ASPHALT RUBBER USAGE GUIDE

State of California Department of Transportation
Division of Engineering Services
Materials Engineering and Testing Services-MS #5
Office of Flexible Pavement Materials
5900 Folsom Boulevard
Sacramento, CA 95819-4612

January 2003

TABLE OF CONTENTS

APPENDIX A

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This Asphalt Rubber Usage Guide is intended for use by California Department of Transportation (Caltrans) design, construction, and maintenance managers and engineers, as well as by field personnel involved in placement of asphalt rubber paving materials including hot mixes and surface treatments. The purpose of this Guide is to provide state-of-the-practice information regarding product selection and use, design, production, construction, and quality control and assurance of the asphalt rubber binder, paving materials and spray applications. The intent is to enable Caltrans to optimize the use of asphalt rubber materials to obtain the advertised benefits. This Guide provides an overview of asphalt rubber (AR) materials, components and binder design, and of the benefits and limitations of these materials. This Guide describes the various types of asphalt rubber products available for use in hot mixes and spray (membrane) applications, and presents criteria for selection and use. It also presents information on:

- Mix design criteria,
- Similarities and differences between asphalt rubber and corresponding conventional asphalt concrete and seal coat applications,
- Cost and environmental considerations related to asphalt rubber materials, and
- Guidelines for construction and inspection considerations for asphalt rubber pavements and surface treatments.

This Guide does not address maintenance, repair, or rehabilitation of asphalt rubber products. Such information will be added to the Flexible Pavement Rehabilitation Manual in the future and to the Maintenance Technical Advisory Guide, as appropriate.

DISCLAIMER

Development of this Guide was sponsored by Caltrans Materials Engineering and Testing Service (METS). The contents of this Guide reflect the views and experience of the authors, who are responsible for the facts and accuracy of the information presented herein. This Guide does not constitute a standard, specification or a regulation.

GLOSSARY OF TERMS

Asphalt rubber – is used as a binder in various types of flexible pavement construction including surface treatments and hot mixes. According to the ASTM definition (ASTM D 8, Vol. 4.03, "Road and Paving Materials" of the Annual Book of ASTM Standards 2001) asphalt rubber is "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles". By definition, asphalt rubber is prepared using the "wet process". Caltrans specifications for asphalt rubber physical properties fall within the ranges listed in ASTM D 6114, "Standard Specification for Asphalt rubber Binder," also located in Vol. 4.03. Recycled tire rubber is used for the reclaimed rubber and is currently referred to as crumb rubber modifier (CRM). The asphalt rubber is formulated and reacted at elevated temperatures and under high agitation to promote the physical interaction of the asphalt cement and CRM constituents, and to keep the CRM particles suspended in the blend. Various petroleum distillates or extender oil may be added to reduce viscosity, facilitate spray applications, and promote workability.

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

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

TYPES OF CRM

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

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

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

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

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

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

CRM PREPARATION METHODS

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

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

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

Shredding – process that reduces scrap tires to pieces 0.023 m^2 and smaller prior to granulation or ambient grinding.

CRM PROCESSING EQUIPMENT

Cracker mill – apparatus typically used for ambient grinding, that tears apart scrap tire rubber by passing the material between rotating corrugated steel drums, reducing the size of the rubber to a crumb particle (generally 4.75 mm to 425 μm sieve).

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 9.5 mm to 2.0 sieve in size.

Micro-mill – process that further grinds crumb rubber particles to sizes below 425 μm sieve.

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

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

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 asphalt rubber binders that are used to make asphalt concrete, and is not recommended for use in interlayers that will be overlaid with asphalt concrete in less than 90 days due to on-going evaporation of volatile components.

Dry process – any method that mixes the crumb rubber modifier dry with the aggregate before the mixture is charged with asphalt binder. The CRM acts as a rubber aggregate in the paving mixture. This method applies only to hot-mix asphalt production.

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

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

Gap-graded – aggregate that is not continuously graded for all size fractions, typically missing or low on one or two of the finer sizes. Gap grading is used to promote stone-to-stone contact in hot-mix asphalt concrete. This type of gradation is most frequently used to make rubberized asphalt concrete-gap graded (RAC-G) paving mixtures.

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

Open-graded – aggregate gradation that is intended to be free draining and consists mostly of 2 or 3 nominal sizes of aggregate particles with few fines and 0 to 4 percent by mass passing the 0.075 mm sieve. Open grading is used in hot-mix applications to provide relatively thin surface or wearing courses with good frictional characteristics that quickly drain surface water to reduce hydroplaning, splash and spray.

Reaction – commonly used term for the interaction between asphalt binder and crumb rubber modifier when blended together at elevated temperatures. The reaction is more appropriately defined as polymer swell. It is not a chemical reaction. It is a physical interaction in which the crumb rubber absorbs aromatic oils and light fractions (small volatile or active molecules) from the asphalt binder, and releases some of the similar oils used in rubber production into the asphalt binder.

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

Rubberized asphalt – asphalt binder modified with CRM that may include less than 15 percent CRM by mass and thus may not comply with the ASTM definition of asphalt rubber (ASTM D 8, Vol. 4.03). In the past, terminal blends (Rubber Modified Binder, RMB) have typically fallen in this category.

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

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 9 and 12 mm depending on the size of the cover aggregate. A SAM is a surface treatment that is used primarily to restore surface frictional characteristics, seal cracks and provide a waterproof membrane to minimize the intrusion of surface water into the pavement structure. SAMs are used for pavement preservation, maintenance, and limited repairs. Asphalt rubber SAMs minimize reflective cracking from an underlying distressed asphalt or rigid pavement, and can help maintain serviceability of the pavement pending rehabilitation or reconstruction operations.

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

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

Terminal blend – a form of the wet process where CRM is blended with hot asphalt binder at the refinery or at an asphalt binder storage and distribution terminal and transported to the asphalt concrete mixing plant or job site for use. This type of rubberized binder (Rubber Modified Binder, RMB) reportedly does not require subsequent agitation to keep the CRM particles evenly dispersed in the modified binder. In the past, such blends normally contained 10 percent or less finely ground CRM by mass (which does not satisfy the ASTM D 8 definition of asphalt rubber) and other additives to eliminate the need for agitation. However, new formulations have reportedly been developed that contain 15 percent CRM by total binder mass.

Truck tires – tires with an outside diameter greater than 660 mm and less than 1520 mm used on commercial trucks and buses.

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

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

Wet process – any method that blends CRM with the asphalt cement before incorporating the binder into the asphalt paving materials. Although most wet process asphalt rubber binders require agitation to keep the CRM evenly distributed throughout the binder, terminal blends or RMB binders may be formulated so as not to require agitation.

1.0 INTRODUCTION AND OVERVIEW

The purpose of this Usage Guide is to provide the California Department of Transportation (Caltrans) state-of-the-practice information regarding product selection and use, design, production, construction, and quality control and assurance of asphalt rubber binder, paving materials and spray applications. It also contains some generally accepted best practices for asphalt rubber binder preparation and mixture placement The intent is to enable Caltrans to optimize the use and handling of asphalt rubber materials in order to obtain the many advertised benefits including increased durability and reduced maintenance.

1.1 WHAT IS ASPHALT RUBBER?

According to the ASTM definition, asphalt rubber (AR) is "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles." By definition, asphalt rubber is prepared using the "wet process." Physical property requirements are listed in ASTM D 6114, "Standard Specification for Asphalt Rubber Binder," located in Vol. 4.03 of the Annual Book of ASTM Standards 2001, and in Caltrans Standard Special Provisions for Asphalt Rubber Binder. The asphalt rubber is produced at elevated temperatures (≥177°C), under high agitation to promote the physical interaction of the asphalt binder and rubber constituents, and to keep the rubber particles suspended in the blend. Various petroleum distillates or extender oil may be added to reduce viscosity, facilitate spray applications, and promote workability.

Recycled tire rubber is used for the reclaimed rubber and is called crumb rubber modifier (CRM). Tire rubber is a blend of synthetic rubber, natural rubber, carbon black, anti-oxidants, fillers, and extender type oils that is soluble in hot paving grade asphalt.

In California, asphalt rubber is specified to include 18 to 22 percent CRM by total mass of the asphalt rubber blend. The CRM must also include 25 ± 2 percent by mass of high natural rubber content scrap rubber that may come from scrap tires or other sources. Caltrans specifications for asphalt rubber physical properties fall within the ranges listed in ASTM D 6114. Caltrans requires use of extender oil as an asphalt modifier in asphalt rubber.

Asphalt rubber should not be confused with other rubberized asphalt products such as the "dry process" in which crumb rubber is substituted for a small proportion of the aggregate and is not reacted with the asphalt binder prior to mixing, or with "terminal blends." Terminal blends are made by the wet process, but historically have included no more than 10 percent ground tire rubber along with other additives. Such low CRM content blends do not achieve sufficient viscosity to perform in AC mixtures in the same manner as the original types of asphalt rubber binders. However, new terminal blends with up to 15 percent CRM have reportedly been developed that might perform more like asphalt rubber. Terminal blends must meet the Caltrans requirements for Rubber Modified Binder (RMB).

Rubberized asphalt concrete (RAC) may be produced using a variety of rubber-modified binders, including asphalt rubber, rubberized terminal blends, RMB materials, or by the dry process.

Both RMB and dry process rubberized AC mixes have had limited usage by Caltrans. Anecdotal reports indicate their performance ranges from very good to poor, but relatively little conclusive data is available about their performance on rehabilitation projects in the California State Highway System. *Consequently, the information presented in this Usage Guide is limited to asphalt rubber paving materials and may not be appropriate for other modified binder or dry process materials.*

1.2 BRIEF HISTORY OF ASPHALT RUBBER

Development of asphalt rubber materials for use as joint sealers, patches, and membranes began in the late 1930s**.** In the early 1950s, Lewis and Welborn of the Bureau of Public Roads (BPR) 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 asphalts, including "a California asphalt of low-gravity, low-sulfur, low-asphaltenes type." The results were published in the October 1954 issue of *Public Roads* along with results of a companion "Laboratory Study of Rubber-Asphalt Paving Mixtures," conducted by Rex and Peck at BPR. The mixtures study looked at a wide range of vulcanized and unvulcanized rubber materials including tread from scrap tires, styrene-butadiene rubber (SBR), natural rubber, polybutadiene, and reclaimed (devulcanized) rubber and at both wet and dry methods of adding them to AC mixtures. Interest and work in this area continued to grow, as did the number of patent applications. In March 1960, the Asphalt Institute held the first Symposium on Rubber in Asphalt in Chicago, IL. It consisted of five paper presentations and discussion.

Charles H. McDonald of the City of Phoenix Arizona worked extensively with asphalt and rubber materials in the 1960s and 1970s 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 patching and surface treatments for repair and maintenance. Asphalt rubber chip seals served effectively as the City's primary pavement maintenance and preservation strategy for arterial roadways for nearly twenty years, until traffic volumes forced a change to thin AC overlays. Gap-graded asphalt rubber concrete mixtures were developed as a successful substitute.

In 1975, Caltrans began experimenting with asphalt rubber chip seals in the laboratory and small test patches located at 03-Yol-84-PM 16+ and 03-Sac-99-PM 20+, with generally favorable results. In 1978, the first Caltrans dry process rubber-modified AC pavement was constructed on SR 50 at Meyers Flat. It included one percent ground rubber by mass added to the dry aggregate prior to mixing with the paving asphalt. Performance was rated good. The first Caltrans rubberized asphalt concrete pavements made with early versions of "wet-process" asphalt rubber binder and dense-graded aggregate were constructed in 1980 at Strawberry (SR 50) and at Donner Summit (I-80). The Strawberry project was an emergency repair to a dramatically failed pavement. The repair included pavement reinforcing fabric (PRF), and a 60 mm layer of DGAC to restore structural capacity, under the thin (30 mm) RAC wearing course. The first three projects are all located in "snow country" at high elevations where tire chains are used in winter. The RAC pavements reportedly performed well in resisting chain abrasion and reflective cracking.

The Ravendale project (02-Las-395) constructed in 1983 significantly changed Caltrans' approach to the use of asphalt rubber. This project presented a typical dilemma. The cost of rehabilitation by overlaying with DGAC was prohibitive, so less costly alternatives were considered, including thinner sections of RAC. The project was designed as a series of 13 test sections that included two different thicknesses each of wet process (dense-graded) and dry process (gap-graded) RAC with SAMI (4 sections), wet and dry RAC at 46 mm thick without SAMI (2 sections), four control sections with different thicknesses of DGAC from 46 to 152 mm, two sections surfaced only by double asphalt rubber chip seals, and one section surfaced with a single asphalt rubber chip. The test sections were monitored over time. The dry process section at this site lasted over 19 years before it was overlaid in 2002. By 1987, it was clear that the thin RAC pavements were performing better than thicker conventional DGAC. Caltrans built more RAC projects and continued to study the performance of RAC constructed at reduced thickness relative to DGAC structural requirements.

Through 1987, Caltrans constructed one or two RAC projects a year. Dense- or open-graded RAC mixes were placed as surface courses at compacted thicknesses ranging from 24 mm for open-graded to 76 mm for RAC-D. Some projects included pavement reinforcing fabric (PRF) and/or a leveling course, and some others included asphalt rubber stress absorbing membrane interlayer (SAMI-R) under the asphalt rubber mixes.

In March 1992 Caltrans published a "Design Guide for Asphalt Rubber Hot Mix-Gap Graded (ARHM-GG)" based on these studies and project reviews. The Guide presents structural and reflection crack retardation equivalencies for gap-graded asphalt rubber mixtures (now designated RAC-G) with respect to DGAC, and with and without SAMI. These equivalencies have since been validated and incorporated in Section 6, Tables 3 and 4 of the Caltrans Flexible Pavement Rehabilitation Manual (June 2001). RAC-G can generally be substituted for DGAC at about one-half the DGAC thickness.

By 1995, over 100 Caltrans RAC projects had been constructed. Cities and counties in California had by then constructed more than 400 asphalt rubber projects, including asphalt rubber chip seals. However some problems occurred, including some cases of premature distress. Caltrans engineers reviewed RAC performance on the Caltrans projects, selected California city and county projects, and 41 Arizona DOT projects. Some of the problems observed were clearly construction related; many of the contractors involved in those projects had little if any experience working with the RAC mixtures.

A Caltrans-Industry review concluded with the observation that asphalt rubber materials can perform very well when properly designed and constructed, and recommended that Caltrans should continue using and studying asphalt rubber. A very important finding was that the distresses observed in RAC pavements generally appeared to progress at a much slower rate than would be expected in a structurally equivalent conventional DGAC pavement. In many of the cases where premature RAC distress (particularly cracking) had occurred, relatively little maintenance was required to achieve adequate pavement service life because the subsequent distress developed slowly. One-third of the Strawberry RAC was reportedly still exposed and performing after 15 years.

By mid-2001, over 210 Caltrans RAC projects had been constructed throughout California. Municipalities and counties also continued to use asphalt rubber for hot mixes and surface treatments with generally good performance. However some of the old problems with product selection, design, and construction continue to arise. Districts 7 and 8 reportedly experienced several major RAC failures.

The purpose of this Guide is to resolve such problems and enhance the performance of asphalt rubber pavements that will be designed and constructed in California in the future.

A Modified Binder (MB) specification was developed in the early 1990s as part of a continuing movement towards performance-based specifications from method type or “recipe” specifications. It has been suggested that the specification be renamed as “RMB,” Rubber Modified Binder. Based on analysis of rheological measurements of samples of asphalt rubber binders and limited evaluations of their field performance, Caltrans researchers developed two new parameters for specifying rubberized binders, using residues aged in the Pressure Aging Vessel (PAV).

- Shear susceptibility of the phase angle delta, SSD, which is related to elastic properties, and
- Shear susceptibility of viscosity, SSV, which is related to stiffness.

Ten pilot projects were constructed between December 1997 and November 1999 to evaluate the performance of materials meeting the MB specification. The MB pilots are located mostly in the coastal regions of California and include both dense-graded and gap-graded mixtures placed over a range of structural sections. These projects were reviewed by a joint Caltrans-Industry group: eight were rated as good, one as fair, and one that exhibited base failure and pumping as poor. Caltrans has prepared a report on these MB pilot projects. However findings to date are limited and additional pilot RMB projects are being planned for construction in 2003-2004, after completion of heavy vehicle simulator trials being conducted at the University of California Berkeley.

1.3 HOW IS ASPHALT RUBBER USED?

Asphalt rubber is used as a binder in various types of asphalt pavement construction including surface treatments and hot mixes. It is also used in crack sealants, which are not a subject of this Guide. For hot mixes, asphalt rubber has been found to be most effective and is most commonly used in gap-graded and open-graded mixes, particularly for surface courses and for thin overlays ≤ 60 mm thick. Terminal blends and MB have been used in dense- and gap-graded mixes. The most common spray application is a chip seal, also called a stress absorbing membrane (SAM). Chip seals are primarily used for maintenance and pavement preservation. Asphalt rubber chip seals may also be overlaid with DGAC or RAC, making them interlayers, typically called SAMI-R. Section 2 provides more detailed information on product selection, usage, and design.

1.4 WHERE SHOULD ASPHALT RUBBER PRODUCTS BE USED?

Asphalt rubber products can be used wherever conventional asphalt concrete (AC) or asphalt surface treatments would be used, but provide better resistance to reflective cracking and fatigue than standard dense-graded asphalt concrete (DGAC). Asphalt rubber hot mixes are typically most effective as thin rehabilitative overlays of distressed flexible or rigid pavements. Arizona has had well-documented success with long-term performance of asphalt rubber overlays of rigid pavements (I-17 Durango Curve in Phoenix, I-19 near Tucson, I-40 near Flagstaff), but California’s experience with this application has been limited.

Caltrans’ structural and reflection crack retardation equivalencies for gap-graded asphalt rubber mixes (called rubberized asphalt concrete, gap-graded, RAC-G) generally allow substitution for DGAC at about one-half the thickness (as referenced in 1.2). The reduced thickness encourages the use of RAC-G mixtures where there are vertical geometric constraints such as curb-and–gutter alignment or underpass clearance.

Temperature is critical for compaction of RAC mixtures. Because asphalt rubber is stiffer than asphalt cement, higher placement and compaction temperatures are usually required. Temperature guidelines for construction operations are presented in Section 4. Because RAC-G is placed in thin layers, ambient temperature, pavement surface temperature and wind have considerable impacts on mat temperature during compaction. Asphalt rubber products should thus be used only where and when weather conditions are favorable for placement. This does not prevent their use at high elevations, but means that paving in such locations should be performed only in good weather, dry conditions, and not in early spring or late fall. Asphalt rubber products have been used with success in most of the geographical and climate zones in California, and in Arizona from low desert through the mountain/alpine climate zones. However, there are coastal areas in California where favorable conditions for asphalt rubber paving operations may not occur often.

1.5 WHERE SHOULD ASPHALT RUBBER PRODUCTS NOT BE USED?

Problems that have been documented typically have been construction issues related to cold temperature paving or late season construction. This indicates that temperature was a major contributing factor. Temperature also affects placement and compaction of conventional mixtures, but is more critical when working with materials that have been modified to increase high temperature stiffness (such as asphalt rubber and polymer modified performance based asphalt, PBA) and are being placed in thin lifts. Asphalt rubber paving materials should not be placed in the following conditions:

- During rainy weather.
- During cold weather with ambient or surface temperatures <13°C.
- Over pavements with severe cracks more than 12.5 mm wide where traffic and deflection data are not available. *NOTE: Traffic and deflection data are basic requirements for Caltrans structural pavement design and rehabilitation. In some cases it may be necessary to add a layer of DGAC and/or SAMI-R before overlaying with RAC to provide sufficient pavement structure.*
- Areas where considerable handwork is required.
- Where haul distances between AC plant and job site are too long to maintain mixture temperature as required for placement and compaction.

1.6 BENEFITS OF ASPHALT RUBBER

The primary reason for using asphalt rubber is that it provides significantly improved engineering properties over conventional paving grade asphalt. Asphalt rubber binders (ARBs) can be engineered to perform in any type of climate. Although current Caltrans Special Provisions for asphalt rubber do not recommend climate-related binder design, as does ASTM D 6114, they do not prevent it. Responsible asphalt rubber binder designers usually consider climate conditions and available traffic data in their design to provide a suitable asphalt rubber product. More information on asphalt rubber binder design is presented in Section 2.

At intermediate and high temperatures, ARB physical properties are significantly different than those of neat paving grade asphalts such as AR-4000. The rubber stiffens the binder and increases elasticity (proportion of deformation that is recoverable) over these pavement operating temperature ranges, which decreases pavement temperature susceptibility and improves resistance to permanent deformation (rutting) and fatigue with little effect on cold temperature properties.

Asphalt rubber also provides the benefit of value-added use of waste tires. The benefits of asphalt rubber are summarized in Table 1-1.

1.7 LIMITATIONS OF ASPHALT RUBBER

Asphalt rubber materials are useful, but they are not the solution to all pavement problems. The asphalt rubber materials must be properly selected, designed, produced, and constructed to provide the desired improvements to pavement performance. Pavement structure and drainage must also be adequate. Limitations on use of asphalt rubber include:

- Mobilization costs for asphalt rubber production equipment. For large projects, this cost can be spread over enough tonnage so that increased unit price may be offset by increased service life, lower maintenance costs, and reduced lift thickness. For small projects, however, mobilization cost is the same, resulting in greater increase in unit price that may not be fully offset.
- Asphalt rubber is not best suited for use in DGAC. The aggregate gradation does not allow sufficient increase in binder content to enhance performance of dense-graded mixes enough to justify the added cost of the asphalt rubber binder.
- Construction may be more challenging, as temperature requirements are more critical. RAC-G and RAC-O must be compacted at higher temperatures than DGAC because rubber stiffens the binders at high temperatures. Also, coarse gap-graded mixtures may be more resistant to compaction due to the stone-on-stone nature of the aggregate structure.

- Potential odor and air quality problems (see Section 1.9 for further information).
- Asphalt rubber materials are often difficult to hand work because of stiffer binder and coarser mixture gradations.
- If work is delayed more than 48 hours after blending the asphalt rubber, some binders may not be usable. The reason is that the CRM has been digested to such an extent that it is not possible to achieve the minimum specified viscosity even if more CRM is added in accordance with specified limits.
- For chip seals in remote locations, hot and/or pre-coated aggregate may not be available because there may not be a hot-mix plant within reasonable haul distance of the job site.

Table 1-1: Summary of Benefits of Asphalt Rubber

RAC contains binders that have:

- Increased viscosity that allows greater film thickness in paving mixes without excessive drain down or bleeding.
- Increased elasticity and resilience at high temperatures.

RAC results in pavements that have:

- Improved durability.
- Improved resistance to surface initiated and fatigue/reflection cracking due to higher binder contents and elasticity.
- Reduced temperature susceptibility.
- Improved aging and oxidation resistance due to higher binder contents, thicker binder films, and anti-oxidants in the tire rubber.
- Improved resistance to rutting (permanent deformation) due to higher viscosity, softening points and resilience (stiffer, more elastic binder at high temperatures).
- Lower pavement maintenance costs due to improved pavement durability and performance.

RAC and asphalt rubber binders can result in:

- Reduced construction times due to thinner lifts.
- Better chip retention in chip seals due to thick films of asphalt.
- Savings in energy and natural resources by using waste products.
- Improved safety due to better long-term color contrast for pavement markings because carbon black in the rubber acts as a pigment that keeps the pavement blacker longer.

1.8 COST CONSIDERATIONS

The unit costs of asphalt rubber products are higher than those of conventional or polymer modified products. The initial cost is one of the reasons that usage of asphalt rubber hot mixes is limited to thin lifts.

Asphalt rubber is generally cost effective when used as thin gap- or open-graded surface courses or overlays of 30 to 60 mm compacted thickness, chip seals and interlayer applications.

Asphalt rubber products have been proven to be very useful tools to rehabilitate severely deteriorated pavements with some remaining structural integrity that experience heavy traffic loadings. In many cases, the reduced thickness of RAC overlays (half of DGAC thickness, with 30 mm minimum) offsets much of the increase in initial cost. The added benefits of reduced maintenance demand and longer service life provided by asphalt rubber materials generally offset any remaining cost difference. Cost effectiveness should be evaluated using Life Cycle Cost Analysis (LCCA).

Using a SAMI-R in place of a layer of AC saves money and speeds construction, providing additional savings. It is not clear whether SAMI-R can be placed more quickly than SAMI-F (PRF), but SAMI-R provides the benefit of reduced overlay thickness for structural adequacy that the fabric does not.

Typical year 2000 in-place costs for both hot mix and chip seals are as follows.

	Hot Mix $/tonne	Chip Seal $/m^2
Conventional	33-38	1.20-1.50
Polymer Modified	38-44	1.50-1.80
RAC-G	49-55	3.00-3.60

Generally RAC-G hot mixes cost about $16/tonne more than conventional mixes, although this may vary with job size. Mobilization and set up of the asphalt rubber binder production equipment costs as much for small jobs as for big ones. Large projects may thus allow some reduction in unit costs because mobilization costs can be spread over a greater RAC tonnage.

In 1998 Caltrans conducted an analysis of RAC and DGAC unit prices versus mix quantity based on data from 1996 and 1997 Caltrans projects. The results were reported in a July 7 memorandum that indicated that unit costs escalate considerably for jobs with less than 2250 tonnes of RAC. The memo suggests that smaller RAC projects may not be cost effective with respect to initial cost. The break point for project size may have changed since then but it is reasonable to assume that if paving can be completed in three days or less, the unit costs are likely to be significantly higher than for larger RAC projects.

The costs of RAC-O and RAC-O (HB) overlays are not listed. These are higher than conventional OGAC because of the higher binder content (1.2 to 1.6 times more for HB (High Binder) than the conventional AR 4000 content). Since OGAC is not considered a structural element, there is no reduction in thickness compared to conventional open-graded mixtures. However, improved durability, particularly resistance to reflective cracking and related reduced maintenance needs, should substantially reduce the overall life cycle costs and help offset the difference in initial cost.

1.9 Environmental Considerations

There are clearly environmental benefits to using asphalt rubber materials, but there are also some issues and concerns regarding emissions from asphalt rubber and hot-mix production and paving operations.

1.9.1 *Benefits*

There are a number of social benefits of using rubber that is ground from recycled scrap tires to build pavements.

1.9.1.1 *Not Contributing to Tire Stockpiles.* The primary benefit is putting newly generated waste tires into a secondary use instead of contributing to tire stockpiles. It has been estimated that over 30 million waste tires are generated in California and over 3 million more waste tires are imported into the State each year, of which about 19 million are recycled yearly. This does not account for tires that have been stockpiled legally or otherwise in the past, although CIWMB reports that stockpiles have been substantially reduced.

1.9.1.2 *Value-Added Use Of Waste Tires.* Burning waste tires for fuel is an effective method of disposal that helps to conserve other energy resources, but the value of the rubber is consumed and disposal of incinerator ash and residues remains an issue. Asphalt rubber paving products provide a "value-added" means of reutilizing the waste rubber material. The rubber enhances the physical properties of the resulting paving materials over the life of the pavement, and thus provides a long-term benefit to tax payers and the motoring public. Estimates indicate that RAC-G uses about 620 tires per lane kilometer per 25 mm of thickness. Or, about 2 tires are used per tonne of RAC-G.

1.9.1.3 *Noise Abatement.* Reduced traffic noise (primarily tire noise) is another important benefit of using asphalt rubber materials that has been documented in Europe (Belgium, France, Germany, Austria, the Netherlands), Canada, Arizona and California (Orange and LA counties). Significant reductions in traffic noise, ranging from 40 to 88 percent, have been measured not only for open-graded but also for gap-graded RAC. However there were unanswered questions regarding how long the noise would remain abated. The Sacramento County Department of Environmental Review and Assessment and a consultant specializing in acoustics and noise control conducted a six-year study on RAC pavements that was finished in 1999. Their results supported the findings of other similar studies referenced within their report. The Sacramento study showed that the RAC continued to keep the traffic noise level down after six years, while noise measured on the conventional DGAC was back up to pre-paving levels within four years.

1.9.2 *Issues and Concerns*

The high temperatures and the highly aromatic extender oils involved in asphalt rubber binder and mixture production would be expected to increase the amount of emissions (fumes and smoke) generated by production and construction of asphalt products. This is not necessarily true. A number of emissions studies have been performed during the last 10 to 15 years, although reports are not currently available for all of them.

The distinctive odor of asphalt rubber continues to trigger concerns about emissions, because people have a natural tendency to think that strong odors indicate a hazard.

1.9.2.1 *Hot Plant Tests.* Plant "stack tests" were performed during asphalt rubber hot mix production in New Jersey (1994), Michigan (1994), Texas (1995), and California (1994 and Bay Area in 2001). The results generally indicate that emissions measured during asphalt rubber production at AC plants remain about the same as for conventional hot mix and that amounts of any hazardous components and particulates remain below mandated limits. The Bay Area emissions tests showed that measured emissions rates of particulate and toxic compounds were consistently lower than the EPA's AP-42 emission factors for conventional hot mix asphalt plants. However in some cases of RAC production there has been a significant rise in particulates within the vapors that has been tied to use of soft asphalt cements that often include extender oils. Raising AC plant operating temperatures typically increases emissions. AC plant emissions generally appear to be more directly influenced by plant operating temperature, burner fuel and the base asphalt than by CRM.

CRM does not include exotic chemicals that present any new health risks. It consists mostly of various types of rubber and other hydrocarbons, carbon black, oils, and inert fillers. Most of the chemical compounds in CRM are also present in paving grade asphalt, although the proportions are likely to differ.

The asphalt rubber binder manufacturing plant does require an air quality permit, but emissions levels are low due to the essentially sealed nature of the process. Only some minimal filtered venting is required.

1.9.2.2 *Exposure of Paving Personnel.* Use of asphalt rubber does not appear to increase health risks to paving personnel, including paver operators, screed person, rakers, roller operators, bootmen on distributor trucks, and other workers. A 2-1/2 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 a number of individual paving workers in direct contact with fumes during hot mix paving operations as well as spray applications. The researchers found that the results "clearly demonstrated that risks associated with the use of asphalt rubber products was negligible". "Emission exposures in asphalt rubber operations did not differ from those of conventional asphalt operations".

The National Institute for Occupational Safety and Health (NIOSH) in cooperation with FHWA has performed evaluations of possible differences in the occupational exposures and potential health effects of crumb rubber modified hot mixes and conventional AC mixes. NIOSH Health Hazard Evaluations were performed at seven paving projects located in Michigan, Indiana, Florida, Arizona, Massachusetts, and at two in California from 1994 through 1997. NIOSH has released some preliminary information on individual projects and a report on the Michigan study was presented at an annual meeting of the Transportation Research Board. These reports indicated that increasing operating temperatures of AC plants seemed to have a greater effect on emissions quantity and content than did adding CRM. However the December 2000 NIOSH report on Health Effects of Occupational Exposure to Asphalt (No. 2001-110) that references these seven projects does not present any of the findings for asphalt mixtures containing CRM. This latest report does not recommend any changes to the 1977 NIOSH criteria for recommended exposure standards, which can be readily accessed through the NIOSH and OSHA web sites.

2.0 ASPHALT RUBBER PRODUCT DESIGN, SELECTION AND USE

Asphalt rubber binders can be used in hot mixes and for spray applications as surfaces or interlayers. This section presents guidance to assist project and pavement designers with selecting the appropriate type of asphalt rubber product for the intended use, for maintenance, rehabilitation, or construction. It also summarizes the state-of–the–practice of asphalt rubber binder design and provides an aid for evaluation of project submittals including asphalt rubber binder designs and quality control plans for binder production.

2.1 RUBBERIZED ASPHALT CONCRETE (RAC) HOT MIXES

Caltrans use of asphalt rubber in hot mixes is limited to gap and open gradations. Use of asphalt rubber is not recommended in dense-graded mixtures because there is insufficient void space to accommodate enough of the modified binder to significantly improve performance of the resulting pavement.

Gap and open-graded RAC mixes are most often used as overlays for maintenance and/or rehabilitation of existing asphalt concrete and Portland cement concrete pavements. RAC is also used as surface (wearing) courses for new pavement construction, most often in residential areas where traffic noise is a consideration. Structural design is performed as for conventional DGAC pavements, and thickness reductions may be applied when gap graded asphalt rubber surface courses are substituted for DGAC.

2.1.1 *Gap Graded Hot Mix*

The most commonly used asphalt rubber product in California is gap graded hot mix (RAC-G). RAC-G lift thickness is limited to a minimum of 30 mm by component aggregate size, and maximum 60 mm based on limited experience with thicker lifts and to economic considerations. Should greater increase in structural capacity be required, a layer of DGAC and/or a SAMI-R may be placed first. The pavement deflection study will determine structural requirements, based upon which the designer will provide such structural section alternatives.

2.1.1.1 *Purpose of RAC-G.* RAC-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 gapped aggregate grading, and often reduced traffic noise. The RAC-G acts as a structural layer in the pavement.

2.1.1.2 *Appropriate Use.* RAC-G can be used for overlay or new construction for a wide range of traffic volumes and loadings. RAC-G can also 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 signalized intersections and driveways, and parking areas. However, RAC-G mixtures (due to their high binder contents) may exhibit some flushing at intersections with heavy truck traffic.

2.1.1.3 *RAC-G Overlay Thickness Design.* Current Caltrans rehabilitation policy is to design an overlay so as to extend the service life of the pavement for ten years, although other design periods can be used. Overlay thickness design is based on the Traffic Index (TI) for the design period and the following three items:

- Structural adequacy upgrade;
- Reflective crack retardation; and
- Ride quality improvement.

Designing a RAC-G overlay involves determining the overlay thickness for a conventional DGAC overlay based on measured pavement deflection, then adjusting the thickness according to structural equivalencies between DGAC and RAC-G. Thickness of DGAC needed to retard reflective cracking and to restore ride are also evaluated. The thickest of these is selected; reductions to pavement thickness are made for a RAC-G alternative for structure and cracking, but not for ride quality. The Caltrans Flexible Pavement Rehabilitation Manual provides details for designing a variety of overlay strategies. Figure 2-1 illustrates the half thickness scenario.

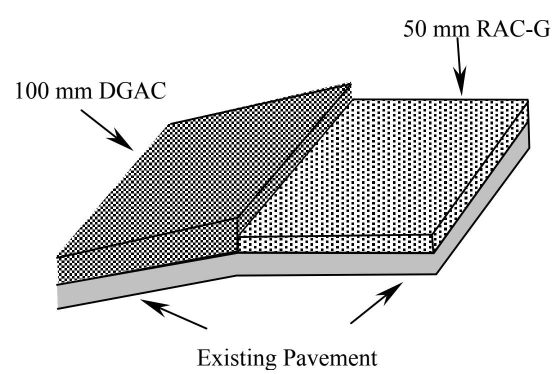

Figure 2-1: Typical RAC-G Overlay

RAC tonnage for half-thickness and equal length is slightly less than half that of the DGAC because unit weights of RAC and DGAC differ as a function of the higher binder content in the RAC. Binder has a much lower specific gravity than aggregate, so RAC has a slightly lower unit weight.

RAC Overlay Systems. RAC overlays may also be placed as two and three layer systems, surfaced with either gap- or open-graded RAC. A two-layer system is typically RAC placed directly on a SAMI-R. SAMI-F (PRF) is not used under RAC because the mix temperature will damage the fabric. When a leveling course is placed prior to application of the SAMI-R, a three-layer system is created as shown in Figure 2-2. SAMI-R provides some limited structural equivalence, of approximately 15 mm of DGAC according to Table 3 of the Caltrans June 2001 Flexible Pavement Rehabilitation Manual.

RAC-G for New Construction. When used for new construction, RAC-G should be directly substituted (1:1) for the top 25 to 50 mm of DGAC (appropriate layer thickness is 2 to 3 times the maximum aggregate size in the RAC-G). Use of the half-thickness equivalence customarily used for Caltrans rehabilitative overlays of distressed pavements is not recommended for new construction due to possible long term effects on the fatigue life of underlying layers of the pavement structure. Caltrans has not yet had enough experience with use of RAC for new construction to evaluate application of equivalency factors that were developed for rehabilitation purposes.

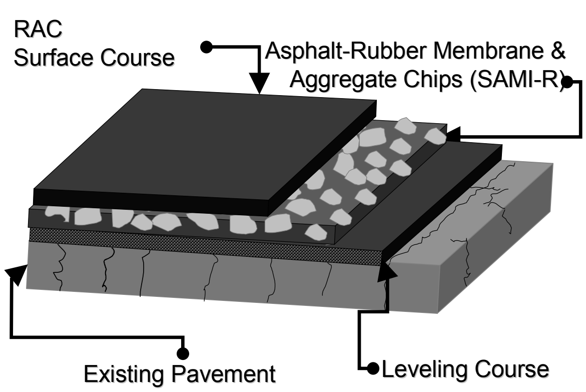

Figure 2-2: Three-Layer System

2.1.1.4 *RAC-G Mixture Design.* Existing California Tests, including CT 367 with Hveem compaction, are used with some modifications as indicated in the Special Provisions for RAC-G. These include allowances for lower Hveem stability, requirements for voids in mineral aggregate (VMA) and significantly higher binder content (7.0 to 9.0 percent by mass of dry aggregate). Air voids contents are similar to dense graded AC and Optimum Bitumen Content (OBC) corresponds to that yielding 4 percent air voids. A finished RAC-G pavement is shown in Figure 2-3.

Figure 2-3: Finished RAC-G Pavement

2.1.2 *Open Graded Hot Mix*

Open graded surface mixes (OGAC) provide good surface frictional characteristics. OGAC pavements 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. Conventional OGAC also reduces traffic noise, although reports of long- term effectiveness of such reduction vary. There are advantages to using OGAC and there are additional advantages to using RAC-O.

The thicker film coating of the asphalt rubber binder increases durability of open-graded pavements. One of the reasons that RAC-O mixtures are durable are that these are relatively low modulus materials, which means that they have lower stress to strain ratios than stiffer materials like DGAC. They move more in response to the same level of loading, and function by flexing and recovering (relaxing, creeping, rebounding, etc.) rather than by being stiff. The high asphalt rubber binder contents render these materials very resilient and resistant to fatigue, but they are not stiff layers and are placed as thin lifts, about 24 to 30 mm thick. Thus, RAC-O and RAC-O (HB) are not considered to be structural elements and no thickness reduction is applied for these uses of asphalt rubber.

Asphalt rubber open graded mixes (RAC–O and RAC-O (HB)) are primarily used as maintenance blankets, and overlays for rehabilitation, including restoration of surface friction.

2.1.2.1 *Advantages of RAC-O.* These include:

- Thicker asphalt rubber binder film provides improved resistance to stripping and oxidative aging.
- RAC-O mixes are highly resistant to reflection of cracks and joints in PCC pavements, and to reflection of severe cracks from underlying AC pavements.

2.1.2.2 *Purpose.* The primary reasons for using RAC-O include:

- Providing a durable, highly flexible pavement surface with enhanced drainage and frictional characteristics that reduces splash and hydroplaning in wet conditions (see Figure 2-4).
- Providing increased resistance to:
  - Rutting
  - Oxidation
  - Reflective cracking
- Reducing traffic noise.

2.1.2.3 *Appropriate Use.* RAC-O is 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. It is highly effective as an overlay of PCC and AC pavements in locations where potential for reflective cracking is severe. RAC-O is also used as a maintenance blanket to restore surface frictional characteristics and to help preserve the underlying pavement. District 2 cautions against use of RAC-O in tire chain areas. Tire chains and snowplow use are both factors that should be considered in selecting surface course material. However Arizona DOT reports no major problems with using RAC-O in alpine chain areas.

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.

Figure 2-4: Free-Draining RAC-O Next To DGAC

2.1.2.4 *RAC-O Mixture Design.* Mixture design is performed according to California Test 368, with asphalt rubber binder content set at 1.2 times the optimum bitumen content for AR-4000, and with a check test for drain off. If long hauls are anticipated, drain off should also be checked for the expected haul time. If excessive, adjustments may be required. For long hauls, reducing mixture temperature for hauling may not be appropriate for complying with minimum requirements for placement temperature

Caltrans is evaluating use of higher asphalt rubber binder contents, 8 to 10 percent by mass of dry aggregate, in some open-graded mixtures. These mixtures are called RAC-O(HB), High Binder. Other agencies have shown that asphalt rubber binder contents can be increased to 10 percent or more by mass of dry aggregate without excessive drain-off because of the high viscosity of the asphalt rubber binder. Such open-graded mixtures have generally provided excellent performance.

2.2 ASPHALT RUBBER BINDER (ARB) DESIGN

Asphalt rubber binders must be properly designed and produced to provide the appropriate level of modification and field performance for the expected climate and traffic conditions. Caltrans Special Provisions for Asphalt rubber Binder require that at least 2 weeks prior to start of construction the Contractor must supply to the Engineer, for approval, an asphalt rubber binder formulation (design or "recipe") that includes results of specified physical property tests, along with samples of all of the component materials. Samples of the prepared asphalt rubber binder must be submitted to the Engineer at least 2 weeks before it is scheduled for use on the project.

2.2.1 *Caltrans Specification Requirements*

Current Caltrans Special Provisions for Asphalt Rubber Binder call for 20 ± 2 percent crumb rubber modifier (CRM) content by total binder mass (see SSP 39-400 for RAC-G and SSP 39-480 for RAC-O.) The CRM must include 25 ± 2 percent by mass of high natural rubber CRM and 75 ± 2 percent scrap tire CRM. Both types of rubber must meet specific chemical and physical requirements including gradation and limits on fabric and wire contaminants. The scrap tire CRM consists primarily of 2 mm to 600 μm sized particles (No. 10 to No. 30 sieve sizes). The high natural rubber CRM is somewhat finer, mostly 1.18 mm to 300 μm sieve sizes. An asphalt modifier, of resinous, high flash point aromatic hydrocarbon compounds (extender oils), is added at a rate of 2.5 to 6 percent by mass of the asphalt binder. AR-4000 is typically specified as the base paving asphalt to be used in asphalt rubber binders.

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

It is important to understand that just mixing together proportions of arbitrarily selected asphalt, CRM and extender oil components within the specified ranges will not necessarily yield a binder that complies with the physical property requirements in the special provisions. Properties of asphalt rubber binders depend directly on the composition, compatibility and relative proportions of the component asphalt and CRM materials and other additives, as well as on the interaction temperature and duration. There are many combinations of suitable materials within the recipe proportions that simply do not provide an appropriate or even usable asphalt rubber binder. That is why binder design and testing procedures are essential to develop satisfactory asphalt rubber formulations.

2.2.2 *Design Considerations*

Most asphalt rubber binders are produced just prior to use, but may be stored at elevated temperatures for 24 hours or more if weather or other factors delay construction. It is important that the asphalt rubber binder properties, particularly the primary field control of viscosity, remain in compliance with specifications when mixed with aggregate or spray-applied. This means that the asphalt rubber binder properties should remain relatively stable over time. Uniformity of binder properties also facilitates RAC production, placement and compaction operations. For this reason, some contractors prefer that all of the different asphalt rubber binders that they use be formulated to remain within a relatively narrow viscosity range, such as 2,000 to 3,000 cP, so that other critical construction operations can be performed in a consistent manner from job to job.

Established asphalt rubber industry standard procedures for laboratory design profile the asphalt rubber interaction over a period of 24 hours by measuring the physical properties of the asphalt rubber binder sampled at specific time intervals. Table 2-1 presents an example of a state-of–the-practice asphalt rubber binder design, similar to what would be submitted by a contractor that routinely works with asphalt rubber materials. *The special provisions do not require that the interaction be monitored and tested over a 24-hour period; they require only that specification compliance be documented with results of tests performed on samples taken after 45 minutes of interaction.* The Engineer may ask if a 24-hour design profile is available for review.

Although AR-4000 is typically specified as the base paving grade asphalt for use in asphalt rubber binders, there are cases where use of a softer grade should be considered in order to provide better long-term performance in resisting low-temperature cracking. The reason is that at cold temperatures of about 5°C and below, the physical properties of the base asphalt binder typically govern asphalt rubber binder behavior. There are two ways to enhance resistance to cold temperature cracking in the asphalt rubber binder and the resulting RAC mixture:

- Start with a softer grade of paving asphalt than AR-4000, such as AR-2000 or for severe cold temperature conditions, possibly AR-1000, or
- Increase the percentage of extender oil to soften the binder.

Both of these approaches would also make the asphalt binder softer at intermediate temperatures of 10-40°C and higher pavement temperatures > 40°C. However, because the CRM increases binder stiffness (typically up to two grades) and elasticity in these intermediate and high temperature ranges without compromising the cold temperature properties, CRM can significantly extend the performance range of most paving asphalts.

For hot climate locations, it is advisable to reduce extender oil dosage to minimize potential for flushing. The high-temperature stiffening effects of CRM do have limits, and in low desert regions it is not unusual for exposed AC pavement temperatures to reach 82°C. Extender oil dosage may be increased for low volume roadways, which tend to crack from lack of use.

2.2.3 *Design Procedure and Criteria*

Caltrans has specified ranges of particular physical properties for asphalt rubber binders that are indicators of the relative amount of modification achieved by CRM interaction. The properties are rotational viscosity, resilience, cone penetration and ring-and-ball softening point. The specification limits are also shown in Table 2-1, along with test results from an actual binder design. Resilience has proved to be one of the best indicators of asphalt rubber field performance in terms of resisting fatigue and reflective cracking. Increased resilience typically indicates improved performance.

The first step an asphalt rubber producer must take in the design process is to obtain samples of the base asphalt binder (usually AR-4000), CRM, and any other additives that will be used for the subject project(s), because asphalt rubber interactions are highly material-specific. Use of extender oil and high natural CRM can help compensate for variability in the other components to some extent, but changes in source or grade of the asphalt cement or CRM can have major impacts on binder properties and would require a new design.

The asphalt rubber binder designer blends trial proportions of the designated components within specification requirements, based on practical experience. The asphalt rubber interaction is then conducted at the specified temperature. Samples of the asphalt rubber binder are taken after various intervals of interaction time as shown in Table 2-1 and tested for specification compliance. This provides a profile of how the asphalt rubber properties behave over time and a reasonable indicator of what to expect during field production, though field data may vary from the lab design. If results of the first trial are not adequate, additional interactions are performed as needed.

Best practice indicates that the asphalt rubber interaction properties (particularly softening point and resilience) should be examined to evaluate whether the extender oil content is appropriate for project environmental and traffic conditions. ASTM D 6114, "Standard Specification for Asphalt Rubber Binder," lists three types of asphalt rubber binder with varying

Table 2-1: Laboratory Asphalt Rubber Binder Design Data

Test erformed	Minutes of Reaction					45 minutes Specification Limits***
	45	90	240	360	1,440	
Viscosity, Haake at 190°C, Pa·s, (10^{-3}), or cP (*See Note)	2400	2800	2800	2800	2100	1500 – 4000
Resilience at 25°C, % Rebound (ASTM D 3407)**	27	--	33	--	23	18 Minimum
Ring & Ball Softening Point, °C (ASTM D 36)	59.0	59.5	59.5	60.0	58.5	52 – 74
Cone Pen. at 25°C, 150g, 5 sec., 1/10 mm (ASTM D217)	39	--	46	--	50	25 – 70

Notes regarding specified test procedures for Asphalt rubber Binder

* *The viscosity test shall be conducted using a hand-held Haake viscometer ….or equivalent.*
** *ASTM D3407was recently replaced by ASTM D 5329 that also includes the referenced test procedure for resilience.*
*** *Per Caltrans specifications 7/2002*

limits on softening point and resilience. The Appendix provides corresponding suggested climate guidelines for type selection that may be used as a reference for such evaluation. Hot, moderate, and cold climate ranges are defined in terms of average monthly minimum and maximum temperatures. Some states have specified asphalt rubber properties based on climate and/or traffic considerations.

The proportions of the components and test results for the selected formulation are reported as part of the asphalt rubber binder design and submitted to the Engineer for approval, as required by Caltrans.

2.3 ASPHALT RUBBER SPRAY APPLICATIONS

Asphalt rubber spray applications may be used as surface treatments or interlayers. Such applications are almost always used for maintenance or rehabilitation of existing pavements, and are very effective at resisting reflective cracking (see Figure 2-5).

2.3.1 *Chip Seals (SAMs)*

Chip seals are used by Caltrans for preventative and major maintenance as follows:

- Correct surface deficiencies.
- Seal raveled pavement surfaces.
- Seal off and protect the pavement structure against intrusion of surface water.
- Protect the pavement surface from oxidation.

In many jurisdictions, chip seals are called stress-absorbing membranes (SAMs). Chip seals do not add structural strength or correct ride roughness problems. Some agencies also use them as an alternate to OGAC to restore surface frictional characteristics where traffic volumes allow.

Figure 2-5: Chip Seal Train

To construct a chip seal, the hot asphalt rubber binder is sprayed on the roadway surface at a rate determined by the Engineer. The binder is immediately covered with a layer of hot pre-coated chips that must be quickly embedded into the binder by rolling before the membrane cools. Best results are achieved with clean nominal 9.5 to 12.5 mm single-sized chips. The standard chip size for Caltrans asphalt rubber seals is 9.5 mm; 12.5 mm chips are used by Caltrans only where ADT is less than 5,000 per lane. Lightweight aggregates may be substituted to minimize windshield breakage by loose chips in areas where traffic is heavy or fast. Pre-coating the aggregate with asphalt cement improves adhesion by removing surface dust and "wetting" the chips. Caltrans requires 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 of asphalt emulsion (diluted 1:1 with water) is sprayed over the chips at a typical rate of 0.14 to 0.27 l/m^2. A light dusting of sand, 1 to 2 kg/m^2 is then applied as blotter as directed by the Engineer.

Note: *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. Embedment and adhesion must be accomplished while the membrane is still hot.*

2.3.1.1 *Advantages*. Asphalt rubber chip seals provide the same benefits as conventional chip seals, but also provide the following additional advantages:

- Significantly longer service life than conventional chip seals.
- Superior long-term performance in resisting reflective cracking.

2.3.1.2 *Purpose*. Asphalt rubber chip seals provide a flexible, waterproof, skid resistant and durable surface that resists oxidation and is highly resistant to reflective cracking. A chip seal is not a structural layer.

2.3.1.3 *Appropriate Uses*. These include:

- Rehabilitation of structurally sound pavements that are cracked or raveled.
- Restoration of surface frictional characteristics (corrective maintenance).
- Routine preventative maintenance to extend the life of AC pavements.

Caltrans Maintenance Manual (Volume 1) includes criteria for use of chip seals and cover aggregate size based on speed limits and average daily traffic. Use of chip seals is not encouraged in areas with heavy trucks or stop-and-go traffic, or at signalized intersections. In locations where speed limits are ≥ 72.4 kph, maximum ADT limit is 30,000.

2.3.1.4 *Asphalt rubber Binder Design.* The special provisions for asphalt rubber binder referenced in Section 2.1 also apply to asphalt rubber binders for chip seals. The asphalt rubber binder design and materials submittals requirements, including test results that verify compliance with asphalt rubber binder physical property specifications, are the same for chip seals as for hot mixes.

2.3.1.5 *Application Rates.* According to Caltrans standard special provisions for asphalt rubber seal coat, SSP37-030, application rates for asphalt rubber chip seals are:

Chip Size	Asphalt Rubber Binder	Stone
12.5 mm	2.5-3 l/m^2	15-22 kg/m^2
9 mm	2.5-3 l/m^2	15-22 kg/m^2

However, the exact rate is to be determined by the Engineer. There are a number of factors that can affect the asphalt rubber binder and cover aggregate application rates including:

- Surface texture of the existing pavement: severely aged, oxidized and open-textured surfaces will absorb more binder than newer tighter surfaces.
- Traffic volumes: typically use smaller chips for higher volumes to reduce potential for vehicle damage by loose chips. Binder application rates can be increased for low traffic volume areas.
- Seasonal temperature ranges: thicker membranes may be used in areas with cool climates.
- Aggregate size: large stone requires more asphalt rubber binder (thicker membrane) to achieve 50 to 70 percent embedment.
- Aggregate gradation: single-sized materials require more asphalt rubber binder than do graded aggregates.

There are methods by which the specified aggregate application rate can be evaluated prior to the start of construction. The easiest 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 (kg/m^2).

To verify if application rates are appropriate, also check the embedment of the cover stone. The stone should be embedded to a depth of about 50 to 70 percent after seating in the lab or by rollers and traffic in the field. Excess chip application interferes with embedment and adhesion.

Excess asphalt rubber application can literally submerge or swallow the chips, and results in flushing/bleeding. 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.

2.3.2 *Asphalt Rubber Stress Absorbing Membrane Interlayers (SAMI-R)*

A SAMI-R is simply an asphalt rubber chip seal that is overlaid with conventional AC or RAC. The SAMI material is very flexible and elastic and has a low modulus; it flexes and creeps to relieve stresses and to heal many of the cracks that do occur. SAMI-R acts to interrupt crack propagation and has been shown to be highly effective in delaying reflective cracking in overlays. The aggregate chips key into the overlay upon compaction to prevent formation of a slippage plane along the relatively thick asphalt rubber membrane.

No fog seal or sand should be applied over a SAMI-R because this could interfere with bonding of the overlay.

SAMIs may be applied to any type of rigid (PCC) or asphalt pavement, and have proved very effective at minimizing reflection of PCC joints. However the Caltrans Maintenance Manual states that if the surface irregularities (rutting in AC or faulting of PCC) exceed 12.5 mm then either a leveling course should be placed or grinding and crack filling are required prior to placing SAMI-R.

2.3.2.1 *Advantages.* These include:

- Highly effective in minimizing reflective cracking in overlays of existing distressed asphalt and jointed portland cement concrete pavements.
- Minimize overlay thickness when reflective cracking is expected to be the primary distress mode and structural capacity is deemed sufficient.
- Provides the benefit of reduced structural overlay thickness that fabric does not.

The Caltrans Flexible Pavement Rehabilitation Manual gives SAMI-R credit for a structural contribution ranging from 15 to 30 mm of RAC, depending on whether structural strength or reflective cracking governs the design.

2.3.2.2 *Purpose.* SAMI-R is a low modulus (non-structural) layer that is used to retard and minimize reflective cracking in overlays placed on it, and to minimize further infiltration of surface water through the pavement structure.

2.3.2.3 *Use.* SAMIs are used under corrective maintenance overlays and are a pavement rehabilitation tool. A SAMI would not be included as part of new construction.

2.3.2.4 *Design.* Design of the asphalt rubber binder is the same as for chip seal. Determination of appropriate binder and cover aggregate application rates is also the same. SAMIs have been assigned an equivalency factor in rehabilitation projects when reflection cracking is the governing distress mode for overlay design.

3.0 PRODUCTION OF ASPHALT RUBBER BINDERS AND MIXTURES

This section presents information and procedures for production of asphalt rubber binder and how use of asphalt rubber binder affects AC mixture production.

3.1 ASPHALT RUBBER BINDER PRODUCTION

Asphalt rubber binder production methods are essentially the same for both hot mix and spray applications. The primary difference is the importance of coordination of asphalt rubber and hot mix production to assure that enough asphalt rubber binder is available to provide the desired AC production rate. Figure 3-1 shows a schematic of asphalt rubber blending. Figure 3-2 shows an example of a typical asphalt rubber production set up at an AC plant. Binders for spray applications are typically produced close to the job site, not necessarily at an AC plant, and must also be coordinated with application operations.

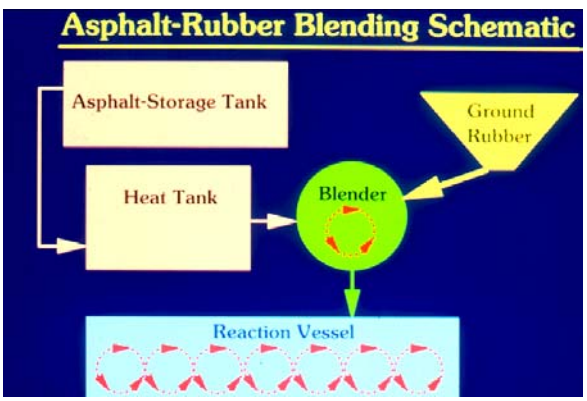

Figure 3-1: Asphalt Rubber Blending Schematic

Equipment for feeding and blending may differ among asphalt rubber types and manufacturers, but the processes are all similar. Temperature is always critical to controlling asphalt rubber manufacture, and temperature gauges or thermometers should be readily visible.

Augers are needed to agitate the asphalt rubber inside the tanks (Fig. 3.3) to keep the CRM particles well dispersed; otherwise the particles tend either to settle to the bottom or float near the surface. Agitation can be verified by periodic observation through the hatch where the auger control is inserted.

CRM may be packaged in 22.7 kg bags that are fed into the blending unit by conveyor (Figure 3-4) or in 0.91 tonne super sacks that are fed into a weigh hopper for proportioning (Figure 3-5). The containers should be clearly labeled and stored in an acceptable manner. Caltrans' acceptance sampling should be coordinated with asphalt rubber personnel to assure that all CRM lots can be sampled as appropriate.

Figure 3-2: Asphalt Rubber Production Set Up At AC Plant

Figure 3-3: Auger For Agitating Asphalt Rubber Storage Tank

The asphalt rubber binder production process depends on temperature, agitation, and time. ***Temperature is critical for process control***. All tanks that store asphalt rubber between initial blending and use must be heated and insulated. Thus, asphalt rubber production equipment and storage tanks should generally be expected to include retort heaters or heat exchangers to heat the asphalt cement and/or asphalt rubber. It is reasonable to assume some heat will be lost in any transfers. Insulated tanks that are heated to elevated temperatures ranging from the specified minimum temperature of 190°C to a maximum of 226°C are used to hold the blended asphalt rubber binder materials and the base paving grade asphalt cement.

Figure 3-4: Conveyor Blending

Figure 3-5: Blending From CRM Weigh Hopper

The asphalt rubber binder must be interacted with agitation for a minimum of 45 minutes at temperatures from 190 to 218°C to achieve the desired interaction between asphalt and rubber. In order to maintain the reaction temperature within the specified range of 190 to 218°C, the asphalt cement must be hot, 204 to 226°C before the design proportions of scrap tire and high natural CRM are added. This is because the CRM is at ambient temperature (not heated) and when added, it drops the binder temperature by about 4 to 10°C.

The component materials are metered into blending units to incorporate the correct proportions of CRM into the paving grade asphalt, and are thoroughly mixed. The asphalt rubber producer is allowed to add the extender oil while adding the rubber, although in some cases the paving asphalt may be supplied with the extender included. If the asphalt rubber producer adds the extender oil, use of a second meter is recommended to best control the proportioning. The meter for the extender oil should be linked to that for the paving grade asphalt.

An asphalt rubber binder processed (interacted) at lower temperatures will never achieve the same physical properties as the laboratory design, although it may achieve the minimum specification values for use. Hand held rotational viscometers (Haake or equivalent) are used to monitor the viscosity of the asphalt rubber interaction over time for quality control and assurance. Before any asphalt rubber binder can be used, compliance with the minimum viscosity requirement must be verified using an approved viscometer.

The asphalt rubber binder must achieve the specified minimum viscosity before spray application or AC production can commence. This go/no-go field test governs use of the asphalt rubber binder. The special provisions do not indicate that the production viscosity results must correlate with the submitted asphalt rubber binder design data, only that they remain within specified limits. As long as the viscosity is in compliance, the asphalt rubber may be used.

3.1.1 *Hold-Over and Reheating*

Caltrans requires that heating be discontinued if asphalt rubber material is not used within 4 hours after the 45-minute reaction period. The rate of cooling in an insulated tank varies, but reheating is required if the temperature drops below 190°C. A reheat cycle is defined as any time an asphalt rubber binder cools below and is reheated to 190 to 218°C. Caltrans allows two reheat cycles, but the asphalt rubber binder must continue to meet all requirements, including the minimum viscosity. Sometimes the binder must be held overnight. The asphalt and rubber will continue to interact at least as long as the asphalt rubber remains liquid; rubber breakdown (digestion) continues during this period. To restore the viscosity to specified levels, it is usually necessary to add more CRM (limit 10 percent more by binder mass) and react the resulting asphalt rubber blend at 190 to 218°C for 45 minutes.

3.1.2 *Documentation*

3.1.2.1 *Certificates of Compliance.* Caltrans requires a certificate of compliance (COC) for every binder constituent as well as for the finished asphalt rubber binder. The COCs must include test results that show conformance of all of these materials to the respective special provisions, including chemical composition of the scrap tire and high natural CRM materials and asphalt modifier (extender oil). COCs for all of the component materials delivered to the site of the asphalt rubber blending operation should be provided to the Engineer. It is current policy for Caltrans representatives to sample components and blended asphalt rubber materials at the mixing site for testing and acceptance.

3.1.2.2 *Asphalt Rubber Binder Design.* The asphalt rubber producer should have on site a copy of the approved asphalt rubber binder design that includes results of specified laboratory tests (see Table 2-1) and proportions of each component.

3.1.2.3 *Asphalt Rubber Binder Production Log.* Most asphalt rubber producers maintain a log of asphalt rubber binder production for each project. This practice has proved very useful and is highly recommended. For each batch of asphalt rubber produced, the log should list the weights of each component used, the reaction start time, and results of all viscosity tests performed, including the time and asphalt rubber binder temperature. *The last three items must be reported to Caltrans daily.* Figure 3-6 presents an example of an asphalt rubber Binder Viscosity Log. It is recommended that the logs should also record when each asphalt rubber batch was metered into the AC plant. The production log should also include all holdover and reheat cycle information including the time that heating was discontinued, the time that reheating began and corresponding asphalt rubber binder temperature, amount and time of CRM addition, and subsequent viscosity test data.

3.1.3 *Sampling and Testing Requirements*

For quality control, sampling and testing frequencies for components of AR binders are listed in Table 3-1. Quality Assurance testing requirements may vary, but sampling requirements typically should not exceed the frequencies shown below.

Tests for CRM gradation and chemical composition may take more time to conduct than for conventional paving materials. Failures to meet these requirements should be evaluated on a case-by-case basis and results of physical property tests of the asphalt rubber binder should also be considered.

Table 3-1: QC Sampling and Testing Frequency

Material	QC Sampling and Testing Frequency*
CRM	Chemical composition Each 225 tonnes
CRM	Gradation and physical properties Each truckload: ≈ each 18 tonnes
Asphalt Rubber Binder	Viscosity: Test every hour during AC production. Retain 4 liters/batch
Paving Asphalt	Each 180 tonnes – sample at point of origin or at mixing site.
Asphalt Modifier	Each 23 tonnes – sample at point of origin or at mixing site.

**Minimum frequency is once for each project.*

3.1.3.1 *CRM Sampling and Testing.* CRM consists of graded particles of ground rubber that tend to agglomerate (clump) in the presence of moisture and may segregate by size. Although CRM manufacturers certify CRM gradation at the plant, segregation may occur during storage and shipping. Segregation is not an issue when the entire container is added to the asphalt rubber blend, but it can affect small samples (approximately 100 grams) obtained for purposes of gradation testing for acceptance. Tube samplers such as grain probes have been used to obtain representative samples of CRM. Caltrans is currently evaluating CRM sampling methods to address these issues and is working to develop a standard method of sampling CRM from shipping containers.

3.1.3.2 *Asphalt Rubber Sampling and Testing.* Caltrans requires the Contractor (typically the asphalt rubber binder producer) to sample the asphalt rubber from the feed line into the AC plant and measure the viscosity at least every hour during RAC production. At least 4 liters of asphalt rubber binder should be wasted to assure that the sampling valve is clear. The sample to be tested should be poured into a clean, dry container that can be sealed and clearly labeled. At least one viscosity test is required for each asphalt rubber batch, and the Engineer is 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 on a daily basis. Figure 3-6 presents a sample Asphalt Rubber Binder Viscosity testing

Project Name/No.	
Date	
Binder Producer	
Tested by	

BINDER FORMULATION **Blend Proportions**

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

Asphalt Rubber Binder (ARB) material must be tested before use to verify compliance with viscosity specification

*Cycle Start Time	Batch Number	Temp. (°C) ARB Tank	Temp. (°C) of Viscosity Test (190 ± 2°C)	Measured Viscosity** Pa•s(x10^{-3})	Time Tested	Comments

Viscometer Make, Model and Serial #:____

**The cycle begins when tank is fully loaded and at 190± 2°C*
*** Measure at 190± 2°C*

Note: *Viscometer reads in units of cP. To convert to metric notation, cP = Pa•s(x10^{-3})*

Figure 3-6: Asphalt Rubber Binder Viscosity Testing Log

Viscosity depends on temperature. It is essential to have a controllable heat source (hot plate, gas stove/burner, etc.) to maintain asphalt rubber sample temperature at 190°C during viscosity measurement.

Because the procedure for testing asphalt rubber binder viscosity in the field is not published on the Internet with the other Caltrans test methods, a description is presented below. The field procedure can be obtained from METS, Office of Flexible Pavement Materials by request.

The open asphalt rubber binder sample container should be set on or over the heat source as appropriate, and the sample should be stirred to prevent scorching or burning. The No. 1 viscometer spindle should be inserted in the hot binder sample near the edge of the can for about 1 minute to acclimate, without plugging the vent holes. This is longer than the Caltrans test method requires, but 10 seconds is not enough time to raise the spindle temperature by 150°C. While acclimating, the sample can be thoroughly stirred and the temperature measured. The probe should then be moved to the center of sample to make the viscosity measurement. The hand held viscometers have a level bubble for proper orientation (probe shaft perpendicular to binder surface and viscometer level) and an immersion depth mark on the shaft. Once leveled, begin probe rotation. The peak viscosity value is read from the scale labeled with the corresponding spindle number (see Figures. 3.7 and 3.8).

Figure 3-7: Hand Held Viscometer Testing

The peak measurement represents the viscosity of the asphalt rubber binder system and is the value that should be reported and logged. As the probe continues to turn, it "drills" into the sample, (i.e., spins rubber particles out of its measurement area) and the apparent viscosity drops to reflect only the liquid phase of the asphalt rubber. It is recommended that three measurements be taken and averaged to determine the viscosity. Between measurements, the viscometer probe should be moved away from the center (without removing it from the asphalt rubber binder sample) and the sample should be thoroughly stirred again.

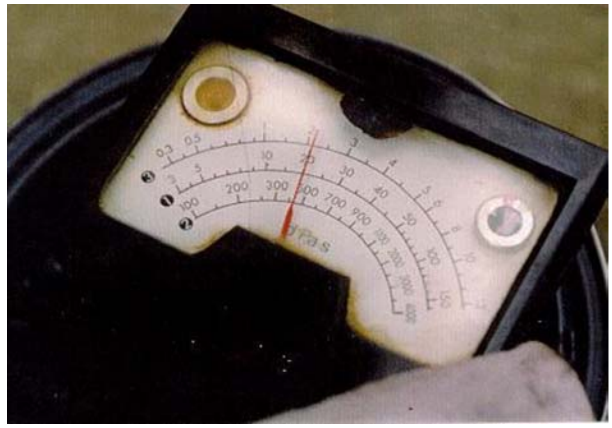

Figure 3-8: Viscometer Reading–Scale No. 1

During asphalt rubber production, field viscosity measurements may vary from the laboratory design by as much as ± 800 centipoise (cP), but should follow a similar pattern of increase and/or decrease over the duration of the asphalt rubber interaction. Larger differences or different patterns can indicate that a change may have occurred in component materials since the original design and testing was performed. In such cases, samples of the reacted asphalt rubber binder should be obtained and tested immediately for specification compliance. As long as the asphalt rubber binder viscosity complies with specification limits, the Contractor may elect to use that batch of binder. However in such cases, there is a risk that the test results may show that the sample does not comply with other specified physical property requirements and that penalties may be applied. Complete and well-maintained asphalt rubber production logs can help limit areas of removal and replacement by recording when and/or where the reject material was used.

Upon request or as agreed during the pre-paving conference, asphalt rubber producer personnel should provide to the Engineer or Inspector samples of reacted asphalt rubber binder for quality assurance and acceptance testing for compliance with the specified property limits.

3.1.3.3 *Terminal Blend Products.* Terminal blend products may be manufactured by different methods and are governed by different specifications than the asphalt rubber binders described in this Asphalt Rubber Usage Guide. These items are not within the scope of this Guide.

3.2 ASPHALT RUBBER HOT MIXES (RAC)

3.2.1 Mix Production

Using asphalt rubber binder has relatively little effect on hot plant operations, for either batch or continuous AC 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 RAC mixtures.

The asphalt rubber production equipment is independent of the AC 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 AC plant pumps cannot handle such viscous materials without risk of damage. A two- or three-way valve is installed in the asphalt feed line that allows the AC plant to switch between using the asphalt rubber binder or the regular paving asphalt in the AC plant tanks, according to demand for various AC 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. Asphalt rubber binder feed rate into the AC plant can be as high as 23 to 27 tonnes of binder per hour. At a mid-band asphalt rubber binder content of 8.0 percent by weight of aggregate, this will accommodate an RAC-G production rate of about 305 to 368 tonnes per hour, but at no time should the CT 109 limits be exceeded. Terminal blends that meet asphalt rubber requirements will usually have relatively low viscosity, but may still require heavy-duty pumps.

RAC production rates may be reduced from DGAC rates due to higher binder content (increased mixing time) and asphalt rubber binder production rate. Planning and coordination between the asphalt rubber binder producer and the AC plant operator is important to minimize impacts on RAC production. The AR binder supplier can in many cases arrange to use more or larger storage and reaction tanks, and schedule materials deliveries and asphalt rubber blending operations to expedite asphalt rubber and mix production. Because of the relatively high mixing temperatures, there is potential for increased emissions of smoke and/or fumes. Reducing the mix production rate usually reduces visible emissions.

3.2.1.1 *Inspection and Troubleshooting of the RAC Mixture.* Both the plant and field inspectors should visually inspect the RAC in the haul truck bed for signs of any problems with the mix and check mix temperature. Measure RAC temperature with a thermometer that has a probe at least 152 mm 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 RAC as it is flows out of the plant discharge chute into the haul truck.

Whenever any type of RAC 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 hot mix 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 Resident Engineer (RE). Test results should be relayed to the RE immediately upon receipt. Some of the potential “trouble” signs to watch for in the mix are as follows.

- 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 RAC 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 RAC 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: Mix is too hot.
- White smoke: Steam – too much moisture. This means that the aggregate was not dried enough prior to mixing with asphalt rubber binder. This may cause the RAC mix to become tender and may contribute to compaction problems or later to pavement distress due to stripping.
- Stiff appearance: Mix may be too cool – check temperature.
- Dull, flat appearance: Indicates low asphalt rubber binder content and/or excessive fines (minus 0.075 mm sieve size). 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. RAC-O, and especially RAC-O(HB) mixtures, may look this way and still meet SSP

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.

The only 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 all of the pertinent information, and should be available for inspection. The Inspector should obtain at least one 3.8 liter sample from each batch of asphalt rubber binder produced for the project to test for compliance with specification limits.

All of the regular activities related to plant inspection for AC production remain the same:

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

3.2.2 *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 asphalt materials and mixtures because they are stiffer than these conventional materials at the typical mixing and compaction temperatures. Temperature is critical to:

- Asphalt rubber binder manufacture
- RAC hot mix production
- RAC delivery
- RAC placement
- RAC compaction.

It is therefore 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 temperature of asphalt rubber binder and hot mix, 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.

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

4.0 CONSTRUCTION AND INSPECTION GUIDELINES

This section presents information and procedures for construction and inspection of asphalt rubber pavements, chip seals and interlayers, including placement, compaction and finishing.

4.1 HOT MIX (RAC) PAVING EQUIPMENT

The field inspector should confirm that the necessary paving equipment is on site before any asphalt rubber hot mix is shipped from the AC plant. Any equipment-related questions or issues should have been resolved in the pre-paving conference. Availability and paving capability may be affected by unanticipated mechanical problems or logistics.

4.1.1 *Haul Trucks*

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

4.1.2 *Material Transfer Vehicle (MTV)*

Use of this type of equipment is optional. MTVs have been described as "surge bins on wheels" and are most often used when smoothness, segregation, or mixture delivery rate are concerns.

4.1.3 *Pavers*

Conventional mechanical self-propelled pavers are used to place RAC mixes. Pavers should be equipped with vibratory screed and screed heaters, automatic screed controls with skid, and comply with all of the pertinent Caltrans specification requirements.

4.1.4 *Rollers*

Rubber tired rollers are not appropriate for compacting RAC mixes because of excessive pick up of the mixture by the tires. All rollers for RAC 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 a little soap to the watering system.

RAC-G mixtures are likely to require more compaction effort than DGAC. Minimum recommended roller weight is 7.3 tonnes and pup rollers cannot provide sufficient compaction. The types of rollers normally include the following:

- **Breakdown roller with vibratory capability.** It is strongly recommended that two breakdown rollers be used, especially if paving width exceeds 3.65 m.
- **Intermediate roller.** These should be of equal or greater width than the breakdown roller(s), or use two intermediate rollers.
- **Finish roller.** These should be a static roller, with a minimum of 7.3 tonnes.
- **Standby roller.** One with vibratory capability should be on site and should be required if only one breakdown roller is available.

4.1.5 *Sand Spreader*

Any Caltrans approved spreader with uniform distribution capabilities to provide a sand blotter for opening the RAC surface to traffic.

4.2 FINAL PREPARATIONS FOR PAVING

Surface preparation must be completed prior to RAC production or spray application. This includes standard items such as removal and replacement of failed pavement and pothole repair (patching), milling or grinding for smoothness and matching elevations, crack filling, etc. Immediately prior to mixture delivery, the surface should be swept and tack coat applied.

4.2.1 *Tack Coat (Paint Binder)*

A tack coat should generally be uniformly applied so as to lightly cover the entire pavement surface to be overlaid. Recommended application rate is 0.1 to 0.3 l/m^2 residual. Area of tack application should be limited to what will be paved over on that day. However, tack coat is not required when a SAMI-R will be placed prior to overlaying, and is not recommended when RAC will be placed directly on a new pavement.

4.2.1.1 *Emulsified Asphalt***.** Caution should be used when ambient and pavement temperatures are marginally cool and emulsion tack coats are to be 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 up 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. Cold or damp conditions and lack of sun all slow evaporation and may delay paving operations.

4.2.1.2 *Paving Grade Asphalt.* Regular paving grade asphalt can also be used as tack (paint binder) and might in some cases be substituted for emulsion due to adverse site conditions. Asphalt tack should be hot enough, about 149 to 176°C, to spray an overlapping fan pattern and not to string out in a manner that leaves much of the surface without tack. If the application rate is not properly controlled, bleeding or delamination may result. Any defective or plugged nozzles must be corrected immediately. If using hot paving asphalt for tack, the distributor truck must have a heater to maintain asphalt temperature and consistency for spray application.

4.3 HOT MIX DELIVERY

Although any type of conventional AC haul truck can be used to transport RAC, when air and pavement surface temperatures are near the minimum specified limits use of bottom dumps is not recommended. It is critical that the RAC does not cool below the minimum placement temperature of 143°C during transport. Tarps are needed to maintain acceptable temperature. Mixture shipment temperatures may range from 149°C on hot days with short hauls up to 174°C for cold days with long hauls; typical maximum is about 163°C.

4.3.1 *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 cheap. Dilute silicone emulsions may also be used.

4.3.2 *Coordinating Mix Delivery and Placement*

Coordination 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 is not removable by rolling. A long line of haul trucks waiting to access the paver generally means that some loads will cool enough to be rejected. MTVs can be used to minimize adverse impacts of irregular mix delivery.

4.3.2.1 *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 (Figure 4-1). 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.

Figure 4-1: Unloading RAC-G Into Paver Hopper

4.3.2.2 *Unloading Hot Mix Into A Material Transfer Vehicle.* This is easier, because MTVs also have a front hopper to receive the mix, but eliminate the problem of bumping the paver. The same method of discharge should be used to flood the MTV hopper as a paver hopper.

4.3.2.3 *Load Tickets. Load tickets should be collected when the mix is discharged from the haul truck.* Yield calculations are typically used to verify overall thickness based on total tonnage and area paved. The standard for DGAC is about 58.6 kg per square meter per 25 mm of thickness. RAC-G is about 5 percent lighter, as the higher binder content reduces the proportion of stone.

4.4 HOT MIX PLACEMENT

Placement of asphalt rubber materials or any AC materials requires good paving practices. Temperature is critical, for proper placement of all AC materials. Asphalt rubber binders are stiffer than conventional paving asphalt at the customary placement and compaction temperatures, so time available for compaction of modified materials is typically shorter than for conventional DGAC mixtures. How much shorter depends on a number of variables that are discussed in section 4.5 on Compaction.

Caltrans special provisions for RAC-G specify minimum atmospheric and pavement surface temperatures of 13°C for mixture placement. When atmospheric and pavement surface temperatures are less than 18°C, spread (lay down) temperature for RAC-G is specified as 143 to 163°C. For site temperatures ≥ 18°C, RAC-G is to be spread at temperatures from 138 to 163°C. Because of the importance of temperature in achieving adequate RAC compaction, operating in the upper half of these respective temperature ranges is strongly recommended.

EXAMPLES OF GOOD PAVING PRACTICES

- 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 so as to minimize segregation by particle size or temperature.
- Maintain mix temperature by using tarps and/or insulated beds on haul trucks.
- Deliver the mixture as a free flowing, homogeneous mass without segregation, crusts, lumps, or significant binder drain-off.
- Coordinate mix production, delivery 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. Ideally, the paver should never stop on the new mat.
- Attention to cold and hot, longitudinal and transverse joints during placement and compaction.
- Use sufficient rollers to achieve adequate breakdown and intermediate compaction and to complete finish rolling within the temperature limits for these operations.

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 environmental conditions improve. Otherwise significant problems in achieving adequate compaction should be expected to occur. Weather conditions may change during the paving operation. If necessary, paving should be stopped until conditions improve.

4.4.1 *Paver Operations*

Paver operations for RAC should not differ from those commonly used for conventional AC, 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 so as 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. Care should be taken to dump fold) the paver 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.

4.4.2 *Raking and Handwork*

Asphalt rubber mixtures are not particularly amenable to raking or handwork. The relatively coarse RAC-G aggregate gradation and stiffer binder make handwork a problem, and may affect the appearance of joints. Handwork and raking of RAC should be minimized, but if required, should be performed immediately before the mix has time to cool. The higher asphalt rubber binder content of RAC-O(HB) makes raking and handwork a little easier. Broadcasting of the mix at joints is not considered good practice and should not be done.

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. RAC placed by hand may not provide a pleasing appearance even if the workmanship is excellent and the best practice is applied.

4.4.3 *Joints*

AC joints are typically defined as longitudinal or transverse, cold or hot. Butt joints are most typical and the practices presented apply to those. Some agencies have adopted wedge joints and/or skewed joints that are not discussed in this Guide.

4.4.3.1 *Longitudinal Joints* are most likely to be cold joints. To provide a good bond with the adjacent pavement, remove any loose material and tack the vertical edge prior to placing hot mix. 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 only about 25 to 38 mm. The screed should be set above the elevation of the cold side by approximately 6 mm for each 25 mm of compacted pavement thickness being placed. Compacted thickness of RAC is generally 30 to 60 mm so the differences in height would range from about 7 to 14.4 mm. This is relatively small compared to maximum stone size in the mix. Since it is difficult to feather RAC mixtures, some raking may be unavoidable. 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 9.5 mm for each 25 mm. The height difference may vary among mixes, so experience and engineering judgment should be used as appropriate.

4.4.3.2 *Transverse Joints.* These may be hot or cold. Hot joints should be treated the same as for conventional DGAC, but the RAC 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 direction. This is usually not practical and they are generally rolled longitudinally.

4.5 HOT MIX COMPACTION

Compaction is essential to the performance of any asphalt pavement. Although asphalt rubber mixtures are very forgiving materials, even they require adequate compaction to achieve the desired performance and durability. The best materials, mix designs, and placement techniques cannot compensate for adverse effects resulting from poor compaction during construction.

The coarse aggregate structure and stiff asphalt rubber binders in RAC-G mixes may require increased compaction effort over conventional DGAC. Compaction depends primarily on temperature and compactive effort. Breakdown compaction of RAC-G mixtures should always be performed in the vibratory mode. This is not necessarily true for RAC-O. Open-graded mixtures respond differently to compaction, and are typically only placed in very thin lifts about 24 to 30 mm thick, with only a couple of compaction passes by breakdown and static rollers. Vibratory compaction is not typically used for thin lifts of RAC-O.

4.5.1 *Temperature Requirements*

According to the Special Provisions for RAC-G, when atmospheric and pavement surface temperatures are less than 18°C, breakdown compaction must be completed before the mat temperature drops below 127°C. For site temperatures ≥18°C, breakdown compaction must be completed before the mat temperature drops below 121°C. ***However, it is strongly recommended that breakdown compaction of RAC-G should be completed before the temperature of the RAC mat drops below 143°C.*** 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. Also, vibratory rolling below the minimum breakdown rolling temperature should not be allowed, nor should vibratory rolling after static (finish) rolling.

4.5.2 *Factors That Affect AC Compaction*

Compaction is affected by many factors including:

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

Thin lifts, cool temperatures and wind reduce the time available for compaction because of temperature loss. Therefore, it is often easier to compact thick lifts (>50 mm thick) than thin ones. The rule of thumb is that the compacted thickness should be at least twice the maximum aggregate size, or three times the nominal maximum aggregate size. 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 coverage required may vary depending on the mix and site conditions during placement. The anticipated roller coverages may need to be adjusted based on temperature 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 RAC mixes.

4.5.3 *Test Strips and Rolling Patterns*

California Test Method 113 is required for pavements with thickness ≥ 60 mm to establish the engineer's approval of equipment and rolling pattern based on achieving a minimum of 95 percent compaction relative to the mix design value. Sixty mm is the upper limit of RAC thickness, so CT 113 may not be required for most RAC pavements although it would be useful. Test strips for thinner RAC lifts are recommended when feasible to indicate what level of compaction effort is needed to achieve adequate in-place density. However, when CT 113 is used, the temperature ranges for the test must be modified for RAC-G. During test strip compaction, both Contractor and agency representatives should correlate their respective nuclear gauge(s) on the test strip according to CT 375.

Gauge data should then be correlated with core results in order for nuclear density to provide accurate data for quality control during paving.

A Paving Check List is included in Appendix A. This handout should be delivered to the contractor for distribution to all members of the construction staff as well as to the Inspector.

4.6 CHIP SEAL CONSTRUCTION

Chip seals are extremely sensitive to construction operations and site conditions, including ambient air temperature and temperatures of the cover aggregate, and underlying pavement. 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 chips must be large enough so as not to be "swallowed" by the membrane. The other is that the distributor nozzles may have a greater tendency to clog due to the presence of discrete rubber particles. This is addressed by appropriate nozzle sizing.

Temperature is absolutely critical to successful chip seal construction whether using conventional paving grade asphalt or asphalt rubber as the binder. Clean or precoated (preferably) hot chips are also critical. Embedment and adhesion of the chips must be accomplished while the asphalt rubber membrane is still hot. A reasonable production rate is about 5 to 7 lane miles per day.

4.6.1 *Chip Seal Equipment*

The equipment required to place a chip seal includes:

- Distributor truck with fume hood 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.
- Hand tools (broom, shovels, etc.).
- Power broom
- Distributor truck to apply a flush coat (typically diluted emulsion)

4.6.2 *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 (snivy) 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. The person who monitors the application for uniformity and nozzle problems is protected from fumes by a pollution hood over the spray bar. Application rate according to Caltrans special provisions is 2.5 to 3.0 l/m^2 and the Resident Engineer determines the exact rate.

Each spray application should start and end on paper (tar paper or roofing felt if possible) to ensure uniformity for the entire 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.

4.6.3 *Chip Application*

The hot pre-coated chips should be applied immediately behind the asphalt rubber binder spray; the chip spreader should follow at a maximum distance of about 20 to 30 meters. The asphalt rubber binder must be fluid so the rock will be embedded by the displacement of the asphalt, preferably to 50 to 70 percent embedment. A chip seal train consisting of binder distributor truck, chip spreader, and roller is shown in Figure 4-2.

Figure 4-2: Chip Seal Train

The standard chip application rate is 15 to 22 kg/m^2, with the exact rate to be determined by the Engineer. Trucks should back into the spreader box and should not cross over any exposed asphalt rubber membrane. This is illustrated in Figure 4-3; 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 loads of the trucks hauling the chips should be regulated to prevent damage to the new seal. 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. Areas that do not get enough aggregate cover (about 85 percent of the total membrane area is a reasonable target) should be covered with additional aggregate (normally by hand), but problems with adhesion may occur, because by then the asphalt rubber has cooled.

Figure 4-3: Spreading Precoated Aggregates

4.6.4 *Rolling Asphalt Rubber Chip Seals*

Pneumatic 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.

Skirts around the tires can help maintain elevated tire temperature to aid compaction. 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 6 to 10 kph so that the rock is set, 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 4-4).

Figure 4-4: Rubber-Tired Rollers With Skirts On Chip Seal

4.6.5 *Sweeping*

Sweeping (brooming) is done at the completion of chip sealing to remove surplus aggregate from the surface of the new chip seal to minimize flying rocks. Sweeping can be done shortly after application, usually within 30 minutes. It is desirable to sweep during the cool period of the day using a rotary power broom (Figure 4-5).

Figure 4-5: Sweeping Chip Seal To Remove Loose Cover Aggregate

Figure 4-6: Finished Chip Seal Before Applying Fog Seal and Sand

4.6.6 *Flush Coat*

The flush coat consists of an application of fog seal over the new asphalt rubber chip seal followed by a sand cover.

4.6.6.1 *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 0.14 to 0.27 l/m^2 or as determined by the Engineer.

4.6.6.2 *Sand cover* is applied immediately after application of the fog seal to prevent pick up and tracking of the chip seal material by vehicle tires. The sand must be clean (free of clay fines or organic material). It is spread in a single application of 1 to 2 kg/m^2, or at a rate determined by the Engineer.

4.6.7 *Traffic Control*

Some form of traffic control is required to keep the initial traffic speed below about 40 kph. 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.

5.0 REFERENCES

American Society of Testing and Materials, "D 8 Standard Terminology Relating to Materials for Roads and Pavements" in *Vol. 4.03, Road and Paving Materials; Vehicle-Pavement Systems*, Annual Book of ASTM Standards 2001, ASTM, West Conshohocken, PA, 2001.

American Society of Testing and Materials, "D 6114 Standard Specification for Asphalt rubber Binder" in *Vol. 4.03, Road and Paving Materials; Vehicle-Pavement Systems*, Annual Book of ASTM Standards 2001, ASTM, West Conshohocken, PA, 2001.

Asphalt Rubber Producers Group, "Rubber Used in Asphalt rubber Applications," *Proceedings*, National Seminar on Asphalt rubber, Kansas City, MO, October 1989.

Bahia, Hussain and Robert Davies, "Effect of Crumb Rubber Modifiers (CRM) on Performance-Related Properties of Asphalt Binders," *Journal*, AAPT, 1994, pp. 414-441.

Baker, Tim, "Production of Crumb Rubber Modifier (CRM) Material," Session 3, Workshop Notes, FHWA Crumb Rubber Modifier Workshop, Atlanta, GA, February 1993.

Caltrans, "Flexible Pavement Rehabilitation Manual," Sacramento, CA June 2001

"Maintenance Manual - Volume 1," Sacramento, CA June 1998, (out of print, but available on Caltrans Website), Caltrans.

Charania, E., Joe O. Cano, and Russell Schnormeier, "A Twenty Year Study of Asphalt rubber Pavements in the City of Phoenix, Arizona," Asphalt Rubber Producers Group 1991.

Chehovits, J.G., "Binder Design Procedures," Session 9, Workshop Notes, FHWA Crumb Rubber Modifier Workshop, Atlanta, GA, February 1993.

Chehovits, J.G. and Hicks, R.G., "Mix Design Procedures," Session 10, Workshop Notes, FHWA Crumb Rubber Modifier Workshop, Atlanta, GA, February 1993.

Doty, R.N., "Flexible Pavement Rehabilitation Using Asphalt rubber Combinations: Progress Report," *TRR 1196*, Transportation Research Board, 1988.

"Crumb Rubber Modifier Workshop Notes, Design Procedures and Construction Practices," *FHWA-SA-93-011*, Federal Highway Administration, 1993.

Epps, Jon A., "Uses of Recycled Rubber Tires in Highways," *NCHRP Synthesis 198*, Transportation Research Board, 1994.

Federal Highway Administration, *National Highway User Survey*, May 1996.

Heitzman, M., "State of the Practice – Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier," *FHWA-SA-92-202*, Federal Highway Administration, May 1992.

Hicks, R.G., et al., "Crumb Rubber Modifier in Asphalt Pavements," *FHWA-SA-95-056*, Federal Highway Administration, September 1995.

Hicks, R.G. and Epps, Jon A., “Evaluation of Caltrans Modified Binder Specifications,” Final Report to RPA, March 1999.

Hicks, R.G. and Epps, Jon A., “Quality Control For Asphalt Rubber Binders And Mixes”, *Proceedings*, AR2000, Portugal, November 2000.

Hicks, R.G., “Asphalt Rubber Design and Construction Guidelines” Final Report to NCRACTC, May 2001.

Holleran, Glynn and Van Kirk, Jack L., “Reduced Thickness Asphalt Rubber Concrete Leads To Cost Effective Pavement Performance”, *Proceedings*, AR2000, Portugal, November 2000.

Holleran, Glynn, “Emulsification of Asphalt Rubber Blends”, *Proceedings*, AR2000, Portugal, November 2000.

Hildebrand, Gary and Van Kirk, Jack L., “Asphalt Rubber Performance Evaluation,” internal Caltrans report, April 18, 1996.

Martignoni, Beatrix, Leni Mathias Leite and Romulo Santo Constantino, “Studies of Asphalt Rubber Using Various Sources of Ground Tire Rubber”, Proceedings, AR2000, Portugal, November 2000.

McDonald, C. H., “Recollections of Early Asphalt rubber History,” *Proceedings*, National Seminar on Asphalt rubber, October 1981.

Nevada DOT, “A Report on the Performance of Crumb Rubber Asphalt Plant Mix Bituminous Surfacing in Nevada”, December 4, 1998.

Nicholson, Lynn and Roschen, Theorn, “Inspection of Rubberized Asphalt Concrete” (County of Los Angeles).

Nokes, W.A., et al, “Caltrans Accelerated Pavement Testing (CAL/APT) Program – Test Results: 1993-1996,” *Proceedings*, 8th International Conference on Asphalt Pavements, Seattle, WA, August 1997.

Oliver, J.W.H., “Modification of Paving Asphalts by Digestion with Scrap Rubber,” *TRR 821*, Transportation Research Board, 1981, pp. 37-44.

Raad, Lutfi, Saboundjian, Steve and Minassian, George, “Field Aging Effects on the Fatigue of Asphalt Concrete and Asphalt rubber Concrete,” presented at Annual Meeting of Transportation Research Board, January 2001.

Rinck, Grace and Napier, Dan, C.I.H., “Exposure of Paving Workers to Asphalt Emissions (When Using Asphalt rubber Mixes)”, Asphalt Rubber Producers Group, Washington D.C., 1991.

Rosner, J.C. and Chehovits, J.G., “Chemical and Physical Properties of Asphalt rubber Mixtures – Phase III,” Vols. 1-5, *FHWA/AZ-82-159*, Arizona DOT, June 1982.

Rostler, F.S., “An Annotated Bibliography on Use of Rubber in Asphalt Pavement.” *FHWA-RD-72-1*, Federal Highway Administration, May 1971.

"Report on the Status of Rubberized Asphalt Traffic Noise Reduction in Sacramento County," November 1999. Sacramento County Department of Environmental Review and Bollard & Brennan, Inc.

Sebaaly, Peter E., et al., "Laboratory Evaluation of Rubber-Modified HMA Mixtures," U. of Nevada-Reno, May 6, 1998.

Shatnawi, Shakir, "Performance of Asphalt Rubber Mixes as Thin Overlays," *Proceedings*, AR2000, Portugal, November 2000.

Shatnawi, Shakir, "Fatigue Performance of Asphalt Concrete Mixes Using a New Repetitive Direct Tension Test." Internal Caltrans report, October 1997.

Takallou, H. Barry, Bahia, Hussain U., Perdomo, Dario and Schwartz, Robert, "Use of Superpave Technology for Design and Construction of Rubberized Asphalt Mixtures," *TRR 1583*, Transportation Research Board, 1997, pp. 71-81.

Transportation Research Board, "*Hot-Mix Asphalt Paving Handbook 2000,"* National Research Council, Washington, D.C., 2000.

Troy, Kenneth, Sebaaly, Peter E., and Epps, Jon, "Evaluation System for Crumb Rubber Modified Binders and Mixtures," *TRR 1530*, Transportation Research Board, 1996, pp. 3-10.

Van Kirk, Jack L., "An Overview of Caltrans Experience with Rubberized Asphalt Concrete," prepared for presentation at the 71st Annual Meeting of the Transportation Research Board, January 1992.

Van Kirk, Jack L., "Caltrans Pavement Rehabilitation using Rubberized Asphalt Concrete," Rubber Division, American Chemical Society, Anaheim, CA, May 1997.

Van Kirk, Jack L. and Holleran, Glynn, "Reduced Thickness Asphalt Rubber Concrete Leads to Cost Effective Pavement Performance", *Proceedings*, AR2000, Portugal, November 2000.

Way, George B., "Flagstaff I-40 Asphalt rubber Overlay Project Nine Years of Success," presented at the 78th Annual Meeting of the Transportation Research Board, January 2000.

Useful Asphalt Rubber Websites:

www.rubberizedasphalt.org
www.dot.ca.gov
www.ciwmb.ca.gov
www.rubberpavements.org
www.fhwa.dot.gov/infrastructure/pavement/niosh.htm
www.fhwa.dot.gov/infrastructure/pavement/crmbrubr.htm
www.tfhrc.gov/pubrds/spring97/crum.htm

APPENDIX A

CHECKLISTS

CHECKLIST OF MATERIALS SUBMITTALS

I. BINDER

A. Binder Formulation ❑

1) Paving Asphalt and Modifiers - % of Total Binder
   a) % Asphalt of Paving Asphalt
   b) % Extender Oil of Paving Asphalt
2) Crumb Rubber Modifier (CRM) - % of Total Binder
   a) % Scrap tire rubber of total rubber
   b) % Natural rubber of total rubber, based on
      i) Specification, and
      ii) Chemical Analysis of natural rubber

B. Rubber Test Documentation ❑

1) Chemical analysis of natural rubber
2) Chemical analysis of scrap tire rubber
3) Fiber content for both types
4) Gradations of tire rubber
5) Gradations of natural rubber

C. Certification of Compliance/Specific Product and Project ❑

1) Asphalt Cement incl. Source and Grade
2) Extender Oil incl. Source and Type ID
3) Scrap Tire Rubber including Source and Type ID
4) Natural Rubber including Source and Type ID

D. Rubber Samples (For matching with materials at plant) ❑

1) Scrap Tire rubber
2) Natural rubber

E. Laboratory Tests for Asphalt Rubber Binder ❑

1) Penetration
2) Resilience
3) Softening Point
4) Viscosity

F. Two binder samples ❑

II. AGGREGATE ❑

A. LA Rattler
B. Crushed Faces
C. Sand Equivalent*
D. K_c and K_f *

III. Mix DESIGN ❑

A. Target gradations within specification
B. Binder content vs. air voids plot (Form TL-306)*
D. Selected binder content (corresponding to specified air voids)
E. Show recommended range (+0%/-.3%)*
G. Stabilometer value* and VMA
H. Target Gradations for specified sieves
I. Bin percentages and sieve analyses for each

** Not applicable to chip seals.*

CHECKLIST FOR PAVING AND CHIP SEALS

I. HOT MIX

A. Pre-Spread ❑

Functional heater element for hot asphalt tack.
Uniform application of tack, at agreed rate of __________.
Joints at proper locations (traffic lane lines or clear of wheel paths in center of lane).
Proper thickness at 0" grind point (screed break at grade break).

B. Compaction Equipment (Steel drum) ❑

Vibratory roller for (breakdown) and another vibratory for backup
Intermediate roller of the same or greater width than the breakdown roller
Finish roller

C. Compaction Process

No vibratory mode when mat temperature is below 121°C.
Intermediate roller operating at all times during paving?

D. Post Compaction ❑

Sand cover is required, but cannot be applied until compaction is complete except as authorized by Caltrans in special circumstances.

II. CHIP SEALS

A. Pre-Spread ❑

Pavement is clean and dry.
Pavement temperature in shade above 13° C.
Air temperature above 16°C.
Hot asphalt coated rocks on site
Nominal size chip size 9.5 mm or 12.5 mm
Trucks lock onto hitch of aggregate spreader
3 rubber tire rollers (two if equivalent coverage), all functional
One functional 8-10 ton steel wheel roller
Sweeper functional
Joints are positioned to avoid wheel paths

B. Spread ❑

Binder application temperature
Binder application rate
Chip spreader following immediately behind (20-30 m) distributor truck
Chip application rate
Lead roller follows immediately behind (20-30 m) chip spreader
Number of coverage's by rubber tire rollers
Joints thoroughly swept 150 mm from edge prior to overlapping application
Overlapping nozzle angled to cut back application rate at joints
Overlap at longitudinal joints, 102 mm maximum

C. Post-Spread ❑

Sweep loose aggregate

**Falling out of compliance with these parameters will be cause a halt in paving operations until reconciled.*