*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 http://www.dot.ca.gov/hq/esc/oe/specs_html/index.html. Where the specifications are relevant, they are referenced in the specific treatment Chapters 4 through 13. This section discusses the main materials used and provides a general explanation of their composition, manufacturing, storage and handling techniques, and addresses special application requirements. In some cases, the materials themselves are derived from a mixture of raw materials. This section will also address some of these issues.

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)
- Cutback Asphalts
- Polymer Modified Asphalts
- Performance Based 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, 1999a).

## 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 or brittle point, asphalt becomes brittle solid. Caltrans requirements for asphalt binders are described in Section 92 of the Standard Specifications.

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### *2.2.2 Paving Asphalt Manufacture*

Several processes are used to specifically manufacture asphalt including:

1. **Steam Distillation**: Steam 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.

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.

4. **Air Blowing**: Air blowing has been used to harden asphalt to create higher viscosity grades. However, this has often led to asphalts with poor aging resistance and some agencies have not allowed asphalt processed in this manner. Light blowing is employed to modify feedstock of specific composition to create multi-grade asphalts of low thermal susceptibility.

### *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.

In the PG system, asphalt is specified by:

- Dynamic Shear Rheometer (DSR) for performance at high and intermediate temperatures
- Bending Beam Rheometer (BBR) for performance at cold temperatures
- Aging Characteristics
- Purity and Safety

Table 2-1 lists the testing equipment and purposes in the PG grading system. Table 2-2 provides the specification for various PG grades, and the following paragraphs provide additional details.

1. **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

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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.

2. **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.

3. **Aging Characteristics**: Aging in asphalt is associated with oxidation and hardening of the asphalt. During processing and while in service in the pavement, asphalt looses 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 (AASHTO R-28).

   In the former aged residue (AR) specification, the properties of the asphalt are measured after aging protocols are performed. In California a rolling thin film oven test is used (California Test Method CT 374) to simulate the aging through the plant and paving operation.

4. **Purity and Safety**: Purity tests are based on the solubility of the asphalt in solvent, with trichloroethane, the most commonly used. Safety tests are based on the flammability or flash point of the fumes emitted by asphalt during heating. Caltrans uses the Cleveland Open Cup test to determine the flash point for asphalt binder material.

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**Table 2-1: Superpave Asphalt Binder Testing equipment and purposes (NCAT, 1996)**

| EQUIPMENT | PURPOSE | PERFORMANCE PARAMETER |
|---|---|---|
| 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 |
| Rotational Viscometer, RV | Measure binder properties at high construction temperature | Handling & pumping |
| Dynamic Shear Rheometer, DSR | Measure binder properties (stiffness and elasticity) at high and intermediate service temperatures | Resistance to permanent deformation (rutting) and fatigue cracking |
| Bending Beam Rheometer, BBR | Measure binder properties at low service temperatures | Resistance to thermal cracking |

**Table 2-2: Performance Graded (PG) Asphalt Grade Specifications (Caltrans, 2006)**

| PROPERTY | AASHTO TEST METHOD | SPECIFICATION GRADE | | | | |
|---|---|---|---|---|---|---|
| | | PG 58-22 A | PG 64-10 | PG 64-16 | PG 64-28 | PG 70-10 |
| Original Binder | | | | | | |
| Flash Point, Minimum °C | T48 | 230 | 230 | 230 | 230 | 230 |
| Solubility, Minimum % [b] | T44 | 99 | 99 | 99 | 99 | 99 |
| Viscosity at 135°C, [c]<br>Maximum, Pa·s | T316 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Minimum G*/sin(delta), kPa | T315 | 58<br>1.00 | 64<br>1.00 | 64<br>1.00 | 64<br>1.00 | 70<br>1.00 |
| RTFO Test [e],<br>Mass Loss, Maximum, % | T240 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| RTFO Test Aged Binder | | | | | | |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Minimum G*/sin(delta), kPa | T315 | 58<br>2.20 | 64<br>2.20 | 64<br>2.20 | 64<br>2.20 | 70<br>2.20 |
| Ductility at 25°C<br>Minimum, cm | T51 | 75 | 75 | 75 | 75 | 75 |
| PAV [f] Aging,<br>Temperature, °C | R28 | 100 | 100 | 100 | 100 | 110 |
| RTFO Test and PAV Aged Binder | | | | | | |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Minimum G*sin(delta), kPa | T315 | 22 [d]<br>5000 | 31 [d]<br>5000 | 28 [d]<br>5000 | 22 [d]<br>5000 | 34 [d]<br>5000 |
| Creep Stiffness,<br>Test Temperature, °C<br>Maximum S-value, MPa<br>Minimum M-value | T313 | -12<br>300<br>0.300 | 0<br>300<br>0.300 | -6<br>300<br>0.300 | -18<br>300<br>0.300 | 0<br>300<br>0.300 |

Notes:

a. For use as asphalt rubber base stock for high mountain and high desert area.
b. The Engineer will waive this specification if the supplier is a Quality Supplier as defined by the Department's "Certification Program for Suppliers of Asphalt."
c. The Engineer will waive this specification if the supplier certifies the asphalt binder can be adequately pumped and mixed at temperatures meeting applicable safety standards.
d. Test the sample at 3°C higher if it fails at the specified test temperature. G*sin(delta) shall remain 5000 kPa maximum.
e. "RTFO Test" means the asphaltic residue obtained using the Rolling Thin Film Oven Test, AASHTO Test Method T240 or ASTM Designation: D 2827. Residue from mass change determination may be used for other tests.
f. "PAV" means Pressurized Aging Vessel.

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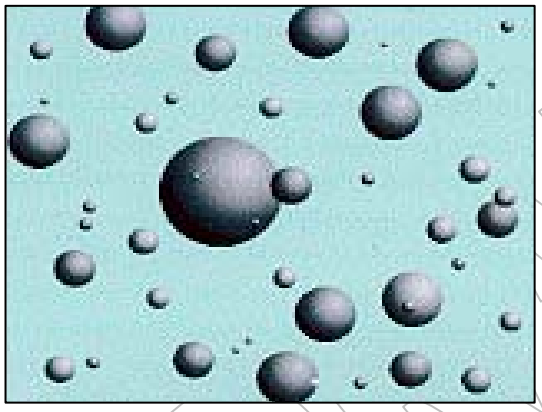
## 2.3 ASPHALT EMULSIONS

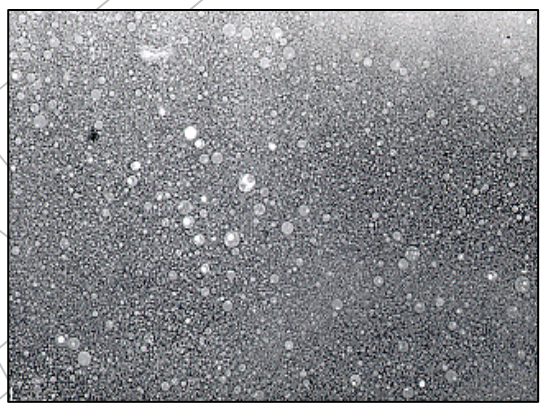
### *2.3.1 Emulsion Constituent*

An emulsion lies between these two extremes and is defined by the size of the particles involved. In an emulsion, the particle sizes range from 3.94 x $10^{-5}$ to 3.94 x $10^{-3}$ inches (1 to 100 μm) in diameter. 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 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).

An emulsion is a dispersion of two or more liquids that will not mix together to form a single homogenous substance. An asphalt emulsion is asphalt dispersed in water. This is not a solution as the two phases (oil in water) are susceptible to separation. So, like a good salad dressing, the oil is stabilized with an emulsifier to keep it dispersed. Figure 2-1 shows an emulsion in schematic and an emulsion micrograph.



**a) Emulsion Schematic**



**b) Emulsion Micrograph**

**Figure 2-1 Asphalt Emulsion Illustrations (Holleran, 1999)**

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The process of separating the asphalt and water is called "breaking" (Holleran, 1999). The process by which the asphalt expels water and dries to an integral film or layer on the aggregate or surface is termed "curing" (Holleran, 1999). The mechanisms associated with breaking and curing are covered elsewhere.

Emulsions allow the formation of an asphalt binder with low enough viscosity for easy 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.

### *2.3.2 Emulsions Manufacture*

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 2-2 shows the cross section of a typical colloid mill, one of the devices that is used to shear the asphalt. It should be noted that there are other methods of shearing the asphalt to produce an

emulsion. These include homogenizers, pressure reducers and pumps. The colloid mill is the 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).

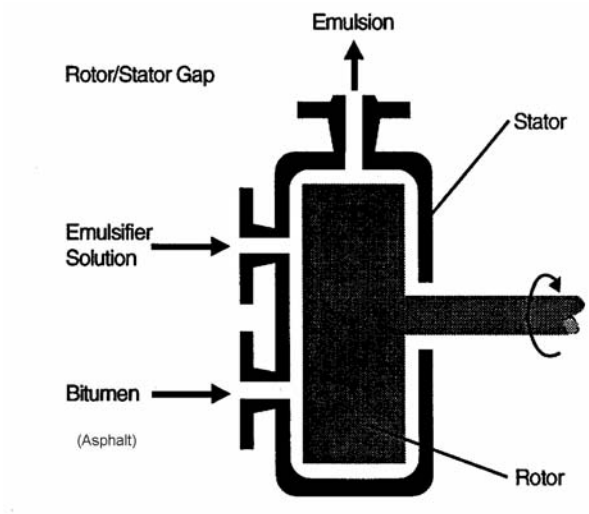


**Figure 2-2 Colloid Mill Cross Section (Holleran, 1999)**

In an emulsion plant several operations must be carried out. Figure 2-3 shows the key elements of an emulsion plant.

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.

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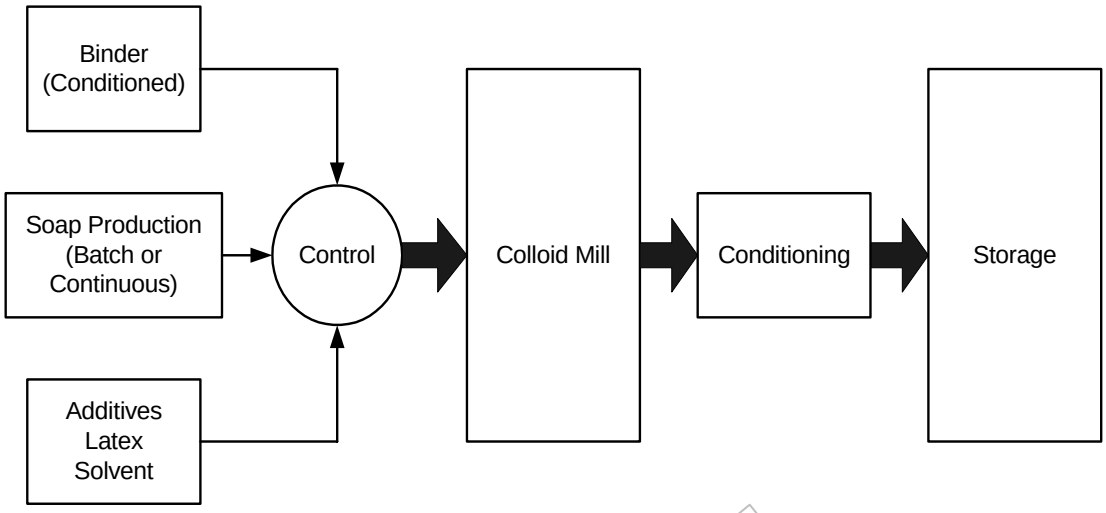


**Figure 2-3 Emulsion Plant Operations Schematic (Holleran, 1996)**

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.

### *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 2-4 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 microsurfacing emulsions. This is due to a cationic emulsion's specific reaction with all compatible aggregates that creates a

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stronger adhesive bond. For the same reason, cationic emulsions are also less susceptible to cooler conditions and dampness than anionic emulsions.

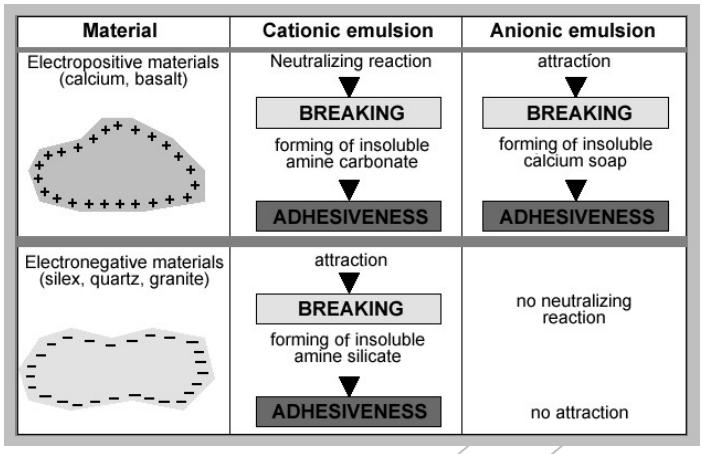


Figure 2-4 Material Compatibility and Reactivity of Emulsions (French Society, 2000)

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 and storage and handling.

### *2.3.5 Specifications and Testing*

1. **Caltrans Specifications**: Caltrans uses several common emulsion types. These are described in detail in Standard Specifications Section 94 (Caltrans, 1999a), and are briefly described below:

   - **Anionic Emulsions**: Rapid Set (RS), Medium Set (MS) and 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). Numbers describe the binder content of the emulsion (1 for lower and 2 for the higher level). In anionic emulsions, these binder content designations are different for different grades; RS-1 is typically 55% minimum binder content, and RS-2 contains 65% minimum. Medium sets are 55 and 65% respectively and SS grades are only designated as SS-1 or SS-1h and are 57% minimum binder content.
   - **Cationic Emulsions**: Rapid set (CRS), Medium set (CMS) and Slow set (CSS). 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. Medium sets are 55 and 65% respectively and SS grades are only designated as CSS-1 or CSS-1h and are 57% minimum binder content.

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- **Polymer Modified Emulsions**: These may be anionic or cationic. They are all rapid set and 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 4 "Chip Seals".
- **Quickset Slurry Emulsions**: These may be anionic or cationic (QS or CQS) and have minimum binder contents of 57%. In general use are polymer modified (latex) versions of these emulsions and they have the letter "L" preceding the designation (e.g., LMCQS-1h). Such emulsions may be made with the hard binder or the softer binder. This is further discussed in Chapter 8 on Slurry Seals.

2. **What the Specifications Mean**: The test methods listed in the specifications (Caltrans, 1999a) 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 to know 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 2-5. This figure indicates that as the binder content of the emulsion increases, so does its viscosity. Emulsions with higher viscosities are more difficult to pump and spray at a given temperature than are emulsions with lower viscosities.
- 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 (as shown in Figure 2-6), and is not re-dispersed, this is an indication that the emulsion may flocculate and coalesce ("break") during storage.
- Demulsability is the measure of an emulsion's resistance to breaking and gives an idea of 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 that is relevant for mixing emulsions with soils or aggregates.
- The sieve test provides an indication of 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 2-7 illustrates the Sieve Test.

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 2-8. The recovery from a torsional load is measured and related to polymer content (the test method used is CT 332).

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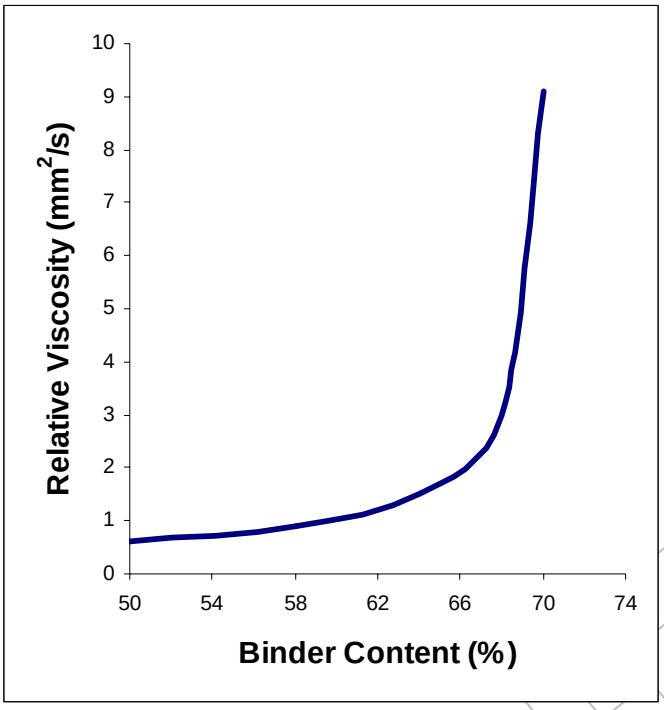


**Figure 2-5 Relative Viscosity Vs Binder Content (Holleran, 2001)**

**1st Step** **2nd Step** **3rd Step**

Figure 2-6 Settlement and Storage Stability Test (French Society, 2000)

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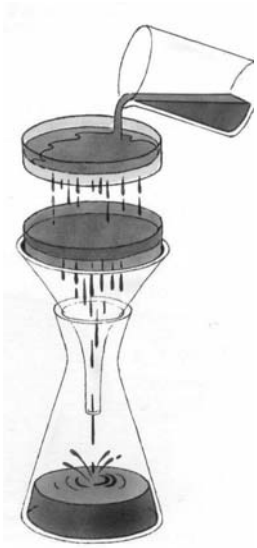

Figure 2-7 Sieve Test

***(Note: Normally only 1 sieve is used in the AASHTO T-59 as used by CT) (French Society, 2000)***

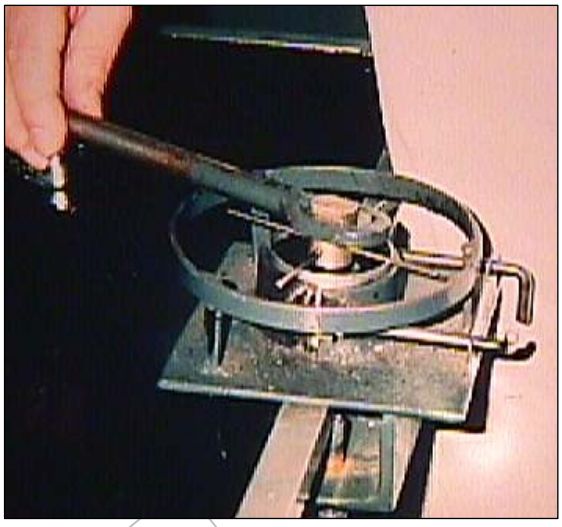

Figure 2-8 Torsional Recovery Test

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## 2.4 CUTBACK ASPHALTS

### *2.4.1 Cutbacks Asphalts*

A cutback is a solution of asphalt in a hydrocarbon solvent (e.g., kerosene, diesel, or naphtha). Solvents are used to reduce the asphalt's viscosity so that the cutback can be pumped and sprayed at lower temperatures (104 to 293°F [40 to 145ºC]) than that required for conventional asphalt. The solvent performs no other function in road applications. The solvent selected depends on the grade of the cutback, which in turn, is based on the expected setting rate.

During the 1970's energy crisis and in response to environmental concerns on volatile emissions (i.e., evaporation of the solvent during the application and curing processes), use of cutbacks has generally been discontinued. In California, only slow and medium cure cutbacks are still made and only slow cure cutbacks are generally specified. The main use for cutbacks is prime coats over aggregate base materials prior to placement of an asphalt-wearing course in new construction.

### *2.4.2 Manufacturing*

Because cutbacks are solutions of asphalt and solvent, they are easily manufactured. This can be done on site by circulation in a tank. In refinery applications, inline blending or emulsion colloid mills have been used to manufacture cutbacks.

### *2.4.3 Specifications and Testing*

The Caltrans cutback specifications are found in the Standard Specifications Section 93, and they are referred to as "Liquid Asphalts" (Caltrans, 1999a).

- Slow curing (SC): these contain a heavy oil solvent. Caltrans has four designations SC-70, SC-250, SC-800, and SC-3000. The number refers to kinematic viscosity of the cutback.

- Medium Cure (MC): these are made with a kerosene type solvent and have the same viscosity designations as SC grades.

The main specifications relate to safety as measured by flash point and water content, viscosity and boiling range of the solvent, application and cure rate, residue percentage for residual application rate, and residue tests to ensure the correct base asphalt grade had been used. The main effect of increasing the viscosity is to increase the application temperature requirements. This is covered in the Standard Specifications Section 93.

## 2.5 POLYMER MODIFIED BINDERS AND PERFORMANCE BASED ASPHALTS

### *2.5.1 Polymers and Polymer Modified Binders*

Polymers are large molecules that are used to enhance the performances of asphalt cement and asphalt concrete pavement, particularly at high temperatures. Depending on the basic polymer units or monomers used, a wide range of properties can be achieved. For engineering purposes 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)
- Ehtylene 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 factory. 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.

Most of these are mechanical issues and are achieved by relatively simple techniques. Figure 2-9 illustrates a typical manufacturing (blending) plant.

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The most important steps in the manufacturing process are dispersion and reaction. This is what 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. Compatible systems usually have superior rheological, aging, and stability properties to those of incompatible systems at the same polymer level (Holleran, 2001). The micrographs in Figure 2-10 show the structure (morphology) of SBS at 3% dispersion in a compatible (a) and incompatible (b) polymer system. The scale for both micrographs is the same.

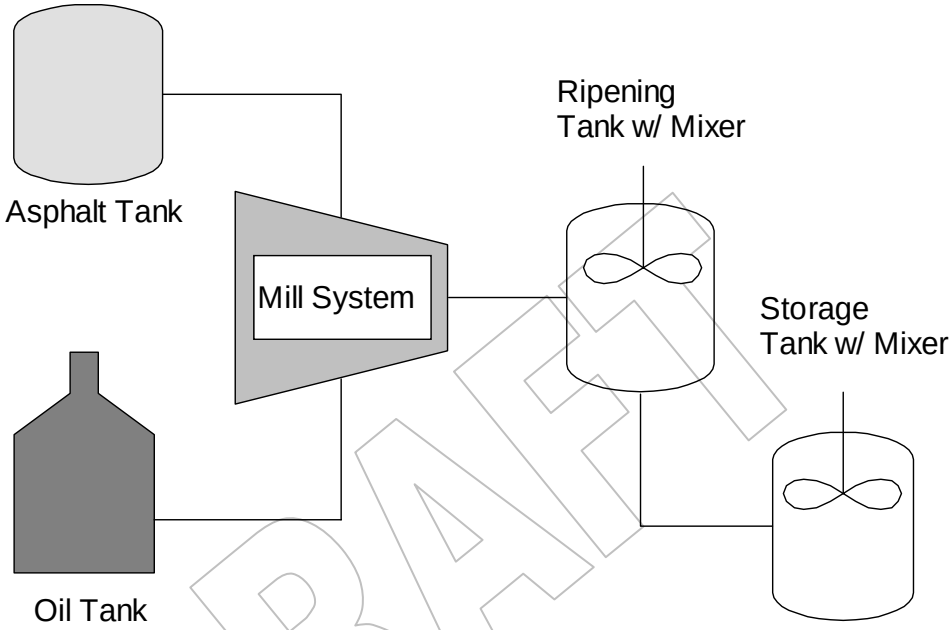


Figure 2-9 Typical Polymer Blending Plant (Holleran, 2001)

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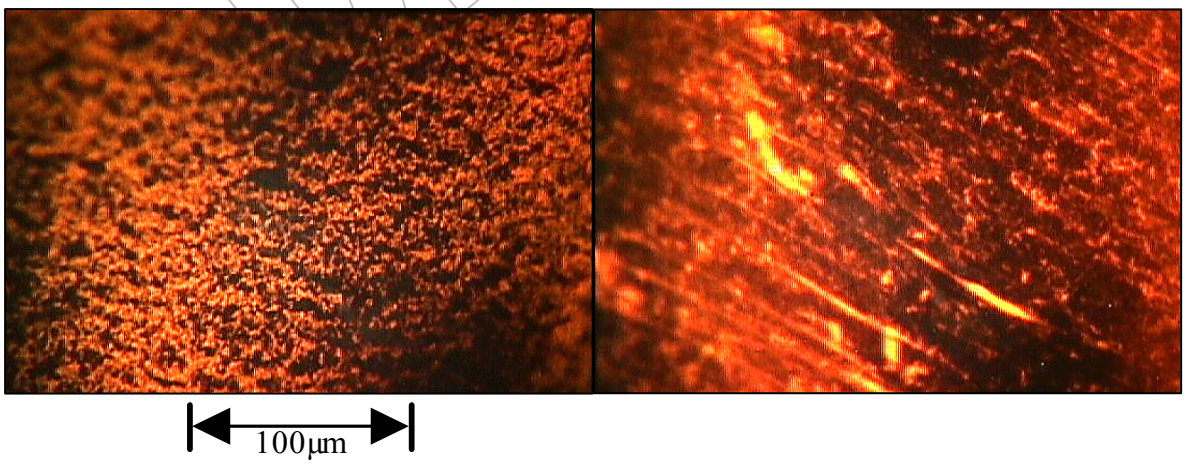


**(a) Compatible System** **(b) Incompatible System**

Figure 2-10 Micrographs of Polymer Systems (Holleran, 2001)

### *2.5.3 Polymer Modified Asphalts*

Caltrans has adopted three specifications for polymer modified asphalt, PG58-34PM, PG64-28PM and PG76-22PM (Table 2-3). The different grades are suited for different climatic applications. The PM specification defines the performance characteristics of the binder. It also incorporates additional specifications for the elastic recovery and phase angle.

The polymer modified asphalts provide better high and low temperature properties than conventional grades and are used in areas with hot summers and cold winters. This is achieved through the use of SBS copolymers.

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Table 2-3 Performance Graded Modified Asphalt Binder (Caltrans, 2006)

| PROPERTY | AASHTO TEST METHOD | SPECIFICATION GRADE | | |
|---|---|---|---|---|
| | | PG 58-34PM | PG 64-28PM | PG 76-22PM |
| Original Binder | | | | |
| Flash Point, Minimum °C | T48 | 230 | 230 | 230 |
| Solubility, Minimum % [b] | T44 | 99 | 99 | 99 |
| Viscosity at 135°C, [c]<br>Maximum, Pa·s | T316 | 3.0 | 3.0 | 3.0 |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Minimum G*/sin(delta), kPa | T315 | 58<br>1.00 | 64<br>1.00 | 76<br>1.00 |
| RTFO Test [e],<br>Mass Loss, Maximum, % | T240 | 0.6 | 0.6 | 0.6 |
| RTFO Test Aged Binder | | | | |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Minimum G*/sin(delta), kPa | T315 | 58<br>2.20 | 64<br>2.20 | 76<br>2.20 |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Maximum (delta), % | T315 | Note d<br>80 | Note d<br>80 | Note d<br>80 |
| Elastic Recovery,<br>Test Temp.<br>Minimum recovery, % | T301 | 25<br>75 | 25<br>75 | 25<br>65 |
| PAV [e] Aging,<br>Temperature, °C | R28 | 100 | 100 | 110 |
| RTFO Test and PAV Aged Binder | | | | |
| Dynamic Shear,<br>Test Temp. at 10 rad/s, °C<br>Minimum G*sin(delta), kPa | T315 | 16<br>5000 | 22<br>5000 | 31<br>5000 |
| Creep Stiffness,<br>Test Temperature, °C<br>Maximum S-value, MPa<br>Minimum M-value | T313 | -24<br>300<br>0.300 | -18<br>300<br>0.300 | -12<br>300<br>0.300 |

Notes:

a. Performance Graded Modified Asphalt Binder (PG Modified) will not be modified using acid modification.
b. The Engineer will waive this specification if the supplier is a Quality Supplier as defined by the Department's "Certification Program for Suppliers of Asphalt."
c. The Engineer will waive this specification if the supplier certifies the asphalt binder can be adequately pumped and mixed at temperatures meeting applicable safety standards.
d. Test temperature is the "temperature at which G*/sin(delta) equal 2.2 kPa". A graph of log G*/sin(delta) plotted against temperature can be used to determine the test "temperature at which G*/sin(delta) is 2.2 kPa". A graph of (delta) versus temperature can also be used to determine delta at "temperature where G*/sin(delta) is 2.2 kPa". Direct measurement of (delta) at the "temperature at which G*/sin(delta) is 2.2 kPa" is also acceptable.
e. "PAV" means Pressurized Aging Vessel.

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### *2.5.4 Performance Based Asphalts*

Caltrans was one of the originators of performance-based asphalts (PBA's) as detailed in SSP S8 M-20 (See Table 2-4) (Caltrans, 1999c). Some PBA's are polymer modified; notably PBA 6a, PBA 6b, and PBA 7. The PBA specification defines the performance characteristics of the binder. It also incorporates many of the standard consistency tests as well as some items that were a precursor to the Strategic Highway Research Program (SHRP) rheological parameters, such as shear susceptibility of delta and viscosity.

The different grades are suited for different climatic applications. PBA 6a and PBA 6b are polymer modified asphalts and provide better high and low temperature properties than AR grades and are used in areas with hot summers and cold winters. This is achieved through the use of SBS copolymers. The main difference is the lower temperature cracking resistance, PBA 6b being superior to PBA 6a by 9 to 11ºF (5 to 6°C). Both products resist rutting at very high pavement temperatures. PBA 6a is also useful in open graded mixes where the application temperatures are at the lower end of the requirements or work is being done at night. This is possible due to PBA 6a's good compaction characteristics in such mixes. PBA 7 is more heavily modified than the other materials and is suitable for high desert areas. This material has better aging resistance and may be used for this purpose in milder climates.

## 2.6 ASPHALT RUBBER

### *2.6.1 Asphalt Rubber Constituent*

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 the 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 made in the field; that is, near to the job site for chip seal applications or at the hot plant site for hot mix applications.

The asphalt rubber specification is a recipe specification and is to some extent is detailed in the SSP's (Caltrans, 1999c). But, they 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 SSP requirements (Caltrans, 1999c). 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 extender oil (high aromatic hydrocarbon) at about 2% - 6% (Caltrans, 1999c).

The asphalt rubber binder improves fatigue life, resistance to rutting, and provides stone retention and crack alleviation in chip seals (Caltrans, 1999d) when compared to other binders. In California, asphalt rubber gap-graded overlays may be reduced up to 50% the thickness of conventional overlays and still provide the same resistance to reflective cracking, however half thickness does not apply to

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structural requirements. Caltrans uses asphalt rubber binders mainly in gap graded and open graded mixes. They are also used as SAM and SAMI seals as a reflection cracking treatment. Caltrans does not currently use asphalt rubber in dense graded mixtures.

Table 2-4 Performance Based Asphalt Binder [a] (Caltrans, xxxx)

| PROPERTY | AASHTO TEST METHOD | SPECIFICATION GRADE | | | |
|---|---|---|---|---|---|
| | | PBA 6A | PBA 6A (MOD) | PBA 6B | PBA 7 |
| Absolute Visc. (60°C), Pas(x10-[1]) [a]<br>Original Binder, Min.<br>RTFO Test Aged Residue [b], Min. | T202 | <br>2000<br>5000 | <br>2000<br>5000 | <br>2000<br>5000 | <br>1100<br>3000 |
| Kinematic Visc. (135°C),$m^2/s(x10^6)$<br>Original Binder, Max.<br>RTFO Test Aged Residue, Min. | T201 | <br>2000<br>275 | <br>2000<br>275 | <br>2000<br>275 | <br>2000<br>275 |
| Absolute Visc. Ratio (60°C), Max.<br>RTFO Test Visc./Orig. Visc. | - | <br>4.0 | <br>4.0 | <br>4.0 | <br>4.0 |
| Flash Point, Cleveland Open Cup, °C<br>Original Binder, Min. | T48 | <br>232 | <br>232 | <br>232 | <br>232 |
| Mass Loss After RTFO Test, % | T240 | 0.60 | 0.60 | 0.60 | 0.60 |
| Solubility in Trichloroethylene, % [c]<br>Original Binder, Min. | T44 | <br>Report | <br>Report | <br>Report | <br>Report |
| Ductility (25°C, 5 cm/min), cm<br>RTFO Test Aged Residue [b], Min. | T51 | <br>60 | <br>60 | <br>60 | <br>60 |
| On RTFO Test Aged Residue, °C<br>1 to 10 rad/sec: SSD [e] ≥ 0 and<br>Phase Angle (at 1 rad/sec) < 72° | [f] | <br><br>- | <br><br>35 | <br><br>- | <br><br>- |
| On Residue from:<br>PAV [g] at temp., °C<br>Or Residue from Tilt Oven[f]<br>(@113°C), hours | R28 | <br>100<br><br>36 | <br>100<br><br>36 | <br>100<br><br>36 | <br>100<br><br>36 |
| [e] SSD ≥ -115(SSV)-50.6, °C | [f] | - | - | - | 25 |
| Stiffness,<br>Test Temperature, °C<br>Max. S-value, MPa<br>Min. M-value | T313 | <br>-24<br>300<br>0.300 | <br>-24<br>300<br>0.300 | <br>-30<br>300<br>0.300 | <br>-6<br>300<br>0.300 |

Notes:

a. Absolute viscosity (60°C) will be determined at one sec-1 using ASTM Designation: D 4957 with Asphalt Institute vacuum capillary viscometers.
b. "RTFO Test Aged Residue" means the asphaltic residue obtained using the Rolling Thin Film Oven Test (RTFO Test), AASHTO Test Method T240 or ASTM Designation: D 2872.
c. There is no requirement; however results of the test shall be reported as part of the certified copy of test results furnished with the Certificate of Compliance.
d. "Residue from Tilt Oven " means the asphalt obtained using California Test 374, Method B, "Method for Determining Asphalt Durability Using the California Tilt-Oven Durability Test."
e. "SSD" means Shear Susceptibility of Delta; "SSV" means Shear Susceptibility of Viscosity.
f. California Test 381.
g. "PAV" means Pressurized Aging Vessel.

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### *2.6.2 Asphalt Rubber Manufacture*

To produce asphalt rubber binder, the asphalt cement is heated to approximately 375° to 440°F (190 to 226°C) at which time the 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 (Caltrans, 1999d). This reaction is similar to the process of swelling that occurs in polymer asphalt systems (Caltrans, 1999b). The reaction is shown schematically in Figure 2-11.

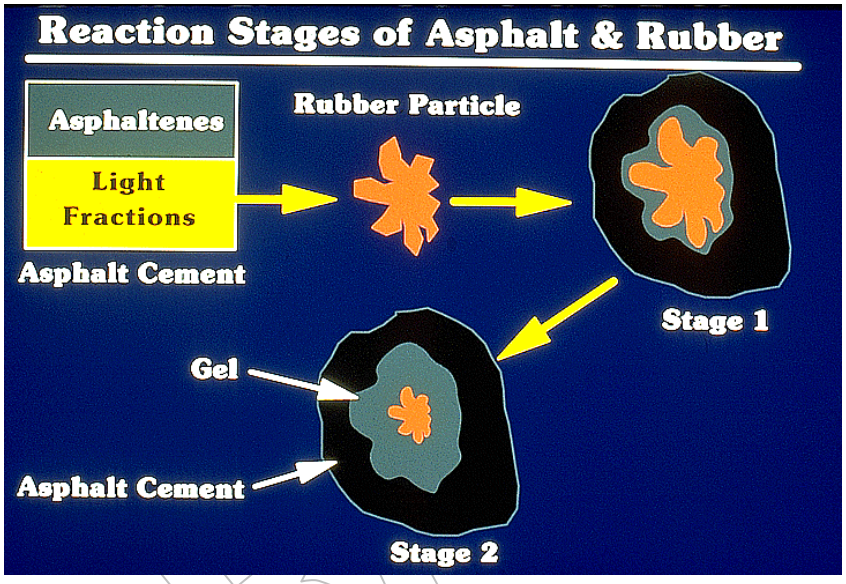


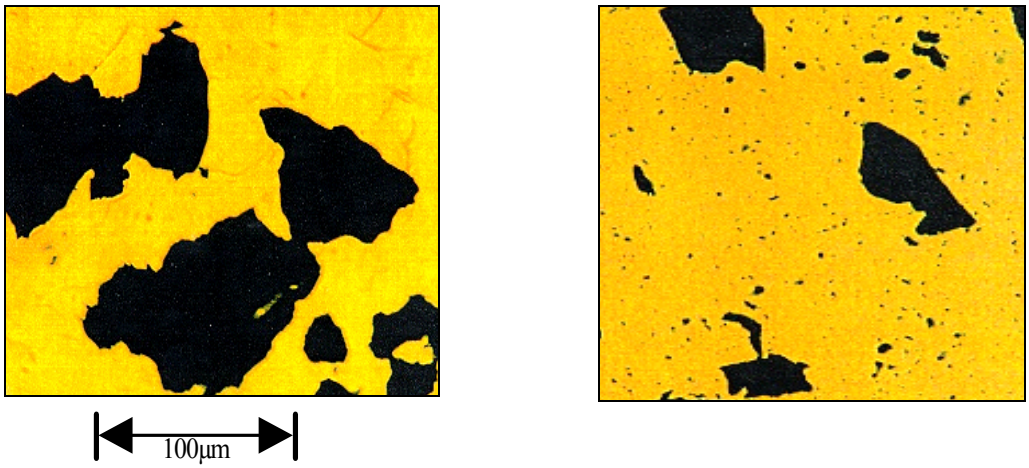

Figure 2-11 **Asphalt Rubber "Reaction**" (Caltrans, 1999d).

How well this model reflects the actual situation 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).

This can be shown by examining micrographs (see Figure 2-12) 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 $3.94 \cdot 10^{-3}$ inches [100µm]). 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.

### *2.6.3 Caltrans Specification Requirements for Asphalt Rubber*

Caltrans SSPs for asphalt rubber binder (ARB) and rubberized asphalt concrete (RAC) mixes are currently being updated to reflect implementation of the performance graded (PG) asphalt binder system and will be incorporated into Section 39 of the Standard Specifications. The following discusses current SSP requirements and recommended changes developed by a Caltrans-Industry working group. For each project, a detailed review of the special provisions and other contract documents is recommended to assure compliance with the project requirements.




**a) Without Extender Oil** **b) With Extender Oil**

**Figure 2-12 Micrographs: Asphalt Rubber Extender Oil Effects (Holleran, 2001)**

The Aged Residue (AR) system of asphalt binder grading is being replaced by the performance graded (PG) system. AR-4000 will no longer be specified as the base asphalt cement for asphalt rubber binders. Instead, 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 change in grading systems should not present any major obstacles to asphalt rubber binder design. However, the base asphalt cement shall not be polymer-modified.

The current specifications for Asphalt Rubber Binder call for 20 ± 2 percent crumb rubber modifier (CRM) content by total binder mass. The CRM must include 25 ± 2 percent by mass of high natural rubber CRM and 75 ± 2 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 µm sieve sizes). The high natural rubber CRM is somewhat finer, mostly No. 16 to No. 50 (1.18 mm to 300 µm sieve sizes).

The extender oil dosage for chip seals will remain at a range of 2.5 to 6 percent by mass of the asphalt cement. However, the minimum extender oil content for use in RAC mixes may be reduced to one percent to minimize potential for flushing and bleeding for hot climate, high traffic index (TI) locations.

Extender oils and high natural CRM are used to enhance the asphalt rubber interaction. Extender oils act as "compatibilizing" agents for the asphalt rubber interaction 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 percent by asphalt rubber binder mass. Use of high natural CRM appears to improve the bond between cover aggregate and the asphalt rubber membrane.

It is important to understand that just mixing together 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 special provisions. Properties of asphalt

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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. That is why binder design and testing procedures are essential to develop satisfactory asphalt rubber formulations.

## 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, etal, 1996). Local sources are generally used but some other materials such as expanded clay (light weight aggregate) or slag may be used if they meet the required specification. In some areas local materials ( ) are not suitable for use in the AC mixes. Major aggregate types that may be encountered in California include (Roberts, etal, 1996):

- Igneous rocks: Volcanic rocks formed from molten rock. Examples are granite and basalt.
- Sedimentary rocks: Rocks formed by the laying down of 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 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. Slag can be from tin, steel, or copper processing. Slag is generally hard but absorbent (typically vesicular)

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

**Chemical Properties**: Chemical properties of aggregates identify the changes an aggregate may go through due to chemical action. Some aggregates contain substances that are soluble in water, are subject to oxidation, hydration or carbonation. The main chemical property that affects asphalt applications, however, is affinity the aggregate has for the asphalt. Asphalt must wet the surface of the aggregate and adhere to it. Failure to do so may produce the phenomena of stripping and disintegration failure of the hot mix or loss of stone in other treatment types 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).

**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 specifies grading requirements for use in HMA in the Standard Specifications Section 39. The 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. In open graded asphalt concrete mixtures, it will determine porosity, while in chip seals and slurry surfacing it will determine seal durability. The individual grading requirements are further discussed in the chapters on treatments 4-13. 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.

- **Cleanliness 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.

- **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.

- **Durability or Soundness:** Aggregates must be resistant to break down due to the cyclic action of wetting and drying and freeze and thaw cycles. CT 214 can be used to determine soundness.

- **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 only fractured faces (CT 205).

- **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. These changes can result in raveling of the pavement. Caltrans uses the Centrifuge Kerosene Equivalent and the Oil Ratio Test (CT 303) test to measure the absorption of aggregate.

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

### *2.7.2 Aggregate Manufacture*

Aggregates are manufactured in 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; which include 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 combination must be chosen to meet the required specifications. Aggregates may also be mixed from gravel deposits.

## 2.8 STORAGE AND HANDLING

The key aspects of storing and handling any product include safety and quality. It is essential to ensure safety in handling at all times and to maintain quality so that the material remains in specification from manufacture to the intended end use.

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This section covers storage and handling of:

- Conventional Asphalt
- Modified Asphalts (including asphalt rubber, polymer modified, and MB's)
- Asphalt Emulsions
- Aggregates

### *2.8.1 Asphalt Binders*

When handled properly, asphalts may be reheated or maintained at elevated temperatures without adverse effects. If asphalt is thermally abused in storage, handling or application, it may harden and compromise service properties.

**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 correct procedures are established and 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 also 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 fired. 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**: In order to minimize oxidation and loss of volatiles, contact with air must be minimized. 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 in entrapped air. Venting is an essential safety precaution and cannot be eliminated to reduce oxidation.

- **Maintaining asphalt homogeneity**: To maintain asphalt homogeneity and avoid temperature variation, the asphalt should be mixed on an intermittent basis. This may be done through circulation or through the use of 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.

- **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.

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Safety hazards can arise from:

- **High Temperatures**: Since asphalt must be stored at high temperatures, safety issues involving 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 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 in mind, 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. The latter is highly toxic and tends to build up in headspace. Proper venting is required to dispose of these 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 manufacture. Allowable storage times are product specific and take into account the rate of property change, which occurs during storage. For example, a conventional asphalt can be stored for several months, a PBA modified grade can be stored for several days, and asphalt rubber is typically formulated overnight (holdovers).

### *2.8.2 Asphalt Emulsions*

Asphalt emulsions are a convenient way of handling asphalt but emulsions may be subject to settlement or breaking prematurely. For this reason storage and handling are important issues. Over time emulsions will become coarser and undergo property changes, to avoid these problems timely use is often required. There are some simple rules for storage and handling of asphalt emulsions and they are discussed below.

**Handling**

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

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- **Pumping**: Pumps are a way of doing work on 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 back 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 as long as the peripheral speed is not too high, less than 300 rpm. Positive displacement pumps may be used, but usually 2-3 thousandths of an inch must be shimmed from the gears to provide adequate clearance and lastly old and worn pumps may be used. Always get expert advice on the appropriate pump to use.

- **Temperature**: When asphalt materials get cold, they shrink. In an emulsion, this means that the asphalt droplets get closer together. This has a number of important consequences. 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 actually freezes, the droplets become frozen in contact and the emulsion will revert to bitumen upon thawing. For most emulsions, this happens if the emulsion gets to below 40°F (4°C). When 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 back to asphalt by the action of flocculation and coalescence. If any part of the emulsion gets hotter than 203°F (95ºC) localized boiling may occur. If this happens, the droplets fuse back into asphalt. This fusing process raises a number of important aspects surrounding the heating process including the following:

    - When heating emulsions do it gently 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.

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**Transport Handling**

Emulsions are generally stable enough to transport. However, a common problem arises when air enters 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 and as a result asphalt particles move to the bottom of the storage container. This movement is referred to as settling. If the particles pack in this way they can stick together (flocculate and coalesce) if this continues the emulsion will eventually turn back into bitumen. This settlement may be controlled to some extent by formulation. If the emulsion particles are fine enough to start with, they will settle more slowly allowing for 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.

It is important to 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. The only way to prevent problems is to start with a very fine emulsion and keep it properly maintained.

## 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 spent 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 1320 gal (5000 L) tank should be circulated for 15 minutes while a 2640 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.

Table 2-5 shows the storage and application temperatures for emulsions currently in use by Caltrans (Asphalt Institute MS-4, 1989), (Holleran, 1998a) & (METS, 2002).

## Cleaning Procedures

For emulsions, cleanliness is very important. A sloppy operation will produce problems. When an emulsion comes in contact with air, it can begin to break. When a cationic emulsion comes into 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.

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- 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.

Rust, dirt, grass or other foreign material should be kept out of the emulsion. This is especially important when working with cationic emulsions as they can break by reacting with foreign materials.

**Table 2-5 Mixing, Spraying and Storage Temperatures of Emulsions**

| PRODUCT | MIXING TEMPERATURE °F (°C) | SPRAYING TEMPERATURE °F (°C) | STORAGE TEMPERATURE °F (°C) |
|---|---|---|---|
| RS-1 | N/A | 68-140 (20-60) | 68-140 (20-60) |
| RS-2 | N/A | 68-140 (20-60) | 122-185 (50-85) |
| MS-1 | 50-158 (10-70) | 68-158 (20-70) | 68-140 (20-60) |
| MS-2 | 50-158 (10-70) | N/A | 122-185 (50-85) |
| MS-2h | 50-158 (10-70) | N/A | 122-185 (50-85) |
| SS-1 | 50-158 (10-70) | 50-140 (10-60) | 50-140 (10-60) |
| SS-1h | 50-158 (10-70) | 50-140 (10-60) | 50-140 (10-60) |
| CRS-1 | N/A | 68-140 (20-60) | 50-140 (10-60) |
| CRS-2 | N/A | 122-185 (50-85) | 122-185 (50-85) |
| CMS-2s | 50-158 (10-70) | N/A | 122-185 (50-85) |
| CMS-2 | 50-158 (10-70) | N/A | 122-185 (50-85) |
| CMS-2h | 50-158 (10-70) | N/A | 122-185 (50-85) |
| CSS-1 | 50-158 (10-70) | 68-140 (20-60) | 50-140 (10-60) |
| CSS-1h | 50-158 (10-70) | 68-140 (20-60) | 50-140 (10-60) |
| PMRS-2 | N/A | 122-185 (50-85) | 122-185 (50-85) |
| PMRS-2h | N/A | 122-185 (50-85) | 122-185 (50-85) |
| PMCRS-2 | N/A | 122-185 (50-85) | 122-185 (50-85) |
| PMCRS-2h | N/A | 122-185 (50-85) | 122-185 (50-85) |
| QS-1 | 50-104 (10-40) | N/A | 50-140 (10-60) |
| QS-1h | 50-104 (10-40) | N/A | 50-140 (10-60) |
| CQS-1 | 50-104 (10-40) | N/A | 50-140 (10-60) |
| CQS-1h | 50-104 (10-40) | N/A | 50-140 (10-60) |
| LMCQS-1h | 50-104 (10-40) | N/A | 50-140 (10-60) |
| MSE | 50-104 (10-40) | N/A | 50-140 (10-60) |

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The main transport requirements are to ensure that correct pumping is used, pumps should be warmed in cool climates. Clean tanks or a switch-load process should be followed. Switch loading is a process by which 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.

**Table 2-6 Acceptable Switch Load Combinations (Asphalt Institute MS-4, 1989)**

| LAST PRODUCT IN TANK | PRODUCT TO BE LOADED | | | |
|---|---|---|---|---|
| | ASPHALT CEMENT | CUTBACK ASPHALT | CATIONIC EMULSION | ANIONIC EMULSION |
| **Asphalt Cement** | OK to Load | OK to Load | Empty to No Measurable Quantity | Empty to No Measurable Quantity |
| **Cutback Asphalt** | Empty to No Measurable Quantity | OK to Load | Empty to No Measurable Quantity | Empty to No Measurable Quantity |
| **Cationic Emulsion** | Empty to No Measurable Quantity | 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 | 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 | Empty to No Measurable Quantity |
| **Any Product Not Listed Above** | Tank Must be Cleaned | Tank Must be Cleaned | Tank Must be Cleaned | Tank Must be Cleaned |

Emulsions are chemical systems. In order to avoid contamination, they should never be mixed with other types of emulsions or with other chemicals.

### *2.8.3 Aggregates*

Aggregates must be handled and stored in a manner that avoids contamination, minimizes degradation and avoids contamination (Asphalt Institute MS-22, 1998). 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 inter-mingling.
- 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 avoided by avoiding stockpiling 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, 1998).
- 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.

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## 2.9 SAMPLING REQUIREMENTS

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

Emulsions, as has been discussed, 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 2h type materials.

### *2.9.1 Sampling Guidelines*

The following guidelines should be followed for sampling materials **(**Asphalt Institute MS-22, 1998):

- Samples of emulsion and binder shall be taken in conformance with the requirements in AASHTO T 40, "Sampling Bituminous Materials," and Section 8-01 and 8-02 of the Construction Manual and California Test Method 125.
- Observe safety procedures.
- Sample binders daily using new, clean, dry 0.26 gal (1 L) cans with screw lids.
- Samples are normally taken from the application lance at the rear of the distributor. 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 has 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 8-01 of the Construction Manual 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.
- 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 Section 39-3.03 "Proportioning" of the Standard Specifications.
- Samples may be taken from a conveyor belt or sampling chute.
- Field samples must be taken from the stockpile. AASHTO T 2 and Section 39 3.03 of the Standard Specifications (Caltrans, 1999a) describe the method.

### *2.9.2 Sample Delivery*

Samples for testing should be delivered to the Transportation Laboratory:

**Division of Materials Engineering and Testing Services**
**Flexible Pavement Materials Branch, MS #5**
**5900 Folsom Boulevard**
**Sacramento, California 95819-4612**

- Samples are not to be shipped C.O.D.

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- Emulsion will be tested for compliance with Section 94, "Asphaltic Emulsions", of the Standard Specifications (Caltrans, 1999a).
- Aggregate samples should be tested for compliance with Section 39 "Asphalt Concrete" or Section 37 "Seal Coats" of the Standard Specifications (Caltrans, 1999a) 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, if an e-mail address is provided on the TL-0101.

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