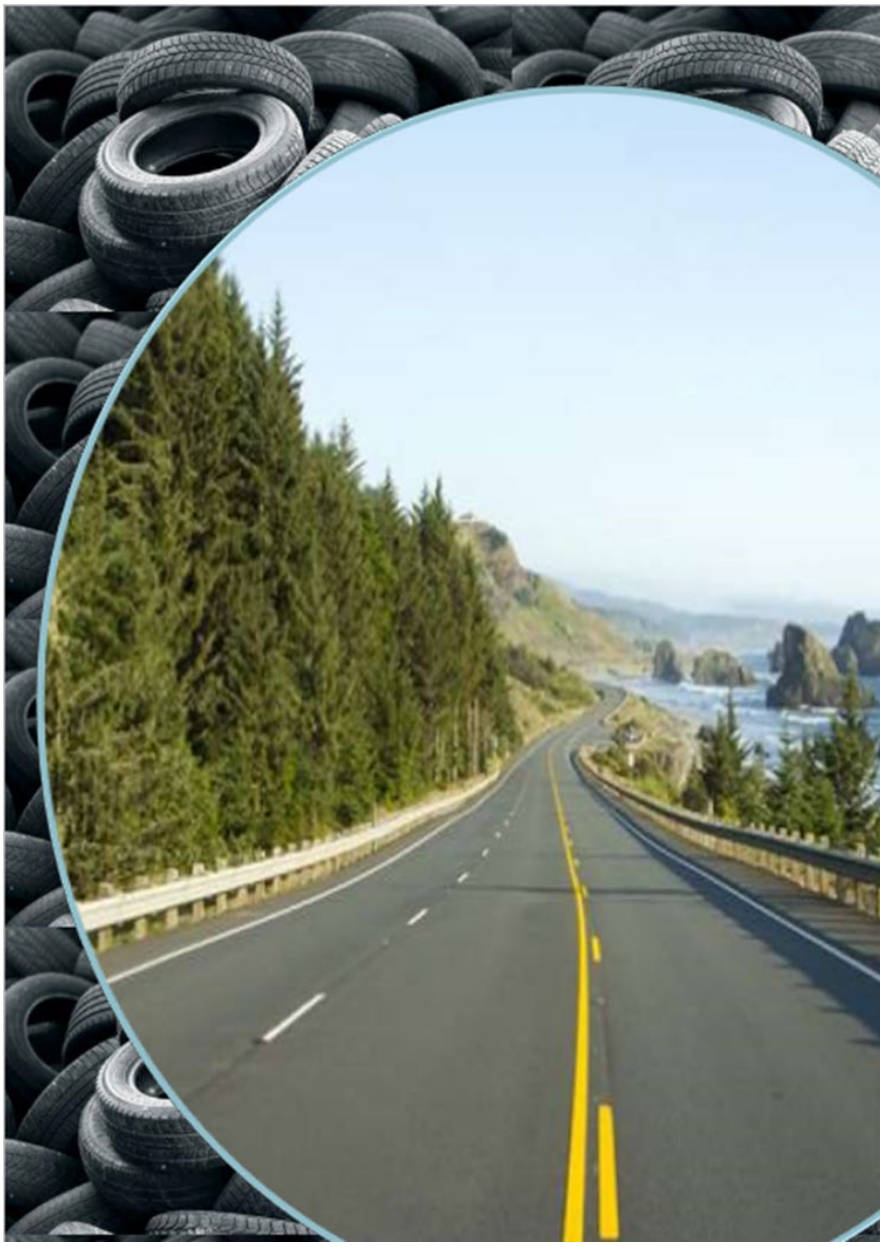
Rubberized Asphalt Concrete

CalRecycle

RAC

RUBBERIZED ASPHALT CONCRETE

A Basic Introduction to RAC Usage



CalRecycle Technology Transfer Series

INDEX

ACRONYMS

Acronym	Definition
ADT	Average daily traffic
APT	Accelerated pavement testing
AR	Asphalt rubber
ARAM	Asphalt rubber aggregate membrane
ARMA-GG	Asphalt rubber hot mix gap-graded (Greenbook)
ARMI	Asphalt rubber membrane interlayer
BBR	Bending Beam Rheometer
CPPC	California Pavement Preservation Center
COC	Certificate of Compliance
CRM	Crumb rubber modifier (modified)
CRUMAC-GG	Crumb rubber-modified asphalt concrete gap-graded (Greenbook)
CTM	California Test Method
DSR	Dynamic Shear Rheometer
HMA	Dense-graded hot mix asphalt
HVS	Heavy vehicle simulator
JMF	Job mix formula
LCCA	Life cycle cost analysis
NIOSH	National Institute for Occupational Safety and Health
PAV	Pressure Aging Vessel
QC	Quality control
RAP	Recycled asphalt pavement
RHMA	Rubberized hot mix asphalt (Caltrans)
RHMA-G	Rubberized hot mix asphalt (gap graded) (Caltrans)
RHMA-O	Rubberized hot mix asphalt (open-graded) (Caltrans)
RHMA-O-HB	Rubberized hot mix asphalt (open-graded high binder) (Caltrans)
RTFO	Rolling Thin-Film Oven
SAM	Stress absorbing membrane
SAMI	Stress-absorbing membrane interlayer
SAMI-R	Rubber-modified SAMI
SBR	Styrene-butadiene rubber
VMA	Voids in mineral aggregate
WMA	Warm mix asphalt

INTRODUCTION

HISTORY OF ASPHALT RUBBER

Development of rubberized asphalt materials for use as joint sealers, patching materials, and membranes began in the late 1930s. In the early 1950s, Lewis and Welborn (1954) conducted an extensive laboratory study to evaluate "The Effect of Various Rubbers on the Properties of Petroleum Asphalts." They used 14 types of rubber powders and three asphalt binders, including "a California asphalt of low-gravity, low-sulfur, low-asphaltenes type." The study looked at a wide range of vulcanized (returns to original shape after loading) and unvulcanized rubber materials including tread from scrap tires, styrene-butadiene rubber (SBR), natural rubber, polybutadiene, and reclaimed (devulcanized) rubber and included both wet and dry methods for adding the rubber to the asphalt mix.

Charles H. McDonald, City of Phoenix, Arizona, worked extensively with asphalt and rubber materials in the 1960s and was instrumental in development of the "wet process" (also called the McDonald process) of producing asphalt rubber. He was the first to routinely use asphalt rubber in hot mix asphalt (HMA) patching and surface treatments for repair and maintenance.

During the 1970s, the use of "large area" asphalt rubber chip seals were used by the City of Phoenix and the Arizona Department of Transportation and development of several asphalt rubber patents. By the late 1980s, use of asphalt rubber binder was included in gap- and open-graded hot mix asphalt mixes. Efforts conducted in the 2000s involved extensive research to quantify performance, environmental impacts, and cost.

Today, asphalt rubber materials have extensive use worldwide in pavement maintenance, preservation, and rehabilitation activities.

CRUMB RUBBER TYPES

Crumb Rubber Modifier

Crumb rubber modifier (CRM) is produced from grinding up whole scrap tires from automobiles, trucks, or buses, tread buffings, and other waste rubber products. A variety of processes and equipment are used to produce a wide range of CRM gradations for use as modifiers in asphalt paving materials (Figure 1).

Caltrans requires CRM to include (Caltrans 2018):

- Ground or granulated crumb rubber
- Consist of 75.0 ± 2.0 percent scrap tire crumb rubber and 25.0 ± 2.0 percent high natural scrap tire crumb rubber by total weight of CRM
- Must be derived from waste tires (Pub Res Code § 42703).

Figure 1. CRM used for wet process.

High Natural Rubber

High natural rubber (high natural CRM) is another type of scrap rubber product that includes 40 to 48% natural rubber or isoprene and a minimum of 50% rubber hydrocarbon according to Caltrans and Southern California Greenbook 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.

ASPHALT RUBBER BINDERS

Asphalt rubber binder components are properly formulated or proportioned to comply with specifications and provide a quality product. The individual components, their proportions, and the blended binder must all meet the applicable specifications. Asphalt rubber binder components include:

- **Crumb rubber**. Asphalt binder includes at least 15% reclaimed tire rubber by weight of total asphalt rubber blend.
- **Asphalt cement (binder).** Defined as “a fluxed or unfluxed asphalt specially prepared as to quality and consistency for direct use in the manufacture of bituminous pavements (ASTM D8).” Asphalt binders come in a variety of grades, designated by the performance grade (PG) binder system. Typically, softer binders are used for rubberized asphalt mixes than for HMA mixes.
- **Additives**. Used in conjunction with the CRM to enhance interaction and produce desirable properties. Typical additives include:
    - Extender oils
    - High natural rubber (HNR)
    - Polymers – typically limited to no agitation
    - Anti-strip agents
    - Warm Mix additives

Table 1. PG Binder by Climate Region

Region	PG Binder
Hot climates	PG 64-16
Moderate climates	PG 58-22
Cold climates	PG 52-28

The interaction between the asphalt binder and the CRM materials is material-specific and depends on:

- Asphalt binder source & grade
- Rubber type & source
- Amount of rubber
- Gradation of rubber
- Interaction time
- Interaction temperature

ASPHALT RUBBER MODIFICATION METHODS

Rubber modification of asphalt mixes is accomplished by two methods: the wet process and the dry process. The dry process involves the addition of crumb rubber to the aggregate prior to mixing with asphalt binder, while the wet process includes adding the crumb rubber to the asphalt binder prior to mixing with the aggregate. While a minor distinction, the selected modification process chosen "greatly affects the interaction between the rubber and asphalt and has a significant effect on the properties of the final product (Schmalzer and Leahy 2014)". The wet process produces a wide variety of CRM binders from high viscosity (field blend) to no agitation (terminal blend) types. Today, the dry process is rarely used. The following provides a brief summary of the wet and dry processes.

Wet Process – High Viscosity

The wet process is a method of modifying the asphalt binder with CRM before incorporating into the asphalt mix or applying it as a chip seal binder. This process requires thorough mixing of the CRM and hot asphalt binder and holding the resulting blend at elevated temperatures for a designated period of time to permit an interaction between the CRM and the asphalt binder.

- Most widely used in Arizona, California, Florida, and Texas
- Typically, contains 18 to 22% crumb rubber
- CRM particle sizes 100% passing #8 to #10 sieve
- Thoroughly mix CRM & other components with hot (400 to 425ºF) asphalt binder
- Interact at 350 to 375ºF for designated period (typical minimums 45 to 60 minutes)
- CRM particles swell, exchange oils with asphalt binder
- Rotational viscosity is primary discriminator
- Binder blend profile
    - Best Practice

- Developed to evaluate compatibility between materials used
- Checks for stability of the blend over time
- Should be required for each project

Remember that the two families of CRM-modified binders, high viscosity and no agitation, are not interchangeable. Neither type should be directly substituted for the other in a hot mix without laboratory testing to determine appropriate adjustments in binder content and possibly aggregate gradation.

Wet Process – No Agitation (Terminal Blend)

Often referred to as terminal blend, the CRM (typically 100% passing #30 sieve or finer) is blended with hot asphalt binder at the refinery or at an asphalt storage and distribution terminal and transported to the HMA plant or job site for use (Figure 2). This type of rubberized asphalt does not require subsequent agitation to keep the CRM particles evenly dispersed in the modified binder.

- Can contain up to 20% crumb rubber
- Particle size typically range from #40 to #80 sieve
- Can also contain polymers
- Typical grade designations include PG-64-28TR, PG70-22TR, PG76-22TR, and MAC-15TR, although the presence of CRM may not be noted in the grade designation; not a “recipe specification”
- Require contractor submittal of Certificate of Compliance (COC)

Figure 2. High viscosity versus no agitation.

Dry Process

Method that includes CRM as a substitute for a portion of the aggregate (typically 1 to 3%) in an asphalt mix, and not as part of the asphalt binder (Figure 3). The CRM acts as a rubber aggregate in the asphalt mix.

- Typically, substitutes CRM for 1 to 3% of aggregate in HMA
- Not considered to modify binder, although some interaction with CRM may occur in place over time (absorbs light fractions)
- CRM gradations have ranged from coarse (1/4-inch) to fine (#80)

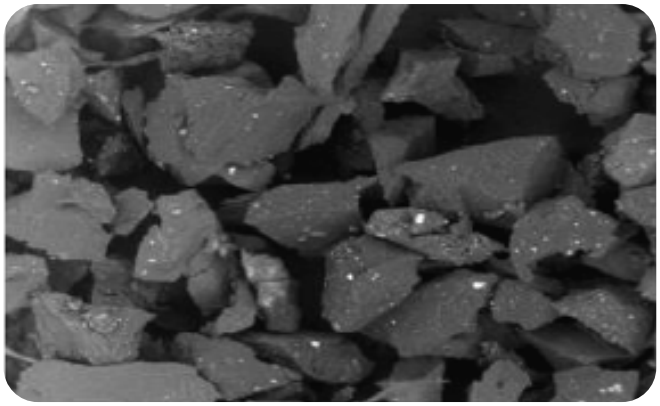


Figure 3. Example of rubber aggregate material (Source: FHWA 2014).

APPLICATIONS

Asphalt rubber has been widely used in:

Spray Applications

- Chip seals
- Asphalt rubber-aggregate membrane (ARAM)
- Stress-absorbing membrane (SAM)

Chip Seals

Chip seals consist of an asphalt binder sprayed on the pavement surface and covered with a thin layer of aggregate (Figure 4 to Figure 7). Terms also include seal coats and bituminous surface treatments; however, these terms may also include other surface treatments such as slurry seals and microsurfacing (not described in this guide). Additional chip seal information includes:

- Used for maintenance or rehabilitation of existing pavements
- Same equipment and general procedures are used for both chip seals and interlayers
- Use with high-viscosity asphalt rubber binders over severely cracked but structurally-sound pavements
- Significantly longer service life than conventional applications, and superior long-term performance in resisting reflective cracking

Figure 4. Spray application of binder.

Figure 5. Applying aggregate.

Figure 6. Rolling to embed aggregate.

Figure 7. Finished chip seal surface.

Interlayers

Typically, a chip seal sandwiched between two HMA layers (Figure 8).

- Stress-absorbing membrane interlayer (SAMI)
- Rubber-modified SAMI (SAMI-R)
- Asphalt rubber membrane interlayer (ARMI)

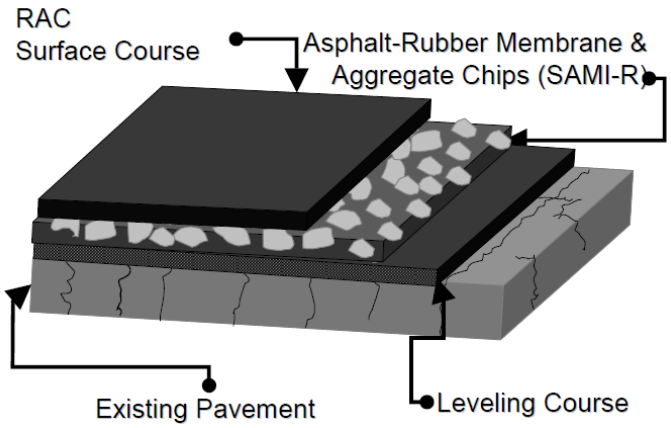


Figure 8. Asphalt rubber interlayers.

HMA Applications

- Gap-graded mixes
    - Proven to be a very effective use of high viscosity asphalt rubber binders
    - Most widely used asphalt rubber product in California
    - Structural application
    - Caltrans often specifies thickness of 1.2 to 2.4 inches
    - Thickness reduction allowed by the Caltrans empirical pavement design method for resistance to reflective cracking when used as an overlay

- Open-graded mixes
    - Widely used in California as surface course
    - Free draining with reduced splash and spray
    - Not considered to add any structural value
    - Provides good surface friction
- Open-graded high-binder mixes
    - Widely used in Arizona as surface course
    - Also used by Caltrans as surface course
    - Not as free draining, but improved durability
- Dense-graded mixes - only with no agitation binders
    - Structural application
    - Inadequate void space to accommodate sufficient asphalt rubber binder to modify behavior
    - Discontinued use with high viscosity binder, but suitable for use with terminal blends

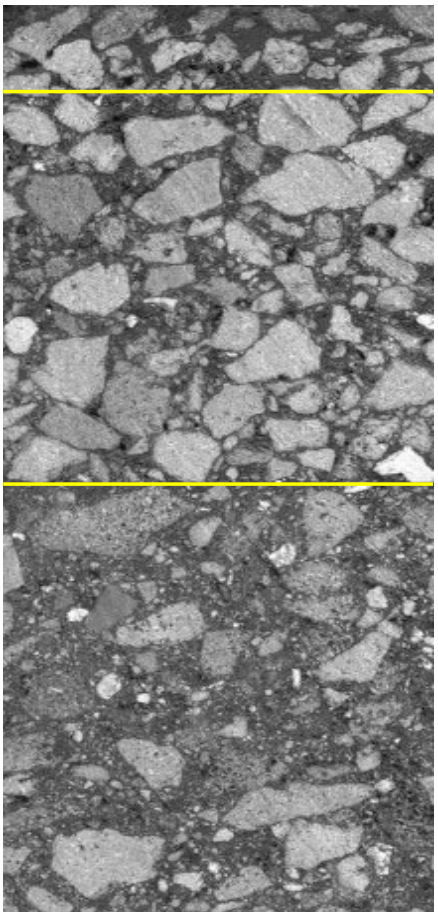


Figure 9. Asphalt rubber mix applications (top layer: open-graded surface course, middle layer: dense-graded mix, and bottom layer: asphalt base) (Source: Way 2012).

GUIDELINES AND SPECIFICATIONS

Guidelines and specifications are readily available and include:

- Caltrans, Asphalt Rubber Usage Guide (Figure 10)
- Caltrans, Standard Specifications
- “Greenbook,” Standard Specifications for Public Works Construction (Figure 11)

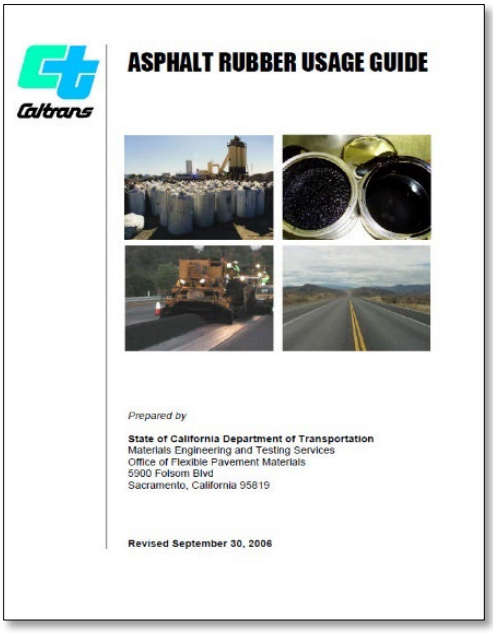


Figure 10. Caltrans Asphalt Rubber Usage Guide.

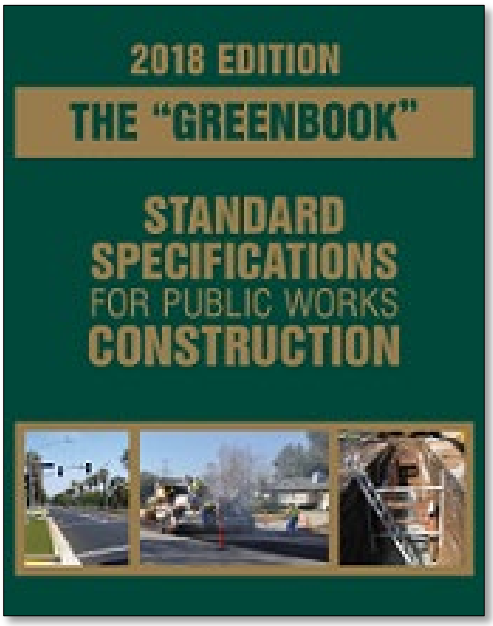


Figure 11. Public Works Standards Greenbook.

Publication Guide Resources

While the information contained in the following resources is geared toward HMA construction, the same principles apply to RHMA.

- Public Works Inspectors Manual, BNI Building News
- Principles of Construction of Hot-Mix Asphalt Pavements, Asphalt Institute, Manual Series Number 22
- Hot-Mix Paving Handbook 2000, AASHTO, FAA, FHWA, NAPA, USACE, APWA, and NACE. Available through National Asphalt Pavement Association
- National Highway Institute (NHI) Hot Mix Asphalt Construction Course

CALTRANS EXPERIENCE

Caltrans has conducted several studies to evaluate asphalt rubber mixtures (e.g., Van Kirk 1989, Shatnawi and Long 2000, Harvey and Bejarano 2001, Cook et al., 2007). The following highlights the results of several studies:

Ravendale Project

The Ravendale project was constructed in 1983 and significantly changed Caltrans use of asphalt rubber. Key details of this project include:

- First California project to use reduced thickness for rubberized HMA (RHMA) compared to conventional dense-graded HMA
- Test sections to evaluate different thicknesses of RHMA and dry process, rubberized asphalt with a SAMI, HMA, and single and double asphalt rubber chip seals
- Performance monitored for nearly 20 years:
    - The dry process section lasted 19 years prior to being overlaid
    - After 5 years, the thin rubberized asphalt sections were performing better than the thicker conventional dense-graded HMA
- Caltrans constructed additional projects to study the performance of reduced thickness asphalt rubber mixes

Reduced Thickness Design

- Interim guidelines developed in 1992
- Currently included in Caltrans *Highway Design Manual*
- Based on laboratory and long-term field data (two decades)
- Supported by research efforts
- Used a deflection-based design method
- Up to 50% reduction in thickness compared to conventional design thickness, where the overlay intent is to retard reflection cracking
- Over 200 reduced thickness projects

1992 Heavy Vehicle Simulator

- Research project conducted in cooperation with the South African Council on Scientific and Industrial Research, University of California Berkeley, and

Dynatest Consulting to verify the reduced thickness theory for asphalt rubber pavements
- The research used accelerated pavement testing (APT) using the heavy vehicle simulator (HVS)
- The research included laboratory testing to support the field testing

Life Cycle Cost Analysis

A life cycle cost analysis (LCCA) of asphalt rubber versus conventional HMA was conducted by the California Pavement Preservation Center (CP2) and found that asphalt rubber overlays are more cost effective in all areas of California (CP2 2012). The study was based on the conservative assumption that a conventional HMA overlay has a life expectancy of 5 years, whereas an asphalt rubber overlay has a life expectancy of 6 years. The study found that cost savings by using asphalt rubber were greatest in the Southern California and Sacramento areas, due to lower price premium for asphalt rubber. Cost savings were also higher for larger projects, and for highways with higher traffic volumes (such as interstates) due to lower user-delay costs. An updated LCCA study was conducted by the CPPC in 2015 and indicated that Caltrans could save about 21% by using asphalt rubber, and the use of asphalt rubber is cost effective over 84% of the time (CP2 2015).

BENEFITS

Pavement Performance

- Replaces conventional mixes where paving temperatures and haul distances are favorable
- Allows higher binder content and increased film thickness, resulting in increased durability (moisture resistance and aging resistance)
- Increases resistance to fatigue and reflection cracking
- Improves aggregate retention
- Minimizes drain-down problems compared to other high-binder mixes such as stone matrix asphalt.
- Increases resistance to bleeding, flushing, and deformation
- Can be used in reduced thickness
- Lower life-cycle costs
- Environmental benefits – recycling tires (Figure 12)

Figure 12. Waste tire pile.

Environmental

- Reduces landfill capacity and tire flotation problems
- Reduces used tire stockpiles
- Value-added products
- Recycling of wastes
- Noise abatement
- Linear tire fill

Air Quality

Several stack emissions and worker exposure studies have been performed throughout the U.S. that have not indicated any increased risk due to CRM-related emissions.

Health & Safety

Numerous studies indicate no increased risk regarding the potential health effects of CRM asphalt compared to conventional asphalt binder. National Institute for Occupational Safety and Health (NIOSH) studies showed that the various exposure measurements evaluated for both HMA and CRM asphalt mixes were below the NIOSH recommended exposure limits.

COST

A study conducted by Hicks and Epps compared the LCCA of asphalt pavements containing conventional and asphalt rubber binders. The LCCA was conducted using information obtained from the Arizona, California, and Texas Departments of Transportation. Study conclusions include:

- For the scenarios evaluated (HMA, conventional friction course, asphalt rubber gap-graded, asphalt rubber open-graded, asphalt rubber friction course,

conventional chip seal, polymer modified chip seal, and AR chip seal), asphalt rubber is a cost-effective alternative
- Considering input variability (e.g., cost, expected life), asphalt rubber alternates would be the best choice of the applications considered
- The cost-effectiveness of asphalt rubber is dependent on the ability to reduce the layer thickness; without a thickness reduction or longer life with equivalent thickness, asphalt rubber alternatives would not be cost effective

CONSIDERATIONS

Use the right tool:

- Increased initial costs must be offset by improved performance
- Not amenable to raking
- Higher temperatures for placement and compaction
- Knowledge of users and good HMA practices

MIX TYPE SELECTION AND USE

Scrap tire and other waste rubber products are used to improve the durability and performance of asphalt paving materials. Rubber modification provides increased resistance to rutting, fatigue and reflective cracking and improved durability due to improved binder properties and increased binder content. The designer specifies the type(s) of mixture(s) to be used in the respective layers of the asphalt pavement structure.

Rubber modification can be a valuable tool when its use is driven by sound engineering principles and the materials are properly selected and applied for the intended uses. To help in selecting the best approach to solving specific pavement needs in your jurisdiction, the following discusses appropriate applications by mix type.

ASPHALT RUBBER HOT MIX

High-viscosity asphalt rubber binders have a thick consistency that allows significant increases in the mix binder content (up to 2% by total mix weight) compared to HMA mixes with similar aggregate gradations. The high-viscosity asphalt rubber binder also minimizes the potential for binder drain down. The high binder content is a primary cause of the documented performance benefit of RHMA (improved resistance to permanent deformation, fatigue and reflective cracking, aging, environmental damage, and durability). However, to capitalize on this feature, the aggregate matrix or skeleton must provide sufficient void space to accommodate the CRM particles and quantity of high-viscosity binder to modify mix behavior. Gap and open aggregate gradations are used to provide the necessary void space. HMA made with high-viscosity asphalt rubber binders are relatively low-modulus materials compared to HMA. They perform based on flexibility and resistance to permanent deformation by elastic recovery rather than stiffness. How well RHMA mixes perform is a function of how much asphalt rubber binder is included.

Figure 13 illustrates the aggregate gradation of dense-, gap-, and open-graded mixes. The figure illustrates the gradation target value ranges for Caltrans 1/2-inch mixes to illustrate the differences in mix gradation. The sieve size openings on the plot have been raised to the 0.45 power. A straight line between the #200 sieve and the nominal maximum aggregate size on a 0.45 power plot indicates that a gradation is near maximum density and minimum porosity. The Caltrans dense-graded mix follows the maximum density line closely, whereas both the gap-graded and open-graded mixes dip below the maximum density line.

Wet-process no-agitation binders may also be highly modified materials, but viscosity remains below the 1,500 cPs threshold that sets apart the behavior of high-viscosity asphalt rubber binders. The amount of no-agitation binder that a mixture will retain may be as much as 0.5% more than the corresponding conventional asphalt cement content for a gap- or open-graded mixture, but significantly less than the amount of high-viscosity binder that can be accommodated. Mixes made with no-agitation binders generally behave much like corresponding conventional HMA.

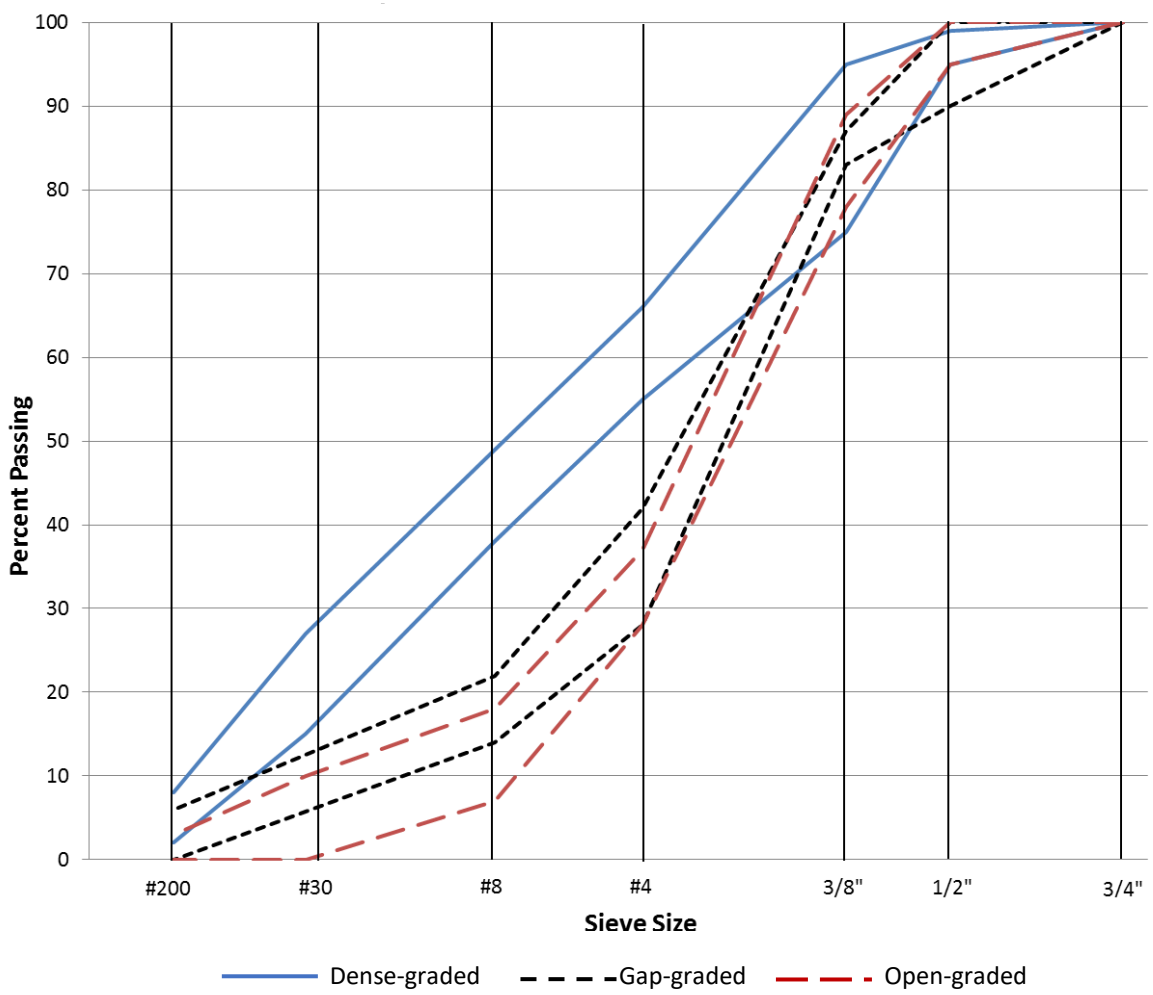


Figure 13. Caltrans ½-inch mixes – sieve sizes raised to 0.45 power.

Dense-Graded Mixes

Dense-graded HMA is not appropriate for use with high viscosity binders because there is not enough void space available (Figure 14). However, dense gradations are well suited for use with no-agitation binders, such as Greenbook MAC-15TR, and should provide similar structural capacity to HMA.

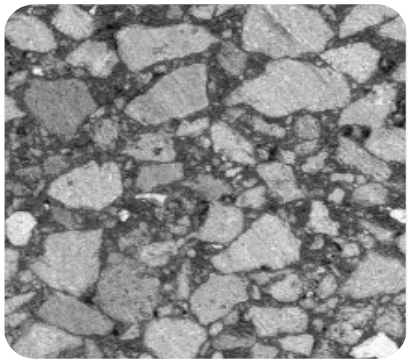


Figure 14. Dense-graded aggregate structure.

Gap-Graded Mixes

Gap-graded mixes have proven to be a very effective use of high-viscosity asphalt-rubber binders, and some use with non-agitated asphalt rubber blends. They are reportedly the most widely used asphalt rubber product in California. Caltrans calls this type of mix rubberized hot mix asphalt (gap graded) (RHMA-G). The Greenbook calls it asphalt rubber hot mix gap-graded (ARHM-GG). For simplicity, RHMA-G will be used in this guide to refer to both the Caltrans and Greenbook asphalt rubber gap-graded mixes. The aggregate structure of gap-graded mixes is shown in Figure 15.

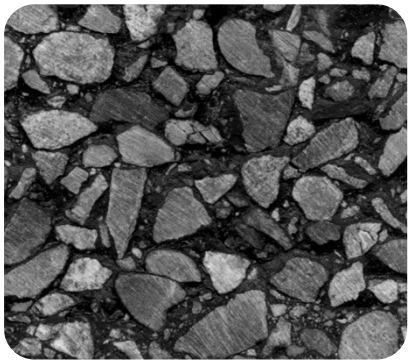


Figure 15. Gap-graded aggregate structure.

RHMA-G mixes provide a durable, flexible pavement surface with increased resistance to reflective cracking, rutting and oxidation, good surface friction characteristics due to the texture provided by the aggregate gradation, and often reduced traffic noise. Minimum requirements for 18% voids in mineral aggregates (VMA) provide space to accommodate enough high-viscosity binder, with binder content requirements ranging from 7.5 to 8.7% by weight of dry aggregate depending on mix class (Greenbook 2018). The 2018 Caltrans Standard Specifications requires the asphalt rubber binder content to be within -0.40 to +0.50 of the job mix formula (JMF).

The RHMA-G acts as a structural layer in the pavement and is most effective at compacted thicknesses ranging from 1.2 to 2.4 inches according to structural analysis and modeling. This supports and corresponds to practice based on empirical experience and economic considerations.

Appropriate uses for RHMA-G include overlays of existing pavements or new construction for a wide range of traffic volumes and loadings. RHMA-G can be used in urban areas where there is considerable stop-and-go traffic for which open-graded mixes would not be suitable. Such areas include numerous signalized intersections and driveways. However, RHMA-G mixtures are not recommended for parking areas as the surface of these low-modulus mixes are likely to scuff when subjected to simultaneous low speed braking and turning movements that are typical in such areas.

Dry-process asphalt rubber mixes are typically gap-graded to provide sufficient space in the aggregate matrix for the CRM particles. The asphalt cement is not considered to be modified by the dry process, although there may be some limited interaction of the CRM with the asphalt cement during mixing at the HMA plant, silo storage, hauling, placement and compaction. However, there are indications that some level of

interaction may continue after construction is completed, which may have pronounced effects on mix design and subsequent pavement performance. Use of the Hveem mix design method, with its extended curing period, should generally account for most of the long-term asphalt absorption by the CRM particles and allow selection of appropriate target asphalt content. If long term aging and absorption are not considered in the mix design procedure, early raveling of the resulting pavement may occur. Care must also 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.

Performance of gap-graded dry-process mixes has been mixed, and overall appears to be more variable than performance of wet-process mixes. Some dry process mixes have performed well for many years.

Failure to account for asphalt absorption by the CRM may have been a contributing factor to several early failures of dry-process mixes.

Open-Graded Mixes

Open-graded mixes have also proven to be a very effective use of high viscosity asphalt rubber binders, and some use of non-agitated blends, although they have been used more extensively in Arizona. Caltrans has specifications for “rubberized hot mix asphalt (open-graded) (RHMA-O)” and “rubberized hot mix asphalt (open-graded high binder) (RHMA-O-HB).” The Greenbook has no equivalent open-graded asphalt mix.

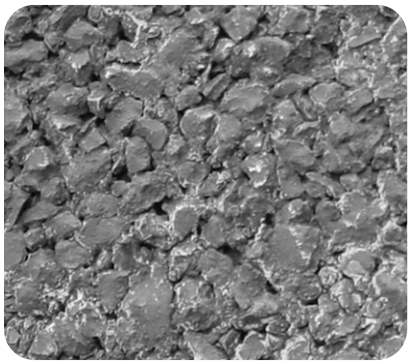


Figure 16. Open-graded aggregate structure.

Open-graded mixes are placed as thin surface layers typically 1 to 1.2 inches thick. They are not considered structural elements; therefore, a thickness reduction is not applied. RHMA-O and RHMA-O-HB provide a durable, highly flexible pavement surface with enhanced drainage and frictional characteristics that reduces splash and spray and hydroplaning in wet conditions. These mixes are also highly resistant to reflection cracking at joints and cracks in concrete pavements and severe cracking in underlying HMA pavements.

RHMA-O mixes provide good surface-friction characteristics and are intended to be free-draining so that surface water can quickly travel through the mat to drain out along the edges of the pavement structure. This reduces splash, spray, and hydroplaning during and immediately after rains and thus improves safety. RHMA-O friction courses

use highly modified binders to address performance and durability issues of conventional open-graded asphalt mixes. Asphalt rubber binder content is determined according to California Test 368.

Caltrans also allows the use of RHMA-O with higher asphalt rubber binder contents (RHMA-O-HB). Extensive experience in Arizona has shown that asphalt- rubber binder contents can be increased to 10 percent or more by mass of dry aggregate without excessive drain-down because of the high viscosity of the asphalt rubber binder. Such rich open-graded mixtures have generally provided excellent performance in a variety of climate zones in Arizona, where they are placed at nominal thickness of ½-inch over asphalt concrete pavements and 1-inch thick over concrete pavements. Although the high-binder-content mixes are not as free-draining as RHMA-O, the thicker film coating of the asphalt rubber binder provides improved resistance to fatigue and reflective cracking, as well as to stripping and oxidative aging. These factors increase the durability of open-graded pavements.

RHMA-O and RHMA-O-HB are appropriate for use as a surface course for overlay or new construction for roadways where traffic flow is essentially uninterrupted by signalization, such as some freeways, rural, and secondary highways. These mixes are highly effective as an overlay of concrete and HMA pavements in locations where potential for reflective and fatigue cracking is severe, and effectiveness increases with increased binder content. They may also be used as a maintenance blanket to restore surface frictional characteristics and to help preserve the underlying pavement. Both types of mixes can provide a smooth, quiet ride. Open-graded asphalt rubber mixes may be considered as an alternative to a chip seal, since they are less sensitive to construction operations and essentially eliminate threat of windshield breakage Open-graded mixes should not be used where there is a significant amount of stop and go traffic or turning vehicles, such as city streets or in parking lots, because the porous pavement is susceptible to damage from leaking vehicle fluids and scuffing from simultaneous low speed braking and turning movements.

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ASPHALT RUBBER SPRAY APPLICATIONS

Asphalt rubber spray applications may be used as surface treatments or interlayers. Such applications are usually used for maintenance or rehabilitation of existing pavements and are very effective at resisting reflective cracking. High-viscosity binders seem to provide greater benefits for spray applications than no-agitation binders. The asphalt rubber binder design and materials submittals requirements, including test results that verify compliance with asphalt rubber binder physical property specifications, are typically the same as for HMA. However, coarser CRM gradations may be used in binders for spray applications if the distributor nozzles are of sufficient size.

Chip Seal

Chip seals are a type of surface treatment that Caltrans calls “asphalt rubber binder chip seal” and the Greenbook refers to as “asphalt rubber aggregate membrane (ARAM)”. Asphalt rubber chip seals provide a flexible, waterproof, skid-resistant, and durable surface that resists oxidation and is highly resistant to reflective cracking. Asphalt rubber chip seals provide the same benefits as conventional chip seals, but also provide the additional advantages of significantly longer service life than conventional chip seals, and superior long-term performance in resisting reflective cracking.

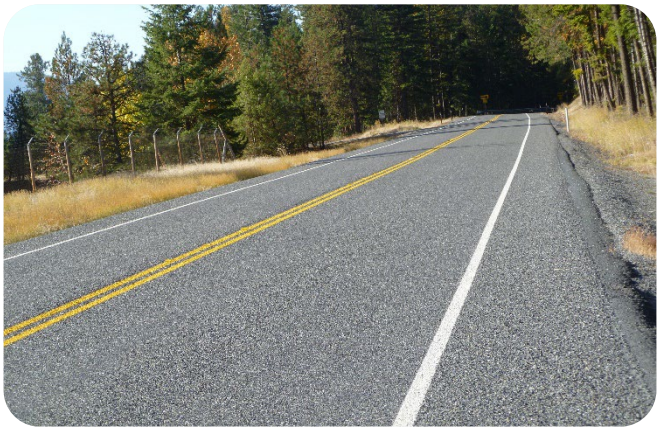

Figure 17. Chip sealed roadway.

Caltrans uses chip seals for preventative and major maintenance to correct surface deficiencies, seal raveled pavement surfaces, seal and protect the pavement structure against intrusion of surface water, and to protect the pavement surface from oxidation. Chip seals do not make any structural contribution nor correct ride roughness problems. However, where traffic volumes allow, some agencies use them as an alternate to conventional open-graded mixes to restore surface frictional characteristics. In areas where traffic is heavy or fast, lightweight aggregates may be substituted to minimize windshield breakage by loose chips. The Caltrans Maintenance Manual, Volume 1 (2014) includes criteria for use of chip seals and cover aggregate size based on speed limits and average daily traffic.

Figure 18. Pull test of chip seal aggregate and asphalt rubber binder.

Chip seals have been used to restore some serviceability to functionally failed (aged and badly cracked) pavements with relatively sound structural capacity until rehabilitation can be performed. However, they are too thin to improve ride, and the aggregate surface may be somewhat noisy and rough to ride on. Appearance may also be an issue, although use of hot pre-coated chips and flush coat may improve appearance as well as durability. Noise and roughness generated are related to aggregate particle size. Larger cover aggregate is noisier and presents a rougher surface appearance.

All chip seals are very sensitive to construction operations and site environmental conditions. With hot-applied seals, the thin binder membrane cools very quickly regardless of its composition. Aggregate embedment and adhesion must be accomplished while the membrane is still hot. Although some references indicate that asphalt rubber seals can be applied at colder temperatures than emulsion seals due to use of hot precoated chips, it is not advisable to place them when the ambient temperature is less than 60ºF. The potential for problems with embedment and adhesion will increase as ambient and surface temperatures decrease.

Cape Seal

Cape Seal is a double surface treatment, consisting of an asphalt rubber chip seal covered with a slurry seal. Conventional slurry seals are typically used, but a rubberized slurry could be substituted. The purpose is the same as for a chip seal; to cover up cracked and aged pavements, minimize further infiltration of surface water, and restore surface friction. The slurry seal surface is quieter than chip seal surface and provides a smooth, uniform, and attractive appearance. Cape seals are most often used on residential streets, or in parking areas for office developments, to enhance appearance of the pavements and reduce tire noise.

Interlayers

Asphalt rubber interlayers, referred to as stress absorbing membrane interlayer (SAMI) or ARAM interlayer, are simply an asphalt rubber chip seal that is overlaid with HMA or RHMA. Interlayers are used under corrective-maintenance overlays and as a pavement rehabilitation tool but would not be included in new construction. The interlayer material is very flexible and elastic and has a low modulus; it flexes and creeps to relieve stresses and to seal cracks. Interlayers act to interrupt crack propagation and have been shown to be highly effective in minimizing reflective cracking in overlays of existing distressed asphalt and jointed concrete pavements. The membrane also provides a seal that minimizes infiltration of surface water through the pavement structure. In cases where reflective cracking is expected to be the primary distress mode and structural capacity is deemed sufficient; interlayers may be used to reduce the required thickness of the overlay.

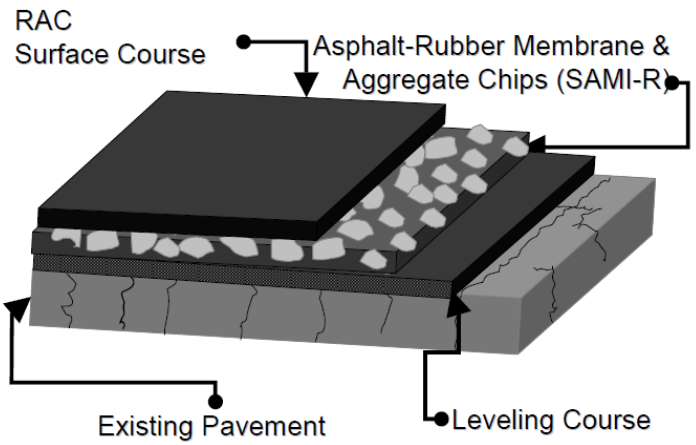

Figure 19. Asphalt rubber interlayers.

Interlayers may be applied to any type of concrete or asphalt pavement and have proved very effective at minimizing reflection of concrete pavement joints. However, as stated in the Caltrans Maintenance Manual, if the surface irregularities (rutting in HMA or faulting of concrete pavements) exceeds 1/2-inch requires either a leveling course or diamond grinding, and crack filling prior to placing the interlayer.

Chip retention is not an issue unless the interlayer will be opened to traffic prior to placement of the overlay. The aggregate chips are keyed into the overlay during compaction and prevent formation of a slippage plane along the relatively thick asphalt rubber membrane. No fog seal or sand should be applied over an interlayer because it could interfere with bonding of the overlay.

Use of chip seals, interlayers, and multiple layer strategies may provide an economic alternative to costly overlays.

MAINTENANCE

Asphalt rubber materials are used for pavement preservation and maintenance purposes. Caltrans primarily uses thin RHMA overlays (possibly over a SAMI) as maintenance blankets and uses single chip seals to restore surface friction. Either gap- or open-graded asphalt rubber overlays may be used, depending on traffic, adequacy of the existing pavement structure, and other site conditions.

RHMA is rarely used for patching unless local plants are manufacturing the mix for concurrent paving projects. It is too expensive to operate an asphalt rubber blender unit for routine repairs, and the demanding placement characteristics makes effective patch construction with RHMA challenging.

Another aspect is maintenance of asphalt rubber pavements and surface treatments. Typical operations include patching and fog sealing, although the period of time between maintenance treatments is expected to be longer than for HMA.

Open-graded mixes should not be used as a patching material, since they will allow the infiltration of surface water. If suitable RHMA is not available, as is usually the case,

polymer-modified or HMA mixes may be used. Good practices for patching HMA also applies to patching RHMA.

Fog sealing is typically used for preservation and may also be applied to RHMA, although the frequency of application would be expected to be decreased. RHMA mixes that were not adequately compacted may require fog sealing more frequently than expected to protect against moisture and other environmental damage. Fog seal application rates should be governed by the condition of the pavement surface. Rich RHMA mixes may only need light fog applications.

Summary

Table 2 provides a summary of mix and material type applications.

Table 2. Asphalt Rubber Mix and Material Applications

Mix/Material Type	Application	Not Appropriate
Dense-graded RHMA w/high viscosity binders	None	All applications
Dense-graded RHMA w/no-agitation binders	Structural layer	None
Gap-graded RHMA	Structural layer (≤ 2.4-inch thickness) Resistant to reflective cracking, rutting and oxidation Reduce tire pavement noise	Parking areas
Open-graded RHMA	Restore surface friction Reduce tire pavement noise Reduce splash, and spray Resist reflective cracking	Structural layer Intersection locations
Chip Seal	Same as conventional chip seal w/longer service life	Same as conventional chip seal
Cape Seal	Same as conventional cape seal	Same as conventional chip seal
Interlayer	Minimize reflective cracking in overlay of asphalt and concrete pavements	New construction Rutting or faulting > 0.5-inch, place leveling course or diamond grind, and crack filling prior to interlayer

DESIGN AND SPECIFICATION

Pavement design has two aspects. The first is structural design, to determine layer thickness needed to support the anticipated traffic loadings and climate conditions over the design period, and the types of materials to be used in each layer of the pavement structure. The second aspect is volumetric mix design, which is a family of laboratory procedures used to determine the appropriate “recipe”, i.e., composite aggregate gradation and binder content of a specific asphalt mixture. Mix designs are developed based on volumetric analysis of mixture specimens fabricated with the designated component materials at a range of binder contents.

There are some differences when CRMs are included, but the fundamental concepts are essentially the same as HMA materials.

STRUCTURAL DESIGN

Approach to structural design depends on the intended purpose for the asphalt rubber pavement, which may include preservation, maintenance, rehabilitation, or new construction as follows.

Maintenance and Preservation

Thin overlays restore ride and surface friction, reduce noise, and provide a pleasing appearance and long-lasting contrast with pavement markings. Such overlays may be gap-graded or open-graded. Gap-graded RHMA mixes act as a structural layer in the pavement and are most effective at compacted thicknesses ranging from 1.2 to 2.4 inches according to structural analysis and modeling. This supports and corresponds to current Caltrans practice based on empirical experience and economic considerations. No structural credit is allowed for open-graded mixes, but these have served very effectively as thin maintenance and/or preservation overlays in Arizona (Figure 20). If ride and structure are satisfactory and traffic conditions allow, an asphalt rubber chip seal may be applied in lieu of a thin overlay. However, chip seal surfaces are generally noisier than HMA, and noise considerations may influence strategy selection.

Figure 20. Asphalt rubber interlayers.

Rehabilitation

For structurally-sound pavements for which resistance to reflective cracking governs overlay thickness design, RHMA-G can provide performance equivalent to an HMA overlay at one-half the required overlay thickness. Where cracking in the existing pavement is severe, a SAMI-R or ARAM interlayer may be applied as a crack interruption layer prior to overlaying. In such cases, Caltrans allows a small structural credit for the effectiveness of SAMI-R at reducing crack reflection, although other agencies do not. If more than 2.4 inches of additional structure is required, a layer of dense-graded asphalt concrete should be placed prior to the RHMA-G overlay.

New Construction

A RHMA-G surface course may be used as a substitute for an equal thickness of HMA and may be used as a structural mix. Open-graded mixes are not allowed a structural credit and should not be substituted for structural layers but may be placed as a surface course over HMA or RHMA. RHMA surface mixes provide smooth, quiet ride, pleasing appearance, and long-lasting contrast with pavement markings, which makes this strategy appealing for use in residential areas. However, due to cost considerations, RHMA thickness for such an application would typically be limited to a maximum of 1.5 inches.

Structural design may be performed using methods such as Caltrans, AASHTO, or PAVExpress (Figure 21 to Figure 23). Caltrans research indicates that RHMA-G mixes have a gravel factor similar to HMA, which indicates similar structural capacity despite the relatively low modulus of RHMA materials, which corresponds to experience and successful practice in Arizona and Texas. However, structural models indicate that RHMA-G mixes are most effective in the upper layer of the pavement structure while

use at lower levels provides no added benefit. Since RHMA mixes are more expensive than HMA, they should be used where it provides the greatest benefit.

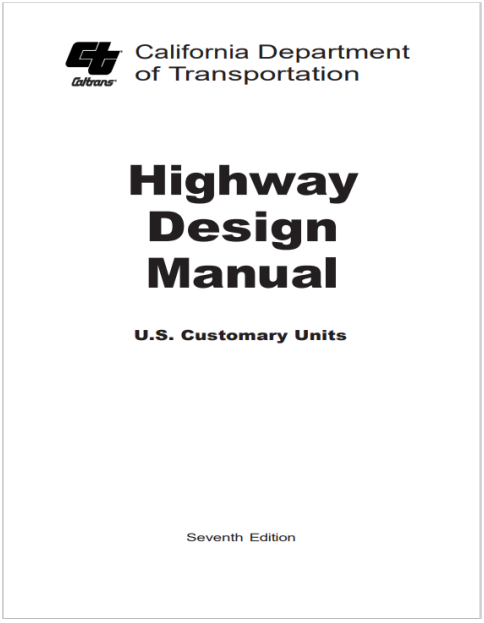

Figure 21. Caltrans Highway Design Manual.

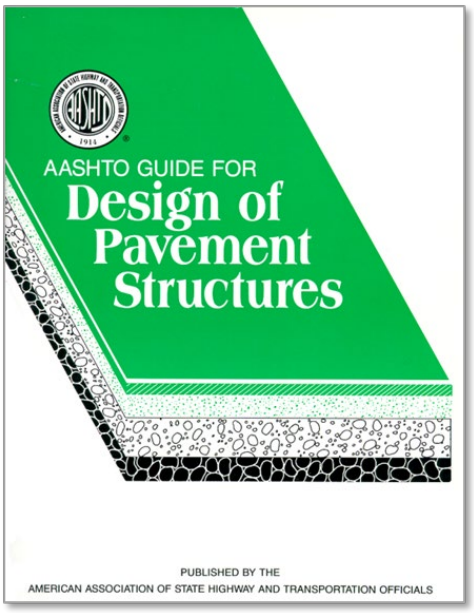

Figure 22. AASHTO Design of Pavement Structures.

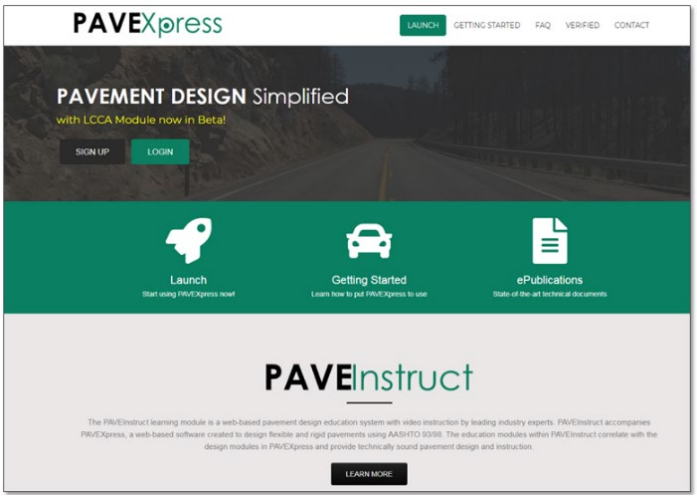

Figure 23. PAVExpress.

The use of the half-thickness equivalence for superior resistance of RHMA overlays to reflective cracking has caused some confusion regarding selection of layer coefficients in the AASHTO design method. Do not use higher layer coefficients for RHMA-G materials than for HMA. The appropriate approach is to determine the needed thickness for a HMA overlay and whether to apply a RHMA thickness reduction for reflective crack resistance. If the pavement section is new construction, no thickness reductions should be applied to the RHMA-G layer. As noted for rehabilitation activities, if more than 2.4 inches of RHMA-G is required to provide the required pavement structure, make up the difference with a layer of HMA. Some trade-offs between thicknesses of individual RHMA-G and HMA layers may be required for purposes of constructability.

CRUMB RUBBER MODIFIER COMPOSITION

Both Caltrans and Greenbook specifications include requirements for the composition of CRM. Caltrans requires CRM sources to be included on the Authorized Materials list, while the Greenbook specifies both the CRM chemical (also required by Caltrans for asphalt rubber chip seals and interlayers) and gradation requirements (Table 3 and Table 4).

Table 3. CRM Chemical Requirements (Greenbook 2018)

Test	Test Method	Scrap Tire	High Natural
Acetone extract, %	ASTM D297	6.0 to16.0	4.0 to 16.0
Ash content, %	ASTM D297	≤ 8.0	N/A
Carbon black content, %	ASTM D297	28.0 to 38.0	N/A
Rubber hydrocarbon, %	ASTM D297	42.0 to 65.0	> 50.0
Natural rubber content, %	ASTM D297	22.0 to 39.0	40.0 to 48.0

Table 4. CRM Gradation Requirements (Greenbook 2018)

Sieve Size	Percent Passing Scrap Tire	Percent Passing High Natural
#8	100	100
#10	98 to 100	100
#16	45 to 75	95 to 100
#30	2 to 20	35 to 85
#50	0 to 6	10 to 30
#100	0 to 2	0 to 4
#200	N/A	0 to 1

Both specifications require the CRM to be ground or granulated combination of scrap tire crumb rubber (75 ± 2.0 percent by total weight of CRM) and high natural scrap tire crumb rubber (25 ± 2.0 percent by total weight of CRM). Caltrans specifications also indicate that the crumb rubber must be derived from waste tires (see California Public Resources Code §42703 for details).

BINDER DESIGN

High viscosity asphalt rubber binders must be properly formulated or proportioned to comply with specifications and to provide a quality product. Individual components that comply with specifications may be combined and interacted in proportions that also fully comply but may yield a binder that is not usable. The interaction between asphalt and CRM materials is material-specific and depends on:

- Asphalt cement source and grade
- Rubber type
- Rubber source
- Amount of rubber
- Gradation of rubber
- Interaction time
- Interaction temperature

An appropriate asphalt rubber binder design must be developed using the designated sources and grades of asphalt, asphalt modifier (if used), and CRM materials (scrap tire, high natural) that will be used for the subject project(s). The binder design should include testing to develop and present a design profile of each specification property value measured from samples taken at intervals over a 24-hour interaction period. The profile should include, at a minimum, results after an initial interaction period of 45 minutes, 4 hours later, and simulated overnight cool down by reducing oven temperature to 275ºF for a period of 14 hours starting at 6 hours after CRM addition to 22 hours after CRM addition. After the cool down, the binder should be reheated to the appropriate temperature for viscosity testing after the 24-hour interaction is completed. Viscosity should also be measured and recorded at 2 and 3 hours after addition of the CRM to identify the expected trends for field production. The design profile must identify

the specific component materials (source or supplier and grade) and proportions thereof used in the design.

Gradation of the individual CRM components shall also be included for information. If any of the components are changed, the design profile would no longer apply.

The design profile indicates the compatibility of the components and the quality and stability of the resulting asphalt rubber binder properties. Viscosity and resilience are the most meaningful indicators of performance and are expected to vary as the asphalt rubber interaction proceeds. Viscosity should remain above the minimum 1,500 centipoise (cPs) value throughout the interaction and should not manifest drastic drops. There is no maximum value for resilience; high resilience typically indicates that the binder should perform well. Table 5 summarizes the Caltrans design profile.

Table 5. Asphalt Rubber Binder Design Profile (Caltrans 2018, Greenbook 2018)

Test	45 min	60 min	90 min	120 min	240 min	360 min	1,440 min	Limit*
Viscosity, cP (ASTM D7741)	X	X	X	X	X	X	X	1,500 to 4,000
Resilience at 25°C, (min, % Rebound) (ASTM D5329)	X	–	–	–	X	–	X	18
Field Softening Point, °C (ASTM D36)	X	–	–	–	X	–	X	52 to 74
Cone Penetrometer, at 25°C 0.1 mm (ASTM D217)	X	–	–	–	X	–	X	25 to 70

*Six hours (360 minutes) after CRM addition, reduce the oven temperature to 275 °F for 16 hours. After the 16-hour (960 minutes) cool down after CRM addition, reheat the binder to the reaction temperature expected during production for sampling and testing at 24 hours (1,440 minutes).
For agencies using Greenbook, see Section 211-4. X denotes required testing.

Submittal of the high viscosity binder design profile should be required for both RHMA and asphalt rubber spray applications. Physical property requirements for the asphalt modifier, crumb rubber, and asphalt rubber binder are shown in Table 6 through Table 8, respectively.

Table 6. Physical Properties Requirements – Asphalt Modifier (Caltrans 2018, Greenbook 2018)

Test Parameter	Test Method	Requirement
Viscosity, @ 100°C, $m^2/s \times 10^{-6}$	ASTM D445	X ± 3*
Flash point, °C	ASTM D92	207 min
Asphaltenes, % mass	ASTM D2007	0.1 max
Aromatics, % mass	ASTM D2007	55 in

*X = asphalt modifier viscosity.

Table 7. Physical Properties Requirements – Crumb Rubber (Caltrans 2018, Greenbook 2018)

Test Parameter	Test Method	Requirement
Scrap tire crumb rubber gradation (% passing #8)	CTM 385*	100
High natural crumb rubber gradation (% passing #10)	–	100
Wire content, %	–	0.01
Fabric content, %	–	0.05
CRM particle length, inch	–	3/16
CRM specific gravity	CTM 208	1.1 to 1.2
Natural rubber content in high natural crumb rubber, %	ASTM D297	40.0 to 48.0

*California Test Method.

Table 8. Physical Properties Requirements – Asphalt Rubber Binder (Caltrans 2018, Greenbook 2018)

Test Parameter	Test Method	Minimum Requirement	Maximum Requirement
Cone Penetration @ 25ºC, 0.10 mm	ASTM D217	25	70
Resilience @ 25ºC, % rebound	ASTM D5329	18	–
Softening Point, °C	ASTM D36	52	74
Viscosity @ 190ºC, cPs*	ASTM D7741	1,500	4,000

*Prepare sample for viscosity test under California Test 388. The viscosity test shall be conducted using a handheld high range analog or digital rotational viscometer such as Rion Model VT-04, Haake Model VT-02 or VT-02 plus with Rotor 1, 24 mm in depth x 53 mm in height, or equivalent. The accuracy of the viscometer shall be verified by comparing the viscosity results obtained with the handheld viscometer to 3 separate calibration fluids of known viscosities ranging from 1,000 to 5,000 cPs. The viscometer will be considered accurate if the values obtained are within 300 cPs of the known viscosity. The known viscosity value shall be based on the fluid manufacturers standard test temperature or the test temperature versus viscosity correlation table provided by the fluid manufacturer. Viscometers used on the project shall be verified to be accurate. The accuracy verification results shall be provided to the Engineer.

ASPHALT RUBBER BINDER TESTS

Cone Penetration ASTM D5 and AASHTO T 49

Measurement is achieved by a penetrometer and presented in tenths of a millimeter (Figure 24). Asphalt rubber binder consistency can be evaluated at low, moderate, and high temperatures. Needle penetration is usually the standard at 39.2°F and 77.0°F. Cone penetration is typically used with asphalt rubber binder with larger particle size crumb rubber (10 mesh and up).

Figure 24. Cone penetration test.

Resilience ASTM D5329

Measures the elastic properties of the asphalt rubber binder and is expressed as a percentage of rebound for the binder. Resilience is one of the most important properties in the specifications and is a more reliable measure of elasticity (Figure 25).

Figure 25. Resilience test.

R&B Softening Point ASTM D36 and AASHTO T 53

Measurement is achieved by the ring and ball method and presented in °F or °C and is an indicator of material stiffness (Figure 26). This shows the tendency of the material to flow at elevated temperatures.

Figure 26. Ring and ball softening test.

Field Viscosity

Measurement is achieved by a rotational viscometer and presented in centipoise (cP) or Pascal seconds (Pa-s). Field viscosity monitors the fluid consistency of asphalt rubber binder to ensure pumpability and to identify binder changes which might affect hot mix placement and compaction (Figure 27). If the Brookfield is the required method for acceptance, then the Haake viscometer should be calibrated and corrected to the Brookfield measurement for field use.

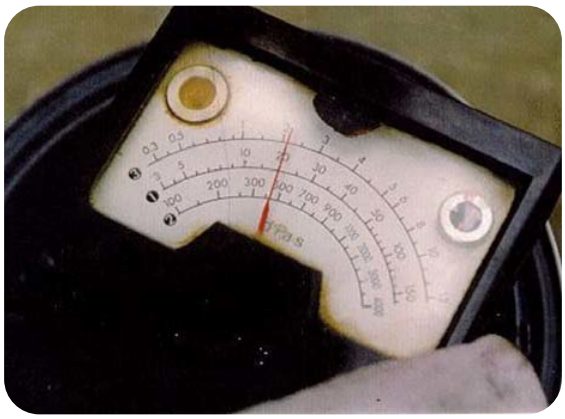

Figure 27. Example for field viscosity test.

MIX DESIGN

RHMA-G

Caltrans specifications require mix designs for RHMA materials to be performed in accordance with MS-2 Asphalt Mix Design Methods (AI 2015) (Figure 28). The Greenbook requires the mix design for ARHM-GG to be in accordance with Caltrans Test Method 367, Method of Test for Determining Optimum Bitumen Content, evaluation of surface flushing is not required.

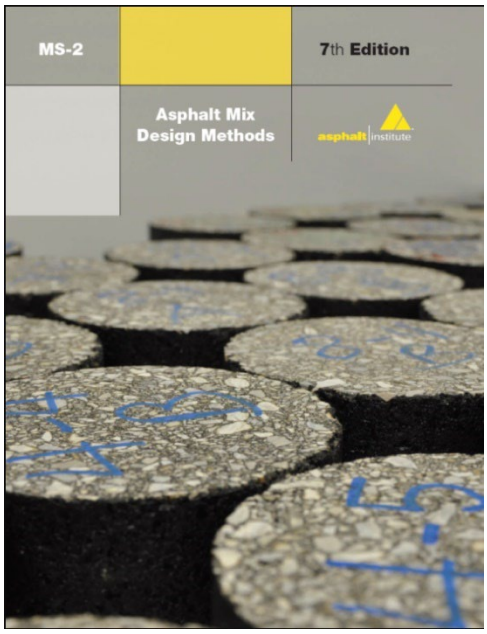

Figure 28. Asphalt Mix Design Methods.

Both specifications revise mixing and compaction temperatures include:

Table 9. Temperature Requirements (Caltrans 2018)

Component	Caltrans	Greenbook
Aggregate mixing temperature	300 to 325°F	290 to 325°F
Asphalt rubber binder mixing temperature	375 to 425°F	325 to 360°F
Compaction temperature	290 to 320°F	290 to 300°F

CRM gradation and content in high-viscosity asphalt rubber binders affects volumetric properties of gap-graded mixes. High-viscosity binders include discrete CRM particles that have swelled as part of the interaction and are actors in the mix design and in the finished pavement product. CRM particle size does matter, and so does the amount of CRM used in the binder. Fine CRM particles provide more surface area per unit volume and tend to interact more thoroughly with the asphalt than do coarser CRM particles. Holding other factors constant, including CRM source, changing from a fine graded CRM to a coarser graded CRM typically requires an increase in CRM content to obtain similar binder properties. Caltrans RHMA-G mix design requirements include:

Table 10. RHMA-G Mix Design Requirements (Caltrans 2018)

Quality Characteristic	Test Method	Requirement
Air voids, %	AASHTO T 269 (Method A)	N_{design} = 4.0
Gyration compaction, #	AASHTO T 312	N_{design} = 50 to 150*
VMA, %	MS-2, *Asphalt Mixture Volumetrics* (AI 2015) Ram pressure may be increased to 825 kPa; specimens may be held at constant height for 90 minutes max.	18.0 to 23.0
Dust proportion	MS-2, *Asphalt Mixture Volumetrics* (AI 2015).	Report only
Hamburg wheel track, min, Number passes at 0.5-inch rut depth	AASHTO T 324 (Modified) Test plant produced RHMA	PG 58: 15,000 PG 64: 20,000 PG 70: 25,000
Hamburg wheel track, min, Number passes at the inflection point	AASHTO T 324 (Modified) Test plant produced RHMA	PG 58: 10,000 PG 64: 12,500 PG 70: 15,000
Moisture susceptibility, dry strength, min, pounds/square inch	AASHTO T 283 Measure bulk specific gravity using AASHTO T 275, Method A.	100
Moisture susceptibility, wet strength, min, pounds/square inch	AASHTO T 283 Measure bulk specific gravity using AASHTO T 275, Method A. Freeze thaw required.	70

*AASHTO T 275 Method A to determine bulk specific gravity; AASHTO T 209 Method A to determine theoretical maximum specific gravity; use a digital manometer and pycnometer for AASHTO T 209.

Aggregate Requirements (Caltrans 2018)

Greenbook mix design requirements for ARHM-GG include:

Table 11. ARHM-GG Mix Design Requirements (Greenbook 2018)

Quality Characteristic	Test Method	Requirement
% MAC-15TR by weight of dry aggregate	–	5.0 to 7.0
Air voids, %	CTM 367	3 to 6
Stabilometer value, %	CTM 304 and 366	23 min
VMA	–	16 min

It may occasionally be necessary to substitute a different CRM gradation in the binder to adjust RHMA mixture volumetrics to meet requirements. Some gap-graded mixes with very few aggregate fines have exhibited increased VMA with increased asphalt rubber binder content, which does not yield an acceptable mix design. This has most often been observed when relatively coarse CRM is used in the binder and indicates that the voids structure is being changed and aggregate particles pushed apart, most likely by the CRM particles. In such cases, changing to a finer CRM in the binder has proved effective in developing a suitable mix design. This phenomenon of “chasing VMA” may not be apparent to mix designers with limited RHMA experience who are not looking for such behavior.

No-agitation binders can be used in gap-graded mixes and will behave similar to polymer-modified asphalt cement during the mix design. Binder drain-down limits the amount of no agitation binder that the mix can hold. The resulting design binder contents are usually significantly lower (≥ 1% by dry weight of aggregate) than for high-viscosity binders with the same aggregate gradation.

RHMA-O and RHMA-O-HB

Mix design methods for RHMA-O and RHMA-O-HB are much simpler. Caltrans mix design specifications for RHMA-O and RHMA-O-HB require the contractor to submit a JMF that specifies the asphalt binder, asphalt modifier, CRM, and their proportions.

Crumb Rubber-modified Asphalt Concrete Gap-Graded (CRUMAC-GG)

CRUMAC-GG includes the combination of asphalt binder, CRM, and aggregate (Greenbook 2018). The CRUMAC-GG mix design requirements are as specified for ARHM-GG, except as follows (Greenbook 2018):

- Proportioning: 82 ± 2percent paving asphalt and 18 ± 2 percent CRM

Table 12. Aggregate Gradation

Sieve Size	CRUMAC-B	CRUMAC-C
#10	98 to 100	100
#16	30 to 50	50 to 70
#30	3 to 13	10 to 20
#50	0 to 6	3 to 8
#100	0 to 2	0 to 3

- Mix aggregate and CRM for a minimum of 5 seconds, add asphalt binder and mix for a minimum of 35 seconds.
- Mix discharge temperature: 320 to 350°F

Tire Rubber-modified Asphalt Concrete (TRMAC)

TRMAC includes the combination of up to 20 percent recycled asphalt pavement (RAP), tire rubber-modified asphalt, and aggregate. Scrap tire rubber is added to the asphalt binder to achieve a smooth and homogenous composition. Mix design requirements are as shown for asphalt concrete, except as follows:

Table 13. TRMAC Gap-graded Mix Design Requirements

Property	Requirement
% MAC-15TR by weight of dry aggregate	5.0 to 7.0
Air voids, %, CTM 367	3 to 6
Stabilometer Value, CTM 304 and 366	23 min
VMA, %	16 min

- Asphalt rubber binder for dense-graded mixes shall be MAC-15TR, PG 64-28TR, and PG 76-22TR and MAC-15TR for gap-graded mixes.

Table 14. TRMAC Dense-graded Mix Original Asphalt Binder Requirements

Original Asphalt Property	Test Method	MAC-15TR
Rubber content, %	Certification	15.0 min
Penetration, @25°C	ASTM D5	40 to 60
Penetration, @4°C	ASTM D5	15 min
Dynamic viscosity, Pa•s	ASTM D2171	5,000 min
Kinematic viscosity, cs	ASTM D2170	1,200 max
Flash point, °F	ASTM D92	446 min
Softening point, °F	ASTM D36	127 min
Solubility, %n	ASTM D2042	97.5 min

Table 15. TRMAC Dense-graded RTFO Binder Requirements

Residue from RTFO Property	Test Method	MAC-15TR
Penetration, @25°C	ASTM D5	20 to 40
Penetration, @4°C	ASTM D5	10 min
Dynamic viscosity, Pa•s	ASTM D2171	20,000 min
Kinematic viscosity, cs	ASTM D2170	2,000 max
% original penetration	ASTM D5	50 min

Table 16. TRMAC Dense-graded Original PG Binder Requirements

Original Asphalt Property	Test Method	PG 64-28TR	PG 76-22TR
Rubber content, %	Certification	15 min	15 min
Viscosity, 135°C, Pa•s	AASHTO T 316	3.0 max	3.0 max
Flash point, °C	AASHTO T 48	230 min	230 min
Solubility, %,	AASHTO T 44	97.5 min	97.5 min
Dynamic shear test temp, °C	AASHTO T 315	64	76
Dynamic shear, 10 rad/s, G*/sinδ, kPa	AASHTO T 315	1.00 min	1.00 min

Table 17. TRMAC Dense-graded RTFO PG Binder Requirements

Residue from RTFO Property	Test Method	PG 64-28 TR	PG 76-22 TR
Mass loss, %	AASHTO T 240	1.00 max	1.00 max
Dynamic shear test temp, °C	AASHTO T 315	64	76
Dynamic shear, 10 rad/s, G*/sinδ, kPa	AASHTO T 315	2.20 min	2.20 min
Elastic recovery, 25°C, %	AASHTO T 301	75 min	65 min
Dynamic shear, temp, °C	AASHTO T 315	80 max	80 max

Table 18. TRMAC Dense-graded Original and RTFO PG Binder Requirements

RTFO and PAV Aged Binder Property	Test Method	PG 64-28 TR	PG 76-22 TR
PAV aging temp, °C	AASHTO R 28	100	110
Dynamic shear, test temp, °C	AASHTO T 315	22	31
Dynamic shear, 10 rad/s, G*/sinδ, kPa	AASHTO T 315	5,000 max	5,000 max
Bending beam test temp, °C	AASHTO T 313	-18	-12
Creep stiffness, MPa	AASHTO T 313	300 max	300 max
m-value	AASHTO T 313	0.300 min	0.300 min

Chip Seals and Interlayers

Mix designs are not required according to Caltrans specifications and the Greenbook. Caltrans requires the SAMI to comply with the 3/8-inch gradation. Both Caltrans and the Greenbook specifications require the use of pre-coated (0.5-1.0% by weight of dry aggregate), pre heated (260 to 325°F) aggregate.

Table 19. Chip Seal and Interlayer Aggregate Gradation

Sieve Size	1/2-inch	3/8-inch
3/4-inch	100	100
1/2-inch	85 to 90	95 to 100
3/8-inch	0 to 30	70 to 85
#4	0 to 5	0 to 15
#8	—	0 to 5
#200	0 to 1	0 to 1

SUBMITTALS

A COC is required for every binder constituent as well as for the finished asphalt rubber binder. The COCs must include test results that show conformance of the materials to the respective special provisions, including chemical composition of the scrap tire and high natural CRM materials and additives, as applicable. COCs for the component materials delivered to site of the asphalt rubber blending operation should be provided to the Engineer, inspector, and project staff.

A copy of the approved asphalt rubber binder design profile includes results of specified laboratory tests and proportions of each component must be available at the asphalt rubber blending site. A log of asphalt rubber binder production shall also be maintained for each project. For each batch of asphalt rubber produced, the log should include component weights, reaction start time, and viscosity results (time and asphalt rubber binder temperature, time when batch was metered into HMA plant). A production log should also include all holdovers and reheat cycle information including the time that heating was discontinued, the time that reheating began and corresponding asphalt rubber binder temperature, CRM addition weight and time if applicable, and subsequent viscosity test results. The following presents an example list of test requirements for an asphalt rubber binder production log and viscosity log, respectively.

Table 20. Example Asphalt Binder Production Log

Test	Method	Specification
Dynamic Shear, @ 64°C, 10 rad/s, G*/ Sinδ, kPa	AASHTO T 315	1.00 min
Viscosity, @ 135°C, Pa•s	AASHTO T 316	3.0 max
Flash Point, °C	AASHTO T 48	230 min
Solubility, %	AASHTO T 44	99.0 min
Tire Rubber Content, wt. %	–	15 min
SBS Polymer Content, wt. %	–	3 min

Table 21. Example RTFO Binder Production Log

RTFO Aged Binder	AASHTO T 240	Specification
Dynamic Shear, @ 64°C, G*/Sino, kPa	AASHTO T 315	2.20 min
Mass Loss, %	AASHTO T 240	1.00 max
Ductility, @ 25°C, 5 cm/min, cm	AASHTO T 51	75 min

Table 22. Example RTFO and PAV Binder Production Log

RTFO and PAV Aged Binder @ 100°C	AASHTO R 28	–
Dynamic Shear, @ 28°C, 10 rad/s, G*/ Sinδ, kPa	AASHTO T 315	5,000 max
Creep Stiffness, @ -6°C, MPa	AASHTO T 313	300 max
m-Value, @ -6°C	AASHTO T 313	0.300 min

Project Name/Number	
Asphalt Rubber (AR) Blender/Supplier	
Location of AR Blending Plant	
RAC Mix Supplier	

ASPHALT RUBBER BINDER FORMULATION **Blend Proportions**

Asphalt Cement PG Grade and Supplier		
Asphalt Modifier Type and Supplier		% by AC mass:
Asphalt Cement and Modifier		% by Asphalt Rubber Binder mass:
Scrap Tire CRM Type & Supplier		% by Asphalt Rubber Binder mass:
High Natural CRM Source & Description		% by Asphalt Rubber Binder mass:

Asphalt Rubber Binder (ARB) material must be tested to verify compliance with minimum viscosity requirement of 1,500 Pa•s (x 10^{-3}) at 375± 3°F before it can be used.

*Cycle Start Date & Time	AR Batch #	Temperature In ARB Tank (°F)	Temp. During Viscosity Test (°F) (375 ± 3°F)	Measured Viscosity** Pa•s(x10^{-3})	Date and Time Sampled	Date and Time Tested	Comments

Viscometer Make, Model and Serial #:_____

Rotor Designation:_____

Test Operator:_____

Figure 29. Asphalt rubber viscosity binder log.

Submittals may include (Caltrans 2018, Greenbook 2018):

Aggregate

- Aggregate gradation for percent passing each sieve size
- Results of quality tests for coarse aggregate, fine aggregate, and aggregate blend
- Source of each aggregate to be used, including producer, location and California Mine Identification number

- Percentage of each aggregate cold feed or hot bin and supplemental fine aggregate used in the mix design
- Typical gradation of each aggregate cold feed or hot bin
- Safety Data Sheet for lime if used

CRM

- Supplier and identification (or type) of scrap-tire and, if used, high-natural CRM
- Typical gradation of each type of CRM material used in the asphalt rubber binder design, percentage of scrap-tire and, if used, high-natural CRM by total mass of the asphalt rubber blend
- If CRM from more than one supplier is used, the above information will be required for each CRM supplier used
- Laboratory test results for specified test parameters
- Safety Data Sheets

Asphalt Rubber Binder

RHMA-G

- Local air district permit issued for asphalt rubber binder blending equipment, if not needed, verification confirming permit not required
- Submit the name of an authorized laboratory to perform quality control (QC), 10 days prior to production
- Safety data sheet for base asphalt binder grade, CRM and asphalt modifier, and blended asphalt rubber components
- Asphalt rubber binder design (binder, modifier, and CRM and proportions) and profile:
    - Log of daily production
    - COC with test results for CRM and asphalt modifier for each truck load delivered to HMA plant
    - Certified weight slips for the CRM and asphalt modifier
    - QC test results on viscosity within 2 business days after sampling
    - QC test results on cone penetration, resilience, and softening point within 3 business days after sampling

RHMA-O and RHMA-O-HB

JMF submittal for the asphalt rubber binder must include (Caltrans 2018):

- Log of daily production
- COC for CRM and asphalt modifier for each truckload delivered to the HMA plant (no more than 5,000 lb of asphalt modifier)
- Certified weight slips for the CRM and asphalt modifier
- Viscosity QC test results
- Cone penetration, resilience, and softening point QC test results

CRUMAC-GG

The contractor submits test results and COC for the paving asphalt and CRM at the time of delivery at the worksite.

TRMAC

The contractor submits a COC for each asphalt rubber binder product.

Antistrip

If antistrip additives are used, the COC includes (Caltrans 2018):

- Submitter's signature and printed name
- Shipment number
- Material type and specific gravity
- Refinery
- Consignee
- Destination
- Quantity
- Contact or purchase order number
- Shipment date

Mixture

- Combined aggregate gradation
- Asphalt rubber binder content
- Density
- Air voids
- VMA
- Stability

PRODUCTION AND CONSTRUCTION

BINDER PRODUCTION

Production methods for asphalt rubber binders are essentially the same for both conventional HMA and spray applications. The primary difference is the importance of coordination of the asphalt rubber and HMA mix production to assure that enough asphalt rubber binder is available to provide the desired HMA production rate. Binders for spray applications are typically produced close to the job site, not necessarily at an HMA plant, and their production must be coordinated with application operations.

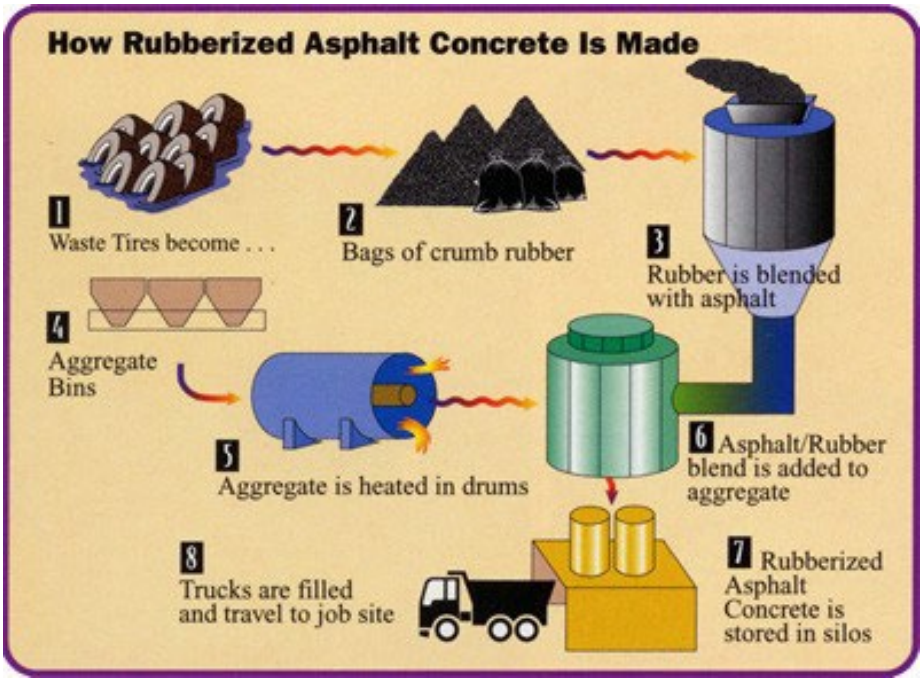

Figure 30. Rubberized asphalt mix production.

The asphalt rubber binder production process is relatively straightforward. The quality of the resulting asphalt rubber binder depends on proportioning, temperature, agitation, and time. Temperature is critical for process control and temperature gauges or thermometers should be readily visible. Tanks that store asphalt rubber between initial blending and use must be heated and insulated. Transfer lines may be wrapped with insulation. Asphalt rubber production equipment and storage tanks generally include retort heaters or heat exchangers to heat the asphalt cement and/or asphalt rubber binder.

Figure 31. Asphalt binder storage tanks.

Asphalt rubber binder must be agitated for a minimum of 45 minutes at 375 to 425°F to achieve the desired interaction between the asphalt binder, CRM, and asphalt modifier (if used). In order to maintain adequate reaction temperature, temperature of the asphalt binder and modifier (if used) must be at least 400ºF before the addition of CRM (added at ambient temperature).

The binder design profile submitted by the asphalt rubber supplier identifies and lists the respective components and their blend proportions (see Design and Specification). It presents results of specification compliance tests on laboratory samples of the subject binder taken over a 24-hour interaction period and indicates the expected pattern of the interaction properties. The design profile should be treated as a guide rather than as a specification, but major departures may indicate production issues that should be addressed immediately.

CRM is typically packaged in 1-ton super sacks that should be clearly labeled and stored to prevent loss or damage. The CRM is fed into a weigh hopper for proportioning along with the asphalt binder and other additives (if used).

Figure 32. CRM stored in super sacks.

Equipment for component feeding and blending may differ among asphalt rubber types and manufacturers, but the processes are similar. The component materials are metered into high shear blending units to incorporate the CRM and additives into the paving grade asphalt binder. The blending units thoroughly mix the CRM and additives into the hot asphalt binder, and the blend is pumped into a heated tank where the asphalt rubber interaction proceeds.

Figure 33. Feeding and blending equipment.

Augers are needed to agitate the high viscosity asphalt rubber inside the tanks to keep the CRM particles well-dispersed; otherwise, the particles tend to settle to the bottom or float near the surface. Agitation can be verified by periodic observation through the port where the auger control is inserted.

Hand-held rotational viscometers (Haake, Rion, or equivalent) are used to monitor the viscosity of the asphalt rubber interaction over time for QC and assurance. Before any asphalt rubber binder can be used for HMA production or spray application, compliance

with the minimum viscosity requirement must be verified using an approved viscometer. If the viscosity results comply and the interaction has proceeded for at least 45 minutes, the asphalt rubber binder may be used for production.

Figure 34. Asphalt rubber binder production.

Holdover and Reheating

If an asphalt rubber material is not used within 4 hours after the 45-minute reaction period, both Caltrans and the Greenbook require that heating be discontinued. Sometimes the binder must be held overnight. The rate of cooling in an insulated tank varies, but reheating is required if the temperature drops below 375ºF. A reheat cycle is defined as any time that an asphalt rubber binder cools below its designated viscosity measurement temperature and is reheated. Two reheat cycles are allowed, but the asphalt rubber binder must continue to meet requirements, including the minimum viscosity.

The asphalt binder and CRM continue to interact as long as they remain liquid. The rubber breaks down (is digested) over time, which reduces viscosity. Up to 10 percent more CRM by asphalt binder mass can be added to restore the viscosity to specified levels. The resulting asphalt rubber blend must be interacted at the designated temperature for 45 minutes and must meet the minimum viscosity requirement before it can be used.

Figure 35. Asphalt rubber binder storage tank.

The Greenbook describes the transfer of holdover binder material from other agencies as long as the initial agency certifies (no more than 20 tons):

- Total weight and type of material
- Percent CRM
- Type and source of asphalt paving grade and modifier
- Date of original mixing
- Number of reheat cycles

Sampling and Testing Requirements

Frequency of sampling and testing may vary depending on the nature of the materials, project size, and available resources. Aside from minimum requirements, additional sampling is recommended whenever changes in any material or its behavior are observed.

Sampling during production and construction is relatively easy and inexpensive, and it is rarely necessary to test every sample obtained. Suggested minimum requirements for QC and acceptance sampling and testing are shown in the following tables, respectively.

Caltrans requires the Contractor (typically the asphalt rubber binder producer) to sample the asphalt rubber from the feed line into the HMA plant and measure the viscosity at least every hour during HMA production. At least one gallon of asphalt rubber binder should be wasted to assure that the sampling valve is clear, and the sample to be tested should be poured into a clean, dry one-gallon container that can be sealed and clearly labeled for possible additional laboratory testing after field viscosity measurements are completed. The Greenbook does not address frequency of sampling and testing for the high viscosity binder.

Figure 36. Hot mix asphalt plant.

At least one viscosity test is required to establish compliance for each asphalt rubber batch and holdover load. The Engineer or Inspector may wish to be notified when the tests will be performed. Caltrans requires that results of all viscosity tests performed, including the time and asphalt rubber binder temperature, be submitted to the Engineer daily. This is good practice for any project with high-viscosity binder.

Table 23. Minimum QC Testing and Sampling Requirements (Caltrans 2018)

Material	Test	Test Method	Sampling Frequency
CRM	Scrap tire crumb rubber gradation	CTM 385	1 per 10,000 pounds
CRM	High natural crumb rubber gradation	CTM 385	1 per 3,400 pounds
CRM	Natural rubber content	CTM 385	1 per 3,400 pounds
CRM	Wire in CRM	–	1 per 10,000 pounds
CRM	Fabric in CRM	CTM 208	1 per 10,000 pounds
CRM	CRM particle length	ASTM D297	1 per 10,000 pounds
Asphalt Rubber Binder	Cone penetration*	ASTM D217	1 per lot
Asphalt Rubber Binder	Resilience*	ASTM D5329	1 per lot
Asphalt Rubber Binder	Softening point*	ASTM D36	1 per lot
Asphalt Rubber Binder	Viscosity (prior to use of each lot)	ASTM D7741	15 minutes prior
Asphalt Modifier	Viscosity	ASTM D445	1 per shipment
Asphalt Modifier	Flash point	ASTM D92	1 per shipment
Asphalt Modifier	Molecular analysis	ASTM D2007	1 per shipment
Aggregate	Gradation	AASHTO T 27	1 per 750 tons and any remaining part
Aggregate	Sand equivalent	AASHTO T 176	1 per 750 tons and any remaining part
Aggregate	Moisture content	AASHTO T 255	1 per 750 tons and any remaining part
Aggregate	Crushed particles	AASHTO T 335	1 per 10,000 tons or 2 per project whichever is greater
Aggregate	Los Angeles Rattler	AASHTO T 96	1 per 10,000 tons or 2 per project whichever is greater
Aggregate	Flat and elongated particles	ASTM D4791	1 per 10,000 tons or 2 per project whichever is greater
Aggregate	Fine aggregate angularity (Method A)	AASHTO T 304	1 per 10,000 tons or 2 per project whichever is greater

*Test first 3 lots, if passing, reduce testing to once for every 3 lots.

Table 24. Minimum Acceptance Testing and Sampling Requirements (Caltrans 2018)

Test	Test Method	Sampling Frequency
Asphalt binder content	AASHTO T 308 (Method A)	1 per 750 tons and any remaining part
HMA moisture content	AASHTO T 329	1 per 2,500 tons, no less than 1 per paving day
Air voids content	AASHTO T 269	1 per 4,000 tons or 2 every 5 paving days, whichever is greater
Voids in mineral aggregate	AI 2015	1 per 10,000 tons or 2 per project, whichever is greater
Dust proportion	AI 2015	1 per 10,000 tons or 2 per project, whichever is greater
Density of core	CTM 375	2 per paving day
Nuclear gauge density	CTM 375	3 per 250 tons or 3 per paving day, whichever is greater
Hamburg wheel track	AASHTO T 324 (Modified)	1 per 10,000 tons or 1 per project, whichever is greater

Rotational viscosity is a go/no-go field test that governs use of the asphalt rubber binder. One-gallon cans are used to provide adequate clearance from the sides and bottom of the container for the viscometer and should be 75 to 85% filled with the asphalt rubber binder. There are currently two methods for testing rotational viscosity of high viscosity asphalt rubber binders:

- Greenbook, Section 211-4
- Caltrans, ASTM D7741

Figure 37. Haake handheld viscometer.

No-agitation binders may be manufactured by different methods and are governed by different specifications than the high-viscosity asphalt rubber binders described herein. No-agitation binders are handled much like polymer-modified asphalt, and the resulting mixtures are more like conventional HMA.

HOT MIX PRODUCTION

Remember that the two families of CRM-modified binders, high viscosity and no agitation, are not interchangeable. Neither type should be directly substituted for the other in a hot mix without laboratory testing to determine appropriate adjustments in binder content and possibly aggregate gradation.

Using asphalt rubber binder has relatively little effect on HMA plant operations, for either batch or continuous HMA plants, except that it may be necessary to increase the plant operating temperature in order to provide the higher mixing and placement temperatures typically required for RHMA mixtures.

The asphalt rubber production equipment is independent of the HMA plant but is usually set up as close to the mixing unit as feasible to minimize the length of the heated and/or jacketed binder feed lines.

The asphalt rubber producer provides special heavy-duty pumps to transfer the asphalt rubber binder, because most HMA plant pumps cannot handle such viscous materials without risk of damage. A two- or three-way valve can be installed in the asphalt feed line that allows the HMA plant to switch between the asphalt rubber binder or the conventional asphalt binder in the HMA plant tanks, according to demand for various HMA products. For drum plants, the asphalt rubber producer is required to use a flow meter that interlocks the asphalt rubber binder feed with the plant aggregate feeds.

An HMA plant production rate of 375 tons/hr using 18% by weight of RHMA will require 27 tons/hour of rubberized asphalt binder.

RHMA production rates may be reduced somewhat from HMA rates due to higher binder content (increased mixing time), higher production temperature, difficulty heating gap- and open-graded mixes, and asphalt rubber binder production rate. However, planning and coordination between the asphalt rubber binder producer and the HMA plant operator can be used to minimize impacts on RHMA production. The binder supplier can in many cases arrange to use more or larger storage and interaction tanks, and schedule materials deliveries and asphalt rubber blending operations to expedite production of asphalt rubber-binder and mix.

Inspection and Troubleshooting

The primary change to the Plant Inspector's normal duties is the addition of monitoring the asphalt rubber production and viscosity results and sampling the asphalt rubber binder and its components. The Asphalt Rubber Binder Production Log and Testing Log should contain the pertinent information and should be available for inspection. The Inspector should obtain at least one one-gallon sample from each batch of asphalt

rubber binder produced for the project to test for compliance with specification limits, and additional samples if any changes in appearance or behavior are observed.

Figure 38. Material sampling.

The normal activities related to plant inspection for HMA production remain the same and include the following items, along with close attention to temperature:

- Observing aggregate storage and handling and plant operations
- Basic sampling and testing procedures for checking aggregate and RHMA characteristics
- Verifying that the correct mixture is being produced according to the design and in compliance with specifications, etc.

Warm Mix Asphalt Technology

Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that allow producers of asphalt concrete, including mixes containing rubberized asphalt, to lower temperatures at which the material is mixed, placed, and compacted. The types of technologies used included water-based (foaming), organic, chemical, or organic. WMA technologies reduce the viscosity of the binder so coating, handling, and compaction can occur at lower temperatures, or more readily at the same temperatures. If WMA is used, it is recommended the technology be selected from a state DOT-approved material list, the name of the technology, foaming water content or percent admixture and method of inclusion as appropriate, and proposed production temperature range be included in the job-mix formula submittal.

If water-injection foam WMA technology is used, the use of foamed asphalt for the mix design is not required. For other WMA additive technologies, the mix design should be prepared or verified using the technology, with samples cured in a forced-air-draft oven at 275°F for four hours prior to testing. Having a technical representative for the WMA technology attend the pre-construction or pre-paving meeting is recommended, particularly for first-time users. Gathering and evaluating any available information regarding the use of the proposed WMA technology in the specific planned rubberized asphalt application is encouraged.

Importance of Temperature

The key to quality in producing asphalt rubber materials and constructing asphalt rubber pavements is temperature control in all aspects of the work. Asphalt rubber materials need to be produced and handled at somewhat higher temperatures than conventional bituminous materials and mixtures because they are stiffer at the typical mixing and compaction temperatures. Temperature is critical to:

- Asphalt rubber binder manufacture
- RHMA production
- RHMA delivery
- RHMA placement
- RHMA compaction.

Figure 39. Handheld thermometers.

It is important to closely monitor temperature of the materials during all phases of asphalt rubber binder and mixture production and construction. The Inspector should have appropriate equipment for checking the temperature of asphalt rubber binder and HMA, including surface and probe-type thermometers that can also measure ambient air temperature, and a heat gun. The asphalt rubber blending, and storage tanks should also be equipped with readily visible thermometers.

Both the plant and field inspectors should visually inspect the RHMA in the haul truck bed for signs of any problems with the mix and check mix temperature. RHMA temperature should be measured with a thermometer that has a probe at least 6 inches long, by sticking the full depth of the probe into the mix. Surface readings are not an accurate indicator. If only a heat gun is available, it will be necessary to measure temperature of the RHMA as it is flows out of the plant discharge chute into the haul truck.

Whenever any type of RHMA mixture problem is suspected, the Inspector should obtain samples immediately and have them tested immediately for gradation and asphalt rubber binder content. In some cases, it may be necessary to check voids properties of compacted HMA specimens.

The Inspector should enter a full description of the problem observed and subsequent activities in the project daily log, and immediately report these observations to the Engineer. Test results should be relayed to the Engineer immediately upon receipt. Some of the potential “trouble” signs to watch for include:

- **Segregation:** Particle size segregation may be difficult to identify in some coarse gap-graded mixtures. There are few fines present and that can sometimes make the RHMA appear segregated even if it is not. Identify the affected truckloads and corresponding placement areas, take samples and test gradation and binder content to verify. It is also recommended that, if possible, samples of RHMA that do not appear segregated should be taken from the same truckload, for comparison. Temperature segregation (hot or cold spots) may be checked with a heat gun or with an infrared camera. The primary concern is differences rather than exact values.
- **Blue smoke**: The presence of excessive blue smoke indicates the mix is too hot.
- **White "smoke"**: Steam, not smoke, which indicates too much moisture in the mix. This means that the aggregate was not dried enough prior to mixing with asphalt rubber binder. This may cause the RHMA mix to become tender and may contribute to compaction problems.
- **Stiff behavior**: Mix may be too cool – check temperature.
- **Dull, flat appearance**: Indicates possible low asphalt rubber binder content and/or excessive fines (minus #200 sieve). Localized areas of dullness may indicate insufficient mixing of the asphalt rubber binder and aggregates or mix segregation. Take samples and test for gradation and binder content.
- **Slumped and shiny**: High asphalt rubber binder content. RHMA-O, and especially RHMA-O-HB mixtures, may look this way and still meet requirements, so this is not always a problem. An old descriptive term for this is "wormy," because the mix seems to almost crawl when watched. Look in the truck bed for binder drain-down, take and test samples for asphalt rubber binder content and gradation.

Safety

Safety is always a consideration when working with hot materials. Conventional HMA mixtures are hot enough to cause burns, and so are asphalt rubber binders and RHMA materials. Personnel should wear appropriate protective gear including but not limited to gloves made for handling hot samples and suitable eye protection.

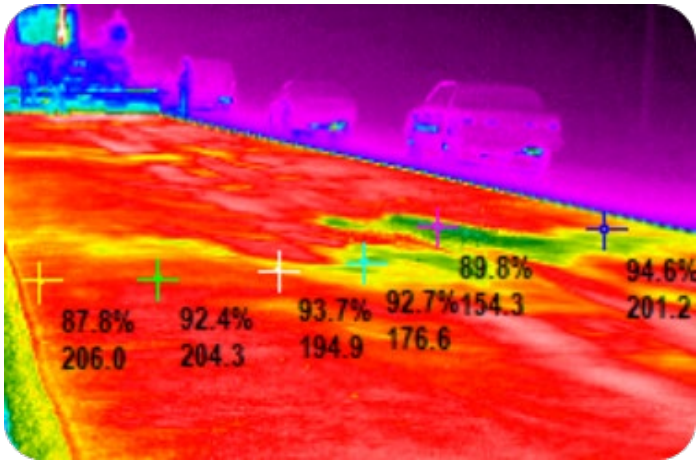

Figure 40. Infrared image of HMA surface.

PAVING EQUIPMENT

Conventional equipment is used to place and compact RHMA materials. The field inspector should confirm that the necessary paving and compaction equipment is on site before any asphalt rubber HMA is shipped from the HMA plant.

Haul Trucks

Any type of trucks that are customarily used for transporting HMA may be used, including conventional end or bottom dumps, or horizontal discharge (live bottom). Trucks hauling RHMA mix should be tarped to retain heat during transport.

Material Transfer Vehicle (MTV)

MTVs have been described as “surge bins on wheels” and are most often used when smoothness, segregation (particle size or temperature) or mixture delivery rate are of concern. Caltrans requires the use of an MTV when placing ARHM-G. The additional transfer points can result in heat loss.

Figure 41. MTVs.

Pavers

Conventional mechanical self-propelled pavers are used to place RHMA mixes. Pavers should be equipped with a vibratory screed and screed heaters, automatic screed controls with ski or other grade and smoothness controls and comply with pertinent specification requirements.

Rollers

Rubber-tired rollers are not appropriate for compacting RHMA mixes because of excessive pick up of the mixture by the tires. Rollers for RHMA must be steel-wheeled (drum) and must be equipped with pads and a watering system to prevent excessive pick-up. It may sometimes be necessary to add soap or other release agent to the watering system.

RHMA-G mixtures are likely to require more compaction effort than HMA due to the relatively coarse nature of the aggregate skeleton. Minimum recommended roller weight is 8 tons. The types of rollers include:

- Breakdown roller with vibratory capability: It is strongly recommended that two breakdown rollers be used to keep up with the paver, especially if paving width exceeds 12 feet.
- Intermediate roller: If not of equal or greater width than the breakdown roller(s), two intermediate rollers may be required.
- Finish roller: May be vibratory or static, but use the static mode for finishing
- Standby roller: One with vibratory capability should be on site and shall be required if only one breakdown roller is available.
- The use of MultiCool or PaveCool software to estimate time available to compact is highly recommended. The relatively thin lifts and high cessation temperatures below which compaction cannot be accomplished often result in a very limited opportunity to achieve density.

Figure 42. Use of steel wheel rollers.

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

FINAL SURFACE PREPARATIONS

Surface preparation must be completed prior to RHMA production or spray application. This includes customary items such as removal and replacement of failed pavement and pothole repair (patching), milling or grinding for smoothness and/or to restore or adjust profile, crack filling and/or sealing. Routing and sealing cracks rather than using the overband method is highly recommended.

Patching should be performed using HMA along with standard good practice procedures. When routing and sealing existing cracks, do not overfill cracks, as excess sealer/filler will cause bumps in the overlay and may migrate up through the RHMA mat during compaction and to create “fat spots.” Fill ruts as necessary. If a leveling course is required, use a fine HMA mix. Immediately prior to mixture delivery, the surface should be swept, and tack coat applied.

Figure 43. Crack sealing.

Figure 44. Patching.

Tack Coat

A tack coat should be uniformly applied to lightly cover the entire pavement surface to be overlaid. Tack coat may consist of paving grade asphalt or emulsified asphalt. Area of tack application should be limited to what will be paved that day. Tack coats are applied to existing pavement (including planed surfaces), between HMA layers, and prior to placement of SAMIs (Caltrans 2018).

Figure 45. Tack coat distributor.

Paving Grade Asphalt: Unmodified paving grade asphalt is preferred as the tack for RHMA mixes. Asphalt tack must be hot enough to spray an overlapping fan pattern that provides a uniform application. The distributor truck must have a heater to maintain asphalt temperature and consistency for spray application. The application rate must be properly controlled to avoid bleeding (too high) or delamination (too low). Any defective or plugged nozzles must be corrected immediately.

Emulsified Asphalt: Recommended application rate is 0.05 to 0.1 gal/yd2 residual, depending on the condition of the existing surface. Caution should be used when ambient and pavement temperatures are marginally cool and emulsion tack coats are used. Emulsion must “break” (i.e., turn from dark brown to black as the suspended asphalt droplets separate from the water) and the water must evaporate prior to paving. Otherwise, the remaining water in the emulsion will turn to steam and rise through the mat. This prevents the tack from establishing the intended bond with the new pavement and the excess moisture may also cause a tender spot in the mix during compaction. Water trapped between pavement layers may cause stripping and delamination. Cold or damp site conditions and lack of sun slow evaporation and may delay paving operations.

Figure 46. Uniform tack coat application.

MIX DELIVERY

The same good practices recommended for HMA delivery should be applied to RHMA materials, along with special attention to temperature. Any type of HMA haul vehicle can be used to transport RHMA. However, use of bottom dumps and windrows is not recommended when air and pavement surface temperatures are marginally cool. It is critical that the RHMA does not cool below the minimum laydown temperature (280ºF to 300ºF, depending on owner agency and temperature at paving site) during transport.

Figure 47. Delivery of asphalt mix using end dump truck.

Tarps may be needed to maintain acceptable mixture shipment temperatures ranging from 290º to 325ºF. Caltrans requires trucks to be tarped if the ambient air temperature drops below 70 ºF (Caltrans 2018).

Coordinating Mix Delivery and Placement

Coordination and balance of binder and mix production with mix delivery, placement, and compaction operations is essential to achieving a smooth finished pavement with a pleasing appearance, the two factors that motorists reportedly consider the most important indicators of pavement quality.

The paver should never have to stop due to lack of material. If it stops on the new mat, the result is either a bump or depression that cannot be removed by rolling. If it pulls off the mat, it may be necessary to construct a transverse joint. A long line of haul trucks waiting to access the paver usually means that some loads will cool too much to be used.

Release Agents

No solvent-based release agents or diesel fuel should be used in haul truck beds because of adverse effects on the asphalt rubber binder. Soapy water (dish or laundry soap) is recommended; it is effective and inexpensive. Dilute silicone emulsions may also be used. Caltrans and other agencies maintain a list of approved release agents.

Figure 48. Do not use solvent-based release agents or diesel fuels.

Loading Haul Trucks

One of the most common causes of particle size segregation is improper loading of haul trucks. To avoid segregation of the HMA material, trucks should be loaded as shown in the illustrations on the right.

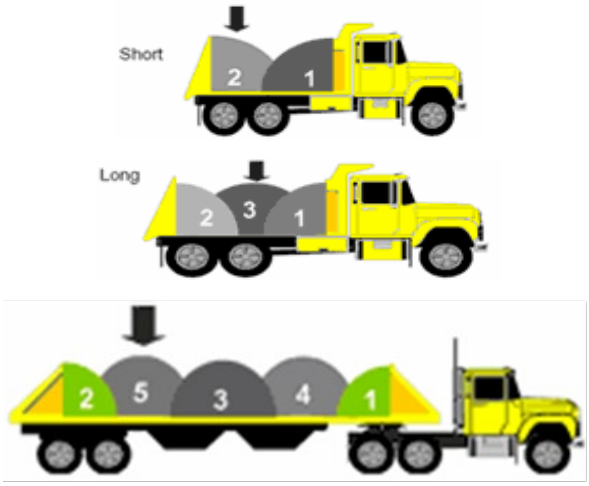

Figure 49. Loading haul vehicles.

Unloading Hot Mix into a Paver Hopper

The haul truck should be centered and backed up to the paver but should stop just short of contacting the push rollers on the front of the paver. After the truck releases its brakes, the paver should move forward to pick up and push the truck forward, instead of the truck bumping the paver. This method helps to minimize screed marks and roughness. End dumps and if used, live bottom trucks, should raise their beds slightly so that the mix slides up against the closed tailgate, then open the gates to discharge the mix in a single mass. This “floods” the paver hopper and helps to minimize potential for mix segregation.

Unloading Hot Mix into a Material Transfer Vehicle

MTVs also have a front hopper to receive the mix and eliminate the problem of bumping the paver. The same method of discharge should be used to flood the MTV hopper as a paver hopper.

Load Tickets

Load tickets should be collected when the mix is discharged from the haul truck to document quantities delivered and used. Yield calculations are typically used to verify overall thickness based on total tonnage, unit weight, and area paved. However, in-place thickness of randomly selected cores should also be measured as a check.

PLACEMENT

Placement of asphalt rubber materials or any HMA materials requires good paving practices. Temperature is critical for proper placement of all HMA materials. Asphalt rubber binders are stiffer than conventional paving asphalt binder at the customary placement and compaction temperatures, so time available for compaction of modified materials is typically shorter than for conventional HMA mixtures. How much shorter depends on several variables that are discussed in the next section on Compaction.

The aggregate size must be considered in conjunction with lift thickness. Industry standards are three times nominal maximum aggregate size (NMAS) for fine-graded mixes and four times NMAS for coarse-graded mixes (Brown et al. 2004). NMAS is defined as one sieve size larger than the first sieve to retain more than 10 percent.

As with conventional HMA, asphalt rubber paving materials should not be placed during rain or when rain is imminent. If site conditions are wet, windy, or too cold, placement should be delayed until conditions improve. Otherwise, expect significant problems in achieving adequate compaction. Weather conditions may change during the paving operation. If necessary, paving should be stopped until conditions improve.

Figure 50. Mix placement.

Caltrans 2018 Standard Specifications for RHMA-G specify minimum ambient air temperature of 55ºF and pavement surface temperatures of 60ºF for mixture placement.

For method compaction, Caltrans requires the first breakdown coverage before the surface temperature drops below 285ºF, all breakdown and intermediate compaction be completed before the surface temperature drops below 250ºF, and all compaction be completed before the surface temperature drops below 200ºF. The Greenbook allows a slightly lower ambient temperature of 50ºF and rising for placement but requires that breakdown compaction start before the mat temperature drops below 290ºF. Placement at minimum ambient and surface temperatures is not recommended, because time available for compaction is very limited and leaves no margin for circumstance or error, resulting in inadequate compaction. When feasible, it is recommended that the minimum ambient temperature requirement for placement be increased to 65ºF. Because of the importance of temperature in achieving adequate RHMA compaction, operating in the mid to upper end of specified temperature ranges is strongly recommended.

Paver Operations

Paver operations for RHMA should not differ from those commonly used for conventional HMA, except perhaps for paying closer attention to the temperature of the mix in the hopper. It is important to the quality of the finished product that the paver be operated to minimize starting and stopping. The importance of coordinating mix delivery with placement cannot be overemphasized.

A consistent paver speed, even if relatively slow, helps maintain a uniform head of material and to control thickness. Hopper wings should either be folded after every load or, preferable, not folded at all. If the wings are folded, care should be taken to fold the hopper wings before mix collected in the corners cools enough to form chunks. However, wings should never be dumped into an empty hopper. Slat conveyors should not be allowed to run empty or nearly so.

Raking and Handwork

Asphalt rubber mixtures are not particularly amenable to raking or handwork. The relatively coarse RHMA-G aggregate gradation and stiffer binder make handwork a problem and may affect the appearance of joints. Luting the joints segregates the mix and interferes with joint compaction. Handwork and raking of RHMA should be minimized, but if necessary, should be performed immediately before the mix cools. The higher asphalt rubber binder content of RHMA-O-HB makes raking and handwork a little easier, but it should still be kept to a minimum. Do not broadcast the mix: it is no longer considered to be good practice.

Figure 51. Raking and handwork.

The lack of fines in the gap- and open-graded mixes can create a somewhat rough and open-looking texture, even when placed by machine. RHMA placed by hand may not provide a pleasing appearance even if the workmanship is excellent and the best practice is applied.

Joints

HMA joints are typically defined as longitudinal or transverse, cold or hot. Longitudinal joints are most likely to be cold joints. Some agencies have adopted wedge joints and/or skewed joints that are not discussed in this Guide; there may be some issues with using wedge joints for RHMA mixes due to the relatively thin lifts and limited time available to compact.

To provide a good bond with the adjacent pavement, remove any loose material and tack the vertical edge prior to placing HMA. To minimize need for raking, it is important to set both the screed overlap and height carefully on the adjacent pass. The screed should overlap the cold material by about 1 to 1.5 inches. The screed should be set above the elevation of the cold side by approximately ¼-inch for each inch of compacted pavement thickness being placed. Roll from the hot side of the longitudinal joint, not the cold side, to make a tight joint.

Compacted thickness of RHMA is generally between about 1 inch and 2.5 inches, which typically yields height differences between adjacent paver passes of about 0.25 to 0.65-inch. Since lack of fines makes it difficult to feather the coarse-graded RHMA-G mixtures, some raking may be unavoidable, but should be kept to the minimum necessary. It is important that material not be removed from the joint, but only "stacked" over the joint if necessary. Extra material should be raked onto the hot side, not the cold.

If the mix is placed by hand rather than machine, the height difference for compaction should be increased to 3/8-inch for each inch of layer thickness. The height difference may vary among mixes, so experience and engineering judgment should be used as appropriate.

Transverse joints may be hot or cold. Hot joints should be treated the same as for conventional HMA, but the RHMA mix will stiffen more quickly. Cold joints should be treated as described for longitudinal joints. Most often, transverse joints are constructed at the end of the paving day or when a lane is finished, using a bulkhead or Kraft paper to provide a vertical butt joint. If the paver runs out the mix, the joint should be constructed where the full compacted thickness is available, and the rest of the mix placed past that point should be removed and wasted. Ideally, transverse joints should be rolled in a transverse or diagonal direction

COMPACTION

Compaction is essential to the performance and durability of any HMA including asphalt rubber mixtures. The best materials, mix designs, and placement techniques cannot compensate for adverse effects that result from poor compaction during construction.

The coarse aggregate structure and stiff asphalt rubber binders in RHMA-G mixes often require more compaction effort than conventional HMA. Compaction depends primarily on temperature and compactive effort. Breakdown compaction of RHMA-G mixtures must be performed in the vibratory mode, and it is advisable to obtain at least 95% of the required density during breakdown rolling.

Figure 52. Roller compaction.

However, vibratory compaction is not used for open-graded mixtures. There are no compaction requirements other than method or roller pattern specifications for open-graded mixes. These are typically placed as surface courses in thin lifts about 1 to 1.2 inches thick. Compaction is achieved with a few passes by rollers operating in the static mode.

Temperature Requirements

Caltrans and Greenbook specification temperature requirements are noted above, but regardless of the specification used, it is strongly recommended that breakdown compaction of RHMA-G should be completed before the temperature of the RHMA mat drops below 280ºF, and compaction be completed before the mat temperature drops below 225oF.

Temperature management is the key to achieving sufficient compaction of RHMA.

It is also recommended that mat temperature be closely monitored during placement and compaction, and that adjustments be made as needed to speed up the compaction process. It may be necessary to add a second breakdown roller. Inability to perform breakdown rolling within the temperature range specified may be cause to terminate paving operations and reject loads. In addition, vibratory rolling below the minimum breakdown rolling temperature should not be allowed, nor should vibratory rolling after static (finish) rolling.

Factors that Affect HMA Compaction

Compaction is affected by many factors including:

- Layer thickness
- Air temperature
- Pavement/ base temperature
- Mix temperature
- Wind velocity
- Sunlight or lack thereof

Paving Rollers

Thin lifts, cool temperatures and wind reduce the time available for compaction because of temperature loss. Therefore, it is generally easier to compact thick lifts (more than 2 inches thick) than thin ones. Adequate lift thickness for the aggregate gradation used is important. Otherwise, there may be problems with compaction due to a tendency for stones to stack and to catch under the screed and be dragged through the mat. When stones stack, they tend to reorient with each paver pass, or to break.

When placing asphalt rubber mixtures, it is important for the breakdown roller to follow immediately behind the paver in order to achieve 95 percent of the required compaction during the vibratory breakdown while the mix is still hot. The number of vibratory coverages required may vary depending on the mix and site conditions during placement. The anticipated roller coverages may need to be adjusted based on mix and site temperatures and wind conditions. Therefore, it is advisable to use two breakdown rollers to keep up with the paver and to obtain sufficient compaction. Intermediate rolling provides relatively little increase in density of RHMA mixes.

Test Strips and Rolling Patterns

Test strips for RHMA-G materials are recommended when feasible to indicate what level of compaction effort is needed to achieve adequate in-place density. During test strip compaction, both Contractor and agency representatives should correlate their respective nuclear gauge(s) on the test strip according to CTM 375. Gauge data should then be correlated with core results for nuclear density to provide accurate data for quality control during paving.

Opening New Pavement to Traffic

Sand Blotter RHMA mixes are relatively binder-rich and the surface may be tacky until the new mat has a chance to cure. To prevent tracking and pickup of the newly placed mat upon opening to traffic, a light dusting of clean sand may be spread on the surface of RHMA pavement at a rate of about 2 to 4 pounds per square yard to act as a blotter.

Opening new RAC Pavement to traffic. If possible, do not allow traffic before mat temperature drops to 150°F to prevent damage to the new surface. At temperatures higher than 150°F, a rock dust or sand blotter may be required to avoid tracking and pickup of the RAC material.

Sand shall be free from clay or organic material. Excess sand shall be removed from the pavement surface by sweeping.

A light application of diluted limewater can also be a very effective bond breaker. Adequate cooling of the RHMA prior to heavy vehicles or heavy traffic volumes is very important. Premature opening to traffic can result in tracking of the surface binder giving the appearance of flushing or bleeding.

Acceptance

Caltrans and Greenbook acceptance requirements for the asphalt rubber binder and the in-place mix include:

Table 25. Asphalt Binder Acceptance Requirements (Caltrans 2018, Greenbook 2018)

Component	Test	Test Method	Requirement
Asphalt Modifier	Viscosity @ 100°C, $m^2/s \times 10^{-6}$	ASTM D445	X ± 3 (Method A)
Asphalt Modifier	Flash point, °C	ASTM D92	207 min
Asphalt Modifier	Asphaltenes, % by mass	ASTM D2007	0.1 max
Asphalt Modifier	Aromatics, % by mass	ASTM D2007	55 min
Crumb Rubber Modifier	Scrap tire crumb rubber gradation (% passing #8 sieve)	CTM 385	100
Crumb Rubber Modifier	High natural crumb rubber gradation (% passing #10 sieve)	CTM 385	100
Crumb Rubber Modifier	Wire in CRM, %	CTM 385	0.01 max
Crumb Rubber Modifier	Fabric in CRM, %	CTM 385	0.05 max
Crumb Rubber Modifier	CRM particle length, inch	N/A	3/16, max
Crumb Rubber Modifier	CRM specific gravity	CTM 208	1.1 to 1.2
Crumb Rubber Modifier	Natural rubber, %	ASTM D297	40.0 to 48.0

Component	Test	Test Method	Requirement
Asphalt Rubber Binder	Cone penetration at 25°C (0.10 mm)	ASTM D217	25 to 70
Asphalt Rubber Binder	Resilience at 25°C, % rebound	ASTM D5329	18 min
Asphalt Rubber Binder	Softening point, °C	ASTM D36	52 to 74
Asphalt Rubber Binder	Viscosity at 190°C, cPs*	ASTM D7741	1,500 to 4,000

*Prepare sample as specified in CTM 388.

Table 26. In-Place Mix Acceptance Requirements (Caltrans 2018, Greenbook 2018)

Test	Test Method	Requirement
Asphalt binder content, %	AASHTO T 308 (Method A)	-0.40 JMF +0.50
Moisture content, %	AASHTO T 329	1.00 max
Air voids @ N_{design}, % (prepare and test 3 briquettes; report average)*	AASHTO T 158	4.0±1.5
VMA laboratory and plant produced, % (engineer determines for mix design verification only)*	MS-2	18.0-23.0
Dust proportion (prepare and test 3 briquettes; report average)	MS-2	Report only
Core density, % (prepare and test 3 briquettes; report average)*	CTM 375	91.0-97.0
Hamburg wheel track, Number passes at 0.5-inch rut depth	AASHTO T 324 (modified)	PG 58: 15,000
Hamburg wheel track, Number passes at 0.5-inch rut depth	AASHTO T 324 (modified)	PG 64: 20,000
Hamburg wheel track, Number passes at 0.5-inch rut depth	AASHTO T 324 (modified)	PG 70: 25,000
Hamburg wheel track, Number passes at inflection point	AASHTO T 324 (modified)	PG 58: 10,000
Hamburg wheel track, Number passes at inflection point	AASHTO T 324 (modified)	PG 64: 12,500
Hamburg wheel track, Number passes at inflection point	AASHTO T 324 (modified)	PG 70: 15,000
Moisture susceptibility, pounds/square inch, dry strength	AASHTO T 283	100 min
Moisture susceptibility, pounds/square inch, wet strength	AASHTO T 283	70 in

*Engineer determines bulk specific gravity determined using AASHTO T 275 Method A and theoretical maximum specific gravity using AASHTO T 209 Method A.

Good Paving Practices

Examples of good paving practices may be found in the *Hot-Mix Asphalt Paving 2000 Handbook,* the Asphalt Institute Manual MS-22 *Principles of Construction of Hot-Mix Asphalt Pavements*, the National Highway Institute course on *Hot-Mix Asphalt Construction*, the Caltrans *Construction Manual*, and various other industry and agency publications. Some of the fundamental guidelines are summarized below:

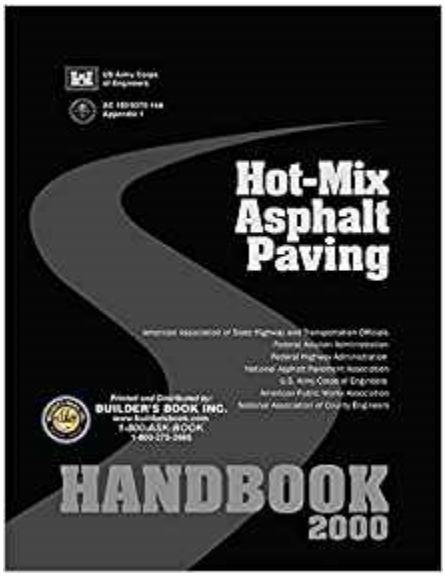

Figure 53. Hot-Mix Asphalt Paving Handbook.

- Use appropriate and properly maintained equipment operated by responsible, well-trained personnel.
- Comply with plans and specifications and pay attention to details.
- Handle the mix to minimize segregation by particle size or temperature.
- Maintain mix temperature by using tarps, insulated beds on haul trucks, or MTVs.
- Deliver the mixture as a free flowing, homogeneous mass without segregation, crusts, lumps, or significant binder drain-down.
- Coordinate mix production, delivery, placement, and paving operations to provide a smooth, uninterrupted flow of material to the paver. MTVs may be used to minimize effects of variations in delivery.
- The paver should never stop on the new mat.
- Use good workmanship in constructing and compacting cold and hot, longitudinal and transverse joints. Allow appropriate overlap and thickness of hot material for roll-down and roll from the hot side.
- Do not lute joints.
- Use enough rollers to achieve adequate breakdown and intermediate compaction and to complete finish rolling within the temperature limits specified for these operations.

CHIP SEAL AND INTERLAYER APPLICATION

The binders used for asphalt rubber chip seals and interlayers are generally the same as those used to make RHMA mixes, using the equipment previously described. SAMIs or ARAMs may be used on the surface or as crack-resistant interlayers under a conventional HMA or RHMA overlay. The primary difference in construction is that a flush coat or fog seal is not applied to the surface of an interlayer prior to placing overlay.

Construction

Chip seals are extremely sensitive to the effects of construction operations and site conditions, including temperature (ambient air and surface temperature and temperature of the cover aggregates). There are only minor practical differences in construction of conventional hot chip seals versus asphalt rubber chip seals. The primary difference is that the asphalt rubber membrane is thicker, and the aggregate chips must be large enough so as not to be “swallowed” by the membrane. Appropriate sizing of distributor nozzles minimizes the tendency to clog due to the presence of discrete rubber particles. Chip seal construction moves relatively rapidly. A reasonable production rate is about 5-7 lane miles per day.

Chip Seal Equipment

The equipment required to place a chip seal includes:

- Distributor truck with fume catcher to spray-apply asphalt rubber membrane
- Chip spreader
- Haul trucks for chips
- Roller(s): Because the surface of the chip seal is the cover aggregate, rubber-tired rollers may be used to embed the aggregate and are recommended for their kneading action and lack of bridging. Steel-wheeled rollers may also be used but may not be as effective for embedding the aggregate.
- Hand tools (broom, shovels, etc.).
- Power broom
- For surface treatments, distributor truck to apply a flush coat or fog seal (typically diluted emulsion) if desired, along with a sand spreader for flush coats.

Asphalt Rubber Spray Application

The distributor must be properly adjusted and operated to apply the proper amount of asphalt rubber binder uniformly over the surface. As for the tack coat, fanning and overlap is necessary to apply the membrane. The nozzle size, spacing, and angle in relation to the spray bar help determine the height of the bar. Streaking may occur if the asphalt rubber binder is too cold, when its viscosity is too high, or the spray bar too low or too high. The person who monitors the application for uniformity and nozzle plugging shall be protected from fumes by a pollution hood over the spray bar. Application rate typically ranges from about 0.55 to 0.65 gallons/yd2. The application rate should be based on the condition of the existing pavement surface; dry, oxidized, raveled or brittle surfaces require higher binder applications, as typically do recent patches.

Figure 54. Binder application.

The application width should be adjusted so that the longitudinal joint (meet-line) is not in the wheel path, but on the centerline or in the center or edge of the driving lanes. After each application, the distance, the width, and the amount of asphalt rubber should be determined to verify the application rate.

Aggregate Application

The binder is immediately covered with a layer of aggregate (chips) that must be quickly embedded into the binder by rolling before the membrane cools. Aggregate application rates can be estimated in the laboratory prior to the start of construction. The easiest method is to simply lay the aggregate one-stone deep on a measured area, weigh the amount of stone required to cover that area and convert to appropriate units. Allowance for some excess, or “float”, should be added to this theoretical spread rate. Typical rates range from about 28 to 44 lb/yd2, with the exact rate to be determined by the Engineer. To verify if application rates for binder and chips are appropriate, also check the embedment of the cover aggregate. Individual chips should be embedded to a depth of about 50-70 percent after seating in the lab or by rollers and traffic in the field.

Figure 55. Aggregate spreader.

Excess chip application interferes with embedment and adhesion. Bidding chips on a square yard basis rather than by the ton helps minimize over-application of cover aggregate. However, the application of slightly more chips than theoretically required ensures enough chips are available to cover all the membrane. Loose stones along the roadway edge after sweeping may indicate excessive chip application and wasted stone, that the asphalt rubber application is too light, or that the binder cooled before embedment and adhesion were achieved. Excess asphalt rubber application can literally submerge or swallow the chips, and results in flushing/bleeding.

Best results are achieved with clean single-sized chips (Caltrans 2007). The standard chip size for Caltrans asphalt rubber seals is nominal 3/8-inch, which may be too small for heavy binder applications. However, Caltrans policy is to use 1/2-inch chips only where the average annual daily traffic (AADT) is less than 5,000 vehicles per lane. Caltrans and Greenbook specifications also include graded cover aggregates with up to 15% by weight passing the #4 sieve. A maximum of 5% passing the 1/4-inch or #4 sieve has been shown to provide a better finished product. Because single-sized chips are not the standard, they may be difficult to obtain.

Pre-coating the aggregate with asphalt cement improves adhesion by removing surface dust and “wetting” the chips. Any paving-grade asphalt can be used for precoating (Greenbook specifies the use of PG 64-10). Caltrans and the Greenbook require that the aggregate chips be delivered to the job site precoated and hot. To further aid chip retention after the chips have been embedded and swept, a fog seal (or flush coat per the Greenbook) of asphalt emulsion (diluted 1:1 with water) is sprayed over the chips at a typical rate of about 0.05 to 0.1 gallon/yd2. A light dusting of sand, about 2 to 4 pounds/yd2, may be applied as a blotter if directed by the Engineer.

Embedment and adhesion of the chips must be accomplished by rolling while the asphalt rubber membrane is still hot. Both Caltrans and the Greenbook indicate that the higher temperatures of the asphalt rubber binder and the use of hot precoated chips allow placement of asphalt rubber chip seal at cooler temperatures than do emulsion binders and at night. However, it is not advisable to place chip seals when ambient or pavement temperature is less than 60º. Such cool conditions leave little margin for variability in materials, application or site temperature conditions.

The chip spreader should follow and maintain a distance of 65 to 100 feet from the asphalt rubber distributor. The asphalt rubber binder must be fluid so the rock will be embedded by the displacement of the asphalt.

Trucks should back into the spreader box and should not cross over any exposed asphalt rubber membrane. This is illustrated in the photo on the right (Spreading Precoated Aggregates); the chip spreader is in the foreground of the photo, and the raised bed of the haul truck can be seen behind the spreader. The speeds and paths of the trucks hauling the chips should be regulated to prevent damage to the new seal and to assist in seating the aggregate. They should turn as little as possible on the new seal.

The chip spreader should be operated at a speed that will prevent the cover aggregate from being rolled as it is being applied. The aggregate supply should be controlled to assure a uniform distribution across the entire box. If an excess of aggregate is spread

in some areas, it should be distributed on the adjacent roadway surface or picked up. However, excess application usually interferes with embedment and adhesion and may lead to future problems with chip loss.

Rolling Asphalt Rubber Chip Seals

Pneumatic-tired rollers are normally used for rolling chip seals because the kneading action of the rubber tires promotes embedment. The tires do not bridge across surface irregularities and depressions, as do steel drums. Unlike RHMA mixes, the tires are in contact with the cover aggregate rather than the asphalt rubber binder, so excessive pickup is rarely a problem.

Rolling of a chip seal is done to orient and embed the rock (get the flat sides down). Rollers should be operated at slow speeds of about 4 to 6 mph so that the rock is set in the binder, not displaced. The number of rollers required depends on the speed of operation, as it takes 2 to 4 passes of the roller to set the rock.

Figure 56. Rolling to embed aggregate into binder.

Sweeping

Sweeping (brooming) removes surplus aggregate from the surface of the new chip seal to minimize flying rocks. Sweeping can usually be started within 30 minutes after chip application. It is desirable to sweep during the cool period of the day using a rotary power broom. The photo at the right shows the surface of a finished asphalt rubber chip seal after sweeping, before application of flush coat and sand. For interlayers, no flush coat or sand is applied.

Figure 57. Sweeping loose aggregate.

Flush Coat

The flush coat consists of an application of fog seal over the new asphalt rubber chip seal followed immediately by a sand cover. The sand cover is applied immediately after application of the emulsion to prevent pick up and tracking of the chip seal material by vehicle tires. The sand must be clean, i.e., free of clay fines or organic material). It is spread using a mechanical device in a single application of about 2 to 6 pounds/square yard or at a rate determined by the Engineer. Loose material should be swept from the roadway within 24 hours of application.

Fog Seals

Fog seals are applied over chip seals to help retain the cover aggregate and provide a more uniform appearance. Fog seals are not applied over SAMI-R because it will be covered with an overlay.

Fog seals typically consist of grade CSS-1, CSS-1h, or CQS-1 asphalt emulsion diluted with 50 percent added water. The standard application rate over asphalt rubber chip seals is about 0.05 to 0.1 gallon per square yard, or as determined by the Engineer.

Traffic Control

Some form of traffic control is required to keep the initial traffic speed on the new chip seal below about 25 mph. Flag persons or signs help, but the most positive means is a pilot car. The primary purpose of the pilot car is to control the speed of the traffic through the project. This traffic will also supply some additional pneumatic tire rolling and kneading action.

HEALTH AND SAFETY

Concerns have been expressed regarding the effects of CRM-modified paving materials on air quality, particularly related to HMA plant emissions and worker health and safety. CRM consists mostly of various types of rubber and other hydrocarbons, carbon black, extender oils, and inert fillers. Most of the chemical compounds in CRM are also present to some extent in paving grade asphalt, although the proportions are likely to differ.

CRM does not include exotic chemicals that present any new health risks. Although several stack emissions and worker exposure studies have been performed throughout the U.S. that have not indicated any increased risk due to CRM-related emissions, concerns seem to persist.

In June 1993, FHWA and the US Environmental Protection Administration (EPA) issued a report on the *Study of The Use of Recycled Paving Material - Report to Congress* which described an analysis of the results of seven studies to compare the relative threats/risks to human health and the environment of HMA to CRM asphalt paving (FHWA/EPA 1993). The report discussed some of the variables that influenced the health and environmental comparison. Conclusions indicated that the data evaluated contained no obvious trends to indicate a significant increase or decrease in emissions attributed to the use of CRM. The FHWA/EPA report recommended further study of this issue. Subsequent studies have been conducted but have not provided enough evidence to change the original conclusions.

Plant Emissions Tests

To evaluate emissions issues, HMA plant "stack tests" were performed during asphalt rubber HMA production in New Jersey (1994), Michigan (O'Connor 1994), Texas (Crockford et al. 1995), and California (AETC 2001). The results generally indicate that emissions measured during asphalt rubber production at HMA plants remain statistically about the same as for HMA and that amounts of any hazardous components and particulates remain below mandated limits (Stout and Carlson 2003). That does not mean that there are no differences in raw emissions data between production of CRM paving materials and HMA; in many cases there are. However, the actual amounts of the various compounds of interest that are measured are typically very small for both HMA and CRM mixes, and the differences measured are not large enough to indicate any adverse impacts.

In 2001, Caltrans investigated emissions at two HMA plants in the San Francisco Bay area. The Bay Area study was the result of severe blue smoke problems that occurred at a plant in November 2000, which were attributed to use of CRM rather than lack of modern emissions controls. A partnership among the Bay Area Air Quality Management District, Caltrans, and paving industry organizations, developed a plan to test HMA plants producing RHMA during summer 2001. The scope of the testing program included the following:

- California Air Research Board Method 429, Determination of Polycyclic Aromatic Hydrocarbons (PAH) Emissions from Stationary Sources
- California Air Research Board Modified Method 5, Determination of Particulate Matter Emissions from Stationary Sources
- Test during production of conventional HMA and RHMA in triplicate at two hot plants
- Testing during normal production runs

The County of Sacramento Public Works Agency conducted stack emission tests at two production facilities, a batch plant and a drum mix plant, to compare emissions during production of RHMA and HMA mixes. The asphalt rubber conformed to Caltrans

requirements for wet-process high-viscosity binder. Although results at the batch plant were influenced by benzene exhaust from haul truck tailpipes in the truck load-out shed (other possible sources were evaluated and ruled out), measured emissions of particulate and specified toxic air contaminants were consistently lower than EPA AP-42*: Compilation of Air Emission Factors* for production of both types of mixes and both types of plants. The results of the stack emission testing included (Roschen 2002):

- Emissions from the production of RHMA are not significantly different than those from the production of HMA
- Asphalt rubber is one of many types of asphalt; and emissions from its production are not dissimilar to the emissions from the production of conventional asphalt binder
- Therefore, existing production plants in the Bay Area that are permitted to produce HMA should be permitted to produce RHMA

Worker Health and Safety

Several studies of worker exposure to potentially hazardous compounds in fumes from CRM-modified asphalt paving materials have been performed. Although the compounds evaluated, terminology and methods may vary among these studies, the same trends are generally repeated. Fumes generated by CRM materials at elevated temperatures compared to HMA mixes often have increased concentrations of several compounds of interest, but these compounds rarely exceed established permissible exposure limits.

NIOSH, in cooperation with FHWA, performed evaluations of possible differences in the occupational exposures and potential health effects of CRM and HMA. NIOSH Health Hazard Evaluations were performed at seven paving projects in Arizona, California, Florida, Indiana, Massachusetts, and Michigan from 1994 through 1997 (Burr et al. 2002). The purposes of the multiple study locations were to assess site-specific information relative to each project to compile results and compare the effects of exposure due to CRM and conventional materials. The assessments included an evaluation of collected area air samples in order to characterize the asphalt fume emission, personal breathing zone air samples to evaluate worker exposures, and a medical component including questionnaires and lung function tests. The NIOSH study showed that the various exposure measurements evaluated for both HMA and CRM asphalt paving were below the NIOSH recommended exposure limits. Based upon the results of the individual study locations, NIOSH did not draw any definitive conclusions regarding the potential health effects of CRM asphalt compared to conventional asphalt. These reports indicate that increases in plant emissions were related to the elevated operating temperatures, not the presence of the CRM.

A 2.5-year study was performed in Southern California to assess the effects of *Exposure of Paving Workers to Asphalt Emissions (When Using Asphalt Rubber Mixes).* The study began in 1989 and results were published in 1991, before fume exhaust ventilation and capture devices were implemented on paving equipment. The study monitored several individual paving workers in direct contact with fumes during HMA paving operations as well as spray applications. The researchers found that emission exposures in asphalt rubber operations did not differ statistically from those of conventional asphalt operations (Rinck and Napier 1991). Based on results of this

study, “there is no evidence to indicate that persons who are involved in the application of asphalt rubber products are at risk from asphalt rubber emissions.”

A worker exposure study of CRM HMA was conducted during highway construction near Holtville, CA (Caltrans Contract Number 11-172504) from November 30 through December 1, 1994 (EnviroGroup nd). Personal exposures were reportedly well under the existing California-OSHA limits. However, measured concentrations of fumes did not vary consistently with respect to mix temperature as has typically been noted in such studies.

In summary, fumes generated by CRM-modified materials at elevated temperatures often have increased concentrations of several compounds of interest compared to conventional asphalt materials, but these rarely exceed established permissible exposure limits. Thus, there is no pattern of evidence that asphalt rubber materials present greater health hazards than conventional asphalt materials.

Water Quality

Water quality is another area of potential concern regarding the use of CRM. Southwestern Laboratories tested leachate from stockpiles of reclaimed CRM pavement milled from IH10 in San Antonio, Texas, to evaluate the potential for contamination of surface runoff and groundwater. Simulated precipitation leachates were prepared to represent the cumulative effects of acid rainwater leaching and were analyzed for the presence of trace metals, volatile organic compounds (VOCs) and semi volatile organic compounds. The only compound of interest that was present at a level above the analytical detection limit was mercury, but levels detected were below EPA limits (Crockford et al. 1995). The report concluded that levels of detectable leachates were too low to be environmentally significant or dangerous.

INSPECTION

MISSION

Your mission is to verify that the final field product is in conformance with the plans and specifications or to document any non-conformance. 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 RHMA 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!

Figure 58. Plant inspection.

INSPECTION AT PLANT

Plant inspection is critical to the success of every RHMA 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
- Check aggregates off the cold feed belt or out of the hot bins 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 RHMA mix for possible laboratory testing. Test as needed.

- Check the temperature of the RHMA in the trucks.
- Haul trucks may need to be covered (tarped) to maintain RHMA 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 SITE

At the construction site, you can 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.

Prior to Paving

For overlays, check existing pavement condition and the following:

- Are cracks over ¼-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 typically require minimum air and pavement temperatures of 55 ºF and rising (verify the requirements for your project). 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.

Figure 59. Steel-wheel roller.

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

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

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

There must be enough 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 290ºF (Greenbook) or 285ºF (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 260ºF.

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

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

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 RHMA 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 RHMA 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?

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

- Is the RHMA mixture smoking excessively? (too hot)
- Is the RHMA mixture stiff? (too cool)
- Is the RHMA mixture shiny or slumped? (Excessive binder - maybe. RHMA mixes may look rich even at correct binder content, so sample and test binder content.)

- Is the RHMA 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 260ºF.

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.

CONCLUSIONS

RHMA 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, RHMA will produce a safe, high-quality, durable, quiet road that is more cost effective than HMA. 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 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.

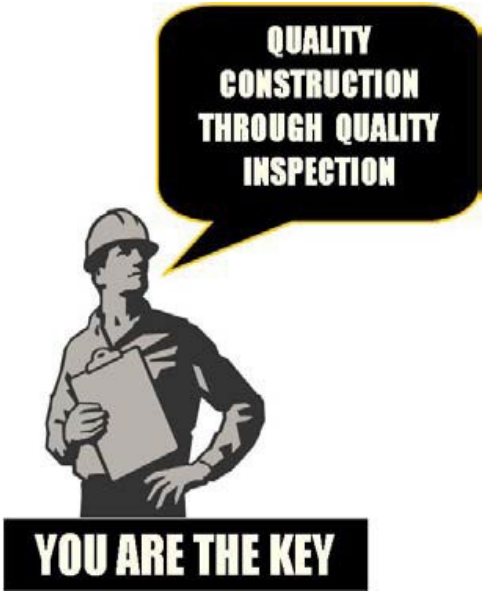

Figure 60. Quality control is key.

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GLOSSARY OF TERMS

Term	Definition
Absorptive capacity	Ability to absorb asphalt influences the total amount of asphalt required. High absorption increases total binder content but not effective binder content.
Affinity to asphalt	Ability of the aggregate to bond with the asphalt binder.
Alligator (fatigue) cracking	Structural failure due to lack of base and/or subgrade support, insufficient pavement thickness, insufficient or aged binder, or water saturation.
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.
Asphalt rubber binder	"A blend of paving grade asphalt cements, ground recycled tire (that is, vulcanized) rubber and other additives, as needed, for use as binder in pavement construction. The rubber shall be blended and interacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles prior to use (ASTM D6114)."
Asphalt rubber	Defined as "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles (ASTM D8)."
Automobile tires	Tires with an outside diameter less than 26 inches used on automobiles, pickups, and light trucks.
Bleeding	Excessive binder content, heavy tack coat, excessive aggregate fines, rounded aggregates, low air void content.
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.
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 sieve size.

Term	Definition
Crumb rubber modifier (CRM)	General term for scrap tire rubber that is reduced in size for use as modifier in asphalt paving materials. produced from grinding up whole scrap tires from automobiles, trucks, or buses, tread buffings, and other waste rubber products. A variety of processes and equipment are used to produce a wide range of CRM gradations for use as modifiers in asphalt paving materials.
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.
Dense-graded	Refers to a continuously graded aggregate blend typically used to make hot mix asphalt with conventional or modified binders.
Design asphalt content	Depends on aggregate gradation (particularly VMA), ability to absorb asphalt, and compaction type and effort. Typically, too much 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 asphalt rubber mixes due to limitations on percentage passing the No. 200 sieve size.
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.
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 HMA mixes 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.

Term	Definition
Ductility	The ability to deform. Discrete CRM particles affect test results, which typically exhibits early fracture.
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.
Edge failure	Insufficient thickness, lack of lateral support, base saturated or heavy wheel loads.
Extender oil	Aromatic oil used to promote the reaction of the asphalt cement and the crumb rubber modifier.
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.
Flashpoint	Temperature at which a sample "flashes" i.e. bursts into flame.
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.
Flush coat	Fog seal followed by sand application.
Fog seal	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 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 sieve size. This type of gradation is most frequently used to make asphalt rubber gap graded paving mixtures.
Granulation	Produces cubical, uniformly shaped, cut crumb rubber particles with a low surface area.

Term	Definition
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 size.
Ground crumb rubber modifier	Irregularly shaped, torn scrap rubber particles with a large surface area, generally produced by a cracker mill.
High natural rubber (high natural CRM)	Scrap rubber product that includes 40-48% natural rubber or isoprene and a minimum of 50% rubber hydrocarbon according to Caltrans and Greenbook 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.
Interaction	The physical exchange between asphalt cement and CRM when blended 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.
Life cycle cost analysis	Tool to determine the most cost-effective option among different competing alternatives.
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.
Longitudinal cracking	Usually manifests along paving joints; if located in the wheel paths, it is typically a precursor to alligator cracking.
Transverse cracking	Typically caused by environmental stresses, such as thermal cracking or block cracking in aged pavements.
Micro-mill	Process that further grinds crumb rubber particles to sizes below the No. 40 (425 mm) sieve size.

Term	Definition
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.
Penetration	Hardness value, also measure of consistency at single temperature.
Performance grade binders	Asphalt binder grading system based on performance characteristic related to climatic and aging conditions.
Permeability	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 typically have larger individual voids.
Potholes	Localized 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.
Raveling	Lean (low binder content) or overheated mix. Low density/under compacted. Aged binder.
Reaction	Commonly used term for the interaction between asphalt cement and crumb rubber modifier when blended 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.
Rotational viscometer	Measures the torque required to rotate a disk in a fluid at a known speed. The torque required to turn an object in a fluid is a function of viscosity.

Term	Definition
Asphalt rubber HMA	Material produced for hot mix applications by mixing asphalt rubber or rubberized asphalt binder with graded aggregate. May be dense-, gap-, or open-graded.
Rubberized asphalt	General term that applies to a broad family of asphalt binder products that contain scrap tire rubber that may or may not comply with the ASTM definition of asphalt rubber.
Shredding	Process that reduces scrap tires to pieces 6 in^2 and smaller prior to granulation or ambient grinding.
Skid resistance	Measures the ability of the asphalt surface to resist skidding or slipping of vehicle tires.
Slipping	High shear strains, lack of bond with underlying layer due to improper tack coating or inadequate cleaning of existing surface.
Specific gravity	Used in volumetric mix design calculations, and for metering during mix production.
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.
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 depending on the size of the cover aggregate. Primarily used 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.
Stress-absorbing membrane interlayer (SAMI)	An asphalt rubber SAM that is overlaid with an asphalt paving mix that may or may not include CRM. The SAMI delays the propagation of the cracks (reflective cracking) through the new overlay. Originally defined as a spray application of asphalt rubber binder and cover aggregate, interlayers now may include asphalt rubber chip seal, fabric, or fine unbound aggregate.

Term	Definition
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 resulting in removal of material.
Terminal blend	See wet process – no agitation.
Thin Film Test	Aging methods.
Rolling Thin Film Test	Test conducted to simulate short term aging of asphalt binder prior to conducting physical property testing. Test involves exposing asphalt binder to elevated temperatures to simulate aging due to manufacturing and placement.
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.
Tread rubber	Scrap tire rubber that consists primarily of tread rubber with less than approximately 5 percent sidewall rubber.
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	Property of resistance to flow (shearing force) in a fluid or semi-fluid (temperature dependent). 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.
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.
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.
Weathering	Insufficient binder content during mix production, loss of binder due to stripping or raveling, overheating, or absorptive aggregates, aging of the binder.

Term	Definition
Wet process	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 or using in a spray application. Includes thorough mixing of the CRM in hot asphalt cement (typically 400ºF to 425ºF) and holding the resulting blend at elevated temperatures (325ºF to 425F) for a designated minimum period of time (typically 45 to 60 minutes) to promote an interaction between the CRM and the asphalt. Other components such as extender oil (asphalt modifier) and high natural CRM may be included, depending on applicable specifications.
Wet process-high viscosity	CRM-modified binders that maintain or exceed the minimum rotational viscosity threshold of 1500 cPs at 375ºF (190ºC) 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%.

Term	Definition
Wet process-no agitation	A form of the wet process where CRM is blended with hot asphalt 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 does not require subsequent agitation to 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. 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 375ºF, that is necessary to significantly increase binder contents above those of conventional HMA mixes without excessive drain-down. One advantage is these products can be applied at much lower temperature without the need for specialized equipment.
Whole tire rubber	Scrap tire rubber that includes tread and sidewalls in proportions that approximate the respective weights in an average tire.
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; gap-graded 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.

APPENDIX – SPECIFICATION TEMPLATES

RUBBERIZED HOT MIX ASPHALT GAP-GRADED

Disclaimer

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Notes on Terminology

Standardization of terminology for pavement materials is problematic in general, and materials containing crumb rubber are no exception. The terminology used in this specification is "**Rubberized Hot Mix Asphalt Gap Graded (RHMA-G)**". This terminology is consistent with current Caltrans specifications. The Greenbook uses the term "**Asphalt Rubber Hot Mix – Gap Graded (ARHM-GG)**".

RUBBERIZED HOT MIX ASPHALT GAP-GRADED

1. General

1.1. Scope

This work consists of constructing a rubberized hot mix asphalt gap graded (RHMA-G) overlay on an existing pavement surface.

1.2. Definitions

RHMA-G: Mixture of paving asphalt, asphalt modifier, crumb rubber modifier, and gap-graded aggregate mixed in a central mixing plant.
Crumb rubber modifier (CRM): Combination of ground or granulated scrap tire and high natural crumb rubber.
Scrap tire crumb rubber: Any combination of:

1. Automobile tires
2. Truck tires
3. Tire buffing

High natural crumb rubber: Material containing between 40 to 48 percent natural rubber.
Fine aggregate: Aggregate passing the no. 4 sieve.
Coarse aggregate: Aggregate retained on the no. 4 sieve.
Asphalt modifier: A resinous, high flash point, and aromatic hydrocarbon.

1.3. Submittals

The Contractor shall comply with all Federal, State, and Local environmental laws, rules, regulations, and ordinances including, but not limited to, air quality requirements.
At least 10 days before starting any RHMA-G activities, submit the name of an authorized laboratory to perform quality control (QC) testing for RHMA-G. The authorized laboratory must comply with the Caltrans Independent Assurance Program (IAP) or possess current AASHTO Material Reference Laboratory (AMRL) accreditation for all required ASTM and AASHTO tests.

AMRL does not certify labs to conduct most of the relevant California Test methods. The Caltrans IAP certifies labs to perform California Test methods, but only labs with active Caltrans projects are eligible to receive the Caltrans accreditation.

The process for a testing laboratory to obtain Caltrans Accreditation is discussed in the Caltrans' Independent Assurance Manual, Procedures for Accreditation of Laboratories and Qualification of Tester. To obtain an accessible version of this document, please go to the following Caltrans web page: Request ADA Compliant Documents.

Contractor shall submit to the Agency a certified volume or weight slip for each delivery of asphalt rubber binder ingredients and RHMA-G.

At least 14 days before use, submit:

1. Four each one-quart cans of mixed asphalt rubber binder
2. Samples of each asphalt rubber binder ingredient
3. SDS for each hazardous material
4. Asphalt rubber binder formulation, including:
   - 4.1. Source and grade of asphalt binder
   - 4.2. Source and type of asphalt modifier
   - 4.3. Each source and type of scrap tire crumb rubber and high natural crumb rubber
   - 4.4. Percentage of asphalt modifier by weight of asphalt binder
   - 4.5. Percentage of combined asphalt binder and asphalt modifier by weight of asphalt rubber binder
   - 4.6. Percentage of scrap tire crumb rubber and high natural crumb rubber by total weight of asphalt rubber binder
   - 4.7. Percentage of scrap tire crumb rubber and high natural crumb rubber by total weight of crumb rubber modifier
   - 4.8. Minimum reaction time and temperature
5. Test results
   - 5.1. Certificate of Compliance showing the asphalt binder is the required PG grade
   - 5.2. Test results showing the asphalt modifier meets the requirements in Table 1
   - 5.3. Test results showing each source of CRM meets the requirements in Tables 2, 3, and 4
   - 5.4. Test results showing the asphalt rubber binder meets the requirements in Tables 5 and 6
   - 5.5. Test results showing the aggregate meets the requirements in Tables 7 and 8
   - 5.6. Test results showing the RHMA-G meets the requirements in Table 9
6. JMF Forms
   - 6.1. Caltrans Contractor Job Mix Formula Proposal form CEM-3511
   - 6.2. Caltrans Contractor Hot Mix Asphalt Design Data form CEM-3512
   - 6.3. Caltrans Hot Mix Asphalt Verification form CEM-3513, if available
   - 6.4. Caltrans Job Mix Formula Renewal form CEM-3514, if available

1.4. Job Mix Formula (JMF)

Contractor shall submit the proposed JMF for each type of RHMA-G to be used. The Contractor is required to submit mix design documentation that has been dated within 12 months of submittal. The Contractor shall submit the test results for the RHMA-G showing that the mixture meets all of the requirements as shown in Section 2.6 of these specifications.

The JMF must be submitted on the Caltrans Contractor Job Mix Formula Proposal form CEM-3511 along with:

1. Mix design documentation on Caltrans Contractor Hot Mix Asphalt Design Data form CEM-3512. Also report the theoretical maximum specific gravity for the RHMA-G.
2. JMF verification on a Caltrans Hot Mix Asphalt Verification form CEM-3513, if available.
3. JMF renewal on a Caltrans Job Mix Formula Renewal form CEM-3514, if available.

The JMF forms do not need to be Caltrans approved, however, the Contractor is encouraged to submit them to the Agency if the Contractor has these forms available.

To obtain an accessible version of these forms, please go to the following Caltrans web page: Request ADA Compliant Documents.

1.5. Quality Control Program

Develop, implement, and maintain a QC program.

Contractor shall prepare and maintain QC records, including:

1. Names and qualifications of:
   1.1. Samplers
   1.2. Testers
   1.3. Inspectors
2. Testing laboratories
3. Testing equipment calibrations and certifications
4. Construction inspection reports
5. Sampling and testing records organized by date and type of material
6. Test results with comparison of quality characteristic requirements
7. Test results in relation to action and any suspension limits
8. Records of corrective actions and suspensions

Contractor shall notify the Agency within 24 hours of any noncompliance identified by the QC program.

1.6. Quality Control Manager

Contractor shall assign a QC manager before the start of the affected work. The QC manager must receive, review, and approve all correspondence, submittals, and reports relating to the QC of materials before they are submitted to the Agency. The QC manager must be the sole individual responsible for:

1. Signing the QC plan
2. Implementing the QC plan
3. Maintaining the QC records

The QC manager must be Contractor's employee or must be hired by a subcontractor providing only QC services. The QC manager must not be employed or compensated by a subcontractor or by any other persons or entities hired by subcontractors who will provide services or material for the project.

1.7. Preconstruction Meeting

At least 3 business days before the start of surfacing and pavement operations, the following Contractor personnel shall attend a preconstruction meeting:

1. Project Manager
2. QC manager
3. Project superintendent
4. Project foreman
5. Plant manager
6. Traffic control foreman
7. Subcontractors' foremen
8. RHMA-G supplier
9. Paving foreman

Contractor shall be prepared to discuss the project specifications and the processes for producing materials and constructing each item of work, including:

1. Quality assurance
   - 1.1. Quality control
   - 1.2. Agency acceptance
2. Placement of materials:
   - 2.1. Training
   - 2.2. Checklists
   - 2.3. Test strips (if required)
3. Contingency plan
4. Issues specific to the project, including:
   - 4.1. Weather
   - 4.2. Alignment and geometrics
   - 4.3. Traffic control issues
   - 4.4. Haul distances
   - 4.5. Presence and absence of shaded areas
   - 4.6. Other local issues

The preconstruction meeting is optional. A preconstruction meeting may not be necessary on small-scale projects. If there will be a large amount of RHMA-G material placed, then a preconstruction meeting is recommended. The Agency may decide whether or not to require the Contractor to conduct a preconstruction meeting, and should edit or delete the preceding section as appropriate.

2. Materials

2.1 Asphalt Binder

Asphalt binder must be **[**PG 58-22**] [**PG 64-16**]**

The Agency may select either PG 58-22 or PG 64-16 binder. Delete the statement for the binder not selected. PG 64-16 is typically preferred for the Central Valley and low altitude areas of Southern California. In Northern coastal, Sierra, and Northeastern California PG 58-22 is typically preferred.

[Asphalt Binder must comply with Section 92 of the current Caltrans Standard Specifications.**]**

[Asphalt Binder must comply with Section 203-1 of the current Greenbook Standard Specifications.**]**

The Agency may choose to reference either the current Caltrans Standard Specifications or the current Greenbook. Delete the statement for the reference not selected.

2.2. Asphalt Modifier

Asphalt modifier must be a resinous, high flash point, aromatic hydrocarbon. Asphalt modifier must comply with the requirements shown in Table 1.

Table 1: Asphalt Modifier for Asphalt Rubber Binder

Quality Characteristic	Test Method	Requirement
Viscosity at 212°F, (cST)	ASTM D445	X ± 3*
Flash point (CL.O.C., °F)	ASTM D92	405 min
Asphaltenes (% mass)	ASTM D2007	0.1 max
Aromatics (% mass)	ASTM D2007	55 min

* *X* denotes the asphalt modifier viscosity from 19 to 36 as proposed by the Contractor. The proposed value *"X"* shall be submitted in writing to the Agency. A change in *X* requires a new asphalt rubber binder submittal.

2.3. Crumb Rubber Modifier

Crumb rubber modifier (CRM) shall consist of a combination of scrap tire CRM and high natural CRM. The scrap tire CRM shall consist of ground or granulated rubber derived from any combination of automobile tires, truck tires or tire buffings. The high natural CRM shall consist of ground or granulated rubber derived from materials that utilize high natural rubber sources. Scrap tire crumb rubber and high natural crumb rubber must be delivered to the asphalt rubber binder production site in separate bags and shall be sampled and tested separately.
Steel and fiber must be separated. If steel and fiber are cryogenically separated, it must occur before grinding and granulating. Cryogenically-produced CRM particles must be large enough to

be ground or granulated. Cryogenically produced CRM particles that pass through the grinder or granulator without being ground or granulated, respectively, shall not be used.
The CRM must comply with the requirements shown in Tables 2, 3 and 4.

Quality Characteristic	Test Method	Requirement
Cone penetration at 77°F (0.0004 inch)	ASTM D217	25–70
Resilience at 77°F (% rebound)	ASTM D5329	18 min
Softening point (°F)	ASTM D36/D36M	125-165
Viscosity at 375°F (cP)[a]	ASTM D7741/D7741M	1,500–4,000

Table 2: Crumb Rubber Modifier Physical Requirements

Quality Characteristic	Test Method	Requirement
Wire in CRM (%)	California Test 385	0.01 max
Fabric in CRM (%)	California Test 385	0.05 max
CRM specific gravity	California Test 208	1.1 to 1.2

Table 3: Crumb Rubber Modifier Chemical Requirements

Quality Characteristic	Test Method	Scrap Tire	High Natural
Acetone extract (%)	ASTM D297	6.0 to 16.0	4.0 to 16.0
Rubber hydrocarbon (%)	ASTM D297	42.0 to 65.0	50.0 min
Natural rubber content (%)	ASTM D297	22.0 to 39.0	40.0 to 48.0
Carbon black content (%)	ASTM D297	28.0 to 38.0	---
Ash content (%)	ASTM D297	8.0 max	---

Table 4: Crumb Rubber Gradation Requirements

Sieve Size	*Scrap Tire, % passing*	*High Natural, % passing*
#8	100	100
#10	98 to 100	100
#16	45 to 75	95 to 100
#30	2 to 20	35 to 85
#50	0 to 6	10 to 30
#100	0 to 2	0 to 4
#200	0	0 to 1

2.4. Asphalt Rubber Binder

Asphalt rubber binder must be a combination of:

1. Asphalt binder
2. Asphalt modifier

3. Crumb rubber modifier

Asphalt rubber binder blending equipment must be authorized under the Caltrans Material Plant Quality Program. The blending equipment must allow the determination of weight percentages of each asphalt rubber binder ingredient.
Asphalt rubber binder must be 80 ± 2 percent by weight asphalt binder and asphalt modifier. The minimum percentage of CRM must be 20 ± 2 percent. CRM must be 75 ± 2 percent by weight scrap tire crumb rubber and 25 ± 2 percent by weight high natural crumb rubber.
Asphalt modifier and asphalt binder must be blended at the production site. Asphalt modifier must be from 2.0 to 6.0 percent by weight of the asphalt binder in the asphalt rubber binder. The asphalt rubber binder supplier determines the exact percentage.
The blend of asphalt binder and asphalt modifier must be combined with the CRM at the asphalt rubber binder production site. Proportion and mix asphalt binder, asphalt modifier, and CRM simultaneously or premix the asphalt binder and asphalt modifier before adding CRM. If premixing the asphalt binder and asphalt modifier, mix them for at least 20 minutes. The asphalt binder and asphalt modifier blend must be from 375 to 440 °F when the CRM is added. Combined ingredients must be allowed to react at least 45 minutes at temperatures from 375 to 425 °F except the temperature shall not be higher than 25 °F below the actual flashpoint of the asphalt modifier. Do not use the asphalt rubber binder during the first 45 minutes of the reaction period.
After reacting for at least 45 minutes, the asphalt rubber binder must comply with the requirements shown in Table 5.

Table 5: Asphalt Rubber Binder

Quality Characteristic	Test Method	Requirement
Cone penetration at 77°F (0.0004 inch)	ASTM D217	25 to 70
Resilience at 77°F (% rebound)	ASTM D5329	18 min
Softening point (°F)	ASTM D36/D36M	125 to 165
Viscosity at 375°F (cP)[a]	ASTM D7741/D7741M	1,500 to 4,000

[a] Prepare sample for viscosity test in accordance with California Test 388.

Stop heating unused asphalt rubber binder 4 hours after the 45-minute reaction period. If the asphalt rubber binder drops below 375°F, reheat before use. Reheating asphalt rubber binder that cools below 375°F is a reheat cycle. Do not exceed two reheat cycles. If reheating, asphalt rubber binder must be from 375 to 425°F before use.
During reheating, scrap tire crumb rubber may be added. Scrap tire crumb rubber must not exceed 10 percent by weight of the asphalt rubber binder. Allow added scrap tire crumb rubber to react for at least 45 minutes. Reheated asphalt rubber binder must comply with the specifications for asphalt rubber binder.
Asphalt rubber binder shall be designed from testing for each quality characteristic and for the reaction temperatures expected during production. The profile must include the same component sources for the asphalt rubber binder used. The 24-hour (1,440-minute) interaction period determines the design profile. At a minimum, mix asphalt rubber binder components, take samples, and perform and record the tests shown in Table 6.

Table 6: Asphalt Rubber Binder Reaction Design Profile

Quality Characteristic	Test Method	45 min [a]	60 min [a]	90 min [a]	120 min [a]	240 min [a]	360 min [a]	1,440 min [a]	Limit[c]
Cone penetration at 77°F (0.0004 inch)	ASTM D217	X [b]	---	---	---	X	---	X	25 to 70
Resilience at 77°C (min, % rebound)	ASTM D5329	X	---	---	---	X	---	X	18
Softening point (°F)	ASTM D36/ D36M	X	---	---	---	X	---	X	125 to 165
Viscosity (cP)[a]	ASTM D7741/ D7741M	X	X	X	X	X	X	X	1,500 to 4,000

[a] Six hours (360 minutes) after CRM addition, reduce the oven temperature to 275°F for 16 hours. After the 16-hour (960 minutes) cool down after CRM addition, reheat the binder to the reaction temperature expected during production for sampling and testing at 24 hours (1,440 minutes).
[b] "*X*" denotes required testing.
[c] The values presented in this table are for binder design only and are not to be used for material acceptance.

The purpose of performing an asphalt rubber binder design profile is to determine if the crumb rubber modifier and asphalt binder are compatible and if the asphalt rubber binder will remain stable. While the Contractor is required to perform the design profile, the design profile is not intended to be used for acceptance of the asphalt rubber binder.

2.5. Aggregate

Reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) are not allowed in RHMA-G.

Aggregate for RHMA-G must comply with the gradation requirements shown in Table 7.

Table 7: Aggregate Gradation Requirements for RHMA-G, Percent Passing by Weight

Sieve Size	*½-inch Target value limit*	*1/2-inch Allowable tolerance*
¾-inch	100	---
½-inch	90 to 98	± 6
3/8-inch	83 to 87	± 5
#4	28 to 42	± 6
#8	14 to 22	± 5
#200	0 to 6	± 2.0

The aggregate must also comply with the requirements shown in Table 8.

Table 8: Aggregate Requirements

Quality Characteristics	Test Method	Requirement
Percent of crushed particles Coarse aggregate (%) One-fractured face Two-fractured faces Fine aggregate (%) (Passing #4 sieve and retained on #8 sieve.) One-fractured face	AASHTO 335	 --- 90 min 70 min
Los Angeles Rattler, Loss at 100 Rev. (%) Los Angeles Rattler, Loss at 500 Rev. (%)	AASHTO T 96	12 40
Sand equivalent (min)[a]	AASHTO T 176	47
Fine aggregate angularity (min, %)[b]	AASHTO T 304, Method A	45

[a] Reported value must be the average of three tests from a single sample. A reading indicator is required in AASHTO T 176, Figure 1. Sections 4.7, "Manual Shaker'" 7.1.2, "Alternate Method Number 2," and 8.4.3, "Hand Method," do not apply. Prepare the stock solution as specified in Section 4.8.1, "Stock solution with formaldehyde," except omit the addition of formaldehyde.

[b] The Agency waives this specification if RHMA-G contains 10 percent or less of nonmanufactured sand by weight of total aggregate unless your JMF fails verification. Manufactured sand is fine aggregate produced by crushing rock or gravel.

2.6. Mixture

RHMA-G mixture must comply with the requirements shown in Table 9.

The Agency may choose either the Superpave method and criteria or the Hveem method and criteria to design the RHMA-G mixture. Delete the mix design section that is not selected

[Table 9: RHMA-G Requirements for Superpave Mix Design

Quality Characteristic	Test method	Requirement
Air voids content (%)	AASHTO T 269	N_{design} = 4.0
Gyration compaction (no. of gyrations)	AASHTO T 312	N_{design} = 50 to 150a
Voids in mineral aggregate (min, %)	SP-2 Asphalt Mixture Volumetrics	18.0 to 23.0
Dust proportion	SP-2 Asphalt Mixture Volumetrics	Report only
Bulk specific gravity	AASHTO T 275, Method A	Report only
Theoretical maximum specific gravity	AASHTO T 209, Method Ab	Report only
Hamburg wheel track (min number of passes at 0.5-inch rut depth) Binder grade: PG 58 PG 64	AASHTO T 324 (Modified)c	 15,000 20,000

Quality Characteristic	Test method	Requirement
Minimum asphalt rubber binder content (%, by total weight of mix)	d	7.5

[a] Superpave gyratory compactor ram pressure may be increased to a maximum of 825 kPa, and specimens may be held at a constant height for a maximum of 90 minutes.
[b] Calculate the air voids content of each specimen using AASHTO T 275, Method A, to determine bulk specific gravity. Use AASHTO T 209, Method A, to determine theoretical maximum specific gravity. Under AASHTO T 209, use a digital manometer and pycnometer when performing AASHTO T 209.
[c] Test plant-produced RHMA-G.
[d] Once determined by the mix design, the production tolerance shall be + 0.5% / -0.4%, but in no case shall the binder content be less than 7.5% by total weight of mix (8.1% by dry weight of aggregate) as determined by California Test 362, 379, or 382.

Determine the quantity of asphalt rubber binder to be mixed with the aggregate for the RHMA-G as follows:

1. Base the calculations on the average of three briquettes produced at each asphalt rubber binder content.
2. Plot asphalt rubber content versus average air voids content for each set of three specimens and connect adjacent points with a best-fit curve.
3. Calculate voids in mineral aggregate for each specimen, average each set, and plot the average versus asphalt rubber binder content.
4. Calculate the dust proportion and plot versus asphalt rubber binder content.
5. From the curve plotted, select the theoretical asphalt rubber binder content at 4 percent air voids.
6. At the selected asphalt rubber binder content, calculate the dust proportion.
7. Record the asphalt rubber binder content as the optimal binder content (OBC).

Laboratory mixing and compaction must comply with AASHTO R 35, except the mixing temperature of the aggregate must be from 300 to 325°F. The mixing temperature of the asphalt rubber binder must be from 375 to 425°F. The compaction temperature of the combined mixture must be from 290 to 320°F.

There are no requirements for the dust proportion for the RHMA-G mixture, but this value must be reported by the Contractor.**]**

[Table 9: RHMA-G Requirements for Hveem Mix Design

Quality characteristic	Test Method	Requirement
Air voids content (%)	AASHTO T 269a	4
Voids in mineral aggregate (%)	Asphalt Institute MS-2	18.0 to 23.0
Dust proportion	Asphalt Institute MS-2	Report only
Bulk specific gravity	AASHTO T 275 Method A	Report only
Theoretical maximum specific gravity	AASHTO T 209 Method Aa	Report only
Moisture susceptibility (psi, dry strength)	AASHTO T 283b	100 min
Moisture susceptibility (psi, wet strength)	AASHTO T 283b,c	70 min
Asphalt rubber binder content (%, by dry weight of aggregate)d	d	8.1 min

[a] Calculate the air voids content of each specimen using AASHTO T 275, Method A, to determine bulk specific gravity. Use AASHTO T 209, Method A, to determine theoretical maximum specific gravity. Under AASHTO T 209, use a digital manometer and pycnometer when performing AASHTO T 209.
[b] Test plant produced RHMA-G.
[c] Freeze thaw required
[d] Once determined by the mix design, the production tolerance shall be + 0.5% / -0.4%, but in no case shall the binder content be less than 7.5% by total weight of mix (8.1% by dry weight of aggregate) as determined by California Test 362, 379, or 382.

The OBC shall be determined by California Test 367, except that Step 2 regarding surface flushing shall not be used. OBC shall be determined by using a void content of 4 percent or less. Compaction shall be in accordance with California Test 34, except for the following:

1. Mixing temperature of asphalt rubber binder shall be from 325 to 360°F.
2. Mixing temperature of aggregate shall be from 290 to 325°F.
3. Compaction temperature shall be from 290 to 300°F.**]**

3. Quality Control

3.1. Asphalt Modifier

Test asphalt modifier under the test methods and frequencies shown in Table 10.

Table 10: Asphalt Modifier Testing Frequencies

Quality characteristic	Test Method	Frequency
Viscosity	ASTM D445	1 per project
Flash point	ASTM D92	1 per project
Asphaltenes	ASTM D2007	1 per project
Aromatics	ASTM D2007	1 per project

3.2. Crumb Rubber Modifier

If multiple sources of scrap tire CRM are used, the tests shall be performed on each source separately. Test CRM under the test methods and frequencies shown in Table 11.

Table 11: Crumb Rubber Modifier Testing Frequencies

Quality characteristic	Test method	Frequency
CRM gradation	California Test 385	1 per shipment
Wire in CRM	California Test 385	1 per shipment
Fabric in CRM	California Test 385	1 per shipment
CRM specific gravity	California Test 208	1 per shipment

3.3. Asphalt Rubber Binder

Test asphalt rubber binder under the test methods and frequencies shown in Table 12.

Table 12: Asphalt Rubber Binder Testing Frequencies

Quality Characteristic	Test Method	Sampling Location	Frequency
Viscosity at 375 °F	ASTM D7741/ D7741M	Reaction vessel	1 per batch of asphalt rubber binder
Cone penetration	ASTM D217	Reaction vessel	1 per batch of asphalt rubber binder
Resilience	ASTM D5329	Reaction vessel	1 per batch of asphalt rubber binder
Softening point	ASTM D36/36M	Reaction vessel	1 per batch of asphalt rubber binder

Retain the sample from each batch. A batch shall consist of all asphalt rubber material that is blended together from the raw materials (asphalt binder, asphalt modifier, CRM). Each time asphalt binder, asphalt modifier, and CRM are blended together the resulting material will be considered a batch.

Log the test results, including time of testing and temperature of the asphalt rubber binder. Submit the log of asphalt rubber binder viscosity test results each day of asphalt rubber binder application to the Agency within 24 hours. The Agency shall be notified of production schedule of all asphalt rubber binder produced for the work. The Agency reserves the right to observe QC testing of the asphalt rubber binder.

3.4. Aggregate

Test the quality characteristics of aggregates under the test methods and frequencies shown in Table 13.

Table 13: Aggregate Testing Frequencies

Quality Characteristic	Test Method	Frequency
Gradation	AASHTO T 27	Startup and 1 per 750 tons
Sand equivalent[a, b]	AASHTO T 176	Startup and 1 per 750 tons
Moisture content[c]	AASHTO T 255	Startup and 1 per 750 tons
Crushed particles	AASHTO T 335	1 per project[d]
Los Angeles Rattler	AASHTO T 96	1 per project[d]
Flat and elongated particles	ASTM D4791	1 per project[d]
Fine aggregate angularity	AASHTO T 304, Method A	1 per project[d]

[a] Reported value must be the average of 3 tests from a single sample

[b] Use of a sand reading indicator is required as shown in AASHTO T 176, Figure 1. Sections 4.7, “Manual Shaker’” 7.1.2, “Alternate Method Number 2,” and 8.4.3, “Hand Method,” do not

apply. Prepare the stock solution as specified in Section 4.8.1, “Stock solution with formaldehyde,” except omit the addition of formaldehyde.
[c] Test at continuous mixing plants only. For lime-treated aggregate, test aggregate before treatment and test for gradation and moisture content during RHMA-G production.
[d] At the discretion of the Agency, testing for crushed particles, Los Angeles Rattler, Flat and elongated particles, and/or fine aggregate angularity performed during the mix design, mix design verification, or mix design renewal may be used in lieu of testing during the project.

3.5. Mixture

Test the quality characteristics of RHMA-G under the test methods and frequencies shown in Table 14.

[Table 14: RHMA-G Requirements for Superpave Mix Design

Quality Characteristic	Test Method	Frequency
Air voids content (%)	AASHTO T 269	1 per 2,000 tons but not less than 1 per paving day
Asphalt rubber Binder Content	Note [a] below	1 per 2,000 tons but not less than 1 per paving day
RHMA-G moisture content	AASHTO T 329	1 per 2,000 tons but not less than 1 per paving day
Voids in mineral aggregate (min, %)	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Dust proportion	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Hamburg wheel track	AASHTO T 324 (Modified)	1 per 10,000 tons but not less than 1 per project
Nuclear gauge density[b]	ASTM D 2950	3 per 250 tons but not less than 3 per paving day

[a] Once the percent asphalt rubber binder is determined by the mix design, the production tolerance shall be + 0.5% / -0.4%, but in no case shall the binder content be less than 7.5% by total weight of mix (8.1% by dry weight of aggregate) as determined by California Test 362, 379, or 382.
[b] Calibrated to cores using CTM 375 or other means.

Laboratory mixing and compaction must comply with AASHTO R 35, except the mixing temperature of the aggregate must be from 300 to 325°F. The mixing temperature of the asphalt rubber binder must be from 375 to 425°F. The compaction temperature of the combined mixture must be from 290 to 320°F.**]**

[Table 14: RHMA-G Requirements for Hveem Mix Design

Quality characteristic	Test method	Frequency
Air voids content (%)	AASHTO T 269	1 per 2,000 tons but not less than 1 per paving day
Asphalt rubber Binder Content	Note [a] below	1 per 2,000 tons but not less than 1 per paving day
RHMA-G moisture content	AASHTO T 329	1 per 2,000 tons but not less than 1 per paving day
Voids in mineral aggregate (min, %)	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Dust proportion	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Moisture susceptibility	AASHTO T 283	1 per 10,000 tons but not less than 1 per project
Nuclear gauge densityb	ASTM D2950	3 per 250 tons but not less than 3 per paving day

[a] Once the percent asphalt rubber binder is determined by the mix design, the production tolerance shall be + 0.5% / -0.4%, but in no case shall the binder content be less than 7.5% by total weight of mix (8.1% by dry weight of aggregate) as determined by California Test 362, 379, or 382.

[b] Calibrated to cores using CTM 375 or other means.

Laboratory compaction shall be in accordance with California Test 304, except for the following: Compaction temperature shall be from 290 to 300°F.**]**

Table 14 should be consistent with Table 9.

4. Construction

4.1. Equipment

4.1.1. Production

All equipment used to blend, store, and transport crumb rubber, asphalt modifier, asphalt rubber binder, and RHMA-G shall comply with the requirements of Caltrans Material Plant Quality Program (MPQP) unless otherwise authorized in writing by the Agency.

The Agency reserves the right to require approval of equipment by the Agency prior to use.

4.1.2. Placing/Spreading

Paving equipment for spreading must be:

1. Self-propelled
2. Mechanical
3. Equipped with a screed or strike-off assembly that can distribute RHMA-G the full width of a traffic lane
4. Equipped with a full-width compacting device
5. Equipped with automatic screed controls and sensing devices that control the thickness, longitudinal grade, and transverse screed slope

Install and maintain grade and slope references. The screed must be heated and produce a uniform RHMA-G surface texture without tearing, shoving, or gouging. The paver must not leave marks such as ridges and indentations.

All trucks transporting RHMA-G to the jobsite shall be completely covered with tarpaulins, which are fully secured, during transport.
Rollers must be equipped with a system that prevents RHMA-G from sticking to the wheels.
Contractor must use a parting agent that does not damage the RHMA-G or impede the bonding of layers.
In areas inaccessible to spreading and compacting equipment:

1. Spread the RHMA-G by any means to obtain the specified lines, grades, and cross sections
2. Use a pneumatic tamper, plate compactor, or equivalent to achieve thorough compaction.

The use of a material transfer vehicle is allowed. The material transfer vehicle must have sufficient capacity to prevent stopping the paver and must be capable of:

1. Either receiving RHMA-G directly from trucks or using a windrow pickup head to load it from a windrow deposited on the roadway surface
2. Remixing the RHMA-G with augers before transferring into the paver's receiving hopper or feed system
3. Transferring RHMA-G directly into the paver's receiving hopper or feed system

4.2. Compaction

The Contractor shall not use a pneumatic-tired roller to compact any RHMA-G material.
Each roller must have a separate operator. Rollers must be self-propelled and reversible.

4.3. Surface Preparation

The Contractor shall remove all existing traffic stripes, markings, crosswalks, stop bars, and legends; and raised pavement markers in areas to receive RHMA-G and any adjacent areas as directed by the Agency. Removal shall be done by sand blasting or grinding and disposing of by the Contractor. Grinding or sand blasting operations shall be conducted to keep all removed pavement material from entering the storm drain system. Said removal shall not occur sooner than 2 calendar days prior to the day that the RHMA-G will be placed.
Existing pavement striping, markings, or markers which are outside the work area and not to be removed, shall be protected by the Contractor. Any striping, markings, or markers to remain damaged or rendered useless by the Contractor's operations shall be restored by the Contractor to the Agency's satisfaction and at the Contractor's expense.
Following herbicide spraying, all vegetation shall be removed from the cracks in the pavement and from all joints between the pavement and concrete gutters by the Contractor.
On the day that a street receives RHMA-G material, it shall be swept without the use of water. Pavement must be completely dry prior to placement of RHMA-G. The Contractor shall not begin any activities related to the placement of RHMA-G on any street until the Agency has approved the street cleaning.
Apply a tack coat on the existing pavement surface and on the vertical surfaces of any curbs, gutters, and construction joints. Apply the tack coat at a rate shown in Table 15, or as otherwise ordered by the Agency:

Table 15: Tack Coat Application Rates for RHMA-G

RHMA-G over:	Minimum residual rates (gal/sq yd) CSS1/CSS1h, SS1,SS1h and QS1h/CQS1h asphaltic emulsion	Minimum residual rates (gal/sq yd) CRS1/CRS2, RS1/RS2 and QS1/CQS1 asphaltic emulsion	Minimum residual rates (gal/sq yd) Asphalt binder and PMRS2/PMCRS2 and PMRS2h/PMCRS2h asphaltic emulsion
Existing pavement	0.07	0.08	0.06

Notify the Agency if asphaltic emulsion is diluted with water. The weight ratio of added water to asphaltic emulsion must not exceed 1 to 1. Measure added water by weight so long as the Contractor furnishes the Agency with weight slips from the weighmaster. Water may be measured by volume so long as the vehicles allow for accurate determination of its contents and each vehicle has a legible identification mark showing its volumetric capacity at any given time.

The application of the tack coat material shall be uniform in appearance and free from ribboning and all other defects. Correct all defective areas of the tack coat where uniform distribution was not achieved prior to placing RHMA-G material over these areas. Placement of RHMA-G material shall not be permitted until the tack coat has broken.

In the event that a scheduled street should become wet due to fog, rain, or any other reason, the placement of RHMA-G shall be suspended until the surface has dried completely, as determined by the Agency.

If using sweeping equipment to clean the streets, the Contractor will perform a minimum of two complete passes over all pavement surfaces. In the event the Agency determines that two passes are not adequate, the Contractor shall re-sweep designated areas as necessary to achieve the appropriate level of pavement cleaning. Completion of sweeping shall be evidence by the absence of all loose particles of paving, all dirt, sand, gravel, leaves, and all other extraneous material. Street sweeping equipment shall be a broom sweeper, or approved equal, in a sufficiently maintained condition to accomplish the sweeping goals of the project. Pavement missed by or inaccessible to broom sweepers shall be swept clean by other methods that are approved by the Agency.

The surface to be overlaid shall be cleaned by the Contractor by washing, scraping, sweeping, blowing, vacuuming or other means as necessary to remove moisture, dirt, grease, or other foreign matter which would reduce the bond between the overlay and the pavement. Prior to the placement of RHMA-G, the Contractor shall completely remove all grease and oil spots deposited by parked cars in the area of work. The application of RHMA-G on any street shall not proceed until the Agency has approved the completion of all oil spot removal.

The above specifications for Surface Preparation are optional. The Agency may decide to enforce require the Contractor to conduct these surface preparation activities. Delete any statements related to surface preparation below that are not selected for enforcement.

4.4. Spreading

RHMA-G shall be spread and compacted at an ambient air temperature of at least 55°F and a surface temperature of at least 60°F.

One important note for the Agency and the Contractor is that the time available to compact RHMA-G material can be very limited. This is because RHMA-G has a high cessation temperature (the temperature below which significant increases in density are not expected regardless of compactive effort applied). This is also exacerbated by the thin lift thicknesses typically used for RHMA-G compared to dense graded mixes. It is strongly recommended that the Agency and Contractor use computer programs such as PaveCool or Multicool to estimate the amount of time available for compaction. All parties should be aware of this prior to any placement of RHMA-G material.

A free copy of PaveCool may be obtained at:
http://www.dot.state.mn.us/app/pavecool/

A free copy of MultiCool may be obtained at:
http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=178&Itemid=331

The Contractor may deposit RHMA-G in a windrow and load it in the paver if the following four conditions apply:

1. Paver is equipped with a hopper that automatically feeds the screed, or if a Materials Transfer Vehicle (MTV) is used.
2. Loading equipment can pick up the windrowed material and deposit it in the paver hopper without damaging base material.
3. Activities for depositing, pickup, loading, and paving are continuous.
4. RHMA-G temperature in the windrow does not fall below 290°F.
5. Tracking of material is controlled in accordance with Section 4.6 of these Specifications

RHMA-G placed in a windrow on the roadway surface must not extend more than 250 feet in front of the paver.

The temperature of the RHMA-G mixture directly behind the paving machine, before any rolling, shall be from 290 to 325°F.

Longitudinal joints in the top layer should be offset six inches from the longitudinal joint in the existing surface layer, if that joint is discernable. The direction of the offset should be towards the lane line, if the joint is not along the lane line. If the longitudinal joint in the existing surface is not discernable, the longitudinal joint shall be along the lane line. A vertical longitudinal joint of more than two inches is not allowed at any time between adjacent lanes open to traffic.

If placing RHMA-G against the edge of existing pavement, cold mill, saw cut or grind the pavement straight and vertical along the joint and remove extraneous material unless the Agency approves placement against the existing pavement edge.

For divided roadways with an RHMA-G lift thickness greater than 2 inches, Contractor may construct a one-foot wide tapered notched wedge joint as a longitudinal joint between adjacent lanes open to traffic. A vertical notch of 0.75-inch maximum must be placed at the top

and bottom of the tapered wedge. The tapered notched wedge must keep its shape while exposed to traffic. Pave the adjacent lane within 1 day. Construct the tapered portion of the tapered notched wedge with an authorized strike-off device. The strike-off device must provide a uniform slope and must not restrict the main screed of the paver. Contractor may use a device attached to the screed to construct longitudinal joints that will form a tapered notched wedge in a single pass. The tapered notched wedge must be compacted to a minimum of 90 percent of theoretical maximum density.

Where a tapered edge is required, use the same type of RHMA-G used for the adjacent lane or shoulder. The edge of roadway where the tapered edge is to be placed must have a solid base, free of debris such as loose material, grass, weeds, or mud. Grade the areas to receive the tapered edge as required. The tapered edge must be placed monolithic with the adjacent lane or shoulder and must be shaped and compacted with a device attached to the paver.

The device must be capable of shaping and compacting RHMA-G to the required cross section as shown. Compaction must be accomplished by constraining the RHMA-G to reduce the cross sectional area by 10 to 15 percent. The device must produce a uniform surface texture without tearing, shoving, or gouging and must not leave marks such as ridges and indentations. The device must be capable of transitioning to cross roads, driveways, and obstructions.

For the tapered edge, the angle of the slope must not deviate by more than ± 5 degrees from the angle shown in the Plans. Measure the angle from the plane of the adjacent finished pavement surface. If paving is done in multiple lifts, the tapered edge must be placed with each lift.

Short sections of hand work are allowed to construct tapered edge transitions.

If widening existing pavement, construct new pavement structure to match the elevation of the existing pavement's edge before placing RHMA-G over the existing pavement.

Unless otherwise approved by the Agency, until the adjoining through lane's top layer has been paved, do not pave the top layer of:

1. Shoulders
2. Tapers
3. Transitions
4. Road connections
5. Driveways
6. Curve widenings
7. Chain control lanes
8. Turnouts
9. Turn pockets

If the number of lanes changes, pave each through lane's top layer before paving a tapering lane's top layer. Simultaneous to paving a through lane's top layer, you may pave an adjoining area's top layer, including shoulders. Do not operate spreading equipment on any area's top layer until completing all compaction activities.

If shoulders or median borders are shown, pave shoulders and median borders adjacent to the lane before opening a lane to traffic.

If shoulder conform tapers are shown, place conform tapers concurrently with the adjacent lane's paving.

4.5. Compaction

Rolling must leave the completed surface compacted and smooth without tearing, cracking, or shoving. If a vibratory roller is used as a finish roller, turn the vibrator off. Do not open new RHMA-G pavement to traffic until its mid-depth temperature is below 160°F. If the surface to be paved is both in sunlight and shade, pavement temperatures are taken in the sun.

The Contractor will use any means necessary to compact the RHMA-G material to 92.0 to 96 percent of the theoretical maximum specific gravity. The Contractor will submit to the Agency, in writing, the compaction method to be used at least 5 days prior to placing any RHMA-G material.

At the option of the Agency, spread **[**sand**] [**rock dust**]** at a rate of 1 to 2 pounds/sq yd on new RHMA-G pavement when finish rolling is complete. **[**Sand must be free of clay and organic matter. Sand must comply with Section 90-1.02C(3) of the current Caltrans Standard Specifications.**] [**Rock dust must comply with Table 200-1.2.1(A) of the current Greenbook.**]**

Keep traffic off the pavement until spreading of the **[**sand**] [**rock dust**]** is complete.

The purpose of spreading sand is to reduce the amount of tracking that happens when a new RHMA-G pavement is first opened to traffic. The Agency may choose to specify Caltrans "sand" or Greenbook "rock dust" to be spread on the new RHMA-G pavement. Delete the option that is not selected. If the RHMA-G pavement has cooled to below 150°F, spreading sand may not be required.

If the situation allows for the use of lime water (50-100 pounds of lime added to 2,000-4,000 gallons of water), this can be a very effective bond breaker that eliminates the dust and cleanup problems of spreading sand. Environmental considerations regarding runoff with potentially high alkalinity into storm drains and related issues are the primary concern.

4.6. Clean Up / Control of Material Tracked From Project

It is the intent of this specification is to minimize the tracking and depositing of RHMA-G and tack beyond the limits of the paved areas of the project.

Windrow paving shall be performed in such a manner as to minimize the pickup and subsequent tracking of material beyond the limits of the area being paved in each shift. Suggested methods include avoiding truck traffic over the windrow, skirting of truck bumpers and undercarriages to minimize adherence of RHMA-G, windrow sizing to minimize contact with subsequent haul vehicles, or such other means that provide for delivery and placement in conformance with these specifications without resulting in objectionable tracking of material. A full-time pick-up broom shall be provided whose operation is dedicated to the removal of any and all material deposited beyond the limits of the area to be paved in each shift. It is the intent of this specification to remove any material tracked or otherwise deposited beyond the paving limits before it adheres to the adjacent paved or other surfaces. One or more dedicated truck clean out areas shall be identified and used for each paving location. Such areas shall meet with the approval of the Engineer and be obtained with written authorization for use from the owner of the property prior to use. Trucks shall proceed to the clean out area immediately after depositing the RHMA-G in the paver hopper, material transfer device, or windrow. All material adhering to the exterior of the truck shall be removed before the truck leaves the clean out

area in such a manner that no material is subsequently deposited on the haul route. The use of any solvents or release agents shall be subject to the approval of the Engineer. The clean out area shall be maintained in a manner conforming to all stormwater and waste disposal regulations, may require the placement of a membrane under the clean out area prior to operations, and shall be returned to its original condition immediately upon cessation of paving operations utilizing the clean out area. Any RHMA-G or tack tracked onto adjacent paved or other surfaces shall be removed to the satisfaction of the Engineer within 24 hours of completion of paving operations utilizing those adjacent surfaces, which shall be considered to include the entire truck haul route(s) between the project location(s) and the plant(s) supplying the RHMA-G. If the adjacent surfaces are not cleaned to the satisfaction of the Engineer within 24 hours, the Engineer reserves the right to employ City forces or an outside contractor to clean the area(s). If City forces are employed, liquidated damages in the amount of $500 per hour times the actual hours required to clean the area(s) will be deducted from monies otherwise due. If an outside contractor is employed, the actual costs for clean-up will be deducted from monies otherwise due.

The costs for minimizing or otherwise controlling tracking and depositing and subsequent clean-up of any materials shall be considered as included in the other items of work and no additional compensation will be provided therefore.

4.7. Pavement Smoothness

The Contractor will produce an RHMA-G pavement where the surface has a uniform appearance and texture, free from any humps or bumps, and free from segregation. The RHMA-G pavement shall be true to grade and cross section. When a 10-foot straightedge is laid on the finished surface parallel to the centerline of the roadway, the finished surface shall not vary from the edge of the straightedge more than 1/8-inch, except at intersections or at changes of grade. Any areas that are not within this tolerance shall be brought to grade immediately following the initial rolling. If the RHMA-G has cooled below the lower limits of the spreading temperatures prescribed in this specification, the surface of the pavement shall be brought to a true grade cross section. The RHMA-G in the area to be repaired shall be removed, by cold milling, to provide a minimum laying depth of 1 inch, or 2 times the maximum aggregate size, whichever is greater, of the new pavement at the join line. Repairs shall not be made to the pavement surface by tampering the thickness at the join lines.

In keeping with Agency standards, the use an inertial profiler and associated appropriate ride quality standards, should be considered.

Whenever compaction of the RHMA-G is complete, place all permanent traffic stripes, pavement markings, crosswalks, stop bars, and raised pavement markers as shown in the Plans or project Specifications. Placement of all pavement markings and raised pavement markers shall be completed within 10 calendar days after compaction of the RHMA-G. Protect newly placed traffic stripes and pavement markings from traffic and other deleterious activities until the paint is thoroughly dry or the thermoplastic is hard enough to bear traffic.

5. Agency Acceptance

The Agency reserves the right to refuse to permit the use of material solely on the basis of a Certificate of Compliance, except for the asphalt modifier and crumb rubber modifier. The

contractor shall allow the Agency or their designee access to observe any and all QC testing being performed. The Contractor must inform the Agency or their designee of the time and location that all QC testing will be performed. Contractor shall deliver samples of materials used to the Agency or permit the Agency or their designee access to obtain samples from any stockpiles or facilities used to store or produce materials used in the RHMA-G upon request at any time during construction. Agency reserves the right to have such materials tested by an independent laboratory for compliance with the requirements in Section 2.
Contractor must submit CalRecycle Form 739-TRP certifying the use of California tires (http://www.calrecycle.ca.gov/Funding/Forms/Tires/CalRecycle739TRP.pdf).

If the project is being funded by a CalRecycle Rubberized Pavement grant, the contractor must fill out the above-noted form and certify the quantity of crumb rubber from California tires. If the project will not be funded by a CalRecycle grant, this statement may be deleted.

The Agency will use the results of the Contractor's QC test results to determine if the materials used for the RHMA-G meet the quality characteristic requirements that are specified herein, provided such QC test results are validated by independent testing performed by or on behalf of the Agency. The Contractor may examine the records and reports of the tests the Agency performs.
The Agency will use the results of the Contractor's QC test results to determine if the materials used for the RHMA-G meet the quality characteristic requirements that are specified herein. The Agency will accept the completed, in-place RHMA-G if the final product is uniform in appearance, free from all visible defects, bumps, and has met the minimum in-place density specified in Section 4.5 and binder content in Section 2.4.

The Agency may edit the preceding section discussing the acceptance criteria for the completed RHMA-G. For instance, the Agency may choose to require all traffic stripes and pavement markings be placed on the completed RHMA-G prior to acceptance.

6. Payment

The payment quantity for RHMA-G is measured based on the combined mixture weight. If recorded batch weights are printed automatically, the bid item for RHMA-G is measured by using the printed batch weights. Contractor shall supply:

1. Time, date, mix number, load number, and truck identification are correlated with a load slip.
2. Each load slip shows the truck's empty weight and the truck's total weight including RHMA-G material.
3. Copy of the recorded batch weights is certified by a licensed weighmaster.

The payment for tack coat is not included in the payment for RHMA-G. The Agency does not adjust the unit price for an increase or decrease in the tack coat quantity.

RUBBERIZED HOT MIX ASPHALT DENSE-GRADED

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Notes on Terminology

Standardization of terminology for pavement materials is problematic in general, and materials containing crumb rubber are no exception. The terminology used in this specification is "Rubberized Hot Mix Asphalt – Dense Graded (RHMA-D)". Different terminologies for similar specifications may be "Terminal Blend Dense Graded Hot Mix" or "PGTR HMA".

RUBBERIZED HOT MIX ASPHALT-DENSE GRADED

1. General

1.1. Scope

This work consists of constructing a Rubberized Dense Grade Asphalt (RHMA-D) overlay on an existing pavement surface.

1.2. Definitions

RHMA-D: Mixture of rubber-modified asphalt binder and dense-graded aggregate mixed in a central mixing plant.

Fine aggregate: Aggregate passing the no. 4 sieve.

Coarse aggregate: Aggregate retained on the no. 4 sieve.

1.3. Submittals

The Contractor shall comply with all Federal, State, and Local environmental laws, rules, regulations, and ordinances including, but not limited to, air quality requirements.

At least 10 days before starting any RHMA-D activities, Contractor shall submit the name of an authorized laboratory to perform Quality Control (QC) testing for RHMA-D. The authorized laboratory must comply with the Caltrans Independent Assurance Program (IAP) or possess current AASHTO Material Reference Laboratory (AMRL) accreditation for all ASTM and AASHTO tests required in Section 2.

AMRL does not certify labs to conduct most of the relevant California Test methods. The Caltrans IAP certifies labs to perform California Test methods, but only labs with active Caltrans projects are eligible to receive the Caltrans accreditation.

The process for a testing laboratory to obtain Caltrans Accreditation is discussed in the Caltrans' Independent Assurance Manual, Procedures for Accreditation of Laboratories and Qualification of Tester (http://www.dot.ca.gov/dist1/d1lab/iap.htm)

Contractor shall submit to the Agency a certified volume or weight slip for each delivery of rubber-modified binder and RHMA-D.

At least 14 days before use, Contractor shall submit:

1. Four each one-quart cans of rubber-modified asphalt binder
2. SDS for each hazardous material
3. Rubber-modified asphalt binder formulation, including:
   - 3.1. Each source and type of crumb rubber modifier
   - 3.2. Percentage of crumb rubber modifier by total weight of rubber-modified asphalt binder
4. Test results
   - 4.1. Certificate of Compliance showing the rubber-modified asphalt binder is the required PG grade

4.2. Certificate of Compliance showing each source of crumb rubber modifier is derived from automobile and/or truck tires
4.3. Test results showing the aggregate meets the requirements in Tables 1 and 2
4.4. Test results showing the RHMA-D meets the requirements in Table 3

5. JMF Forms
   5.1. Caltrans Contractor Job Mix Formula Proposal form CEM-3511
   5.2. Caltrans Contractor Hot Mix Asphalt Design Data form CEM-3512
   5.3. Caltrans Hot Mix Asphalt Verification form CEM-3513, if available
   5.4. Caltrans Job Mix Formula Renewal form CEM-3514, if available

1.4. Job Mix Formula (JMF)

Contractor shall submit the proposed JMF for each type of RHMA-D to be used. The Contractor is required to submit mix design documentation that has been dated within 12 months of submittal. The Contractor shall submit the test results for the RHMA-D showing that the mixture meets all of the requirements as shown in Section 2.3 of these specifications.
The JMF must be submitted on the Caltrans Contractor Job Mix Formula Proposal form CEM-3511along with:

1. Mix design documentation on Caltrans Contractor Hot Mix Asphalt Design Data form CEM-3512. Also report the theoretical maximum specific gravity for the RHMA-D.
2. JMF verification on a Caltrans Hot Mix Asphalt Verification form CEM-3513, if available.
3. JMF renewal on a Caltrans Job Mix Formula Renewal form CEM-3514, if available.

The JMF forms do not need to be Caltrans approved, however the Contractor is encouraged to submit Caltrans approved forms if they are available.
All Caltrans JMF forms can be found online at: http://www.dot.ca.gov/hq/construc/forms.htm

1.5. Quality Control Program

Contractor shall develop, implement, and maintain a QC program.
Contractor shall prepare and maintain QC records, including:

1. Names and qualifications of:
   1.1. Samplers
   1.2. Testers
   1.3. Inspectors
2. Testing laboratories
3. Testing equipment calibrations and certifications
4. Construction inspection reports
5. Sampling and testing records organized by date and type of material
6. Test results with comparison of quality characteristic requirements
7. Test results in relation to action and any suspension limits
8. Records of corrective actions and suspensions

Contractor shall notify the Agency within 24 hours of any noncompliance identified by the QC program.

1.6. Quality Control Manager

Contractor shall assign a QC manager before the start of the affected work. The QC manager must receive, review, and approve all correspondence, submittals, and reports relating to the QC of materials before they are submitted to the Agency. The QC manager must be the sole individual responsible for:

1. Signing the QC plan
2. Implementing the QC plan
3. Maintaining the QC records

The QC manager must be Contractor's employee or must be hired by a subcontractor providing only QC services. The QC manager must not be employed or compensated by a subcontractor or by any other persons or entities hired by subcontractors who will provide services or material for the project.

1.7. Preconstruction Meeting

At least 3 business days before the start of surfacing and pavement operations, the following Contractor personnel shall attend a preconstruction meeting with:

1. Project Manager
2. QC manager
3. Project superintendent
4. Project foreman
5. Plant manager
6. Traffic control foreman
7. Subcontractors' foremen
8. RHMA-D supplier
9. Paving foreman

Contractor shall be prepared to discuss the project specifications and the processes for producing materials and constructing each item of work, including:

1. Quality assurance
    1.1. Quality control
    1.2. Agency acceptance
2. Placement of materials:
    2.1. Training
    2.2. Checklists
    2.3. Test strips (if required)
3. Contingency plan
4. Issues specific to the project, including:
    4.1. Weather
    4.2. Alignment and geometrics
    4.3. Traffic control issues
    4.4. Haul distances
    4.5. Presence and absence of shaded areas
    4.6. Other local issues

The preconstruction meeting is optional. A preconstruction meeting may not be necessary on small-scale projects. If there will be a large amount of RHMA-D material placed, a preconstruction meeting is recommended. The Agency may decide whether or not to require the Contractor to conduct a preconstruction meeting, and should edit or delete the preceding section as appropriate.

2. Materials

2.1. Rubber-modified Asphalt Binder

Rubber-modified asphalt binder shall be **[**PG 76-22 M with a minimum of 15% scrap tire rubber that meets the requirements in Section 92 of the current Caltrans Standard Specifications, except the solubility requirement is waived if the Dynamic Shear Rheometer test on original binder result (G*/sin(delta)) at 76° C is less than or equal to 2.00 kPa.**] [**PG 64-28 M with a minimum of 15% scrap tire rubber that meets the requirements in Section 92 of the current Caltrans Standard Specifications, except the solubility requirement is waived if the Dynamic Shear Rheometer test on original binder result (G*/sin(delta)) at 64° C is less than or equal to 2.00 kPa.**] [**MAC15TR that meets the requirements in Section 203-14 of the current Greenbook.**]**

The Agency may select either PG 76-22M, PG64-28M or MAC15TR binder. Delete the statement for the binder not selected.

Typically, the PG 64-28 M binder is preferred for most applications in California, with the exception of the hottest areas, such as the Mojave Desert and the hottest portions of the Central Valley. PG 76-22 M is also preferred for severe traffic conditions in more moderate climates, such as airfields, ports and roadways subjected to heavy, slow-speed trucks and busses. In general, the PG 64-28 M binder will have better resistance to cracking, whereas the PG 76-22 M binder will have better resistance to rutting and shoving.

2.2. Aggregate

Up to 15% of the aggregate by weight may be replaced with reclaimed asphalt pavement (RAP). Recycled asphalt shingles (RAS) are not allowed in RHMA-D.

It is generally acknowledged that up to 15% RAP can be allowed in HMA without special consideration of the effect of the recycled binder on the end product. However, higher quantities of RAP and RAS may result in an unacceptably stiff and brittle binder, leading to early cracking. These effects vary according to the source of the recycled material.

Aggregate for RHMA-D must comply with the gradation requirements shown in Table 1.

Table 1: Aggregate Gradation Requirements for RHMA-D, Percent Passing by Weight

Sieve Size	*¾-inch Target value limit*	*¾-inch Allowable tolerance*	*½-inch Target value limit*	*½-inch Allowable tolerance*	*3/8-inch Target value limit*	*3/8-inch Allowable tolerance*
1 inch	100	---	100	---	100	---
¾-inch	90 to 98	±5	100	---	100	---
½-inch	70 to 90	±6	95 to 98	±5	100	---

3/8-inch	---	---	72 to 95	±5	95 to 98	±5
#4	42 to 58	±5	52 to 69	±5	55 to 75	±5
#8	29 to 43	±5	35 to 55	±5	30 to 50	±5
#30	10 to 23	±4	15 to 30	±4	15 to 35	±5
#200	2 to 7	±2]	2 to 8	±2]	2 to 9	±2]

Delete the gradation not selected.

The aggregate must also comply with the requirements shown in Table 2.

Table 2: Aggregate Requirements

Quality Characteristics	Test Method	Requirement
Percent of crushed particles Coarse aggregate (min, %) One-fractured face Two-fractured faces Fine aggregate (min, %) (Passing #4 sieve and retained on #8 sieve) One-fractured face	AASHTO T 335	 95 90 70
Los Angeles Rattler, Loss at 100 Rev. Los Angeles Rattler, Loss at 500 Rev.	AASHTO T 96	12 max 40 max
Sand equivalent[a]	AASHTO T 176	47 min
Flat and elongated particles (% by weight at 5:1)	ASTM D4791	10 max
Fine aggregate angularity (%)[b]	AASHTO T 304, Method A	45 min

[a] Reported value must be the average of 3 tests from a single sample. The use of a reading indicator is required as shown in AASHTO T 176, Figure 1. Sections 4.7, "Manual Shaker'" 7.1.2, "Alternate Method Number 2," and 8.4.3, "Hand Method," do not apply. Prepare the stock solution as specified in Section 4.8.1, "Stock solution with formaldehyde," except omit the addition of formaldehyde.

[b] The Agency waives this specification if RHMA-D contains 10 percent or less of nonmanufactured sand by weight of total aggregate unless the JMF fails verification. Manufactured sand is fine aggregate produced by crushing rock or gravel.

2.3. Mixture

RHMA-D mixture must comply with the requirements shown in Table 3.

The Agency may choose to specify either the Superpave method and criteria or the Hveem method and criteria to design the RHMA-D mixture. Delete the mix design section that is not selected

[Table 3: RHMA-D Requirements for Superpave Mix Design

Quality Characteristic	Test Method	Requirement
Air voids content (%)	AASHTO T 269[a]	$N_{initial}$ > 8.0 N_{design} = 4.0 N_{max} > 2.0
Gyration compaction (no. of gyrations)	AASHTO T 312	$N_{initial}$ = 8.0 N_{design} = 85 N_{max} = 130
Voids in mineral aggregate (min, %)[b] Gradation: 3/8-inch 1/2-inch 3/4-inch	SP-2 Asphalt Mixture Volumetrics	 15.5 to 18.5 14.5 to 17.5 13.5 to 16.5
Dust proportion	SP-2 Asphalt Mixture Volumetrics	0.6-1.3
Bulk Specific gravity	AASHTO T 275 Method A	Report only
Theoretical maximum specific gravity	AASHTO T 209 Method A[a]	Report only
Hamburg wheel track (number of passes at 0.5-inch rut depth)	AASHTO T 324 (Modified)[b]	25,000 min
Binder Content (%, by total weight of mix)	[c]	–

[a] Calculate the air voids content of each specimen using AASHTO T 275, Method A, to determine bulk specific gravity. Use AASHTO T 209, Method A, to determine theoretical maximum specific gravity. Use a digital manometer and pycnometer when performing AASHTO T 209.

[b] Test plant-produced RHMA-D.

[c] Once the percent binder is determined by the mix design, the production tolerance shall be + 0.5% / -0.4%.

Determine the quantity of asphalt rubber binder to be mixed with the aggregate for the RHMA-D as follows:

1. Base the calculations on the average of 3 briquettes produced at each asphalt rubber binder content.
2. Plot asphalt rubber content versus average air voids content for each set of 3 specimens and connect adjacent points with a best-fit curve.
3. Calculate voids in mineral aggregate for each specimen, average each set, and plot the average versus asphalt rubber binder content.
4. Calculate the dust proportion and plot versus asphalt rubber binder content.
5. From the curve plotted, select the theoretical asphalt rubber binder content at 4 percent air voids.
6. At the selected asphalt rubber binder content, calculate the dust proportion.
7. Record the asphalt rubber binder content as the Optimal Binder Content (OBC).

Laboratory mixing and compaction must comply with AASHTO R 35, except the mixing temperature of the aggregate must be from 300 to 350°F. The mixing temperature of the binder must be from 290 to 325°F. The compaction temperature of the combined mixture must be from 275 to 300°F.**]**

[Table 3: RHMA-D Requirements for Hveem Mix Design

Quality Characteristic	Test Method	Requirement
Air voids content (%)	AASHTO T 269 [a]	4
Voids in mineral aggregate (min, %)[b] Gradation: 3/8-inch 1/2-inch 3/4-inch	SP-2 Asphalt Mixture Volumetrics	 15.5 to 18.5 14.5 to 17.5 13.5 to 16.5
Dust proportion	Asphalt Institute MS-2	0.6 to 1.3
Bulk Specific gravity	AASHTO T 275 Method A	Report only
Theoretical maximum specific gravity	AASHTO T 209 Method A [a]	Report only
Moisture susceptibility (psi, dry strength)	AASHTO T 283	100 min
Moisture susceptibility (psi, wet strength)	AASHTO T 283[b,c]	70 min
Binder content (%, by total weight of mix)[d]	[d]	–

[a] Calculate the air voids content of each specimen using AASHTO T 275, Method A, to determine bulk specific gravity. Use AASHTO T 209, Method A, to determine theoretical maximum specific gravity. Use a digital manometer and pycnometer when performing AASHTO T 209.

[b] Test plant-produced RHMA-D.

[c] Once the percent asphalt rubber binder is determined by the mix design, the production tolerance shall be + 0.5% / -0.4%.

The optimal binder content (OBC) shall be determined by California Test 367, except that Step 2 regarding surface flushing shall not be used. OBC shall be determined by using a void content of 4 percent or less. Compaction shall be in accordance with California Test 34, except for the following:

1. Mixing temperature of binder shall be from 300 to 350°F.
2. Mixing temperature of aggregate shall be from 290 to 325°F.
3. Compaction temperature shall be from 275 to 300°F.**]**

3. Quality Control

3.1. Aggregate

Test the quality characteristics of aggregates under the test methods and frequencies shown in Table 4.

Table 4: Aggregate Testing Frequencies

Quality Characteristic	Test Method	Frequency
Gradation	AASHTO T 27	Startup and 1 per 750 tons
Sand equivalent[a, b]	AASHTO T 176	Startup and 1 per 750 tons
Moisture content[c]	AASHTO T 255	Startup and 1 per 750 tons
Crushed particles	AASHTO T 335	1 per project[d]
Los Angeles Rattler	AASHTO T 96	1 per project[d]
Flat and elongated particles	ASTM D4791	1 per project[d]
Fine aggregate angularity	AASHTO T 304, Method A	1 per project[d]

[a] Reported value must be the average of 3 tests from a single sample
[b] Use of a sand reading indicator is required as shown in AASHTO T 176, Figure 1. Sections 4.7, "Manual Shaker'" 7.1.2, "Alternate Method Number 2," and 8.4.3, "Hand Method," do not apply. Prepare the stock solution as specified in Section 4.8.1, "Stock solution with formaldehyde," except omit the addition of formaldehyde.
[c] Test at continuous mixing plants only.
For lime-treated aggregate, test aggregate before treatment and test for gradation and moisture content during RHMA-D production.
[d] At the discretion of the Agency, testing for crushed particles, Los Angeles Rattler, flat and elongated particles, and/or fine aggregate angularity performed during the mix design, mix design verification, or mix design renewal may be used in lieu of testing during the project.

3.2. Mixture

Test the quality characteristics of RHMA-D under the test methods and frequencies shown in Table 5.

[Table 5: RHMA-D Requirements for Superpave Mix Design

Quality Characteristic	Test Method	Frequency
Air voids content (%)	AASHTO T 269	1 per 2,000 tons but not less than 1 per paving day
Asphalt rubber Binder Content	Note [a] below	1 per 2,000 tons but not less than 1 per paving day
RHMA-D moisture content	AASHTO T 329	1 per 2,000 tons but not less than 1 per paving day
Voids in mineral aggregate (min, %)	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Dust proportion	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Hamburg wheel track	AASHTO T 324 (Modified)	1 per 10,000 tons but not less than 1 per project
Nuclear gauge density [b]	ASTM D 2950	3 per 250 tons but not less than 3 per paving day

[a] Once the percent asphalt rubber binder is determined by the mix design, the production tolerance shall be + 0.5% / -0.4%.
[b] Calibrated to cores using CTM 375 or other means acceptable to the Agency.
Laboratory mixing and compaction must comply with AASHTO R 35, except the mixing temperature of the aggregate must be from 300 to 325°F. The mixing temperature of the asphalt rubber binder must be from 375 to 425°F. The compaction temperature of the combined mixture must be from 290 to 320°F.**]**

[Table 5: RHMA-D Requirements for Hveem Mix Design

Quality Characteristic	Test Method	Frequency
Air voids content (%)	AASHTO T 269	1 per 2,000 tons but not less than 1 per paving day
Asphalt rubber Binder Content	Note [a] below	1 per 2,000 tons but not less than 1 per paving day
RHMA-D moisture content	AASHTO T 329	1 per 2,000 tons but not less than 1 per paving day
Voids in mineral aggregate (min, %)	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Dust proportion	SP-2 Asphalt Mixture Volumetrics	1 per 2,000 tons but not less than 1 per paving day
Moisture susceptibility	AASHTO T 283	1 per 10,000 tons but not less than 1 per project
Nuclear gauge density[b]	ASTM D 2950	3 per 250 tons but not less than 3 per paving day

[a] Once the percent asphalt rubber binder is determined by the mix design, the production tolerance shall be + 0.5% / -0.4%.

[b] Calibrated to cores using CTM 375 or other means.

Laboratory compaction shall be in accordance with California Test 34, except compaction temperature shall be from 290 to 300°F.**]**

The Agency may choose to specify either the Superpave method and criteria or the Hveem method and criteria to design and evaluate the RHMA-D mixture. Delete the section for the method and criteria that is not selected. Selected Table 5 should be consistent with selected Table 3.

4. Construction

4.1. Equipment

4.1.1. Placing/Spreading

Paving equipment for spreading must be:

1. Self-propelled
2. Mechanical
3. Equipped with a screed or strike-off assembly that can distribute RHMA-D the full width of a traffic lane
4. Equipped with a full-width compacting device
5. Equipped with automatic screed controls and sensing devices that control the thickness, longitudinal grade, and transverse screed slope

Install and maintain grade and slope references. The screed must be heated and produce a uniform RHMA-D surface texture without tearing, shoving, or gouging. The paver must not leave marks such as ridges and indentations.

All trucks transporting RHMA-D to the jobsite shall be completely covered with tarpaulins, which are fully secured, during transport.

In areas inaccessible to spreading and compacting equipment:

1. Spread the RHMA-D by any means to obtain the specified lines, grades, and cross sections
2. Use a pneumatic tamper, plate compactor, or equivalent to achieve thorough compaction.

The use of a material transfer vehicle is allowed. The material transfer vehicle must have sufficient capacity to prevent stopping the paver and must be capable of:

1. Either receiving RHMA-D directly from trucks or using a windrow pickup head to load it from a windrow deposited on the roadway surface
2. Remixing the RHMA-D with augers before transferring into the paver's receiving hopper or feed system
3. Transferring RHMA-D directly into the paver's receiving hopper or feed system

4.1.2. Compaction

Each roller must have a separate operator. Rollers must be self-propelled and reversible.

4.2. Surface Preparation

The Contractor shall remove all existing traffic stripes, markings, crosswalks, stop bars, and legends; and raised pavement markers in areas to receive RHMA-D and any adjacent areas as directed by the Agency. Removal shall be done by sand blasting or grinding and disposing of by the Contractor. Grinding or sand blasting operations shall be conducted to keep all removed pavement material from entering the storm drain system. Said removal shall not occur sooner than 2 calendar days prior to the day that the RHMA-D will be placed.

Existing pavement striping, markings, or markers which are outside the work area and not to be removed, shall be protected by the Contractor. Any striping, markings, or markers to remain damaged or rendered useless by the Contractor's operations shall be restored by the Contractor to the Agency's satisfaction and at the Contractor's expense.

Following herbicide spraying, all vegetation shall be removed from the cracks in the pavement and from all joints between the pavement and concrete gutters by the Contractor.

On the day that a street receives RHMA-D material, it shall be swept without the use of water. Pavement must be completely dry prior to placement of RHMA-D. The Contractor shall not begin any activities related to the placement of RHMA-D on any street until the Agency has approved the street cleaning.

Apply a tack coat on the existing pavement surface and on the vertical surfaces of any curbs, gutters, and construction joints. Apply the tack coat at a rate shown in the following table, or as otherwise ordered by the Agency:

Table 6: Tack Coat Application Rates for RHMA-D

RHMA-D over	Minimum Residual Rates (gal/sq yd) CSS1/CSS1h, SS1,SS1h and QS1h/CQS1h asphaltic emulsion	Minimum Residual Rates (gal/sq yd) CRS1/CRS2, RS1/RS2 and QS1/CQS1 asphaltic emulsion	Minimum Residual Rates (gal/sq yd) Asphalt binder and PMRS2/PMCRS2 and PMRS2h/PMCRS2h asphaltic emulsion
New HMA (between lifts of new material)	0.04	0.05	0.04
Existing pavement	0.05	0.07	0.05
Milled surface	0.06	0.08	0.06

Notify the Agency if asphaltic emulsion is diluted with water. The weight ratio of added water to asphaltic emulsion must not exceed 1 to 1. Measure added water by weight so long as the Contractor furnishes the Agency with weight slips from the weighmaster. Water may be measured by volume so long as the vehicles allow for accurate determination of its contents and each vehicle has a legible identification mark showing its volumetric capacity at any given time.

The application of the tack coat material shall be uniform in appearance and free from ribboning and all other defects. Correct all defective areas of the tack coat where uniform distribution was not achieved prior to placing RHMA-D material over these areas. Placement of RHMA-D material shall not be permitted until the tack coat has broken.

In the event that a scheduled street should become wet due to fog, rain, or any other reason, the placement of RHMA-D shall be suspended until the surface has dried completely, as determined by the Agency.

[If using sweeping equipment to clean the streets, the Contractor will perform a minimum of two (2) complete passes over all pavement surfaces. In the event the Agency determines that two (2) passes are not adequate, the Contractor shall re-sweep designated areas as necessary to achieve the appropriate level of pavement cleaning. Completion of sweeping shall be evidence by the absence of all loose particles of paving, all dirt, sand, gravel, leaves, and all other extraneous material. Street sweeping equipment shall be a broom sweeper, or approved equal, in a sufficiently maintained condition to accomplish the sweeping goals of the project. Pavement missed by or inaccessible to broom sweepers shall be swept clean by other methods that are approved by the Agency.**]**

The surface to be overlaid shall be cleaned by the Contractor by washing, scraping, sweeping, blowing, vacuuming or other means as necessary to remove moisture, dirt, grease, or other foreign matter which would reduce the bond between the overlay and the pavement. Prior to the placement of RHMA-D, the Contractor shall completely remove all grease and oil spots deposited by parked cars in the area of work. The application of RHMA-D on any street shall not proceed until the Agency has approved the completion of all oil spot removal.

The above specifications for Surface Preparation are optional. The Agency may decide to enforce require the Contractor to conduct these surface preparation

activities. Delete any statements related to surface preparation below that are not selected for enforcement.

4.3. Spreading

Spread and compact RHMA-D at an ambient air temperature of at least 50°F and a surface temperature of at least 55°F.

The Contractor may deposit RHMA-D in a windrow and load it in the paver if:

1. Paver is equipped with a hopper that automatically feeds the screed, or if a Materials Transfer Vehicle (MTV) is used.
2. Loading equipment can pick up the windrowed material and deposit it in the paver hopper without damaging base material
3. Activities for depositing, pickup, loading, and paving are continuous
4. RHMA-D temperature in the windrow does not fall below 270°F

RHMA-D placed in a windrow on the roadway surface must not extend more than 250 feet in front of the paver.

The temperature of the RHMA-D mixture directly behind the paving machine, before any rolling, shall be at least 240°F.

Longitudinal joints in the top layer should be offset six inches from the longitudinal joint in the existing surface layer, if that joint is discernable. The direction of the offset should be towards the lane line, if the joint is not along the lane line. If the longitudinal joint in the existing surface is not discernable, the longitudinal joint shall be along the lane line. A vertical longitudinal joint of more than two inches is not allowed at any time between adjacent lanes open to traffic.

If placing RHMA-D against the edge of existing pavement, cold mill, saw cut or grind the pavement straight and vertical along the joint and remove extraneous material unless the Agency approves placement against the existing pavement edge.

For divided roadways with an RHMA-D lift thickness greater than two inches, Contractor may construct a one-foot wide tapered notched wedge joint as a longitudinal joint between adjacent lanes open to traffic. A vertical notch of 0.75-inch maximum must be placed at the top and bottom of the tapered wedge. The tapered notched wedge must keep its shape while exposed to traffic. Pave the adjacent lane within 1 day. Construct the tapered portion of the tapered notched wedge with an authorized strike-off device. The strike-off device must provide a uniform slope and must not restrict the main screed of the paver. Contractor may use a device attached to the screed to construct longitudinal joints that will form a tapered notched wedge in a single pass. The tapered notched wedge must be compacted to a minimum of 90 percent of theoretical maximum density.

Where a tapered edge is required, use the same type of RHMA-D used for the adjacent lane or shoulder. The edge of roadway where the tapered edge is to be placed must have a solid base, free of debris such as loose material, grass, weeds, or mud. Grade the areas to receive the tapered edge as required. The tapered edge must be placed monolithic with the adjacent lane or shoulder and must be shaped and compacted with a device attached to the paver.

The device must be capable of shaping and compacting RHMA-D to the required cross section as shown. Compaction must be accomplished by constraining the RHMA-D to reduce the cross sectional area by 10 to 15 percent. The device must produce a uniform surface texture without

tearing, shoving, or gouging and must not leave marks such as ridges and indentations. The device must be capable of transitioning to crossroads, driveways, and obstructions.
For the tapered edge, the angle of the slope must not deviate by more than ±5 degrees from the angle shown in the Plans. Measure the angle from the plane of the adjacent finished pavement surface. If paving is done in multiple lifts, the tapered edge must be placed with each lift.
Short sections of hand work are allowed to construct tapered edge transitions.
If widening existing pavement, construct new pavement structure to match the elevation of the existing pavement's edge before placing RHMA-D over the existing pavement.
Unless otherwise approved by the Agency, do not pave the top layer of any of the following until the adjoining through lane's top layer has been paved:

1. Shoulders
2. Tapers
3. Transitions
4. Road connections
5. Driveways
6. Curve widenings
7. Chain control lanes
8. Turnouts
9. Turn pockets

If the number of lanes changes, pave each through lane's top layer before paving a tapering lane's top layer. Simultaneous to paving a through lane's top layer, you may pave an adjoining area's top layer, including shoulders. Do not operate spreading equipment on any area's top layer until completing all compaction activities.
If shoulders or median borders are shown, pave shoulders and median borders adjacent to the lane before opening a lane to traffic.
If shoulder conform tapers are shown, place conform tapers concurrently with the adjacent lane's paving.

4.4. Compaction

Rolling must leave the completed surface compacted and smooth without tearing, cracking, or shoving. If a vibratory roller is used as a finish roller, turn the vibrator off. Do not open new RHMA-D pavement to traffic until its mid-depth temperature is below 160°F. If the surface to be paved is both in sunlight and shade, pavement temperatures are taken in the sun.
The Contractor will use any means necessary to compact the RHMA-D material to 92.0 to 97.0 percent of the theoretical maximum specific gravity. The Contractor will submit to the Agency, in writing, the compaction method to be used at least 5 days prior to placing any RHMA-D material.

4.5. Pavement Smoothness

The Contractor will produce an RHMA-D pavement where the surface has a uniform appearance and texture, free from any humps or bumps, and free from segregation. The RHMA-D pavement shall be true to grade and cross section. When a 10-foot straightedge is laid on the finished surface parallel to the centerline of the roadway, the finished surface shall not vary from the edge of the straightedge more than 1/8-inch, except at intersections or at

changes of grade. Any areas that are not within this tolerance shall be brought to grade immediately following the initial rolling. If the RHMA-D has cooled below the lower limits of the spreading temperatures prescribed in this specification, the surface of the pavement shall be brought to a true grade cross section. The RHMA-D in the area to be repaired shall be removed, by cold milling, to provide a minimum laying depth of 1 inch, or 2 times the maximum aggregate size, whichever is greater, of the new pavement at the join line. Repairs shall not be made to the pavement surface by tapering the thickness at the join lines.

In keeping with Agency standards, the use of an Inertial Profiler and associated appropriate ride quality standards should be considered.

Whenever compaction of the final surface lift is complete, place all permanent traffic stripes, pavement markings, crosswalks, stop bars, and raised pavement markers as shown in the Plans or project Specifications. Placement of all pavement markings and raised pavement markers shall be completed within 10 calendar days after compaction of the final surface lift. Protect newly placed traffic stripes and pavement markings from traffic and other deleterious activities until the paint is thoroughly dry or the thermoplastic is hard enough to bear traffic.

5. Agency Acceptance

The Agency reserves the right to refuse to permit the use of material solely on the basis of a Certificate of Compliance, except for the asphalt modifier and crumb rubber modifier. The contractor shall allow the Agency or their designee access to observe any and all QC testing being performed. The Contractor must inform the Agency or their designee of the time and location that all QC testing will be performed. Contractor shall deliver samples of materials used to the Agency or permit the Agency or their designee access to obtain samples from any stockpiles or facilities used to store or produce materials used in the RHMA-D upon request at any time during construction. Agency reserves the right to have such materials tested by an independent laboratory for compliance with the requirements in Section 2 for acceptance purposes.

Contractor must submit CalRecycle Form 739-TRP certifying the use of California tires (http://www.calrecycle.ca.gov/Funding/Forms/Tires/CalRecycle739TRP.pdf).

If the project is being funded by a CalRecycle Rubberized Pavement grant, the contractor must fill out the above-noted form and certify the quantity of crumb rubber from California tires. If the project will not be funded by a CalRecycle grant, this statement may be deleted.

The Agency will use the results of the Contractor's QC test results to determine if the materials used for the asphalt rubber chip seal meet the quality characteristic requirements that are specified herein, provided such QC test results are validated by independent testing performed by or on behalf of the Agency. The Contractor may examine the records and reports of the tests the Agency performs.

The Agency will use the results of the Contractor's QC test results to determine if the materials used for the RHMA-D meet the quality characteristic requirements that are specified herein. The Agency will accept the completed, in-place RHMA-D if the final product is uniform in

appearance, free from all visible defects, bumps, and has met the minimum in-place density specified in Section 4.4 and binder content in Section 2.3

The Agency may edit the preceding section discussing the acceptance criteria for the completed RHMA-D. For instance, the Agency may choose to require all traffic stripes and pavement markings be placed on the completed RHMA-D prior to acceptance.

6. Payment

The payment quantity for RHMA-D is measured based on the combined mixture weight. If recorded batch weights are printed automatically, the bid item for RHMA-D is measured by using the printed batch weights. Contractor shall supply:

1. Time, date, mix number, load number, and truck identification are correlated with a load slip.
2. Each load slip shows the truck's empty weight and the truck's total weight including RHMA-D material.
3. Copy of the recorded batch weights is certified by a licensed weighmaster.

The payment for tack coat is not included in the payment for RHMA-D. The Agency does not adjust the unit price for an increase or decrease in the tack coat quantity.

RUBBER-MODIFIED ASPHALT CHIP SEAL

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Notes on Terminology

Standardization of terminology for pavement materials is problematic in general, and materials containing crumb rubber are no exception. The terminology used in this specification is "Rubber-modified Asphalt Chip Seal". Different terminologies for similar specifications may be "Terminal Blend Chip Seal" or "PGTR Seal Coat".

RUBBER-MODIFIED ASPHALT CHIP SEAL

1. General

1.1. Scope

This work consists of constructing a chip seal with rubber-modified asphalt binder.

1.2. Definitions

Scrap tire crumb rubber: Any combination of:

1. Automobile tires
2. Truck tires
3. Tire buffing

1.3. Submittals

The Contractor shall comply with all Federal, State, and Local environmental laws, rules, regulations, and ordinances including, but not limited to, air quality requirements.

At least 10 days before starting any rubber-modified asphalt chip seal activities, Contractor shall submit the name of an authorized laboratory to perform QC testing. The authorized laboratory must comply with the Caltrans Independent Assurance Program or possess current AASHTO Material Reference Laboratory (AMRL) accreditation for all ASTM and AASHTO tests required in Section 2.

AMRL does not certify labs to conduct most of the relevant California Test methods. The Caltrans IAP certifies labs to perform California Test methods, but only labs with active Caltrans projects are eligible to receive the Caltrans accreditation.

The process for a testing laboratory to obtain Caltrans Accreditation is discussed in the Caltrans' Independent Assurance Manual, Procedures for Accreditation of Laboratories and Qualification of Tester (http://www.dot.ca.gov/dist1/d1lab/iap.htm).

Contractor shall submit a certified volume or weight slip for each delivery of rubber-modified asphalt binder.

At least 14 days before use, Contractor shall submit:

1. Four each one-quart cans of rubber-modified asphalt binder
2. SDS for each hazardous material
3. Rubber-modified asphalt binder formulation, including:
   - 3.1. Each source and type of crumb rubber modifier
   - 3.2. Percentage of crumb rubber modifier by total weight of rubber-modified asphalt binder
4. Test results
   - 4.1. Certificate of Compliance showing the rubber-modified asphalt binder is the required PG grade

4.2. Certificate of Compliance showing each source of crumb rubber modifier is derived from automobile and/or truck tires
4.3. Test results showing the screenings meets the requirements in Tables 1 and 2

1.4. Quality Control Program

Contractor shall develop, implement, and maintain a QC program.
Contractor shall prepare and maintain QC records, including:

1. Names and qualifications of:
   1.1. Samplers
   1.2. Testers
   1.3. Inspectors
2. Testing laboratories'
3. Testing equipment calibrations and certifications
4. Construction inspection reports
5. Sampling and testing records organized by date and type of material
6. Test results with comparison of quality characteristic requirements
7. Test results in relation to action and any suspension limits
8. Records of corrective actions and suspensions

Within 24 hours, the Contractor shall notify the Agency of any noncompliance identified by the QC program.

[Within 10 days of beginning the modified binder seal coat operation, the Contractor's independent testing laboratory shall conduct the Vialit Test Method for aggregate in Chip Seals, French Chip for the retention requirement and submit a signed copy of a test results report to the Agency. The report will not be considered for acceptability testing. The Vialit Test Method is available at: http://www.dot.ca.gov/hq/esc/ctms/index.html.**]**

This is an optional requirement. The Agency may decide to include this requirement or may remove it. If the Agency chooses not to enforce this requirement, delete this paragraph.

1.5. Quality Control Manager

Contractor shall assign a QC manager before the start of the affected work. The QC manager must receive, review, and approve all correspondence, submittals, and reports relating to the QC of materials before they are submitted to the Agency. The QC manager must be the sole individual responsible for:

1. Signing the QC plan
2. Implementing the QC plan
3. Maintaining the QC records

The QC manager must be the Contractor's employee or must be hired by a subcontractor providing only QC services. The QC manager must not be employed or compensated by a subcontractor or by any other persons or entities hired by subcontractors who will provide services or material for the project.

1.6. Materials

1.6.1. Rubber-modified Asphalt Binder

Rubber-modified asphalt binder shall be **[**PG 76-22 M with a minimum of 15% scrap tire rubber that meets the requirements in Section 92 of the current Caltrans Standard Specifications, except the solubility requirement is waived if the Dynamic Shear Rheometer test on original binder result (G*/sin(delta)) at 76° C is less than or equal to 2.00 kPa.**]** **[**PG 64-28 M with a minimum of 15% scrap tire rubber that meets the requirements in Section 92 of the current Caltrans Standard Specifications, except the solubility requirement is waived if the Dynamic Shear Rheometer test on original binder result (G*/sin(delta)) at 64° C is less than or equal to 2.00 kPa**]** **[**MAC15TR that meets the requirements in Section 203-14 of the current Greenbook.**]**

The Agency may select either PG 76-22 M, PG 64-28 M or MAC15TR binder. Delete the statement for the binder not selected.

Typically, the PG 64-28 M binder is preferred for most applications in California, with the exception of the hottest areas, such as the Mojave Desert and the hottest portions of the Central Valley. In general, the PG 64-28 M binder will have better resistance to cracking, whereas the PG 76-22 M binder will have better resistance to bleeding and shoving.

1.6.2. Screenings

Screenings for rubber-modified asphalt chip seal must comply with the gradation requirements shown Table 1.

Table 1: Rubber-Modified Asphalt Chip Seal Screenings Gradation, Percent Passing by Weight

Sieve Size	*Coarse*	*Medium*	*Fine*
¾-inch	**[**100	**[**100	**[**100
½-inch	85 to 90	95 to 100	100
3/8-inch	0 to 15	70 to 85	100
#4	0 to 5	0 to 15	5 to 30
#8	---	0 to 5	0 to 10
#16	---	---	0-5
#200	0 to 1**]**	0 to 1**]**	0 to 1**]**

Delete the columns for the gradations not selected.

The screenings must also comply with the requirements shown in Table 2.

Table 2: Rubber-Modified Asphalt Chip Seal Screenings Requirements

Quality Characteristic	Test Method	Requirement
Cleanness Value (min)	California Test 227	80
Durability (min)	California Test 229	52
Los Angeles Rattler Loss (100 Revolutions, %, max)	ASTM C 131	10
Los Angeles Rattler Loss (500 Revolutions, %, max)	ASTM C 131	40
Film Stripping (%, max)	California Test 302	25

2. Quality Control

2.1. Rubber-modified Asphalt Binder

The Contractor shall provide a Certificate of Compliance for each truckload of rubber-modified asphalt binder delivered to the jobsite.

2.2. Screenings

Each stockpile of uncoated screenings must be sampled and tested. Make available all stockpiles to the Agency for Quality Assurance testing and notify the Agency a minimum of one full working day prior to pre-coating. Maintain discrete stockpiles at the asphalt plant.
Test the quality characteristics of screenings under the test methods and frequencies shown in Table 3.

Table 3: Screenings QC Testing

Quality Characteristics	Test Method	Frequency
Gradation	ASTM C 136	1 per day per stockpile [a]
Cleanness value	California Test 227	1 per day per stockpile [a]
Durability	California Test 229	1 per day per stockpile [a]

[a] The Contractor is only required to test the stockpiles from which the screenings for that day's work are being taken from.

3. Construction

3.1. Equipment

3.1.1. Placing/Finishing Rubber-modified Asphalt Chip Seal

Self-propelled distributor truck for applying rubber-modified asphalt binder must have the following features:

1. Heating unit
2. Internal mixing unit
3. Pumps that spray rubber-modified asphalt binder within 0.05 gal/sq yd of the specified rate
4. Fully circulating spray bar that applies rubber-modified asphalt binder uniformly
5. Tachometer
6. Pressure gauges
7. Volume measuring devices
8. Thermometer

9. Observation platform on the rear of the truck for an observer on the platform to see the nozzles and unplug them if needed.

Self-propelled power brooms that clean the existing pavement and remove loose screenings without dislodging screenings set in the rubber-modified asphalt binder.

Pneumatic tired rollers must be self-propelled and reversible. Pneumatic tires must be of equal size, diameter, type and ply. The roller must carry at least 1,500 lb of load on each wheel, and each tire must have an air pressure of 100 ± 5 psi. Steel wheel rollers must be self-propelled and reversible. The roller must be operated in stated mode at all times and may not exceed 10 tons in weight.

Screenings haul trucks must have tailgates that discharge screenings and devices to allow locking onto the rear screenings spreader hitch. The dump beds must not push down on the spreader when fully raised. Dump beds must not spill screenings on the roadway when transferred to the spreader hopper. All haul trucks must have tarpaulins to cover precoated screenings.

Self-propelled screenings spreader must have a screenings hopper in the rear, belt conveyors that carry the screenings to the front, and a spreading hopper capable of providing a uniform screening spread rate over the entire width of the traffic lane in one application.

3.2. Surface Preparation

The Contractor shall remove any existing traffic stripes, markings, crosswalks, stop bars, and legends; and raised pavement markers in areas to receive rubber-modified asphalt chip seal as required by the Plans or project Specifications. Removal shall be done by sand blasting or grinding and disposing of by the Contractor. Grinding or sand blasting operations shall be conducted to keep all removed pavement material from entering the storm drain system.

The Agency shall specify, either in the Plans or project Specifications, the existing traffic stripes, markings, crosswalks, stop bars, legends, and raised pavement markers to be removed prior to placement of the rubber-modified chip seal. While not all painted stripes and markings may need to be removed, the Agency should rely on experience and knowledge gained from past chip seal projects in the local area to determine which pavement markings should be removed to ensure the rubber-modified chip seal will bond to the existing pavement surface.

Existing pavement striping, markings, or markers which are outside the work area and not to be removed, shall be protected by the Contractor. Any striping, markings, or markers to remain damaged or rendered useless by the Contractor's operations shall be restored by the Contractor to the Agency's satisfaction and at the Contractor's expense.

Before applying rubber-modified asphalt binder, cover manholes, valve and monument covers, grates, or other exposed facilities located within the area of application with plastic or oil-resistant construction paper secured by tape or adhesive to the facility being covered. Reference the covered facilities with enough control points to locate the facilities after the application of the rubber-modified asphalt chip seal. Remove coverings promptly to return the facilities to service prior to the end of the same shift the seal coat is placed.

Immediately before applying the rubber-modified asphalt binder, the surface shall be clean and completely dry. Cleaning shall be performed by sweeping, flushing, or other means necessary to

remove all loose particles of paving, all dirt, and all out extraneous material. The Contractor shall clean all streets from face of curb to face of curb in the project area as necessary to ensure the pavement surface is sufficiently cleaned to provide for a bond between the existing pavement surface and seal coat. Any cleaning of the pavement surface immediately before placing rubber-modified asphalt chip seal shall be performed without water. The application of rubber-modified asphalt binder on any street shall not proceed until the Agency has approved the street cleaning.

In the event that a scheduled street should become wet due to fog, rain, or any other reason, the placement of rubber-modified asphalt chip seal shall be suspended until the surface has completely dried as determined by the Agency.

The Contractor shall remove all vegetation material growing in the street or on the interface of the asphalt surface with the lip of concrete gutter prior to placing rubber-modified asphalt binder.

[The removal of all existing pavement markings and traffic stripes shall not occur sooner than 2 calendar days prior to the day that the rubber-modified chip seal is to be placed.**]**

[If using sweeping equipment to clean the streets, the Contractor will perform a minimum of two complete passes over all pavement surfaces. In the event the Agency determines that two passes are not adequate, the Contractor shall re-sweep designated areas as necessary to achieve the appropriate level of pavement cleaning. Completion of sweeping shall be evidence by the absence of all loose particles of paving, all dirt, sand, gravel, leaves, and all other extraneous material. Street sweeping equipment shall be a broom sweeper, or approved equal, in a sufficiently maintained condition to accomplish the sweeping goals of the project. Pavement missed by or inaccessible to broom sweepers shall be swept clean by other methods that are approved by the Agency. The Contractor shall provide whatever flushing, compressed air, or other cleaning methods are necessary to remove all dirt, vegetation, and loose material from the pavement.**]**

[Prior to the application of the rubber-modified asphalt chip seal, the Contractor shall completely remove all grease and oil spots deposited by parked cars in the area of work. Grease build up greater than 1/32-inch shall be removed by scrapping or other mechanical methods. The application of rubber-modified asphalt binder on any street shall not proceed until the Agency has approved the completion of all oil spot removal.**]**

The above three specifications for Surface Preparation are optional and each one is independent of the others. The Agency may decide to enforce require the Contractor to conduct these surface preparation activities. Delete any statements related to surface preparation below that are not selected for enforcement.

3.3. Precoating Screenings

Precoating of screenings is required.

Precoating of screenings must be performed at a central mixing plant. The plant must be authorized under the Caltrans Material Plant Quality Program (MPQP).

Do not recombine fine materials collected in dust control systems except from primary dust collection devices such as cyclone collectors or knock-out boxes with any other aggregate used in the production of screenings.

For rubber-modified asphalt chip seal, screenings must be preheated from 260 to 325°F. **[**Coat with any of the asphalts specified in the table titles "Performance Graded Asphalt Binder" in section 92 of the current Caltrans Standard Specifications.**] [**Coat with any of the asphalts in the Greenbook Section 203-1.**]** The asphalt must be from 0.5 to 1.0 percent by weight of dry screenings. The Agency determines the exact rate.

Do not stockpile preheated and/or precoated screenings.

The Agency may choose to reference either the current Caltrans Standard Specifications or the current Greenbook. Delete the statement for the reference not selected.

3.4. Rubber-Modified Asphalt Binder Application

The rubber-modified asphalt binder may only be applied if:

1. The pavement temperature is above 55°F
2. The ambient temperature is from 60 to 105°F
3. The pavement is clean and dry
4. Wind conditions are such that uniform rubber-modified asphalt binder coverage can be achieved
5. Rain is not imminent

The rubber-modified asphalt binder shall be applied when the temperature of the rubber-modified asphalt binder is between 330 and 375°F.

Prevent vehicles from driving on rubber-modified asphalt binder before spreading screenings.

Do not apply rubber-modified asphalt binder during high wind conditions. If authorized, Contractor may adjust the distributor bar height and distribution speed and use shielding equipment during high wind conditions. However, if the weather conditions do not allow for uniform placement of the rubber-modified asphalt binder, the Agency may decide to suspend construction activities by the Contractor at no cost to the Agency. The Contractor may not resume construction activities until after receiving approval from the Agency.

In the course of construction where the rubber-modified asphalt binder distributor truck creates a joint by stopping at some point along the length of the roadway, the screenings spreader shall stop short of this joint, leaving a small strip of uncovered rubber-modified asphalt binder. This is to prevent an overlapping double thickness joint from being created once

work resumes. Transverse joints of this type shall be constructed by beginning spraying of the rubber-modified asphalt binder on the uncovered rubber-modified asphalt binder from before the work stoppage and proceed along the roadway. All reasonable precautions shall be taken to avoid skips and overlaps at joints. Any defect shall be corrected at the Contractor's expense by use of a shovel and/or broom prior to continuing operations. Plan your operations to minimize transverse joints.

The longitudinal joint between adjacent applications of screenings shall coincide with the line between designated traffic lanes. Longitudinal joints shall be overlapped for complete coverage. The overlap shall be from 2 to 4 inches. At longitudinal joints with screenings, the edge shall be broomed back and blended to eliminate differences in elevation. The joints shall be free from ridges and depressions and shall have a uniform appearance consistent with the adjacent sealed surface. Defects shall be corrected at the Contractor's expense.

Joints between areas of rubber-modified binder without screenings shall be made by overlapping rubber-modified binder distributions. The excess material shall be properly dispersed by spreading with a squeegee or rake over a larger area of freshly applied rubber-modified binder.

If the rubber-modified asphalt chip seal will be applied in a cul-de-sac, the Contractor shall submit plans for the construction methods in these areas. The Contractor shall submit plans that include, but not limited to, diagrams showing how the distributor truck and screenings spreader will move through the work area at least 5 days before any rubber-modified asphalt chip seal may be placed in cul-de-sac areas in order to minimize overlapping of the binder.

When placing rubber-modified asphalt chip seals in cul-de-sac, rubber-modified asphalt shall be covered in screenings within 5 minutes of application and initial rolling of the screenings shall begin within 3 minutes after spreading.

Caution should be exercised in applying rubber-modified chip seals in cul-de-sacs. Quality construction is difficult and obtaining an even application of binder and chips requires careful fore-thought. Overlapping applications of binder in particular may result in bleeding and shoving.

The application of rubber-modified binder to areas not accessible with the distributor bar on the distributor truck shall be accomplished by using handheld squeegees or other means approved by the Agency. If using Agency-approved methods, the Contractor will apply the rubber-modified asphalt binder at a comparable rate and uniformly as the distributor truck in these areas. Care shall be taken to apply screenings while the binder is still hot enough to allow proper embedment.

Apply the rubber-modified asphalt binder at the following rates:

1. For Coarse Screenings, from 0.35 to 0.5 gallons per square yard
2. For Medium Screenings, from 0.30 to 0.45 gallons per square yard
3. For Fine Screenings, from 0.25 to 0.35 gallons per square yard

The Agency determines the exact rate. The Contractor must apply binder to within 10 percent of the determined application rate.

The above rubber-modified asphalt binder application rates are meant as recommended values. Based on the local conditions, materials, weather, and other factors, a rubber-modified asphalt binder application rate outside of the ranges provided above may be necessary to achieve acceptable chip retention. Care should be taken by the Agency and Agency when determining the rubber-modified asphalt binder application rate that will be used.
[All areas of the existing pavement surface that have patching shall be precoated conventional emulsion or paving-grade asphalt binder prior to the full application of the rubber-modified asphalt chip seal. These areas will be identified by the Agency and shall be precoated with rubber-modified asphalt binder 1 hour before full application of the rubber-modified asphalt chip seal begins.**]**

The Agency may select to include the above specification relating to precoating the existing pavement surface with emulsion or asphalt binder. These patches could absorb some of the rubber-modified asphalt binder during chip seal application, causing decreased film thickness and effectiveness of the chip seal. Delete these statements if precoating with emulsion or asphalt binder will not be directed.

3.5. Screenings Application

During transit, cover precoated screenings for rubber-modified binder chip seal with tarpaulins, which are fully secured, at all times.
Prevent vehicles from driving on rubber-modified asphalt binder before spreading screenings.
At the time of application, precoated screenings for rubber-modified binder chip seal must be from 225 to 325°F.
Spread screenings at a uniform rate over the full lane width in one application. Operate the spreader at speeds slow enough to prevent screenings from rolling over after dropping. If the spreader is not moving, screenings must not drop. If the spreader stops and screenings drop, remove the excess screenings before resuming activities.
The screenings spreader shall be an appropriate distance behind the rubber-modified asphalt binder distribution truck such that screenings are applied to the rubber-modified asphalt binder within one minute. The screenings spreader shall be within 200 feet of the distribution truck at all times.
Spread screenings at the following rates:

1. For Coarse Screenings, from 25 to 40 pounds /sq yd.
2. For Medium Screenings, from 18 to 30 pounds per square yard.
3. For Fine Screenings, from 16 to 24 pounds per square yard.

The Agency determines the exact rate. Spread screenings to within 10 percent of the determined application rate. The application of the finished rubber-modified binder chip seal shall be uniform in appearance and free of defects.

The above screenings application rates are meant as recommended values. Based on the local conditions, materials, weather, and other factors, a screenings application rate outside of the ranges provided above may be necessary to achieve proper coverage of the rubber-modified asphalt binder. Care should be

taken by the Agency and Agency when determining the screenings application rate that will be used.

3.6. Rolling and Sweeping

Perform initial rolling within 90 seconds of spreading screenings. Do not spread screenings more than 200 feet ahead of the initial rolling.

A coverage must consist of the number of passes a roller needs to cover the width. A pass must be 1 roller movement parallel to the rubber-modified binder chip seal application in either direction. Overlapping passes are part of the coverage being made and are not part of a subsequent coverage. Do not start a coverage until completing the previous coverage.

Initial rolling of the rubber-modified binder chip seal shall consist of a minimum of 1 one coverage with pneumatic-tried roller(s). A minimum of 3 coverages with pneumatic tired rollers, after the initial rolling, shall be made on the rubber-modified binder chip seal.

After completion of rolling with pneumatic tired rollers, one and only one coverage shall be performed with a steel-wheeled roller, not to exceed 10 tons in weight. Use of steel wheel roller shall be immediately discontinued if it fractures the aggregate screenings.

Sweeping shall be a multi-step operation following final rolling of the screenings. Initial sweepings shall be performed and loose screenings shall be removed without dislodging the screenings set in the rubber-modified binder prior to acceptance.

Three additional sweepings shall be performed. The first sweeping shall be done one calendar day after placement of the rubber-modified binder chip seal, the second two calendar days after placement of the rubber-modified binder chip seal, and the final sweeping shall occur from five to seven calendar days after placement of the rubber-modified binder chip seal.

The Contractor must remove all loose chips from the street surface by sweeping the chips off of the roadway. Removal of excess screenings shall be completed before uncontrolled traffic is permitted on the completed rubber-modified seal coat. A broom sweeper may not be able to remove excess chips in areas where chips cannot be swept off the roadway, such as a cul-de-sac and areas with curb and gutter. The Contractor is responsible for removing these chips through the use of a vacuum sweeper or other acceptable means as approved by the Agency.

The use of any sweeper that causes damage to the rubber-modified binder chip seal coat shall be immediately discontinued. Any voids caused by automobile tires, poor adhesion of chips to rubber-modified asphalt binder, or any other cause shall be the Contractor's responsibility to patch prior to removing traffic control devices at no additional cost to the Agency.

Failure to provide adequate sweeping will result in the Agency preforming said work at the Contractor's sole expense, which shall be deducted from any monies due to the Contractor. Sweeping by Agency forces shall not relieve the Contractor of any liability arising from his/her failure to comply with these Specifications.

The traffic control on roadways scheduled to receive a newly constructed rubber-modified binder chip seal shall be performed as specified in the project Special Provisions and the Agency Standard Specifications.

Whenever the final sweeping or brooming of the rubber-modified asphalt chip seal is complete, place all permanent traffic stripes, pavement markings, crosswalks, stop bars, and raised pavement markers as shown in the Plans or project Specifications. Placement of all pavement

markings and raised pavement markers shall be completed from 2 to 10 calendar days after placement of the rubber-modified binder chip seal. Protect newly placed traffic stripes and pavement markings from traffic and other deleterious activities until the paint is thoroughly dry or the thermoplastic is hard enough to bear traffic. If multiple pavement stripes will be placed, the centerline strip shall be placed first before all other traffic stripes

4. Agency Acceptance

The Agency reserves the right to refuse to permit the use of material solely on the basis of a Certificate of Compliance. The Contractor shall allow the Agency of their designee access to observe any QC testing being performed. The Contractor must inform the Agency or their designee of the time and location that all QC testing will be perform.

[Contractor must submit CalRecycle Form 739-TRP certifying the use of California tires (http://www.calrecycle.ca.gov/Funding/Forms/Tires/CalRecycle739TRP.pdf).**]**

If the project is being funded by a CalRecycle Rubberized Pavement grant, the contractor must fill out the above-noted form and certify the quantity of crumb rubber from California tires. If the project will not be funded by a CalRecycle grant, this statement may be deleted.

[The Agency will use the results of the Contractor's QC test results to determine if the materials used for the rubber-modified chip seal meet the quality characteristic requirements that are specified herein. The Contractor shall deliver samples of materials used to the Agency or permit the Agency or their designee access to obtain samples from any stockpiles or facilities used to store or produce materials used in the rubber-modified chip seal upon request at any time during construction. Agency reserves the right to have such materials tested by an independent laboratory for compliance with the requirements in Section 2 for verification and acceptance purposes. The Contractor may examine the records and reports of the tests the Agency performs.**]**

[The Agency will accept the completed, in-place rubber-modified chip seal if the final product is uniform in appearance, free from all visible defects, bumps, areas of poor chip retention, and has been swept to remove all loose chips.**]**

The Agency may edit the preceding section discussing the acceptance criteria for the completed rubber-modified asphalt chip seal. For instance, the Agency may choose to require all traffic stripes and pavement markings be placed on the completed rubber-modified asphalt chip seal prior to acceptance.

5. Payment

[The payment quantity for rubber-modified asphalt chip seal is square yard, and such price shall include full compensation for specified surface preparation, removals, sweeping, and sanding if necessary, and for doing all the work and materials involved in constructing the rubber-modified asphalt chip seal complete in place.**]**

[The payment quantity for the precoated screenings is tons measured after the screenings preheated and precoated with asphalt binder. Contractor shall supply:

1. Time, date, mix number, load number, and truck identification are correlated with a load slip.
2. Each load slip shows the truck's empty weight and the truck's total weight including precoated screenings material.
3. Copy of the recorded batch weights is certified by a licensed weighmaster.

The payment quantity for the rubber-modified asphalt binder is tons. Contractor shall supply:

1. Time, date, mix number, load number, and truck identification are correlated with a load slip.
2. Each load slip shows the truck's empty weight, the truck's total weight including rubber-modified asphalt binder, and the truck's final weight after spraying rubber-modified asphalt binder.
3. Copy of the recorded batch weights is certified by a licensed weighmaster.**]**

The payment quantity for rubber-modified chip seal may be either square yard or by ton of binder and chips. Delete the statements for the payment quantity not selected. In general payment by square yards is easier to budget for and to measure, however payment by tons gives the Agency more ability to adjust application rates to suit conditions.

[Submit CalRecycle Form 739-TRP certifying the use of California tires (http://www.calrecycle.ca.gov/Funding/Forms/Tires/CalRecycle739TRP.pdf).**]**

If the project is being funded by a CalRecycle Rubberized Pavement grant, the contractor must fill out the above-noted form and certify the quantity of crumb rubber from California tires. If the project will not be funded by a CalRecycle grant, this statement may be deleted.

ASPHALT RUBBER CHIP SEAL

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Notes on Terminology

Standardization of terminology for pavement materials is problematic in general, and materials containing crumb rubber are no exception. The terminology used in this specification is "Asphalt Rubber Chip Seal". This specification is similar to the Greenbook specification for "Asphalt Rubber and Aggregate Membrane (ARAM)". In Caltrans specifications, the term "Asphalt Rubber Seal Coat" is used.

ASPHALT RUBBER CHIP SEAL

1. General

1.1. Scope

This work consists of constructing a chip seal using asphalt rubber binder.

1.1.1. Definitions

Crumb rubber modifier (CRM): Combination of ground or granulated scrap tire and high natural crumb rubber.

Scrap tire crumb rubber: Any combination of:

1. Automobile tires
2. Truck tires
3. Tire buffing

High natural crumb rubber: Material containing between 40 to 48 percent natural rubber.

Asphalt modifier: A resinous, high flash point, and aromatic hydrocarbon.

Descending viscosity reading: Subsequent viscosity reading at least 5 percent lower than the previous viscosity reading.

1.2. Submittals

The Contractor shall comply with all Federal, State, and Local environmental laws, rules, regulations, and ordinances including, but not limited to, air quality requirements.

At least 5 days before use, Contractor shall submit the permit issued by the local air district for asphalt rubber binder production equipment and application equipment. If an air quality permit is not required by the local air district for producing asphalt rubber binder, submit verification from the local air district that an air quality permit is not required.

At least 10 days before starting any asphalt rubber chip seal activities, Contractor shall submit the name of an authorized laboratory to perform QC testing. The authorized laboratory must comply with the Caltrans Independent Assurance Program (IAP) or possess current AASHTO Material Reference Laboratory (AMRL) accreditation for all ASTM and AASHTO tests required in Section 2.

The Agency should consider changing the number of days before starting work that the Contractor is required to submit the air quality permit and the name of the laboratory performing the Contractor's QC testing to suit their needs.

AMRL does not certify labs to conduct most of the relevant California Test methods. The Caltrans IAP certifies labs to perform California Test methods, but only labs with active Caltrans projects are eligible to receive the Caltrans accreditation.

The process for a testing laboratory to obtain Caltrans Accreditation is discussed in the Caltrans' Independent Assurance Manual, Procedures for Accreditation of Laboratories and Qualification of Tester (http://www.dot.ca.gov/dist1/d1lab/iap.htm).

Submit a certified volume or weight slip for each delivery of asphalt rubber binder ingredients.
At least 14 days before use, Contractor shall submit:

1. Four each one-quart cans of mixed asphalt rubber binder
2. Samples of each asphalt rubber binder ingredient
3. SDS for each hazardous material
4. Asphalt rubber binder formulation, including:
   - 4.1. Source and grade of asphalt binder
   - 4.2. Source and type of asphalt modifier
   - 4.3. Each source and type of scrap tire crumb rubber and high natural crumb rubber
   - 4.4. Percentage of asphalt modifier by weight of asphalt binder
   - 4.5. Percentage of combined asphalt binder and asphalt modifier by weight of asphalt rubber binder
   - 4.6. Percentage of scrap tire crumb rubber and high natural crumb rubber by total weight of asphalt rubber binder
   - 4.7. Percentage of scrap tire crumb rubber and high natural crumb rubber by total weight of crumb rubber modifier
   - 4.8. Minimum reaction time and temperature
5. Test results
   - 5.1. Certificate of Compliance showing the asphalt binder is the required PG grade
   - 5.2. Test results showing the asphalt modifier meets the requirements in Table 1
   - 5.3. Test results showing each source of CRM meets the requirements in Tables 2, 3, and 4
   - 5.4. Test results showing the asphalt rubber binder meets the requirements in Tables 5 and 6
   - 5.5. Test results showing the screenings meets the requirements in Tables 7 and 8

1.3. Quality Control Program

Contractor shall develop, implement, and maintain a QC program.
Contractor shall prepare and maintain QC records, including:

1. Names and qualifications of:
   1.1. Samplers
   1.2. Testers
   1.3. Inspectors
2. Testing laboratories
3. Testing equipment calibrations and certifications
4. Construction inspection reports
5. Sampling and testing records organized by date and type of material
6. Test results with comparison of quality characteristic requirements
7. Test results in relation to action and any suspension limits
8. Records of corrective actions and suspensions

Contractor shall notify the Agency within 24 hours of any noncompliance identified by the QC program.

1.4. Quality Control Manager

Contractor shall assign a QC manager before the start of the affected work. The QC manager must receive, review, and approve all correspondence, submittals, and reports relating to the QC of materials before they are submitted to the Agency. The QC manager must be the sole individual responsible for:

1. Signing the QC plan
2. Implementing the QC plan
3. Maintaining the QC records

The QC manager must be the Contractor's employee or must be an employee of a subcontractor that is providing only QC services. The QC manager must not be employed or compensated by a subcontractor or by any other persons or entities hired by subcontractors who will provide services or material for the project.

2. Materials

2.1. Asphalt Binder

Asphalt binder must be **[**PG 58-22**] [**PG 64-16.**]**

The Agency may select either PG 58-22 or PG 64-16 binder. Delete the statement for the binder not selected.

PG 64-16 is typically preferred for the Central Valley and low altitude areas of Southern California. In Northern coastal, Sierra, and Northeastern California PG 58-22 is typically preferred.

[Asphalt Binder must comply with Section 92 of the current Caltrans Standard Specifications.**]**
[Asphalt Binder must comply with Section 203-1 of the current Greenbook Standard Specifications.**]**

The Agency may choose to reference either the current Caltrans Standard Specifications or the current Greenbook. Delete the statement for the reference not selected.

2.2. Asphalt Modifier

Asphalt modifier must be a resinous, high flash point, aromatic hydrocarbon. Asphalt modifier must comply with the requirements shown in Table 1.

Table 1: Asphalt Modifier for Asphalt Rubber Binder

Quality Characteristic	Test Method	Requirement
Viscosity at 100 °C (cP)	ASTM D445	X ± 3 [a]
Flash point (C.L.O.C., °C)	ASTM D92	207 min
Asphaltenes by mass (%)	ASTM D2007	0.1 max
Aromatics by mass (%)	ASTM D2007	55 min

[a] X denotes the asphalt modifier viscosity from 19 to 36 as proposed by the Contractor. The proposed value "X" shall be submitted in writing to the Agency. A change in X requires a new asphalt rubber binder submittal.

2.3. Crumb Rubber Modifier

Crumb rubber modifier (CRM) shall consist of a combination of scrap tire CRM and high natural CRM. The scrap tire CRM shall consist of ground or granulated rubber derived from any combination of automobile tires, truck tires or tire buffings. The high natural CRM shall consist of ground or granulated rubber derived from materials that utilize high natural rubber sources. Scrap tire crumb rubber and high natural crumb rubber must be delivered to the asphalt rubber binder production site in separate bags and shall be sampled and tested separately.

Steel and fiber must be separated. If steel and fiber are cryogenically separated, it must occur before grinding and granulating. Cryogenically produced CRM particles must be large enough to be ground or granulated. Cryogenically produced CRM particles that pass through the grinder or granulator without being ground or granulated, respectively, shall not be used.

The CRM must comply with the requirements shown in the Tables 2, 3 and 4.

Table 2: Crumb Rubber Modifier Physical Requirements

Quality Characteristic	Test Method	Requirement
Wire in CRM (%)	California Test 385	0.01 max
Fabric in CRM (%)	California Test 385	0.05 max
CRM specific gravity	California Test 208	1.1 to 1.2

Table 3: Crumb Rubber Modifier Chemical Requirements

Quality Characteristic	Test Method	Scrap Tire	High Natural
Acetone extract (%)	ASTM D297	6.0 to 16.0	4.0 to 16.0
Rubber hydrocarbon (%)	ASTM D297	42.0 to 65.0	50.0 min
Natural rubber content (%)	ASTM D297	22.0 to 39.0	40.0 to 48.0
Carbon black content (%)	ASTM D297	28.0 to 38.0	---
Ash content (%)	ASTM D297	8.0 max	---

Table 4: Crumb Rubber Gradation Requirements, Percent Passing by Weight

Sieve Size	*Scrap Tire*	*High Natural*
#8	100	100
#10	98 to 100	100
#16	45 to 75	95 to 100
#30	2 to 20	35 to 85
#50	0 to 6	10 to 30
#100	0 to 2	0 to 4
#200	0	0 to 1

2.4. Asphalt Rubber Binder

Asphalt rubber Binder must be a combination of:

1. Asphalt binder
2. Asphalt modifier
3. Crumb rubber modifier

Asphalt rubber binder blending equipment must be authorized under the Caltrans Material Plant Quality Program. The blending equipment must allow the determination of weight percentages of each asphalt rubber binder ingredient.

Asphalt rubber binder must be 80 ± 2 percent by weight asphalt binder and asphalt modifier. The minimum percentage of CRM must be 20.0 ± 2 percent. CRM must be 75 ± 2 percent by weight scrap tire crumb rubber and 25 ± 2 percent by weight high natural crumb rubber.

Asphalt modifier and asphalt binder must be blended at the production site. Asphalt modifier must be from 2.5 to 6.0 percent by weight of the asphalt binder in the asphalt rubber binder. The asphalt rubber binder supplier determines the exact percentage.

The blend of asphalt binder and asphalt modifier must be combined with the CRM at the asphalt rubber binder production site. The asphalt binder and asphalt modifier blend must be from 375 to 440°F when the CRM is added. Combined ingredients must be allowed to react at least 45 minutes at temperatures from 375 to 425°F except the temperature shall not be higher than 10°F below the actual flashpoint of the asphalt rubber binder.

After reacting for at least 45 minutes, the asphalt rubber binder must comply with the requirements shown in Table 5.

Table 5: Asphalt Rubber Binder

Quality Characteristic	Test Method	Requirement
Cone penetration at 77°F (0.0004 inch)	ASTM D217	25 to 60
Resilience at 77°F (% rebound)	ASTM D5329	18 to 40
Softening point (°F)	ASTM D36/D36M	55 to 88
Viscosity at 375°F (cP)[a]	ASTM D7741/D7741M	1,500 to 2,500

[a] Prepare sample for viscosity test in accordance with California Test 388.

Maintain asphalt rubber binder at a temperature from 375 to 415°F.

Stop heating unused asphalt rubber binder 4 hours after the 45-minute reaction period. If the asphalt rubber binder drops below 375°F, reheat before use. Reheating asphalt rubber binder that cools below 375°F is a reheat cycle. Do not exceed two reheat cycles. If reheating, asphalt rubber binder must be from 375 to 415°F before use.

During reheating, you may add scrap tire crumb rubber. Scrap tire crumb rubber must not exceed 10 percent by weight of the asphalt rubber binder. Allow added scrap tire crumb rubber to react for at least 45 minutes. Reheated asphalt rubber binder must comply with the specifications for asphalt rubber binder.

Design the asphalt rubber binder from testing you perform for each quality characteristic and for the reaction temperatures expected during production. The profile must include the same component sources for the asphalt rubber binder used. The 24-hour (1,440-minute) interaction period determines the design profile. At a minimum, mix asphalt rubber binder components, take samples, and perform and record the tests shown in Table 6.

Table 6: Asphalt Rubber Binder Reaction Design Profile

Quality characteristic	Test Method	45 min [a]	60 min [a]	90 min [a]	120 min [a]	240 min [a]	360 min [a]	1,440 min [a]	Limit[c]
Cone penetration at 77°F (0.0004 inch)	ASTM D217	Xb	---	---	---	X	---	X	25 to 60
Resilience at 77°F (% rebound)	ASTM D5329	X	---	---	---	X	---	X	18 to 50
Softening point (°F)	ASTM D36	X	---	---	---	X	---	X	55 to 88
Viscosity (cP)a	ASTM D7741	X	X	X	X	X	X	X	1,500 to 2,500

[a] Six hours (360 minutes) after CRM addition, reduce the oven temperature to 275°F for 16 hours. After the 16-hour (960 minutes) cool down after CRM addition, reheat the binder to the reaction temperature expected during production for sampling and testing at 24 hours (1,440 minutes).

[b] X denotes required testing.

[c] The values presented in this table are for binder design only and are not to be used for material acceptance.

The purpose of performing an asphalt rubber binder design profile is to determine if the crumb rubber modifier and asphalt binder are compatible and if the asphalt rubber binder will remain stable. While the Contractor is required to perform the design profile, the design profile is not intended to be used for acceptance of the asphalt rubber binder.

2.5. Screenings

Screenings for asphalt rubber chip seal must comply with the gradation requirements shown in Table 7.

Table 7: Asphalt Rubber Chip Seal Screenings Gradation, Percent Passing by Weight

Sieve Size	*Coarse*	*Medium*	*Fine*
3/4-inch	100	100	100
1/2-inch	85 to 90	95 to 100	100
3/8-inch	0 to 15	70 to 85	100
#4	0 to 5	0 to 15	5 to 30
#8	---	0 to 5	0 to 10
#16	---	---	0 to 5
#200	0 to 1	0 to 1	0 to 2

Delete the columns for the gradations not selected.

Do not recombine fine materials collected in dust control systems except from primary dust collection devices such as cyclone collectors or knock-out boxes with any other aggregate used in the production of screenings.

The screenings must also comply with the requirements shown in Table 8.

Table 8: Asphalt Rubber Chip Seal Screenings Requirements [a]

Quality Characteristic	Test Method	Requirement
Cleanness Value	California Test 227	80 min
Durability	California Test 229	52 min
Los Angeles Rattler Loss (100 Revolutions, %)	ASTM C 131	10 max
Los Angeles Rattler Loss (500 Revolutions, %)	ASTM C 131	40 max
Film Stripping (%)	California Test 302	25 max

[a] Test the screenings prior to pre-coating.

3. Quality Control

3.1. General

The Contractor must submit all QC testing results to the Agency within 7 calendar days of receiving test results.

The Contractor must notify the Agency immediately if a QC test result falls outside of the material property requirements shown in Section 2. The Agency may stop production and construction activities by the Contractor if two test results in a row for any of the materials fall outside of the specified requirements in Section 2. The Contractor may not begin construction activities until the Contractor performs corrective action and demonstrates to the Agency that the material is within the specified requirements.

3.2. Asphalt Modifier

Test asphalt modifier under the test methods and frequencies shown in Table 9.

Table 9: Asphalt Modifier Testing Frequencies

Quality Characteristic	Test Method	Frequency [a]
Viscosity	ASTM D445	1 per project
Flash point	ASTM D92	1 per project
Asphaltenes	ASTM D2007	1 per project
Aromatics	ASTM D2007	1 per project

[a] Certificate of Compliance from CRM supplier/producer showing the material meets these requirements may be used in lieu of QC testing.

3.3. Crumb Rubber Modifier

If multiple sources of scrap tire CRM are used, the tests shall be performed on each source separately. Test CRM under the test methods and frequencies shown in Table 10.

Table 10: Crumb Rubber Modifier Testing Frequencies

Quality Characteristic	Test Method	Frequency [a]
CRM gradation	California Test 385	1 per shipment
Wire in CRM	California Test 385	1 per shipment
Fabric in CRM	California Test 385	1 per shipment
CRM specific gravity	California Test 208	1 per shipment

[a] Certificate of Compliance from CRM supplier/producer showing the material meets these requirements may be used in lieu of QC testing.

3.4. Asphalt Rubber Binder

Test asphalt rubber binder under the test methods and frequencies shown in Table 11.

Table 11: Asphalt Rubber Binder Testing Frequencies

Quality Characteristic	Test Method	Sampling Location	Frequency
Viscosity at 375°F [a]	ASTM D7741/D7741M	Reaction Vessel or Distribution Truck	1 per distribution truck
Descending viscosity[a]	ASTM D7741/D7741M	Reaction Vessel or Distribution Truck	1 per distribution truck
Cone penetration[b]	ASTM D217	Distribution Truck	1 per day of asphalt rubber binder production
Resilience[b]	ASTM D5329	Distribution Truck	1 per day of asphalt rubber binder production
Softening point[b]	ASTM D36/36M	Distribution Truck	1 per day of asphalt rubber binder production

[a] Tested in the field by an IAP certified technician. Start taking viscosity readings at least 45 minutes after adding crumb rubber modifier and continue taking viscosity readings every 30 minutes until 2 consecutive descending viscosity readings have been obtained and the final viscosity, as measured at the distribution truck on the job site immediately prior to application, is within the specification requirements.

[b] Tested at independent AMRL-accredited lab.

Retain the sample from each batch. A batch shall consist of all asphalt rubber material that is blended together from the raw materials (asphalt binder, asphalt modifier, CRM). Each time asphalt binder, asphalt modifier, and CRM are blended together will be considered a batch.

Log the test results, including time of testing and temperature of the asphalt rubber binder. Submit the log of asphalt rubber binder viscosity test results for each day of asphalt rubber binder application to the Agency within 24 hours. The Agency shall be notified of production schedule of all asphalt rubber binder produced for the work. The Agency reserves the right to observe QC testing of the asphalt rubber binder.

3.5. Screenings

Each stockpile of uncoated screenings must be sampled and tested. Make available all stockpiles to the Agency for Quality Assurance testing and notify the Agency a minimum of one full working day prior to pre-coating. Maintain discrete stockpiles at the asphalt plant.
Test the quality characteristics of screenings under the test methods and frequencies shown in Table 12.

Table 12: Screenings QC Testing [a]

Quality Characteristics	Test Method	Frequency
Gradation	ASTM C 136	1 per day per stockpile[b]
Cleanness value	California Test 227	1 per day per stockpile[b]
Durability	California Test 229	1 per day per stockpile[b]

[a] Test screenings prior to precoating.
[b] The Contractor is only required to test the stockpiles from which the screenings for that day's work are being taken from.

4. Construction

4.1. Equipment

4.1.1. Production

All equipment used to blend, store, and transport crumb rubber, asphalt modifier, and asphalt rubber binder shall comply with the requirements in Section 2-12 of Caltrans Material Plant Quality Program (MPQP) unless otherwise authorized in writing by the Agency.
The Agency reserves the right to require approval of equipment prior to use.

4.1.2. Placing/Finishing

Self-propelled distributor truck for applying asphalt rubber binder must have the following features:

1. Heating unit
2. Internal mixing unit
3. Pumps that spray asphalt rubber binder within 0.05 gal/sq yd of the specified rate
4. Fully circulating spray bar that applies asphalt rubber binder uniformly
5. Tachometer
6. Pressure gauges
7. Volume measuring devices
8. Thermometer
9. Observation platform on the rear of the truck for an observer on the platform to see the nozzles and unplug them if needed.

Self-propelled power brooms that clean the existing pavement and remove loose screenings without dislodging screenings set in the asphalt rubber binder.

Pneumatic tired rollers must be self-propelled and reversible. Pneumatic tires must be of equal size, diameter, type and ply. The roller must carry at least 1,500 lb of load on each wheel, and each tire must have an air pressure of 100 ± 5 psi.
Steel wheel rollers must be self-propelled and reversible. The roller must be operated in static mode at all times and may not exceed 10 tons in weight.
Screenings haul trucks must have tailgates that discharge screenings and devices to allow locking onto the rear screenings spreader hitch. The dump beds must not push down on the spreader when fully raised. Dump beds must not spill screenings on the roadway when transferred to the spreader hopper. All haul trucks must have tarpaulins to cover precoated screenings.
Self-propelled screenings spreader must have a screenings hopper in the rear, belt conveyors that carry the screenings to the front, and a spreading hopper capable of providing a uniform screening spread rate over the entire width of the traffic lane in one application.

4.1.3. Surface Preparation

The Contractor shall remove any existing traffic stripes, markings, crosswalks, stop bars, legends, and raised pavement markers in areas to receive asphalt rubber chip seal as required by the Plans or project Specifications. Removal shall be done by sand blasting or grinding and disposing of by the Contractor. Grinding or sand blasting operations shall be conducted to keep all removed pavement material from entering the storm drain system.
The Agency shall specify, either in the Plans or project Specifications, the existing traffic stripes, markings, crosswalks, stop bars, legends, and raised pavement markers to be removed prior to placement of the asphalt rubber chip seal. While not all painted stripes and markings may need to be removed, the Agency should rely on experience and knowledge gained from past chip seal projects in the local area to determine which pavement markings should be removed to ensure the asphalt rubber chip seal will bond to the existing pavement surface.
Existing pavement striping, markings, or markers which are outside the work area and not to be removed, shall be protected by the Contractor. Any striping, markings, or markers to remain damaged or rendered useless by the Contractor's operations shall be restored by the Contractor to the Agency's satisfaction and at the Contractor's expense.
Before applying asphalt rubber binder, cover manholes, valve and monument covers, grates, or other exposed facilities located within the area of application with plastic or oil-resistant construction paper secured by tape or adhesive to the facility being covered. Reference the covered facilities with enough control points to locate the facilities after the application of the asphalt rubber chip seal. Remove coverings promptly to return the facilities to service prior to the end of the same shift the seal coat is placed.
The Contractor shall remove all vegetation material growing in the street or on the interface of the asphalt surface with the lip of concrete gutter prior to placing asphalt rubber binder.
Immediately before applying the asphalt rubber binder, the surface shall be clean and completely dry. Cleaning shall be performed by sweeping, flushing, or other means necessary to remove all loose particles of paving, all dirt, and all out extraneous material. The Contractor shall clean all streets from face of curb to face of curb in the project area as necessary to ensure the pavement surface is sufficiently cleaned to provide for a bond between the existing pavement surface and seal coat. Any cleaning of the pavement surface immediately before

placing asphalt rubber chip seal shall be performed without water. The application of asphalt rubber binder on any street shall not proceed until the Agency has approved the street cleaning.

In the event that a scheduled street should become wet due to fog, rain, or any other reason, the placement of asphalt rubber chip seal shall be suspended until the surface has completely dried as determined by the Agency.

[The removal of all existing pavement markings and traffic stripes shall not occur sooner than 2 calendar days prior to the day that the asphalt rubber chip seal is to be placed.**]**

[If using sweeping equipment to clean the streets, the Contractor will perform a minimum of two complete passes over all pavement surfaces. In the event the Agency determines that two passes are not adequate, the Contractor shall re-sweep designated areas as necessary to achieve the appropriate level of pavement cleaning. Completion of sweeping shall be evidence by the absence of all loose particles of paving, all dirt, sand, gravel, leaves, and all other extraneous material. Street sweeping equipment shall be a broom sweeper, or approved equal, in a sufficiently maintained condition to accomplish the sweeping goals of the project. Pavement missed by or inaccessible to broom sweepers shall be swept clean by other methods that are approved by the Agency. The Contractor shall provide whatever flushing, compressed air, or other cleaning methods are necessary to remove all dirt, vegetation, and loose material from the pavement.**]**

[Prior to the application of the asphalt rubber chip seal, the Contractor shall completely remove all grease and oil spots deposited by parked cars in the area of work. The application of asphalt rubber binder on any street shall not proceed until the Agency has approved the completion of all oil spot removal.**]**

The above three specifications for Surface Preparation are optional and each one is independent of the others. The Agency may decide to enforce require the Contractor to conduct these surface preparation activities. Delete any statements related to surface preparation below that are not selected for enforcement.

4.1.4. Precoating Screenings

Precoating of screenings is required.

Precoating of screenings must be performed at a central mixing plant. **[**The plant must be authorized under the Caltrans Material Plant Quality Program (MPQP).**]**

The Agency may choose to not require MPQP authorization. MPQP authorization is only available to contractors with Caltrans projects.

Do not recombine fine materials collected in dust control systems except from primary dust collection devices such as cyclone collectors or knock-out boxes with any other aggregate used in the production of screenings.

For asphalt rubber chip seal, screenings must be preheated from 260 to 325°F. **[**Coat with any of the asphalts specified in the table titles "Performance Graded Asphalt Binder" in section 92 of the current Caltrans Standard Specifications.**] [**Coat with any of the asphalts in section 203-1 of the current Greenbook**]**. The asphalt must be from 0.5 to 1.0 percent by weight of dry screenings. The Agency determines the exact rate.

Do not stockpile preheated and/or precoated screenings.

The Agency may choose to reference either the current Caltrans Standard Specifications or the current Greenbook. Delete the statement for the reference not selected.

4.1.5. Asphalt Rubber Binder Application

The asphalt rubber binder may only be applied if:

1. The pavement temperature is above 55°F.
2. The ambient temperature is from 60 to 105°F.
3. The pavement is clean and dry.
4. Wind conditions are such that uniform asphalt rubber binder coverage can be achieved.
5. Rain is not imminent.

The asphalt rubber binder shall be applied when the temperature of the asphalt rubber binder is between 385 and 415°F.

Prevent vehicles from driving on asphalt rubber binder before spreading screenings.

Do not apply asphalt rubber binder during high wind conditions. If authorized, Contractor may adjust the distributor bar height and distribution speed and use shielding equipment during high wind conditions. However, if the weather conditions do not allow for uniform placement of the asphalt rubber binder, the Agency may decide to suspend construction activities by the Contractor at no cost to the Agency. The Contractor may not resume construction activities until after receiving approval from the Agency.

In the course of construction where the asphalt rubber binder distributor truck creates a joint by stopping at some point along the length of the roadway, the screenings spreader shall stop short of this joint, leaving a small strip of uncovered asphalt rubber. This is to prevent an overlapping double thickness joint from being created once work resumes. Transverse joints of this type shall be constructed by beginning spraying of the asphalt rubber binder on the uncovered asphalt rubber binder from before the work stoppage and proceed along the roadway. All reasonable precautions shall be taken to avoid skips and overlaps at joints. Any defect shall be corrected at the Contractor's expense by use of a shovel and/or broom prior to continuing operations. Plan your operations to minimize transverse joints.

The longitudinal joint between adjacent applications of screenings shall coincide with the line between designated traffic lanes. Longitudinal joints shall be overlapped for complete coverage. The overlap shall be from 2 to 4 inches. At longitudinal joints with screenings, the edge shall be broomed back and blended to eliminate differences in elevation. The joints shall be free from ridges and depressions and shall have a uniform appearance consistent with the adjacent sealed surface. Defects shall be corrected at the Contractor's expense.

Joints between areas of asphalt rubber binder without screenings shall be made by overlapping asphalt rubber binder distributions. The excess material shall be properly dispersed by spreading with a squeegee or rake over a larger area of freshly applied asphalt rubber binder.

If the asphalt rubber chip seal will be applied in a cul-de-sac, the Contractor shall submit plans for the construction methods in these areas. The Contractor shall submit plans that include, but not limited to, diagrams showing how the distributor truck and screenings spreader will move through the work area at least 5 days before any asphalt rubber chip seal may be placed in cul-de-sac areas in order to minimize overlapping of the binder. When placing asphalt rubber chip seals in cul-de-sac, asphalt rubber shall be covered in screenings within 5 minutes of application and initial rolling of the screenings shall begin within 3 minutes after spreading.

Caution should be exercised in applying asphalt rubber chip seals in cul-de-sacs. Quality construction is difficult and obtaining an even application of binder and chips requires careful fore-thought. Overlapping applications of binder in particular may result in bleeding and shoving.

The application of asphalt rubber binder to areas not accessible with the distributor bar on the distributor truck shall be accomplished by using handheld squeegees or other means approved by the Agency. If using Agency-approved methods, the Contractor will apply the asphalt rubber binder at a comparable rate and uniformly as the distributor truck in these areas. Care shall be taken to apply screenings while the binder is still hot enough to allow proper embedment.

Apply the asphalt rubber binder at a rate from 0.55 to 0.65 gallons per square yard. The Agency determines the exact rate. The Contractor must apply binder to within 10 percent of the determined application rate.

There are several factors that will affect the selection of the binder application rate including, but not limited to, traffic levels and existing pavement condition. It is important that the Agency responsible for determining the asphalt rubber binder

application rate is educated on these factors so that the most appropriate application rate is chosen.

The Caltrans Maintenance Technical Advisory Guide discusses selecting the application rate (http://www.dot.ca.gov/hq/maint/FPMTAGChapter7-ChipSeals.pdf)

[All areas of the existing pavement surface that have patching shall be precoated with conventional emulsion or paving-grade asphalt binder prior to the full application of the asphalt rubber chip seal. These areas will be identified by the Agency and shall be precoated with emulsion or asphalt binder 1 hour before full application of the asphalt rubber chip seal begins.**]**

The Agency may select to include the above specification relating to precoating the existing pavement surface with emulsion or asphalt binder. These patches could absorb some of the asphalt rubber binder during chip seal application, causing decreased film thickness and effectiveness of the chip seal. Delete these statements if precoating with emulsion or asphalt binder will not be directed.

4.1.6. Screenings Application

During transit, cover precoated screenings for asphalt rubber chip seal with tarpaulins at all times.

Prevent vehicles from driving on asphalt rubber binder before spreading screenings.

At the time of application, precoated screenings for asphalt rubber chip seal must be from 225 to 325°F.

Spread screenings at a uniform rate over the full lane width in one application. Operate the spreader at speeds slow enough to prevent screenings from rolling over after dropping. If the spreader is not moving, screenings must not drop. If the spreader stops and screenings drop, remove the excess screenings before resuming activities.

The screenings spreader shall be an appropriate distance behind the asphalt rubber binder distribution truck such that screenings are applied to the asphalt rubber binder within one minute. The screenings spreader shall be within 200 feet of the distribution truck at all times.

Spread screenings at a rate from 28-40 pounds /sq yd. The Agency determines the exact rate.

Spread screening to within 10 percent of the determined application rate. The application of the finished asphalt rubber chip seal shall be uniform in appearance and free of defects.

4.1.7. Rolling and Sweeping

Perform initial rolling within 90 seconds of spreading screenings. Do not spread screenings more than 200 feet ahead of the initial rolling.

A coverage must consist of the number of passes a roller needs to cover the width. A pass must be one (1) roller movement parallel to the asphalt rubber chip seal application in either direction. Overlapping passes are part of the coverage being made and are not part of a subsequent coverage. Do not start a coverage until completing the previous coverage.

Initial rolling of the asphalt rubber chip seal shall consist of a minimum of one (1) coverage with pneumatic-tried roller(s). A minimum of three (3) coverages with pneumatic tired rollers, after the initial rolling, shall be made on the asphalt rubber chip seal.

After completion of rolling with pneumatic tired rollers, one and only one coverage shall be performed with a steel-wheeled roller, not to exceed 10 tons in weight. Use of steel wheel roller shall be immediately discontinued if it fractures the aggregate screenings.
Sweeping shall be a multi-step operation following final rolling of the screenings. Initial sweepings shall be performed and loose screenings shall be removed without dislodging the screenings set in the asphalt rubber binder prior to acceptance.
Three additional sweepings shall be performed. The first sweeping shall be done one calendar day after placement of the asphalt rubber chip seal, the second two calendar days after placement of the asphalt rubber chip seal, and the final sweeping shall occur from five to seven calendar days after placement of the asphalt rubber chip seal.
The Contractor must remove all loose chips from the street surface by sweeping the chips off of the roadway. Removal of excess screenings shall be completed before uncontrolled traffic is permitted on the completed asphalt rubber seal coat. A broom sweeper may not be able to remove excess chips in areas where chips cannot be swept off the roadway, such as a cul-de-sac and areas with curb and gutter. The Contractor is responsible for removing these chips through the use of a vacuum sweeper or other acceptable means as approved by the Agency.
The use of any sweeper that causes damage to the asphalt rubber chip seal coat shall be immediately discontinued. Any voids caused by automobile tires, poor adhesion of chips to asphalt rubber binder, or any other cause shall be the Contractor's responsibility to patch prior to removing traffic control devices at no additional cost to the Agency.
Failure to provide adequate sweeping will result in the Agency preforming said work at the Contractor's sole expense, which shall be deducted from any monies due to the Contractor. Sweeping by Agency forces shall not relieve the Contractor of any liability arising from his/her failure to comply with these Specifications.
The traffic control on roadways scheduled to receive a newly constructed asphalt rubber chip seal shall be performed as specified in the project Special Provisions and the Agency Standard Specifications.
Whenever the final sweeping or brooming of the asphalt rubber chip seal is complete, place all permanent traffic stripes, pavement markings, crosswalks, stop bars, and raised pavement markers as shown in the Plans or project Specifications. Placement of all pavement markings and raised pavement markers shall be completed within from 2 to 10 calendar days after completion of final sweeping or brooming of the asphalt rubber chip seal. Protect newly placed traffic stripes and pavement markings from traffic and other deleterious activities until the paint is thoroughly dry or the thermoplastic is hard enough to bear traffic. If multiple pavement stripes will be placed, the centerline strip shall be placed first before all other traffic stripes.

5. Agency Acceptance

The Agency reserves the right to refuse to permit the use of material solely on the basis of a Certificate of Compliance, except for the asphalt modifier and crumb rubber modifier. The Contractor shall allow the Agency or their designee access to observe any QC testing being performed. The Contractor must inform the Agency or their designee of the time and location that all QC testing will be performed.
[Contractor must submit CalRecycle Form 739-TRP certifying the use of California tires (http://www.calrecycle.ca.gov/Funding/Forms/Tires/CalRecycle739TRP.pdf). **]**

If the project is being funded by a CalRecycle Rubberized Pavement grant, the contractor must fill out the above-noted form and certify the quantity of crumb rubber from California tires. If the project will not be funded by a CalRecycle grant, this statement may be deleted.

[The Agency will use the results of the Contractor's QC test results to determine if the materials used for the asphalt rubber chip seal meet the quality characteristic requirements that are specified herein. The Contractor shall deliver samples of materials used to the Agency or permit the Agency or their designee access to obtain samples from any stockpiles or facilities used to store or produce materials used in the asphalt rubber chip seal upon request at any time during construction. Agency reserves the right to have such materials tested by an independent laboratory for compliance with the requirements in Section 2 for verification and acceptance purposes. The Contractor may examine the records and reports of the tests the Agency performs.**]**

[The Agency will accept the completed, in-place asphalt rubber chip seal if the final product is uniform in appearance, free from all visible defects, bumps, areas of poor chip retention, and has been swept to remove all loose chips.**]**

The Agency may edit the preceding section discussing the acceptance criteria for the completed, in-place, asphalt rubber chip seal. For instance, the Agency may choose to require all traffic stripes and pavement markings be placed on the completed asphalt rubber chip seal prior to acceptance.

6. Payment

[The payment quantity for asphalt rubber chip seal is square yard, and such price shall include full compensation for specified surface preparation, removals, sweeping, and sanding if necessary, and for doing all the work and materials involved in constructing the asphalt rubber chip seal complete in place.**]**

[The payment quantity for the precoated screenings is tons measured after the screenings preheated and precoated with asphalt binder. Contractor shall supply:

1. Time, date, mix number, load number, and truck identification are correlated with a load slip.
2. Each load slip shows the truck's empty weight and the truck's total weight including precoated screenings material.
3. Copy of the recorded batch weights is certified by a licensed weighmaster.

The payment quantity for the asphalt rubber binder is tons. Contractor shall supply:

1. Time, date, mix number, load number, and truck identification are correlated with a load slip.
2. Each load slip shows the truck's empty weight, the truck's total weight including asphalt rubber binder, and the truck's final weight after spraying asphalt rubber binder.
3. Copy of the recorded batch weights is certified by a licensed weighmaster.**]**

The payment quantity for asphalt rubber chip seal may be either square yard or by ton of binder and chips. Delete the statements for the payment quantity not selected.

In general payment by square yards is easier to budget for and to measure, however payment by tons gives the Agency more ability to adjust application rates to suit conditions.

DATA FOR CHARTS, GRAPHS, AND INFOGRAPHICS

Figure 1. Caltrans. 2006. *Asphalt Rubber Usage Guide.*
Figure 2. Federal Highway Administration (FHWA). 2014. *The Use of Recycled Tire Rubber to Modify Asphalt Binder and Mixtures*, Washington, DC.
Figure 3. CalRecycle. 2011. *Rubberized Asphalt Concrete: A* Basic *Introduction to RAC Usage*, Technology Transfer Series RAC-101.
Figure 4. CalRecycle. 2011. *Rubberized Asphalt Concrete: A* Basic *Introduction to RAC Usage*, Technology Transfer Series RAC-101.
Figure 5. CalRecycle. 2011. *Rubberized Asphalt Concrete: A* Basic *Introduction to RAC Usage*, Technology Transfer Series RAC-101.
Figure 6. CalRecycle. 2011. *Rubberized Asphalt Concrete: A* Basic *Introduction to RAC Usage*, Technology Transfer Series RAC-101.
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