

# Rubberized Asphalt Concrete



# Inspection Guide



## RAC-105

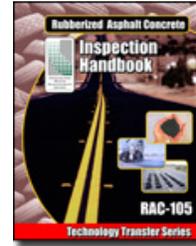
## Technology Transfer Series



# Inspection Guide

Technology Transfer **RAC-105**

## Inspection Guide RAC-105



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### INSPECTION MISSION

Your mission is to verify that the final field product is in conformance with the plans and specifications.

As a construction inspector, you are the vital link between the designer and the final field product. Your knowledge of the material and equipment used to manufacture and place Rubberized Asphalt Concrete (RAC) coupled with your expertise in the proper construction techniques needed to ensure a high-quality, long-lasting roadway surface will determine the performance of the final product.

*Remember, the contract documents (plans, specifications, etc.) provide minimum requirements. Any deviations below these minimum requirements will reduce the useful life of the pavement and incur additional unplanned maintenance costs.*

Your Job Is Important! It is critical to the success of the projects you oversee!

### FOREWORD

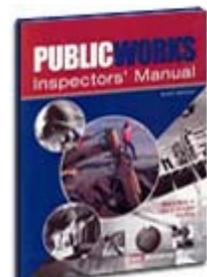
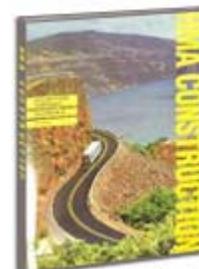
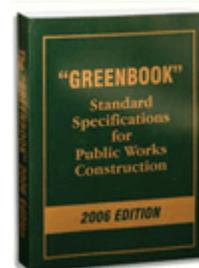
This easy-to-carry field guide is intended to provide you with basic information about RAC mix design, manufacture, and pavement surface preparation and construction techniques. The goal of the Technology Center is to give you brief, yet substantial, information in a checklist format rather than providing full descriptions of how to perform each function.

While the information presented in this field guide is geared toward the construction of RAC, the same principles apply to the construction of conventional asphalt concrete pavements. For more detailed information, we recommend the following publications:

**"Greenbook"** Standard Specifications for Public Works Construction, BNI Building News

**Public Works Inspectors Manual**, BNI Building News

**Principles of Construction of Hot-Mix Asphalt Pavements**, Asphalt Institute, Manual Series No. 22



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**Hot-Mix Paving Handbook 2000**, AASHTO, FAA, FHWA, NAPA, U.S.A.C.E., APWA and NACE. Available through National Asphalt Pavement Association

**National Highway Institute** (NHI) Hot Mix Asphalt Construction Course - FHWA

### ADVANTAGES OF RAC

California generates over 30 million scrap tires annually.

- Ensures long-lasting, durable pavement that resists reflective cracking.
- Saves money. By using its superior resistance to reflective cracking, a RAC resurfacing project can save as much as \$20,000 per lane mile over AC by placing a thinner section (2 inches RAC vs. 4 inches AC).
- Provides a highly skid-resistant surface, reduces tire noise by 50% - 80%, and resists rutting and shoving.
- Uses over 2,000 tires per lane mile in a 2-inch thick resurfacing project, making RAC environmentally friendly.
- Provides excellent color contrast for striping and marking.

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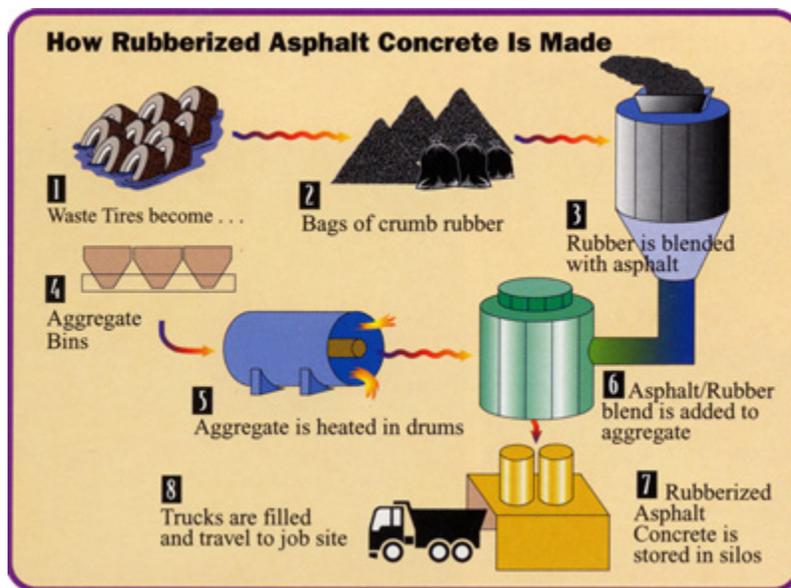
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### HOW RAC IS PRODUCED

RAC is made by blending crumb rubber from scrap tires, asphalt cement, and properly graded, sound aggregates in specified proportions in a central mixing plant. Other additives such as high natural rubber and extender oil may be included as appropriate.



*Crumb rubber from scrap tires*



### Wet Process

Blending of the crumb rubber is generally done by the "wet process" in which the crumb rubber is blended and interacted with the hot asphalt cement prior to adding the asphalt rubber binder to the aggregates.

Currently the "wet process" is the only process permitted by the GREENBOOK, and is the primary process used by CALTRANS. Two different types of binders may be made by the wet process: high viscosity (meets ASTM definition of asphalt rubber including minimum viscosity of 1,500 cPs, or 1.5 Pascal seconds) and no agitation, which is often referred to as terminal blend and has viscosity <1,500 cPs. Viscosity is the discriminator for appropriate use. The information herein applies to high viscosity asphalt rubber materials.

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### **Refinery Process (No agitation binders):**

This patented process, which has been used in Texas since 1995 digests the crumb rubber into the asphalt cement at the refinery so that no agitation is required. A number of refineries in California and Arizona are now producing similar products, such as PG 76-22TR+, MAC-10TR, and MB binders, most of which are proprietary. This process typically uses only about half the amount of Crumb Rubber Modifier (CRM) used to make high viscosity asphalt rubber binders. Because of the low viscosity, the total no agitation binder content of hot mixes is considerably lower than provided by high viscosity binders (example: 5.5% vs. 8.5%).

### **Dry Process**

The "dry process" mixes the rubber particles with the aggregate prior to the addition of the asphalt.

CALTRANS has special provisions for RUMAC, a generic dry process mix made with gap-graded aggregates, but rarely uses this type of CRM modification. Recently constructed test sections are being monitored to evaluate potential for wider use.

## COMPOSITION OF RAC

### **Aggregates**

Gap graded RAC-G, ARHM-GG-C (B and D gradations may also be specified). Nominal  $\frac{3}{4}$ " and  $\frac{1}{2}$ " gap-graded or open-graded mixes may be used.

### **Asphalt Rubber Binder:**

Asphalt Modifier: 2.5-6% by weight of asphalt; Caltrans may reduce minimum for hot climate areas to 1%.

Asphalt Cement+ Modifier: 80 +/- 2%

CRM (Scrap tire and High Nat'l): 20+/- 2% by total binder weight, including 25+/-2% high natural CRM

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### MIX DESIGNS AND CERTIFICATIONS

A mix design is provided by the contractor and reviewed by the Agency. The contractor certifies that the mix provided corresponds to the submitted mix design.

#### **A mix design should include:**

- Combined aggregate gradation
- Binder content
- CRM content (scrap tire and high natural)
- CRM gradation (scrap tire and high natural)
- Maximum density – Rice
- Laboratory density- Hveem
- Air voids at laboratory density
- Voids in mineral aggregate (VMA)
- Hveem Stability

### EQUIPMENT

At the Plant:

A typical asphalt plant consists of the following:

- Aggregate storage bins
- A weighing device to measure specific amounts from each bin onto a cold feed belt or into a pug mill
- A heated storage tank for the asphalt cement
- A drum dryer to dry and heat the aggregates
- A mixing drum or pug mill to mix the aggregate with the asphalt binder
- A storage silo to temporarily store the asphalt concrete



*Plant overview*

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- A weighing device to drop the AC into the trucks for delivery to the job.
- A RAC plant adds equipment to blend the crumb rubber with the asphalt cement (wet process) or aggregates (dry process).

**Pavers** RAC is placed with a conventional, mechanical, self-propelled Paver designed specifically to distribute a layer of RAC (or any AC paving mix) to a predetermined thickness.

**Rollers** Compaction is done with self-propelled, vibrating steel wheel rollers. Rubber tired rollers are not permitted due to potential for pick up. Vibratory mode is used for the break down coverages, and static mode for intermediate and finish rolling.



*Windrow paving*

## SURFACE PREPARATION

The existing pavement to be resurfaced shall be clean with all cracks over 1/4 inch filled (do not overfill) and all badly deteriorated sections removed and replaced.

Longitudinal and transverse joints shall be milled. An approved tack coat (preferably paving grade asphalt) shall be applied evenly at the specified rate over the entire surface to be paved.

## INSPECTION AT THE PLANT

Plant inspection is critical to the success of every RAC project.

Problems observed at the plant can be corrected immediately to ensure that the material delivered to the site conforms to the specifications.



Important Items to watch for at the plant:

- Verify that the scales have been certified for accuracy.
- Check aggregate bins for properly sized material in each bin

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- Check aggregates off the cold feed belt for proper gradation
- Monitor the proportioning devices to verify that the proper amount of crumb rubber is added to the asphalt cement and to ensure that the proper amount of asphalt rubber binder is added to the aggregates.
- Check the viscosity of the asphalt rubber binder to make sure that it meets requirements and that the crumb rubber is thoroughly blended and interacted with the asphalt cement.
- Take samples of the crumb rubber, aggregates, asphalt cement, asphalt rubber binder, and RAC mix for possible laboratory testing. Test as needed.
- Check the temperature of the RAC in the trucks.
- Haul trucks should be covered (tarped) to maintain RAC mix temperature.
- Maintain an accurate log of test samples, aggregate gradations, CRM quantities, viscosity measurements and corresponding temperatures of the asphalt rubber binder.

## INSPECTION AT THE SITE

At the construction site, you have the opportunity to help ensure that the materials and the lay down procedures are consistent with those that will result in a high-quality product. By working with the contractor's foreman, you help resolve potential problems and correct irregularities.



It is extremely important, however, to remember that you should not direct the work - that is the contractor's responsibility.



*Contracting Personnel at Construction Site*

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### Prior to Paving

For overlays, check existing pavement condition and the following:

- Are cracks over 1/4 inch filled? Is application of sealant too heavy?
- Are the badly deteriorated areas repaired?
- Are the joints milled?
- Is the surface clean?
- Has the tack coat been properly applied?

Check the ambient temperature and the temperature of pavement to be resurfaced. Specifications require minimum air and pavement temperatures of 55 °F and rising. At minimum temperatures, little time is available for compaction.

Check to ensure that the paver and the rollers are the proper type and that they are in good working order.

Verify that the specified number of rollers is on the job and that there is a trained operator available for each.

Remember, compaction is the key to long-lasting pavement and compaction depends on the temperature of the mat.

There must be a sufficient number of breakdown rollers to cover the width of each paver pass immediately behind the paver. The Greenbook requires higher temperatures for mix delivery and compaction than Caltrans specifications. Breakdown compaction should start before mix temperature drops below 290°F (Greenbook) or 280°F (Caltrans). To meet compaction requirements, it is typically necessary to achieve at least 95% of the required compaction during breakdown rolling, before the mat temperature drops below 260°F.

Verify that the method of delivery of the RAC is appropriate for the job and weather conditions (end dumps vs. bottom dumps). When weather is marginally cool, windrows are not recommended.

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### During Paving

- Collect load tickets on a regular basis and calculate the yield to ensure that the proper thickness is being placed.
- Physically verify mat thickness at spot locations.
- Verify that the paver is operating at a speed that is consistent with the delivery of the mix. Pavers should not have to wait between loads of mix and loads of mix should not have to wait to unload.
- Verify that the screed height is not being adjusted unnecessarily



*Steel Drum Vibratory Roller*

### Watch for the following activities:

- Are the trucks carefully backing up to the paver?
- Is the paver pushing the trucks?
- Does the rate of loading the RAC into the hopper result in a full hopper without spilling over the sides?
- Is the roller drive wheel forward?
- Are the roller wheels kept wet to avoid picking up the RAC mix? Are the scraper pads effective?
- Is the roller operator reversing directions on existing or newly cooled pavement?
- Is the roller operator rolling the joints properly and rolling the mat from the low side toward the high side?



*Belly Dump*

Do not use or allow rubber tire rollers on asphalt rubber projects



Steel-wheeled rollers only - Vibratory mode essential for breakdown coverage

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Visually inspect the RAC as the trucks dump it into the hopper by checking the following:

- Is the RAC mixture smoking? (too hot)
- Is the RAC mixture stiff? (too cool)
- Is the RAC mixture shiny or slumped? (Excessive binder - maybe. RAC mixes may look rich even at correct binder content, so sample and test binder content.)
- Is the RAC mixture segregated? (Improper mixing or handling – maybe. Gap- and open-graded mixes can look segregated due to limited fines, so sample and test aggregate gradation and binder content.)
- Verify that the breakdown roller(s) follow immediately behind the paver and that the breakdown rolling is completed before the mat reaches 260°F.

### After Paving

- Check the compacted pavement surface for roller marks, scuffing, irregularities, smoothness, etc.
- Verify relative compaction by nuclear gauge or lab testing of pavement cores.
- Check the longitudinal and transverse joints for evenness, texture, and ride.
- Keep an accurate record of the tons placed and the area that was paved. Note any rejected loads or unusual occurrences.

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## CONCLUSION

RAC is a proven product that will stretch your agency's roadway maintenance funds and help reduce the stockpiles of scrap tires in California. When used in appropriate situations and constructed properly, RAC will produce a safe, high-quality, durable, quiet road that is more cost effective than conventional asphalt concrete. However, quality construction is a must!

As the eyes and ears of the agency you represent, you are charged with a great responsibility. Each project has been designed in accordance with accepted criteria using specifications that are, in reality, minimum requirements for the quality of the materials and the workmanship. Your job is to verify that the final field product conforms to the plans and specifications. It is an important job. It deserves your full attention.

Remember: Quality construction can only be obtained through quality inspection ... you are the key!

**QUALITY  
CONSTRUCTION  
THROUGH QUALITY  
INSPECTION**



**YOU ARE THE KEY**

### GLOSSARY

**Asphalt rubber binder (ARB)** – is used in various types of flexible pavement construction including surface treatments and hot mixes. According to the ASTM definition (ASTM D 8, Vol. 4.03, “Road and Paving Materials” of the Annual Book of ASTM Standards 2006) asphalt rubber is “a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles”. By definition, asphalt rubber binder is prepared using the “wet process”. Caltrans specifications for ARB physical properties fall within the ranges listed in ASTM D 6114, “Standard Specification for Asphalt Rubber Binder,” also located in Vol. 4.03. Recycled tire rubber is used for the reclaimed rubber and is currently referred to as crumb rubber modifier (CRM). The asphalt cement and CRM are mixed and interacted at elevated temperatures and under high agitation to promote the physical interaction of the asphalt cement and CRM constituents. During ARB production and storage, agitation is required to keep the CRM particles suspended in the blend. Various petroleum distillates or extender oil may be added to reduce viscosity, facilitate spray applications, and promote workability. (See Wet Process)

**Automobile tires** – tires with an outside diameter less than 26 inches (660 mm) used on automobiles, pickups, and light trucks.

**Crumb rubber modifier (CRM)** – general term for scrap tire rubber that is reduced in size for use as modifier in asphalt paving materials. Several types are defined herein. A variety of processes and equipment may be used to accomplish the size reduction as follows:

#### Types of CRM

**Ground crumb rubber modifier** – irregularly shaped, torn scrap rubber particles with a large surface area, generally produced by a crackermill.

**High natural rubber (Hi Nat)** – scrap rubber product that includes 40-48 percent natural rubber or isoprene and a minimum of 50 percent rubber hydrocarbon according to Caltrans requirements. Sources of high natural rubber include scrap tire rubber from some types of heavy truck tires, but are not limited to scrap tires. Other sources of high natural rubber include scrap from tennis balls and mat rubber.

**Buffing waste** – high quality scrap tire rubber that is a byproduct from the conditioning of tire carcasses in preparation for re-treading. Buffings contain essentially no metal or fiber.

**Tread rubber** – scrap tire rubber that consists primarily of tread rubber with less than approximately 5 percent sidewall rubber.

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**Tread peel** – pieces of scrap tire tread rubber that are also a by-product of tire re-treading operations that contain little if any tire cord.

**Whole tire rubber** – scrap tire rubber that includes tread and sidewalls in proportions that approximate the respective weights in an average tire.

### CRM Preparation Methods

**Ambient grinding** - method of processing where scrap tire rubber is ground or processed at or above ordinary room temperature. Ambient processing is typically required to provide irregularly shaped, torn particles with relatively large surface areas to promote interaction with the asphalt cement.

**Cryogenic grinding** – process that uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles with relatively small surface area. This method is used to reduce particle size prior to grinding at ambient temperatures.

**Granulation** – produces cubical, uniformly shaped, cut crumb rubber particles with a low surface area.

**Shredding** – process that reduces scrap tires to pieces 6 in.2 (0.023 m<sup>2</sup>) and smaller prior to granulation or ambient grinding.

### CRM Processing Equipment

**Cracker mill** – apparatus typically used for ambient grinding, that tears apart scrap tire rubber by passing the material between rotating corrugated steel drums, reducing the size of the rubber to a crumb particle generally No. 4 to No. 40 (4.75 mm to 425 mm) sieve size.

**Granulator** – apparatus that shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance, reducing the rubber to cubicle particles generally 3/8 in. to No. 10 sieve (9.5 mm to 2.0 mm) in size.

**Micro-mill** – process that further grinds crumb rubber particles to sizes below the No. 40 (425 mm) sieve size.

**Dense-graded** – refers to a continuously graded aggregate blend typically used to make hot-mix asphalt concrete (HMA) pavements with conventional or modified binders.

**Devulcanized rubber** – rubber that has been subjected to treatment by heat, pressure, or the addition of softening agents after grinding to alter physical and chemical properties of the recycled material.

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**Diluent** – a lighter petroleum product (typically kerosene or similar product with solvent-like characteristics) added to asphalt rubber binder just before the binder is sprayed on the pavement surface for chip seal applications. The diluent thins the binder to promote fanning and uniform spray application, and then evaporates over time without causing major changes to the asphalt rubber properties. Diluent is not used in ARB to make HMA, and is not recommended for use in interlayers that will be overlaid with HMA in less than 90 days due to on-going evaporation of volatile components.

**Dry process** – any method that includes scrap tire CRM as a substitute for 1 to 3 % of the aggregate in an asphalt concrete paving mixture, not as part of the asphalt binder. The CRM acts as a rubber aggregate in the paving mixture. This method applies only to production of CRM-modified AC mixtures. A variety of CRM gradations have been used, ranging from coarse rubber (1/4 in. to plus No. 8 (6.3 to 2.36 mm) sieve sizes) to “Ultrafine” minus No. 80 (180 µm) sized CRM. Caltrans has a special provision for RUMAC which includes an intermediate CRM gradation specification. Care must be taken during the mix design to make appropriate adjustments for the low specific gravity of the CRM compared to the aggregate material to assure proper volumetric analysis. Several methods have been established for feeding the CRM dry with the aggregate into hot plant mixing units before the mixture is charged with asphalt cement. Although there may be some limited interaction of the CRM with the asphalt cement during mixing in the AC plant, silo storage, hauling, placement and compaction, the asphalt cement is not considered to be modified in the dry process.

**Extender oil** – aromatic oil used to promote the reaction of the asphalt cement and the crumb rubber modifier.

**Flush coat** – application of diluted emulsified asphalt onto a pavement surface to extend pavement life that may also be used to prevent rock loss in chip seals or raveling in HMA.

**Gap-graded** – aggregate that is not continuously graded for all size fractions, but is typically missing or low on some of the finer size fractions (minus No. 8 (2.36 mm) or finer). Such gradations typically plot below the maximum density line on a 0.45 power gradation chart. Gap grading is used to promote stone-to-stone contact in HMA and is similar to the gradations used in stone matrix asphalt (SMA), but with relatively low percentages passing the No. 200 (75 µm) sieve size. This type of gradation is most frequently used to make rubberized asphalt concrete-gap graded (RAC-G) paving mixtures.

**Interaction** – the physical exchange between asphalt cement and CRM when blended together at elevated temperatures which includes swelling of the rubber particles and development of specified physical properties of the asphalt and CRM blend to meet requirements. Although often referred to as reaction, interaction is not a chemical reaction but rather a physical interaction in which the CRM absorbs aromatic oils and light fractions (small volatile or active molecules) from the asphalt cement, and releases some of the similar oils used in rubber compounding into the asphalt cement. The interaction may be more appropriately defined as polymer swell.

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**Lightweight aggregate** – porous aggregate with very low density such as expanded shale, which is typically manufactured. It has been used in chip seals to reduce windshield damage.

**Open-graded** – aggregate gradation that is intended to be free draining and consists mostly of 2 or 3 nominal sizes of aggregate particles with few fines and 0 to 4 percent by mass passing the No. 200 (0.075 mm) sieve. Open grading is used in hot-mix applications to provide relatively thin surface or wearing courses with good frictional characteristics that quickly drain surface water to reduce hydroplaning, splash and spray.

**Reaction** – commonly used term for the interaction between asphalt cement and crumb rubber modifier when blended together at elevated temperatures (see Interaction).

**Recycled tire rubber** – rubber obtained by processing used automobile, truck, or bus tires (essentially highway or “over the road” tires). Chemical requirements for scrap tire rubber are intended to eliminate unsuitable sources of scrap tire rubber such as solid tires; tires from forklifts, aircraft, and earthmoving equipment; and other non-automotive tires that do not provide the appropriate components for asphalt rubber interaction. Non-tire rubber sources may be used only to provide High Natural Rubber to supplement the recycled tire rubber.

**Rubberized asphalt** - asphalt cement modified with CRM that may include less than 15 percent CRM by mass and thus may not comply with the ASTM definition of asphalt rubber (ASTM D 8, Vol. 4.03). In the past, terminal blends (wet process, no agitation CRM-modified asphalt binders including Modified Binder (MB) materials) have typically fallen in this category.

**Rubberized asphalt concrete (RAC)** – material produced for hot mix applications by mixing asphalt rubber or rubberized asphalt binder with graded aggregate. RAC may be dense-, gap-, or open-graded.

**RUMAC** – generic type of dry process RAC mixture that has taken the place of proprietary dry process systems such as PlusRide.

**Stress-absorbing membrane (SAM)** – a chip seal that consists of a hot asphalt rubber binder sprayed on the existing pavement surface followed immediately by an application of a uniform sized cover aggregate which is then rolled and embedded into the binder membrane. Its nominal thickness generally ranges between 3/8 and 1/2-inch (9 and 12 mm) depending on the size of the cover aggregate. A SAM is a surface treatment that is used primarily to restore surface frictional characteristics, seal cracks and provide a waterproof membrane to minimize the intrusion of surface water into the pavement structure. SAMs are used for pavement preservation, maintenance, and limited repairs. Asphalt rubber SAMs minimize reflective cracking from an underlying distressed asphalt or rigid pavement, and can help maintain serviceability of the pavement pending rehabilitation or reconstruction operations.

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**Stress-absorbing membrane interlayer (SAMI)** - originally defined as a spray application of asphalt rubber binder and cover aggregate. However, interlayers now may include asphalt rubber chip seal (SAMI-R), fabric (SAMI-F), or fine unbound aggregate.

**Stress-absorbing membrane interlayer-Rubber (SAMI-R)** – SAMI-R is an asphalt rubber SAM that is overlaid with an asphalt paving mix that may or may not include CRM. The SAMI-R delays the propagation of the cracks (reflective cracking) through the new overlay.

**Terminal blend** – See Wet Process – No Agitation

**Truck tires** – tires with an outside diameter greater than 26 inches (660 mm) and less than 60 inches (1520 mm); used on commercial trucks and buses.

**Viscosity** – is the property of resistance to flow (shearing force) in a fluid or semi-fluid. Thick stiff fluids such as asphalt rubber have high viscosity; water has low viscosity. Viscosity is specified as a measure of field quality control for asphalt rubber production and its use in RAC mixtures.

**Vulcanized rubber** – crude or synthetic rubber that has been subjected to treatment by chemicals, heat and/or pressure to improve strength, stability, durability, etc. Tire rubber is vulcanized.

**Wet Process** - the method of modifying asphalt binder with CRM produced from scrap tire rubber and other components as required before incorporating the binder into the asphalt paving materials. Caltrans requires the use of extender oil and addition of high natural CRM. The wet process requires thorough mixing of the crumb CRM in hot asphalt cement (375°F to 435°F, 190°C to 224°C) and holding the resulting blend at elevated temperatures (375°F to 425°F, 190°C to 218°C) for a designated minimum period of time (typically 45 minutes) to permit an interaction between the CRM and asphalt. Caltrans specification requirements include an operating range for rotational viscosity and cone penetration, and minimum values of softening point and resilience.

The wet process can be used to produce a wide variety of CRM modified binders that have corresponding respective ranges of physical properties. However the most important distinctions among the various blends seem to be related to rotational viscosity of the resulting CRM-asphalt cement blend at high temperature (threshold is 1,500 centipoises (cPs) or 1.5 Pa/sec at 375°F (190°C) depending on governing specification) and whether or not the blend requires constant agitation to maintain a relatively uniform distribution of rubber particles. Viscosity is strongly related to the size of the scrap tire CRM particles and tire rubber content of the CRM-modified blend. CRM gradations used in the wet process are typically minus No. 10 (2 mm) sieve size or finer. CRM-modified binders with viscosities = 1,500 cPs at 375°F (190°C) should be assumed to require agitation.

**Wet Process-No Agitation** - a form of the wet process where CRM is blended with hot asphalt cement at the refinery or at an asphalt storage and distribution terminal and transported to the HMA mixing plant or job site for use. This type of rubberized asphalt (which includes Rubber Modified Binder, RMB) does not require subsequent agitation to

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keep the CRM particles evenly dispersed in the modified binder. The term “terminal blend” is often used to describe such materials, although they may also be produced in the field. Therefore, calling them terminal blends is unnecessarily restrictive and the preferred description for this type of binder is “wet process-no agitation”. Such binders are typically modified with CRM particles finer than the No. 50 (300 µm) sieve size that can be digested (broken down and melted in) relatively quickly and/or can be kept dispersed by normal circulation within the storage tank rather than by agitation by special augers or paddles. Polymers and other additives may also be included. In the past, rubber contents for such blends have generally been = 10% by mass of asphalt or total binder (which does not satisfy the ASTM D 8 definition of asphalt rubber), but current reports indicate some California products now include 15% or more CRM. Although such binders may develop a considerable level of rubber modification, rotational viscosity values rarely approach the minimum threshold of 1500 (cPs) or 1.5 Pa/s at 375°F (190°C), that is necessary to significantly increase binder contents above those of conventional HMA mixes without excessive drain-down.

**Wet Process-High Viscosity** - CRM-modified binders that maintain or exceed the minimum rotational viscosity threshold of 1500 cPs at 375°F (190°C) over the interaction period should be described as “wet process–high viscosity” binders to distinguish their physical properties from those of wet process-no agitation materials. These binders require agitation to keep the CRM particles evenly distributed. They may be manufactured in large stationary tanks or in mobile blending units that pump into agitated stationary or mobile storage tanks. Wet process-high viscosity binders include asphalt rubber materials that meet the requirements of ASTM D6114. Wet process-high viscosity binders typically require at least 15% scrap tire rubber to achieve the threshold viscosity. Caltrans requires a minimum total CRM content of 18%.

### Aggregates for Asphalt Concrete

#### Classification of Rock

- Sedimentary
- Igneous
- Metamorphic

#### Aggregate Sources

- Natural aggregates - gravel, sand
- Processed aggregates - crushed aggregate
- Synthetic aggregates - blast furnace slag

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### Maximum Particle Size and Gradation

- Specified for each asphalt concrete paving mix
- Coarse aggregate - retained on the No. 4 sieve
- Fine aggregate - passes the No. 4 sieve
- Mineral filler/dust - passes the No. 200 sieve

### Specific Gravity

- Aggregates of low specific gravity cover a larger volume per ton and, therefore, require a higher percentage of asphalt cement.
- Aggregates of high specific gravity cover a lower volume per ton and, therefore, require a lower percentage of asphalt cement.

### Cleanliness

- Free of unsuitable material
- Toughness
- Abrasion resistant

### Particle Shape

- Crushed particles interlock to provide strength.
- Fine, rounded particles provide workability but act as ball bearings in the mix so content should be limited. Many agencies limit such materials to a maximum of 15% of the total aggregate to minimize adverse effects on aggregate interlock and VMA.

### Surface Texture

- Asphalt tends to strip from smooth surfaces.

### Absorptive Capacity

- Ability to absorb asphalt influences the total amount of asphalt required. High absorption increases binder content.

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### Affinity to Asphalt

- Ability of the aggregate to bond with the asphalt binder

### Asphalt

#### Characteristics

- Black cementitious material made up largely of hydrocarbons
- A visco-elastic plastic material - brittle and hard when cold; soft and viscous when hot

#### Classifications

- Asphalt cement (paving grade asphalt)
- Liquid asphalt (mixed with cutbacks) - not used in RAC
- Emulsified asphalt (mixed with water) - not used in RAC

#### Physical Properties

- Durability
- Adhesion
- Temperature susceptibility - CRM modification reduces temperature susceptibility
- Aging and hardening

#### Testing of Asphalts

The following tests are used for asphalt rubber binders, but not for testing Performance Graded (PG) asphalt

**Viscosity** - ability to flow, consistency - temperature dependent

**Penetration** - hardness value, also measure of consistency at single temperature

**Flashpoint** - temperature at which a sample "flashes" i.e. bursts into flame

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**Thin Film Test/Rolling Thin Film Test** - aging methods

**Ductility** – discrete CRM particles affect test results, typically exhibits early fracture.

**Stability** – limited to emulsions. For no agitation binders, use separation test and specification compliance testing to evaluate stability of properties

**Specific Gravity** – used in volumetric mix design calculations, and for metering during mix production

### Mix Design Methods

- Marshall Mix Design Method
- Hot mix asphalt paving mixes, one-inch maximum size aggregate (for 4-inch molds)
- Determines optimum asphalt cement content for a particular blend of aggregates.
- Principal features are: 1) a density/void analysis and 2) a Marshall stability/ flow test.

### HVEEM Mix Design Method

- Hot mix paving, one-inch maximum size aggregate
- Principal features are:
- Centrifuge Kerosene Equivalent
- Hveem Stability test
- Swell test (permeability)
- Air voids
- Bleeding/flushing.

### Mix Design Characteristics

- Mix design of asphalt and rubberized asphalt paving mixes is a trade-off between high binder content to enhance long term durability and performance, and sufficient in-place void space to avoid rutting, instability, flushing and bleeding.
- Air voids provide spaces for the movement of the asphalt cement or asphalt rubber binder within the compacted mix.
- High air voids indicate relatively low density and increased permeability of the compacted mix. The maximum design target is 6% air voids, for special high volume and/or hot climate conditions.
- Low density typically results in raveling and/or stripping, increased susceptibility to aging, fatigue, and environmental damage, and related reduced service life.
- Low air voids indicate relatively high density and increased tendency for asphalt flushing, and mixture rutting and shoving. The minimum design target is 3% air voids.

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- High density also enhances resistance to fatigue and environmental damage, long term performance and durability, as long as in-place air voids are sufficient to prevent bleeding or instability.

### **Voids in Mineral Aggregate (VMA)**

- Total voids excluding those permeable to water and asphalt. VMA is a function of aggregate gradation, particle shape and texture.
- Proper VMA provides sufficient space for binder, which results in durable asphalt film thickness.

### **Design Asphalt Content**

- Depends on aggregate gradation (particularly VMA), ability to absorb asphalt, and compaction type and effort. Hveem and Marshall Methods will yield different results for the same mixture.
- Mineral filler greatly affects design asphalt binder content. Too much filler fills the voids, reduces VMA, and has high demand for binder which results in a dry mix. Too little filler results in a wet mix. However very little filler is used in RAC mixes due to limitations on percentage passing the No. 200 sieve size.

### **Mix Design Properties**

#### **Stability**

- Ability to resist shoving and rutting, i.e. permanent deformation.
- Dependent on internal friction of the aggregates (interlock) and the cohesion of the asphalt binder to the aggregate surface.
- Angular aggregate particles with a rough surface texture result in pavements with high stability.

#### **Durability**

- Ability to resist changes in the asphalt (polymerization and oxidation), aggregate disintegration, and stripping of the asphalt film
- Durability can be enhanced by increasing the asphalt binder, and achieving proper compaction

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### Impermeability

- Related to the air void content and the characteristics of the voids (whether they are interconnected, the size of voids, and whether the voids are at the surface). The size of the voids is related to the sizes of the aggregate particles; large stone mixes have larger individual voids.

### Workability

- Workability describes the ease with which the mix can be placed and compacted.
- Harsh mixes (coarse aggregates, few fines) tend to have low workability - RAC-G mixes are not amenable to handwork
- Tender mixes (too much sand or rounded aggregate particles) tend to shove during rolling.
- Temperature of the mix greatly affects workability.

### Flexibility

- Ability to adjust to gradual changes in the subgrade or unequal stresses in overlays across cracks without cracking.
- Open or gap-graded mixes have more flexibility than dense-graded mixes because of higher asphalt rubber binder content and, therefore, are used when resistance to reflective cracking is desired.

### Fatigue Resistance

- Ability to resist repeated bending and deflection under wheel loads
- Low air void content and high asphalt content increase fatigue resistance.
- High viscosity asphalt-rubber binders have been shown to be highly resistant to fatigue cracking

### Skid Resistance

- Measures the ability of the asphalt surface to resist skidding or slipping of vehicle tires. Rough pavement has higher skid resistance than smooth or flushed pavements.

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### Typical Asphalt Paving Failures

#### Edge Failure

- Insufficient thickness, lack of lateral support, base saturated or heavy wheel loads

#### Weathered or Dry Surface

- Insufficient binder content during mix production, loss of binder due to stripping or raveling, overheating, or absorptive aggregates

#### Pot Holes

- Structural failure due to lack of base and/or subgrade support, insufficient pavement thickness, or segregated mix. Water infiltration is generally an important contributing factor.

#### Alligator (Fatigue) Cracking

- Structural failure due to lack of base and/or subgrade support, insufficient pavement thickness, insufficient or aged binder, or water saturation

#### Bleeding and Instability

- Excessive binder content, heavy tack coat, excessive aggregate fines, rounded aggregates, low air void content

#### Raveling

- Lean (low binder content) or overheated mix
- Low density/under compacted

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### Slipping

- High shear stresses, lack of bond with underlying layer due to improper tack coating or inadequate cleaning of existing surface

### Stripping

- Loss of binder, most often due to moisture damage or aggregate surface characteristics.

### Surface Erosion

- Water running or standing on pavement for long periods of time
- Soft aggregates

### Longitudinal or Transverse Cracking

- Reflective cracks from existing pavement - difficult to prevent. Resistance to reflective cracking is one of the primary performance benefits of asphalt-rubber hot mixes.
- Longitudinal cracking usually manifests along paving joints; if located in the wheel paths, it is a precursor to alligator cracking