup> edition 2020). Specific guidelines are as follows:

- Stockpile areas should be clean and stable to avoid contamination from the surrounding area.
- Stockpiles should be on free draining grades to avoid moisture entrapment.
- Stockpiles should be separated for different aggregate sizes to prevent intermingling.
- Segregation or separation of a blended aggregate is the primary concern. Segregation occurs mostly with coarse aggregates, but even slurry-combined aggregate may segregate in the stockpile or on handling if it gets too dry. Segregation may be minimized by not stockpiling aggregate in a cone shape. Acceptable stockpile shapes are either horizontal or radial. Making each end dump load a separate pile, each adjacent to the next, makes horizontal stockpiles. Radial stockpiles are made with a radial stacker (Asphalt Institute MS-22, 3<sup>rd</sup> edition, 2020).
- Degradation of the aggregate creating fines can be avoided by handling the stockpile as little as possible. In chip seal or slurry surfacing applications, re-screening may be considered.

## 2.9 SAMPLING REQUIREMENTS

The following is the standard sampling requirements for testing. Sampling is a significant issue for emulsions. Samples must be sent immediately for testing to ensure they are representative of the material used in the field.

Emulsions change and coarsen with storage and handling. This may result in an emulsion that is out of specification when tested despite being in specification when sampled and used. This is especially true of high binder PMCRS-2 and PMCRS-2h type materials.

### 2.9.1 Sampling Guidelines

The following guidelines should be followed for sampling materials (Asphalt Institute 3<sup>rd</sup> edition MS-22, 2020):

- Samples of emulsion and binder shall be taken in conformance with the requirements in Sections 6.07, 6.08 and 6.09 of the Construction Manual, 2022, and California Test Method (CTM) 125. Testers must be certified on CTM 125 to perform sampling.
- Observe all safety procedures.
- Sample binders daily using new, clean, dry 0.26 gal. (1 L) cans with screw lids.
- Samples are normally taken from the sampling port near the rear of the distributor truck. Drain off sufficient material through the nozzle to ensure removal of any material lodged there.
- Samples should be taken after one-third and not more than two-thirds of the load have been removed.
- Do not submerge sample containers in solvent or wipe containers with solvent saturated cloths. Use a clean, dry cloth, only immediately after sampling, to clean containers.
- Attach a Sample Identification Form (TL-0101) to each material sample in accordance with Section 6 of the Construction Manual (2022) and instructions printed on the TL-0101 booklet.
- Protect the TL-0101 against moisture and stains.
- Provide the e-mail address of the Resident Engineer on the TL-0101 form.
- Emulsions have a shelf life. It is important that all samples be sent to the Transportation Laboratory daily.
- Aggregates should be sampled according to the contractual requirements.
- Samples of aggregate shall be taken according to Caltrans "Authorization Criteria for Innocuous Aggregates".
- Samples may be taken from a conveyor belt or sampling chute.
- Field samples must be taken from the stockpile per CTM 125, and Standard Specifications (Caltrans 2025 Standard Specifications).
- If aggregate requires lime treatment, sample stockpile prior to lime treatment.

### 2.9.2 Sample Delivery

Samples for testing should be delivered to the appropriate laboratory: District Laboratory and then shipped to Translab if necessary.

The following should be noted:

- Samples are not to be shipped C.O.D.
- Emulsion will be tested for compliance with Section 94, “Asphaltic Emulsions”, of the Caltrans 2025 Standard Specifications.
- Aggregate samples should be tested for compliance with Section 39 “Asphalt Concrete” or Section 37 “Seal Coats” of the Caltrans 2025 Standard Specifications, as appropriate.
- Test results are mailed to Resident Engineers. To expedite return of test results, test cards can be e-mailed to the Resident Engineers.

## 2.10 REFERENCES

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*Note: Caltrans manuals referenced above may have later editions than those cited. Refer to the latest editions of these references for the most current information.*