ASPHALT RUBBER DESIGN AND CONSTRUCTION GUIDELINES

VOLUME I – DESIGN GUIDELINES

by

R.G. Hicks, P.E.
Professor Emeritus
Department of Civil Engineering
Oregon State University
Corvallis, OR 97331

prepared for

Northern California Rubberized Asphalt Concrete Technology Center (NCRACTC)
906 G Street, Suite 510
Sacramento, CA 95814

and the

California Integrated Waste Management Board (CIWMB)
1001 I Street
Sacramento, CA 95812

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FOREWORD

The intent of this document is to encourage use of asphalt rubber by local agencies in California. It includes information on all aspects of asphalt rubber use including:

- design
- construction
- economics
- benefits and limitations.

The guidelines are designed to provide information to agencies that will ensure success during production and placement of asphalt rubber strategies. This document was the vision of a partnering effort involving the following groups:

- Caltrans (CT)
- California Integrated Waste Management Board (CIWMB)
- Rubber Pavements Association (RPA).

These groups (plus others) also provided technical input in the development of these guides.

Information contained in this guide is disseminated through the Rubberized Asphalt Concrete Technology Centers (Northern California or Southern California). For further information on asphalt rubber use and specification, please refer to the following web sites:

- http://www.rubberizedasphalt.org
- http://www.ciwmb.ca.gov
- http://www.rubberpavements.org
- http://www.tfhrc.gov/pubrds/spring97/crum.htm

Volume I of this guide presents a summary of the key information needed to use asphalt rubber. Volume II contains detailed supporting information used in the development of the Volume I summary.

R. Gary Hicks
Professor Emeritus
Oregon State University
Corvallis, Oregon  97331
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DISCLAIMER

This document is disseminated by the Northern California Rubberized Asphalt Concrete Technology Center and the CIWMB. The contents of the report reflect the views of the author who is solely responsible for the facts and the accuracy of the material presented. The contents do not necessarily reflect the official views of the Center.
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Executive Summary

A. GENERAL APPLICATION GUIDELINES

1. **What is Asphalt rubber?**  Asphalt rubber is a mixture of 18-22% crumb rubber, asphalt cement and in some cases extender oil, which is reacted at elevated temperatures prior to being mixed with aggregate. Two types of asphalt rubber (wet process) are used in California, Type 1 and Type 2. Type 1 contains rubber only from ground tires. Type 2 contains rubber from both ground tires and natural rubber. Caltrans uses type 2 binders only because of improved reflection cracking resistance. The products are not to be confused with asphalt rubberized asphalt products such as “terminal blends” (generally less than 10% ground tire rubber plus a polymer additive) or the “dry process” (where the crumb rubber is added as an aggregate and is not fully reacted with the asphalt.

2. **How is asphalt rubber used?**  Asphalt rubber has been used both in hot mix applications and in spray applications (e.g., chip seals, SAM, SAMIs) especially when reduced overlay thickness is desired for controlling grades and against existing medians. Asphalt rubber has been used in dense-graded, gap-graded and open-graded mixtures. It is now most commonly used in California in gap- and open-graded mixes. It is also used in spray applications. The most common spray application is a chip seal, using a heavy application of asphalt rubber followed by an application of stone.

3. **Where should asphalt rubber products be used?**  Asphalt rubber hot mixes can be used anywhere conventional mixes is used. Temperature and weather conditions can affect when the product can be placed. Asphalt rubber chip seals can be used where conventional chips seals are used, but offer improved performance benefits such as limited rock loss, reflection crack mitigation and longer surface lives. Also, a rubber chip seal can be used in combination with a rubber overlay to form a stress absorbing membrane interlayer (SAMI) in lieu of full reconstruction.

4. **What are the benefits of asphalt rubber products?**  There are several benefits including the following;
   - Improved resistance to surface initiated cracking due to higher binder contents
   - Improved aging and oxidation resistance due to higher binder contents
   - Improved resistance to fatigue and reflection cracking due to higher binder contents
   - Improved resistance to rutting due to higher viscosity and softening points
   - Increased night-time visibility due to contrast in the pavement and striping
   - Reduced tire noise due to increased binder film thickness and open texture
   - Reduced splash and spray during rain storms due to open texture
   - Reduced construction times because less material is placed
   - Lower pavement maintenance costs due to improved pavement performance
   - Better chip retention due to thick films of asphalt
   - Lower life cycle costs due to improved performance
   - Savings in energy and natural resources by using waste products

5. **What are the limitations of asphalt rubber products?**  These include the following:
   - Higher units costs, which are offset by using reduced thickness, resulting in lower life cycle costs. As such, they are primarily used for surface courses only.
   - In the past, variable performance due mainly to poor construction practices or construction during inclement weather. These deficiencies have been corrected through improved specifications
   - More challenging construction, due to more restrictive temperature requirements
   - Potential odor and air quality problems
   - Difficult to handwork

6. **Where should asphalt rubber products not be used?**  Asphalt rubber has been used successfully in most geographical and climatic zones in California. Problems that have been reported have been related to construction issues related to cold weather paving or late season construction. Specific cases where asphalt rubber should **not** be constructed include;
• During cold weather (ambient conditions below 13°C (55°F)) or rainy conditions
• On severely cracked pavements where traffic and deflection data are not available. AR overlays have performed very well over cracked pavements as long as the cracks are not over 12.5 mm (_inch) wide
• Areas requiring lots of handwork
• Where haul distances from the hot plant to the job location are excessive and the AR mix would cool below the allowable pavement temperature

B. APPLICATION GUIDELINES

1. Hot Mix. Asphalt rubber hot mix can be placed on existing pavements to reduce deterioration caused by weathering, raveling and oxidation. It also provides an improved wearing surface with good surface friction and ride characteristics. Asphalt rubber hot mix can also be used on portland cement concrete pavements or bridge decks. In these cases, the mix is used to minimize reflection cracking, to improve surface friction, and to reduce noise. Asphalt rubber hot mixes, like any other mix, are not a cure all to all pavement problems. If placed in cool conditions where adequate compaction cannot be achieved early raveling might occur. Because of the improved cracking resistance, the layer thickness of asphalt rubber hot mix can be reduced in comparison to conventional hot mix. This reduced thickness makes asphalt rubber more cost effective when the overall design factors are considered. AR mixes are also susceptible to flushing when placed in stop zones such as intersections.

2. Chip Seals. Asphalt rubber chip seals can be applied to existing pavements as a surface seal or as an interlayer after a thin AC leveling course has been placed. The chip seal provides good skid resistance and improves the durability of the pavement. It does not add structural strength to the pavement nor does it correct longitudinal roughness problems, but is equivalent to 50 mm (2 in.) of HMA in preventing reflection cracking.

3. Interlayers. Asphalt rubber chip seals are also used as interlayers in 2 or 3 layer systems to help slow reflective cracking.

C. PLACEMENT GUIDELINES

1. Hot Mix. Asphalt rubber hot mixes should not be placed when the ambient (or surface) temperature is below 13°C (55°F) or during rainy weather. It is important to complete the asphalt rubber projects before cold weather begins. The mixture must be compacted while it is hot to achieve good performance and because of the tacky nature of the finished product, the compacted surface should be sanded prior to permitting traffic on the surface.

2. Chip Seals. Asphalt rubber chip seals should not be placed when the ambient (or surface temperature) is below 13°C (55°F) or during wet weather. The binder should be placed on a clean dry surface. The ambient temperature at application should not exceed 40°C (105°F).

D. GENERAL INFORMATION

1. Background. Asphalt rubber (or the “wet process”) has been used in the United States since the early 60s. First developed in Arizona, it is now widely used by many agencies in spray applications and in hot mixes, as well as a crack sealant. California and Arizona are two of the largest users of asphalt rubber. The other major user includes the state of Texas. Other products often referred to as rubberized asphalt, have also been used. These products include the “dry process” where crumb rubber is added during the mixing operation and the crumb rubber does not fully react with the asphalt. “Terminal blends” used in California and Florida generally contains less than 10% crumb rubber as well as a polymer additive. These different processes produce different characteristics when placed in a pavement, but are often marketed as equals to asphalt rubber.

2. Description. The components of asphalt rubber commonly used include the asphalt cement and 18-22 crumb rubber including a component of high natural rubber, and for the type 2 binder some extender oil. The mixture is reacted at elevated temperatures for 45 minutes (min.) to allow the asphalt and rubber to react. The binder is
then used in either a hot mix or spray application. In California, the binder is most widely used in gap- or open-graded mixes. In spray applications, the binder is used for chip seals (ARCS) or inter-layers (SAMI).

3. **Thickness Design.** Because of the improved properties of the binder, the Caltrans design procedure allows the thickness of the asphalt rubber to be reduced up to 50% when compared to conventional hot asphalt mixes. (See Appendix C.) This thickness reduction was based on the performance of field tests and confirmed by accelerated performance tests conducted in South Africa and by UC Berkeley.

4. **Mix Design.** For open-graded mixes, the mix design is similar to that used for conventional open graded mixes, with a factor applied to the resulting binder content. For gap-graded mixes, the properties generally used to establish the binder content are voids, VMA or local experience. Stability requirements are reduced compared with conventional mixes. Moisture sensitivity does not seem to be a problem with these mixes. Where problems might occur, the moisture sensitive aggregates can be treated with lime.

5. **Mix Properties.** Asphalt rubber mixes generally have greater fatigue lives due to the higher binder contents and greater rutting resistance due to the higher binder viscosity. They are also generally more permeable than conventional mixes and this reduces the splash and spray during periods of rain.

6. **Cost Effectiveness.** The initial unit costs for asphalt hot mixes and chip seals are significantly higher than conventional materials. Because, the hot mixes can be used in reduced thickness and the chip seals last longer than the conventional product the asphalt rubber is generally cost effective over 80% of the time for an analysis period of 30-40 years. (See Appendix E.)

7. **Environmental Benefits.** Asphalt rubber contains a waste product which possesses superior properties to conventional asphalt. In California about 1400 (Type 2) to 2000 (Type 1) tires are used in each lane-mile using a layer thickness of 50 mm (2 in.). Currently, terminal blends use about one-third to one-half this amount of rubber.
GLOSSARY OF TERMS

Ambient ground rubber – processing where scrap tire rubber is ground or processed at or above ordinary room temperature.

ARCO-ARM-R-SHIELD (Arizona refining process) – an asphalt-rubber blend process that was developed in 1975. The blend is composed of approximately 20 percent rubber (of which 40 percent is devulcanized and 60 percent ground ambient vulcanized) and 80 percent AR-4000/8000 with 2 to 4 percent Witco extender oil. The granulated rubber has gradings in which 98 percent pass the No. 16 mesh and 8 percent pass the No. 100 mesh.

Asphalt rubber – a blend of ground tire rubber (generally fine ground No. 16 to No. 25 crumb rubber) and asphalt cement, which is used as the “binder” in various types of pavement construction. It generally consists of 18 to 22 percent ground tire rubber by total weight of the blend. The blend is formulated at elevated temperatures to promote the chemical and physical bonding of the two constituents. Various petroleum distillates or extender oils may be added to the blend to reduce viscosity, increase sprayability, and promote workability.

Asphalt-rubber concrete – implies the use of an asphalt-rubber blend (binder) with dense-graded aggregates in a hot-mix application.

Asphalt-rubber hot-mix – implies the use of an asphalt rubber binder with a dense-, gap-, or open-graded aggregate in a hot-mix application.

Asphalt-rubber friction course – implies the use of an asphalt-rubber blend (binder) with open-graded aggregates in a hot-mix application.

Automobile tires – tires with an outside diameter less than 66 cm (26 in.) used on automobiles, pickups, and light trucks.

Buffing waste – high quality scrap tire rubber that is a byproduct from the conditioning of tire carcasses in preparation for retreading.

Cape seal – an application of an AR chip seal followed by an application of a slurry seal. This produces a quiet smooth pavement surface.

Crackermill – process 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 micron [No. 4 to No. 40 sieve]).

Crumb rubber modifier – a general term for scrap tire rubber that is reduced in size and is used as modifier in asphalt paving materials.

Cryogenically ground rubber – process that freezes the scrap tire rubber and crushes the rubber to the particle size desired prior to being ground.

Dense-graded – a continuously graded aggregate used in hot-mix applications.

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

Diluent – a lighter petroleum product (typically kerosene) added to asphalt-rubber binder just before the binder is sprayed on the pavement surface.

Dry process – any method that mixes the crumb rubber modifier with the aggregate before the mixture is charged with asphalt binder. This method applies only to hot-mix asphalt production.

Extender oil – an aromatic oil used to supplement the reaction of the asphalt and the crumb rubber modifier.

Flush coat – an application of an emulsified asphalt onto the new pavement surface to prevent rock loss in chip seals or raveling in HMA.

Gap-graded – a continuously graded aggregate with one or two of the finer sizes missing and used in hot-mix applications.

Granulated crumb rubber modifier – cubical, uniformly shaped, cut crumb rubber particle with a low surface area, which is generally produced by a granulator.

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

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

Micro-mill – process that further reduces a crumb rubber to a very fine ground particle, reducing the size of the crumb rubber below 425 microns (No. 40 sieve).

Open-graded – an aggregate gradation which is mostly 2 to 3 sizes with few fines.
PlusRide – a patented form of a rubber-modified asphaltic mix. The product was developed in 1960 in Sweden and patented under the name PlusRide in the United States and Rubit in Sweden. It uses coarse rubber particles (6 mm to 0.6 mm [1/4 in. to 1/16 in.]) as rubber-filled aggregates, generally about 3 percent weight of mix. The rubber is added directly to a gap-graded aggregate so that a relatively dense-grading between the aggregate and rubber is obtained.

Reaction – the interaction between asphalt cement and crumb rubber modifier when blended together. The reaction, more appropriately defined as polymer swell, is not a chemical reaction. It is the absorption of aromatic oils from the asphalt cement into the polymer chains of the crumb rubber.

Recycled tire rubber – rubber obtained by processing used automobile, truck, or bus tires. (Note: Solid tires; tires from fork lifts, aircraft, and earthmoving equipment; other nonautomotive tires; and nontire rubber sources are excluded.)

Rubber aggregate – crumb rubber modifier added to hot-mix asphalt mixture using the dry process, which retains its physical shape and rigidity.

Rubber-modified asphalt concrete – a hot-mix asphalt-concrete mixture with dense-graded aggregates using a rubber-modified asphalt.

Rubberized asphalt – same meaning as wet process or a modified asphalt binder containing a crumb rubber modifier.

SAM – the abbreviation for a stress-absorbing membrane. A SAM is used primarily to mitigate reflective cracking of an existing distressed asphaltic or rigid pavement. It comprises an asphalt-rubber blend sprayed on the existing pavement surface followed immediately by an application of a uniform aggregate which is then rolled and embedded into the binder layer. Its nominal thickness generally ranges between 9 and 12 mm (3/8 and 1/2 in.). In southern California, this is referred to as an Asphalt Rubber Aggregate Membrane (ARAM).

SAMI – the abbreviation for a stress-absorbing membrane interlayer. The interlayer may be an asphalt-rubber chip seal, fabric, fine unbound aggregate, or an open-graded asphalt layer. A SAMI is a SAM that is applied beneath an asphalt overlay (which may or may not contain rubber in the mix).

Shredding – process that reduces scrap tires to pieces 0.15 m$^2$ (6 in.$^2$) and smaller.

Stress-absorbing membrane (SAM) – a surface treatment using an asphalt-rubber spray application and cover aggregate.

Stress-absorbing membrane interlayer (SAMI) – a membrane beneath an overlay designed to resist the stress and strain of reflective cracks and delay the propagation of the cracks through the new overlay. The membrane is often a spray application of asphalt-rubber binder and cover aggregate.

Terminal blend – a process where the crumb rubber modifier is blended with asphalt at the refinery or terminal. Normally the blend contains 10% or less crumb rubber. Examples include TARMAC and Polyfalt.

Three layer system – system developed by Arizona as a means of restoring the rideability of a badly cracked, warped, or faulted PCC pavement. The principle is equally valid for asphalt-concrete pavements. As currently used, the TLS consists of two thin (12.5 mm to 19 mm [1/2 in. to 3/4 in.]) conventional open-graded friction course layers placed around a low-modulus SAMI (approximately 9 mm [3/8 in.] thick). The bottom open-graded friction course layer is placed directly on the existing pavement and functions, in part, as a leveling course.

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

Truck tires – tires with an outside diameter greater than 66 cm (26 in.) and less than 152 cm (60 in.); used on commercial trucks and buses.

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

Wet process – any method that blends crumb rubber modifier with the asphalt cement before incorporating the binder in the asphalt paving project.

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

1.1 DESIRABLE CHARACTERISTICS OF PAVEMENTS

Owners of pavements are interested in having pavements which possess the following characteristics:

- **Smoothness.** The public demands smooth pavements with a quiet ride. A recent Federal Highway Administration (FHWA) survey (1996) indicated ride to be the most important feature to users of pavements.
- **Durability.** Agencies and private owners of pavements want them to withstand the detrimental effects of traffic and environment for the expected service lives.
- **Safety.** Users expect the pavements they operate on to be safe. They should offer good skid resistance, be free of surface defects, provide contrast for lane markings, minimize splash and spray and pavement glare, etc.
- **Aesthetics.** Users of pavements are also concerned with the appearance of the pavement surface. Patches, and other irregularities in the surface, indicate the pavement is not durable and often results in roughness/safety problems.

Pavements are generally asphalt or portland cement concrete surfaced. This manual is a design guide for asphalt surfaced roads containing an asphalt rubber binder.

1.2 ATTRIBUTES OF ASPHALT RUBBER PAVEMENTS

Paving with asphalt rubber offers several advantages including:

- **Durability.** Asphalt rubber pavements have excellent durability in terms of cracking and aging resistance.
- **Constructability.** Asphalt rubber pavements are machine placed and can be used by traffic almost immediately; no delay is required to allow the pavement to cure.
- **Economics.** Asphalt rubber pavements are cost effective. Their construction costs, as well as long life (when properly designed and constructed), are important attributes. In addition, the time required to maintain and rehabilitate asphalt rubber pavements reduces the user delays when compared with other pavement materials.
- **Recyclability.** A major attribute of asphalt rubber pavements is its ability to be completely recycled. Not only can the aggregates be reused, but the asphalt rubber binder retains much of its cementing properties and can also be reused in a mix. However, there are still concerns regarding whether air quality standards can be met.
- **Versatility.** The versatility of asphalt rubber is evident all across the state of California and throughout other parts of the United States. Many of California’s streets and roads are surfaced with asphalt rubber, a clear testimony to its cost effectiveness, constructability, and ease of maintenance.
- **Safety.** Asphalt rubber pavements provide safe surfaces with good surface friction for all users. Open-graded (or gap-graded) mixes offer additional advantages for roads such as reduced splash and spray under wet conditions.
- **Reduced maintenance.** Asphalt rubber pavements result in reduce maintenance when properly designed and constructed.
- **Reduction in noise.** Lower tire noise has been demonstrated when using asphalt rubber pavements (e.g., 3 to 5 dB).
- **Savings in energy and natural resources.** Use of reduce thickness layers results in savings in energy and natural resources. In addition, the AR mixes last longer so overlays need not occur as often.

1.3 ORGANIZATION OF GUIDE

This design guide is organized into the following chapters:

- Chapter 2 presents an overview of the use of asphalt rubber including its history, advantages and limitations. It also includes information on asphalt rubber production and supply as well as selected performance studies conducted by Caltrans and local agencies in California.
- Chapter 3 presents a summary of the design considerations needed for both new construction and rehabilitation and maintenance. It also includes cost data and specifications for asphalt rubber applications.
Chapter 4 presents information on asphalt binder design and mixture design for both hot mixes and chip seals.

Chapter 5 summarizes the important asphalt rubber construction issues for asphalt mixes. It includes sections on binder production, hot mix production, placement and compaction, and quality control and assurance.

Chapter 6 presents important construction information for spray applications including materials application and quality control and assurance.

Chapter 7 discusses the important technical issues, including production rates and QC, and handling utilities. The importance of pre-construction meetings to ensure the success of a project is also summarized.

Chapter 8 describes some of the more important environmental issues related to using asphalt rubber including social benefits, health concerns and recyclability.

Chapter 9 summarizes some of the ongoing/future developments which will impact the use of asphalt rubber. This includes changes in QC/QA specifications, development of performance-based specifications, warranty specifications, and implementation of Superpave.

Chapter 10 is a compilation of the references cited.

1.4 LIMITATIONS AND USE OF MANUAL

This guide is intended to be used by agencies, architects, engineers, and consultants who design and specify asphalt pavements for streets and highways. The guide is designed to help determine the mix type and structural requirements to provide a durable and smooth riding surface.

The approach used in the development of the thickness recommendations is consistent with the procedure used by the California DOT. It is expected this guide can be used to develop a standard of practice for the design of asphalt rubber pavements used as city streets, county roads, and state highways.
This chapter provides a brief overview of the history of asphalt rubber, some of the production and supply issues, and a summary of asphalt rubber project reviews by Caltrans and local agencies.

2.1 HISTORY

2.1.1 Overview

Asphalt rubber has been used in asphalt mixtures since the early 1960s. The documentation is extensive, but disjointed, making a summary of its historic development difficult. Asphalt rubber is defined as a “wet process” in which the crumb rubber partially reacts with asphalt cement prior to use. It has been used in the following applications:

- crack sealants
- spray applications
- binders in hot mixes.

Typically, asphalt cement and crumb rubber are reacted at high temperatures and aromatic oils (extender oils) may be added.

The process was pioneered by Charles H. McDonald in the mid-1960s. His experimental work with Atlos Rubber, Arizona DOT, and Sahuaro Petroleum and Asphalt Company resulted in the development of commercial binder systems. In the mid-1970s, Arizona Refining Company (ARCO) also developed an asphalt rubber binder system. These early systems represent the foundation of the products currently used today.

From the mid-1970s through the early 1980s, Arizona DOT sponsored comprehensive research programs to develop a fundamental understanding of the asphalt rubber binders. The research indicated that the properties of asphalt rubber mixtures vary depending on rubber type, rubber gradation, rubber concentration, asphalt type, asphalt concentration, type and concentration of extender oil, and reaction time and temperature. The influence of these variables on binder properties is discussed in more detail by Epps (1994). The asphalt rubber described in this guide is not to be confused with the following:

- terminal blends, a process which combines small amounts of crumb rubber and asphalt cement, which is held in tanks for extended periods of time
- the dry process where the crumb rubber modifier is substituted for aggregate

In the 1970s, California DOT began evaluating asphalt rubber for use in spray applications and on hot mixes in the 1980s. This early work resulted in the development of their current thickness design guide for mixes containing asphalt rubber, or up to a 2:1 reduction in thickness when compared with conventional hot mixes (Van Kirk, 1992, 1997). Other agencies, including Arizona and Texas, continued their use of asphalt rubber for both spray applications and hot mixes during this period.

In 1992, a federal mandate on the use of asphalt rubber was instituted. This resulted in several studies by the Federal Highway Administration to help the SHAs implement the mandated use including

- Phase I Research – Conducted by the University of Florida to summarize current practices and identify research needs for Phase II.
- Phase II Research (Hicks et al., 1995) – Conducted by Oregon State University to develop guidelines for mix thickness design; develop guidelines for construction and field QC; establish long-term performance of mixes containing CRM; and evaluate the recyclability of mixes containing CRM.
- WRI Research – This study consisted of a fundamental evaluation of asphalt rubber binders including the effect of asphalt composition and time and temperature of reaction.
- NCHRP Synthesis (Epps, 1994) – This consisted of summary of the state of practice, including all processes containing CRM.

Before all the above studies were complete, the mandate was repealed and the patents on the asphalt rubber binder had expired.

This resulted, particularly in Arizona and California, in a number of new producers of asphalt rubber binders. It came at a time when California was expanding their use of asphalt rubber because of good early performance. As a result, many projects constructed during this period experienced early distress, either because they were used in the wrong place, were not constructed properly, or the binder did not meet specifications (Van Kirk and Hildebrand, 1995).

The early distress exhibited in the asphalt rubber projects prompted Caltrans to begin research on a performance related specification (PRS) to minimize the distress noted (Reese, 1994 and 1995). It also prompted them to partner with industry to develop an improved recipe specification to minimize the impact of the other construction issues. The proposed PRS is still undergoing evaluation and is not discussed in this chapter.
guide. The revised recipe specification is still the primary specification used and projects constructed with it were evaluated in 1999.

2.1.2 Advantages of AR

AR has several advantages including the following:

• Good durability – in terms of resistance to cracking and aging
• Environmentally friendly – makes use of a waste material
• Versatility – can be used in most maintenance and rehabilitation activities, or in reduced thickness
• Longer lasting color – for better contrast with striping and marking
• Cost effective – although the initial costs are greater than conventional mix, the life cycle costs are generally lower
• Reduced maintenance - for both chip seals and hot mix

2.1.3 Limitations of AR

AR has performed well in many applications, but it is not without problems. Some of the limitations include:

• Raveling and Flushing – Problems such as early raveling or flushing have been reported. These are often related to construction quality control, a topic which will be discussed in more detail in a later chapter.
• Cracking – Like most pavements, AR will exhibit cracking, either fatigue or reflection cracking. However, its resistance to cracking is very good when used in the correct application and/or thickness. Many of the reported problems of early cracking have been associated with the use of AR as a last resort to correct a badly distressed pavement.
• Tackiness of Product. Asphalt rubber mixes are more prone to track exiting pavement surfaces.

2.2 ASPHALT RUBBER PRODUCTION AND SUPPLY ISSUES

Asphalt rubber consists of the following ingredients:

• asphalt cement,
• crumb rubber modifier including high natural rubber (HNR), and
• in most cases an extender oil.

Typically, 18 to 22 percent ground rubber is blended with the asphalt cement and reacted for a minimum of 45 minutes at elevated temperatures. The result is a thick elastic material called asphalt rubber.

2.2.1 Ingredients

Most asphalt cements can be used in the production of asphalt rubber; however, they do not behave the same when reacted with the CRM. In all cases, the user of asphalt rubber should require an AR binder design to insure the asphalt cement and CRM are compatible.

The CRM is normally produced through ambient grinding techniques. The rubber processed generally consists of

• whole passenger and truck tires,
• tread peel from over the road vehicles,
• buffings generated as a by-product of the retreading process.

The resultant product is tested for the following properties

• gradation,
• moisture,
• chemical properties including ash content, carbon black, hydrocarbons, natural rubber.

The items normally checked include gradation and moisture content. It is important that the rubber be certified by the supplier as meeting specification.

2.2.2 Asphalt Rubber

The asphalt rubber used in California includes the above items as indicated below:

• Type 1 AR consists of only crumb rubber from scrap tires.
• Type 2 AR consists of 75% crumb rubber from scrap tires and 25% from a high natural rubber source and an extender oil because of improved reflection cracking.

Caltrans recommends the use of Type 2 binders and most cities and counties use Type 2 binders. However, some California cities/counties as well as the state of Arizona use Type 1 binders.

2.2.3 Small vs. Large Jobs

The unit cost of asphalt rubber is higher than that of conventional asphalt products. This can pose a problem for agencies wishing to initiate a construction program that uses asphalt rubber, even though there may be lower project costs when used in reduced thickness. Also, when AR mixes are being produced,
the hot plant can not make conventional asphalt without a storage silo.

Small jobs will result in high unit costs because of the cost of mobilization. Larger jobs (or volumes) will lessen the impact of the mobilization costs and result in a more competitive product. Agencies wishing to become involved with asphalt rubber should consider combining projects with other agencies to obtain more competitive prices.

2.3 ASPHALT RUBBER CASE HISTORIES/PROJECT REVIEWS

2.3.1 Caltrans

Asphalt rubber use in California began in the late 1970s and early 1980s. Caltrans first used asphalt rubber binders in spray applications in the late 1970s followed by use in hot mix in the early 1980s. The results of this work can be found in the following studies:

- Performance related specifications – see papers by Reese (1994, 1995)
- Project reviews (1995) – by Van Kirk and Hildebrand (Appendix A)
- Project reviews (1999) – see Appendix A

The various project reviews suggest the following:

1) **AR Chip Seals** – These have performed well in most cases. Although the initial costs tend to be much higher, the life cycle costs indicate the AR chip seals are cost effective.

2) **AR Hot Mixes** – The early project reviews suggest Caltrans has not always had success with AR in hot mixes. Part of the early distress was associated with quality control and/or using the product in the wrong application. The 1999 reviews indicated that projects constructed since 1995 (with the new recipe specification) show significant improvement in early performance.

2.3.2 Local Agencies

A number of local agencies have used asphalt rubber since the mid- to late 1980s. These agencies include, but are not limited to, those included in Table 2.1. Selected project reviews for these agencies are given in Appendix B. Significant findings are as follows:

- Asphalt rubber products, whether used in spray seals or in hot mixes, have performed very well.
- Despite the higher initial costs of the asphalt rubber products, they have proven cost effective over the design life. Costs can be reduced by combining projects with adjacent agencies or by advertising projects so that they coincide with paving on AR jobs by other agencies.

Table 2.1. Examples of Cities/Counties in California Using Asphalt Rubber

<table>
<thead>
<tr>
<th>Counties</th>
<th>Contra Costa, Los Angeles, Orange, Riverside, Sacramento, San Diego, Santa Barbara, Santa Clara</th>
</tr>
</thead>
</table>
3.0 ASPHALT RUBBER DESIGN CONSIDERATIONS
3.1 USES

Asphalt rubber has been used in several applications in California since the late 1970s. These uses include the following:

- **Spray Applications** – Asphalt rubber binders are used for
  - Chip Seals – An application of AR binder followed by an application of chip seal aggregate
  - Interlayers – An application of an AR chip seal prior to an HMA overlay
  - Cape Seals – An application of an AR chip seal followed by a slurry seal.
- **Hot Mixes** – AR has been used in the following mix types
  - Dense-Graded Mixes – Generally 6 to 8%* AR is included in a dense-graded rock. Gap-Graded Mixes – Generally 7 to 9%* AR is included in a gap-graded rock to produce a mixture with a thick film of AR binder around the rock.
  - Open-Graded Mixes – Generally 6 to 8%* AR is included in an open-graded rock for use as the surface layer. This mix is used to reduce splash and spray due to surface water.
  - Open-Graded Mixes (High Binder) – Generally 8 to 10%* AR is included. These mixes have thick binder films for good durability.

*% by dry weight of aggregate

3.2 NEW CONSTRUCTION

Although not widely used in new construction projects at the present time, asphalt rubber can be and has been used as a part of new construction projects. On these projects, the AR mixes have been used at the same thickness as the conventional mix. In some cases, they have been used in reduced thickness ranging from 25 to 50% (up to 60 mm reduction) when compared with conventional mixes.

3.2.1 Pavement Design Process

Caltrans’ design process is based on their standard design methodology that allows partial substitution of mixes containing asphalt rubber for conventional wearing course in new construction. The design process would allow substitution of up to 60 mm (2.4 in.) of asphalt rubber in place of a conventional dense-graded asphalt concrete (DGAC).

As an example, consider a pavement with a traffic index (TI) of 11. The design that does not include asphalt rubber would require about 180 mm (7.2 in.) of DGAC over a class 2 aggregate base. As an alternative, 60 mm (2.4 in.) of asphalt rubber mix could be placed over 60 mm (2.4 in.) of DGAC over the same aggregate base, saving approximately 60 mm (2.4 in.) of mix. When using AR in reduced thickness for new construction, the designer must ensure rutting of the underlying layers will not take place.

3.2.2 Design Strategies

Asphalt rubber mixes have generally been used on the wearing surface to minimize top-down surface cracking and provide long-term durability. However, because of the improved fatigue properties of asphalt rubber, they could also be used in the underlying layers to minimize bottom-up fatigue cracking. When AR mixes are placed over cracked pavements, the cracking that develops in the AR overlay usually starts at the bottom and propagates to the surface. In these cases the use of interlayers (e.g., SAMIs) are recommended.

3.3 REHABILITATION APPLICATIONS

Most of the current applications which involve the use of asphalt rubber (wet process) are for maintenance and/or rehabilitation of existing pavements. Asphalt rubber products have been used to maintain and rehabilitate either existing asphalt concrete or portland cement concrete pavements.

3.3.1 Pavement Design Process

Caltrans developed a design procedure for asphalt rubber overlays that is based on several assumptions as well as field observations. These include:

- Cracking over overlays is caused by a combination of traffic loads and movement of the underlying pavement.
- Asphalt rubber mixes can withstand higher deflections than conventional asphalt mixes without cracking.
- The reflection crack retardation of asphalt rubber mixes is greater than conventional mixes.

Based on these results, as well as results of subsequent field tests, Caltrans developed the design approach given in Appendix C and summarized below:

- Table 3.1 or 3.2 is used to determine the asphalt rubber overlay thickness (with or
without the use of a stress absorbing membrane).

- Table 3.1 is used if structural needs (deflection) controls while Table 3.2 is used if reflection crack retardation controls.

Overall, the use of asphalt rubber in asphalt rubber mixes allows a reduction in overlay thickness when compared to that required for conventional asphalt concrete. Also the use of a SAMI layer is equivalent to 45 mm (0.15 ft.) in layer equivalency.

### 3.3.2 Pavement Evaluation/Deflection Studies

As a part of a rehabilitation effort, the existing pavement is usually evaluated for current condition and for structural adequacy. Most agencies generally use the following sets of information to determine the type and the thickness of the overlay:

- An assessment of the type and amount of cracking, rutting, or other pavement distress
- An assessment of the traffic (volume and trucks) to arrive at the design traffic over the design period.
- A measure of the surface deflection to determine the structural properties of the pavement section. Normally this would involve the use of either a Falling Weight Deflectometer (FWD) or other acceptable deflection devices.

These items are used to determine the overlay thickness and/or surface preparation required prior to the overlay.

---

### Table 3.1. Structural Equivalencies for Resurfacing*

<table>
<thead>
<tr>
<th>DGAC</th>
<th>ARHM-GG</th>
<th>ARHM-GG on a SAMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.10²</td>
<td>—</td>
</tr>
<tr>
<td>0.20</td>
<td>0.10</td>
<td>—</td>
</tr>
<tr>
<td>0.25</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>0.30</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>0.35</td>
<td>0.20</td>
<td>0.15</td>
</tr>
<tr>
<td>0.40</td>
<td>0.20</td>
<td>0.15</td>
</tr>
<tr>
<td>0.45</td>
<td>0.15³</td>
<td>0.20</td>
</tr>
<tr>
<td>0.50</td>
<td>0.15²</td>
<td>0.20</td>
</tr>
<tr>
<td>0.55</td>
<td>0.20³</td>
<td>0.15³</td>
</tr>
<tr>
<td>0.60</td>
<td>0.20⁴</td>
<td>0.15⁴</td>
</tr>
</tbody>
</table>

Notes:

*Thickness(ft.) and 30 cm = 1 ft.
1. The maximum allowable non-experimental equivalency for ARHM-GG is 2:1.
2. The minimum allowable ARHM-GG lift thickness is 0.10’.
3. Place 0.15’ of new DGAC first.
4. Place 0.20’ of new DGAC first.
5. ARHM-GG may not prevent cold weather induced transverse cracks.

---

### Table 3.2. Reflection Crack Retardation Equivalencies*

<table>
<thead>
<tr>
<th>DGAC</th>
<th>ARHM-GG</th>
<th>ARHM-GG on a SAMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.10¹</td>
<td>—</td>
</tr>
<tr>
<td>0.20</td>
<td>0.10</td>
<td>—</td>
</tr>
<tr>
<td>0.25</td>
<td>0.15</td>
<td>—</td>
</tr>
<tr>
<td>0.30</td>
<td>0.15</td>
<td>—</td>
</tr>
<tr>
<td>0.35¹</td>
<td>0.15 or 0.20³</td>
<td>0.10⁴</td>
</tr>
</tbody>
</table>

Notes:

*Thickness (ft.) and 30 cm = 1 ft.
1. The minimum allowable ARHM-GG lift thickness is 0.10’.
2. A DGAC thickness of 0.35’ is the maximum thickness recommended by Caltrans for reflection crack retardation.
3. Use 0.15 if the crack width is < 1/8” and 0.20 if the crack width is ≥ 1/8”.
4. Use if crack width is ≥ 1/8”. If < 1/8”, use another strategy.
5. ARHM-GG may not prevent cold weather induced transverse cracks.
3.3.3 Design Strategies

Typically, asphalt rubber overlays (Figure 3.1) or two or three layer systems (shown in Figures 3.2 and 3.3) are used in rehabilitation applications. The asphalt rubber overlay can either be a gap- or open-graded mix whereas the two/three layer system consists of an asphalt rubber interlayer overlain with asphalt rubber hot mix. Gap-graded mixes can also be used in mill and fill operations as long as they are well compacted with low voids.

Use of asphalt rubber reduces the propagation of reflection cracks from the underlying layer and improves the durability of the surface to resist thermal and/or shrinkage cracks. AR mixes have been used successfully over both asphalt or portland cement concrete pavements.

3.4 MAINTENANCE APPLICATIONS

Asphalt rubber products have been widely used for maintaining existing pavements. The most widely used products include asphalt rubber chip seals or thin hot mix overlays (< 30 mm or 1.2 in.).

3.4.1 Types of Pavement Maintenance

Currently, most agencies practice one of the following types of maintenance as a part of their pavement preservation program;

- **Preventive Maintenance** – a planned maintenance treatment, applied prior to significant distress, that preserves the pavement, retards future deterioration, and maintains or improves the pavement without increasing the structural capacity. Figure 3.4 shows a typical deterioration curve and the timing of the different maintenance treatments.

- **Corrective Maintenance** – maintenance performed once a deficiency such as loss of friction, rutting, cracking, or raveling occurs in the pavement.

Asphalt rubber chip seals and other hot mix overlays have been used successfully for either type of maintenance.

3.4.2 Design Strategies

Asphalt rubber chip seals can be used on most existing asphalt pavements to correct surface deficiencies and extend the life of the pavement. They can also be used in combination with a thin hot mix overlay for a maintenance treatment to address significant cracking problems. Both gap- and open-
graded asphalt rubber mixes have been used on maintenance applications. An example of a field evaluation of various maintenance treatments is given in Appendix D. This test section was funded by CIWMB and monitored by Caltrans.

### 3.4.3 Field Performance

The test sections near Woodland, California, indicated that asphalt rubber chip seals and thin hot mix overlays are excellent maintenance treatments. The performance surveys conducted to date indicate the following:

- Gap- and open-graded asphalt rubber overlays (< 25 mm or 1 in.) perform better than similar mixes containing conventional binders.
- Asphalt rubber chip seals perform better than conventional chip seals.

Use of an asphalt rubber interlayer (SAMI) improved the ability of hot mix to retard reflection cracking. For more details on the test sections and the latest performance survey, please refer to appendix D.

### 3.5 Other Design Considerations

For each application described above (new construction, rehabilitation, and maintenance), a number of other design considerations apply if the project is to be successful. These other design considerations are discussed in this section.

#### 3.5.1 Minimum Lift Thickness

Minimum lift thickness is important for the following reasons:

- **Heat Retention** – Placing thin asphalt concrete mixes can cause the mix to cool rapidly and prevent it from being well compacted.
- **Constructability** – The ratio of the lift thickness to maximum aggregate size should be greater than 2.0 to 3.0 to make certain the coarse aggregate does not cause tears in the surface or is crushed during compaction.

#### 3.5.2 Special Attention Areas

Intersections, freeway ramps, and truck climbing lanes all experience slow moving and heavy traffic. These areas are prone to rutting and the use of asphalt rubber increases the rutting resistance by increasing the viscosity of the binder. Some agencies reduce the asphalt rubber binder content about _% to increase stability and minimize the chance for rutting and bleeding.

#### 3.5.3 Climate Considerations

The following climate considerations must be taken into account when using AR strategies:

- **Temperature** – Asphalt rubber is more sensitive to temperature. Mixing and placement temperatures must be followed closely. Mixes placed in cool temperatures (< 13°C or 55°F) are prone to poor compaction and early distress, unless special measures are used.
- **Moisture** – Excess surface moisture or rain during construction can also lead to early distress. Most specifications require asphalt rubber mixes to be placed on dry pavement.

#### 3.5.4 Surface Preparation

Since asphalt rubber products are generally used for resurfacing over existing pavement, the existing surfaces must be properly prepared. This includes:

- **Crack Sealing** – All cracks over 6 mm should be filled with a crack sealant at least 6 months prior to the overlay.
- **Patching** – Badly deteriorated areas of the existing surface should be removed and replaced with hot mix. If cold mix with volatiles are used they can soften the overlay.
- **Milling** – If the surface is uneven, milling can provide a good working platform. Often the
surface is milled to the full depth of the overlay to eliminate the need for feathering.

- **Leveling course.** If the surface is uneven, a leveling course can be place to provide a smooth working surface.
- **Tack Coat.** Just prior to placing the new surface, a tack coat must be applied.
- **Grinding.** This is used to remove raised marks and to remove thermoplastic stop bars and pavement legends.

### 3.5.5 Traffic Considerations

Asphalt rubber products can be used in most traffic situations; however, because of the nature of the product, the following special considerations should be followed:

- **Traffic Control.** Adequate traffic control is very important when placing AR mixes. If traffic is allowed on the hot mat, pick-up will occur resulting in permanent scars or poor performance.
- **Stickiness.** In California, sand is applied after compaction to prevent pick-up or tracking. In Arizona, lime water can be used to prevent pick-up. Lime water is not permitted by Caltrans.

### 3.5.6 Linkage to Pavement Management Systems (PMS)

Most agencies have some sort of pavement management system. It is important to include asphalt rubber products in the PMS to determine life expectancy of the different treatments. A good PMS will also provide useful information on:

- Expected life of various maintenance and rehabilitation treatments.
- Compare the differences in performance between AR and conventional mixes.
- Cost effectiveness of treatments.

### 3.6 ASPHALT RUBBER SPECIFICATIONS

A variety of specifications are available for asphalt rubber chip seals and hot mix. Caltrans and other local agencies using the products have developed them.

#### 3.6.1 Important Factors

A specification for an asphalt rubber product should contain the following besides the information in the agencies standard specification:

- The requirements for the physical and chemical properties of the crumb rubber, including the rubber gradation.
- A requirement that the crumb rubber be certified by the supplier as to its physical and chemical properties.
- The sampling and testing procedures for the crumb rubber and for the asphalt rubber should be clearly defined.
- The asphalt rubber blender (supplier) should be required to provide a design for the asphalt rubber binder.
- The hot mix contractor should be required to provide a job mix formula that specifies the source, composition, and properties of the aggregates, asphalt rubber binder and additives for each mixture supplied. Mix designers should be familiar with the unique characteristics of AR mixes.
- The importance of mixing and compaction temperature must be emphasized. It is more critical for asphalt rubber products to ensure good pavement performance.
- The method of mixing and blending the asphalt cement and crumb rubber should be clearly defined, particularly with regard to mixing temperatures and cure times.
- The equipment to be used for compaction needs to be specified. Pneumatic rollers are not used for hot mix, but can be used for chip seals to ensure uniform embedment into the AR binder.

#### 3.6.2 Example Specifications

Appendix E provides example specifications for hot mix and for chip seals from the following agencies:

- Caltrans – ARHM-GG, ARHM-OG, and asphalt rubber chip seal. Caltrans is currently updating their terminology and specifications.
- Greenbook – Sections 203-11, 203-12, 302-9, and 302-10.
- Sacramento County – ARHM-GG and AR chip seal.

All of these specifications have been used to produce successful AR projects. There are other specifications that have produced good mixes, but have not been included such as the one for AR dense graded mixes.

#### 3.6.3 Need for Uniform Specifications
As more agencies become involved with the use of asphalt rubber products, it is imperative that more uniform specifications be adopted. In the author’s opinion, one failure can have the same effect as canceling 100 successes. Both state and local agencies should strive to develop a uniform, statewide performance based specification that can be used by all agencies and which will ensure more consistent performance.

3.7 COSTS

3.7.1 Initial Costs

The unit costs of asphalt rubber are higher than those of conventional or polymer modified products. Typical in-place costs for both hot mix and chip seals are given below (1999):

<table>
<thead>
<tr>
<th></th>
<th>Hot Mix*</th>
<th>Chip Seal $/yd²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>30-35</td>
<td>1.00-1.25</td>
</tr>
<tr>
<td>Polymer Modified</td>
<td>35-40</td>
<td>1.25-1.50</td>
</tr>
<tr>
<td>Asphalt Rubber</td>
<td>45-50</td>
<td>2.50-3.00</td>
</tr>
</tbody>
</table>

* Generally asphalt rubber hot mixes run $10-15/ton more than conventional mixes. It could be more or less depending on job size. Lower unit costs will result with recent larger jobs. Current (2001) costs are greater due to increases in energy and fuel costs.

The higher initial costs can only be offset if there is a life extension associated with the use of asphalt rubber, if the asphalt rubber can be used in reduced thickness, or where noise mitigation is required.

Typical component costs for hot mix operations are as follows:

- **Crumb rubber modifier.** CRM costs runs about 0.15-17 $/lb. For a mix with 7.5% asphalt by weight of mix, this is about 30 lbs/ton of mix or about $4.50-5.00/ton in additional material costs
- **Asphalt binder.** For most hot mix applications, the binder is increased about 2%. At a cost of $160/ton for asphalt cement, this amounts to about $3.20 in additional costs.
- **Blending the binder.** The cost of labor and equipment to blend the binder at the job site ranges from about $6 to 10/ton

The total increase in cost for this example ranges from about $13 to 18 /ton increase. Depending on the job size, this number could be more or less than the numbers shown.

3.7.2 Life Cycle Costs

Appendix F presents the results of a study to evaluate the cost effectiveness of asphalt rubber over a period of 40 years. The life cycle cost analysis performed clearly shows that asphalt rubber, when used in hot mix or chip seals, is a cost effective treatment for most of the scenarios evaluated. However, there were a few instances where the gain in performance was not sufficient to offset the increased cost; hence, AR was not cost effective in these instances.

3.7.3 Other Cost Examples

Asphalt rubber is often considered as a treatment in lieu of mill, fill and overlay or total reconstruction. The asphalt rubber hot mix or chip seal may function as a temporary or long-term solution in these instances. A specific examples of the savings which can result in these applications is given below for Hemet, California:

<table>
<thead>
<tr>
<th>Option</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1- Standard overlay of 135 mm AC</td>
<td>$337,000</td>
</tr>
<tr>
<td>Option 2- Reconstruction (75 mm AC over 345 mm AB)</td>
<td>$824,000</td>
</tr>
<tr>
<td>Option 3- AR overlay (48 mm AR over 39 mm AC)</td>
<td>$263,000</td>
</tr>
</tbody>
</table>

Similar cost savings have been reported by other agencies as well (RACTC, 1999).
4.0 ASPHALT RUBBER MATERIALS ISSUES

This chapter provides a brief overview of the asphalt binder materials and binder design as well as important mixture design considerations for hot mixes and chip seals.

4.1 ASPHALT RUBBER BINDER

Asphalt rubber binders are used in both hot mix applications and in spray applications. There are slight differences in the materials used to produce the binders used in California (Type 1 and Type 2). Caltrans uses Type 2 only for improved reflection cracking in HMA and rock retention in chip seals.

4.1.1 Materials

The materials used to produce asphalt rubber consist of the following:

- **Crumb Rubber Modifier** – Tire rubber, the principal component of CRM, is primarily a composite of natural rubber, synthetic rubber, and carbon black. Raw material may be delivered to the processing plant as whole, cut, or shredded tires, or buffing wastes. The materials are reduced to size either through ambient grinding/granulating or by cryogenic breakdown prior to ambient grinding.

  Specifying CRM is normally done in terms of physical and/or chemical properties. Commonly specified properties include: size/gradation, specific gravity, acetone extract, ash, carbon black, rubber hydrocarbon, and natural rubber content. The size/gradation of the CRM can influence the interaction of the asphalt rubber blend – a coarser CRM gradation generally requires a longer time to react than a fine grind. Typical rubber gradations are shown in Table 4.1.

  Chemical properties of the rubber are important and have been established to define the CRM material. These requirements insure the use of auto/truck tires in CRM materials. The inclusion of specification requirements for ash, carbon black, and rubber hydrocarbon insures that unacceptable materials (i.e., conveyor belts) are not used.

- **Asphalt Cement** – Asphalt cement can affect the final asphalt rubber binder product in several ways. It must be compatible with the CRM. Compatibility is controlled by the chemical composition of both the asphalt cement and the CRM as demonstrated by an increase in the viscosity of the asphalt rubber blend with time. Most of the CRM produced today is a homogenous blend of different rubber polymers; hence, compatibility is primarily dependent on the properties of the asphalt cement rather than the composition of the CRM material.

  The asphalt cement’s chemical composition can vary greatly depending on crude source. If the crude source is low in aromatics, compatibility problems can develop because of a lack of aromatics for the CRM to absorb. Extender oils are often used to provide the required aromatics (e.g., Type 2 binders).

  The grade of the asphalt cement is also important. Both the low temperature and high temperature properties are affected by the
asphalt grade. The softer the grade of the base asphalt, the better will be the low temperature properties. The rubber increases the high temperature viscosity. Some agencies tailor the grade of the asphalt to coincide with the climate the AR mix will be placed in (e.g. Arizona DOT).

4.1.2 Binder Design

The agency should require the asphalt rubber supplier furnish a binder design that includes the source and quantity of CRM and extender oil (if used) and the viscosity of the asphalt rubber blend vs. time and temperature. This allows the agency and the paving contractor to evaluate the time/temperature stability of the blend.

4.2 Mixture Design – HMA

4.2.1 Materials

Crumb rubber modified binders have been used in open-, gap-, and dense-graded mixtures. The use of asphalt rubber requires that the binder be correctly designed and formulated for the specific application and that the aggregate gradation be selected. Because of the differences in physical properties of the asphalt rubber binder, standard mix design procedures have been modified slightly.

4.2.2 Design Methodologies

The purpose of a mix design is to select the correct blend of aggregate and asphalt rubber binder for a specific application. The relative proportion of these materials determines how the mixture will perform in the pavement. Two mix design methods are commonly used to determine the proportion of the ingredients,

- Marshall Method
- Hveem Method

The Hveem method is most widely used in California. Most agencies require the mix design be completed at least 15 days prior to the start of paving using the same materials that will be used in the actual paving.

In general, mix designs determine the optimum amount of AR binder to be used with the project aggregate. The design focuses on the following mix characteristics and the influence these have on mix behavior. These characteristics include:

- Stability
- Moisture sensitivity

4.2.3 Temperature Considerations

When mixing and compacting asphalt rubber binder with aggregate, it is important to control the temperatures during these processes. Mixing the asphalt rubber binder with the aggregate is accomplished using standard mechanical mixers and should be completed within 1-2 minutes after the addition of the binder to the mix. Compaction of the mixture is accomplished using standard Marshall or Hveem procedures.

Typical laboratory mixing and compaction temperatures for the different mix types are as follows:

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Mixing Temperatures, ( C ) (( F )*</th>
<th>Compaction Temperatures, ( C ) (( F )**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense-Graded</td>
<td>149-163 (300-325)</td>
<td>143-149 (290-300)</td>
</tr>
<tr>
<td>Gap-Graded</td>
<td>149-163 (300-325)</td>
<td>143-149 (290-300)</td>
</tr>
</tbody>
</table>

*Minimum aggregate temperature. Minimum binder temperature = 190\(^\circ\)C (375\(^\circ\)F)

** Minimum mix temperature

4.2.4 Binder Contents

Binder contents resulting from the mix design process vary depending on the aggregate type and gradation. Typical binder contents for asphalt rubber mixes used in California are as follows:

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Binder Content, %*</th>
<th>% Higher than Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense-Graded</td>
<td>6-8</td>
<td>20</td>
</tr>
<tr>
<td>Gap-Graded</td>
<td>7-9</td>
<td>40-50</td>
</tr>
<tr>
<td>Open-Graded</td>
<td>6-8</td>
<td>50-60</td>
</tr>
</tbody>
</table>

*By weight of dry aggregate

4.3 MIX DESIGN – CHIP SEALS

4.3.1 Materials

In these applications, the asphalt rubber is spray applied to an existing pavement surface and then covered with a single size chip. The materials include:
- **AR Binder** – essentially the same as used for HMA, except a high natural rubber CRM is used for better chip retention
- **Aggregate** – the aggregate used in these applications is a clean single-size chip, nominal size of 9 to 12.5 mm (3/8 to 1/2 in.)

The purpose of the chip seal is to provide a waterproof, skid resistant, and durable surface to resist oxidation and cracking. AR chip seals provide superior performance in their resistance to reflection cracking when compared to other types of chip seals.

### 4.3.2 Design Methodology

Chip seals should be designed to ensure the proposed materials are of sufficient quality and have the desired properties for a successful chip seal project.

Several basic factors affect the application rates of the binder and the rock including:
- the surface texture of the existing pavement
- traffic volumes and seasonal temperature ranges (the binder application is increased slightly for roads with lower traffic volumes and in areas with cooler summers)
- the size of the rock used for the cover aggregate (larger stone more binder)
- the quality of the rock (one size aggregates need a heavier application of binder)

Other factors may affect the application rates of the asphalt such as:
- Rates may be increased for
  + lower air or pavement temperatures
  + open or dry pavement surfaces
- Rates may be reduced for
  + fat or flushing pavements
  + higher traffic volumes/weights

### 4.3.3 Typical Application Rates

The most common way to determine the amount of binder is to use past experience. However, there is a simple test to determine if the application rate used is correct, i.e., the stone should be embedded in asphalt to a depth of about 50-70% after rolling and traffic have fully seated them.

There are also several methods of determining the proper amount of cover aggregate including:
- experience, or
- laying the aggregate one stone deep on a one-square yard surface and weighing it.

The proper rock cover is when 10-15% asphalt binder can be seen through the newly laid rock. Enough cover aggregate should be spread to prevent pickup under traffic or there should not be a surface of rock on the shoulders after the surface has been boomed and is being used by traffic.

Typical application rates for AR chip seals in California are

<table>
<thead>
<tr>
<th>Chip Size</th>
<th>Binder gal/yd²</th>
<th>Stone lbs/yd²</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 mm (1/2 in.)</td>
<td>0.55-0.65</td>
<td>28-40</td>
</tr>
<tr>
<td>9 mm (3/8 in.)</td>
<td>0.55-0.65</td>
<td>28-40</td>
</tr>
</tbody>
</table>
This chapter reviews the procedures used in terms of handling the crumb rubber, blending it with the asphalt, and the construction process including plant operations, placement, and compaction. It also covers important issues dealing with quality control and quality assurance of AR hot mix.

5.1 BINDER PRODUCTION, MIXING, AND HANDLING

The asphalt cement and the crumb rubber are blended into a homogeneous asphalt-rubber system, which is then reacted at elevated temperatures for a minimum of 45 minutes. The time required to disperse, blend and react the crumb rubber is dependent on a number of factors including the chemistry of the asphalt cement and crumb rubber as well as the particle size and texture of the rubber and the temperature of the blended material. The finer the material, the quicker it will react. Also, the reaction time will decrease as the reaction temperature increases. Adding crumb rubber to the virgin asphalt drops the temperature of the asphalt cement by 14 to 28°C (25 to 50°F). Therefore, the asphalt cement is often delivered at elevated temperatures of 190-218°C (375-425°F).

5.1.1 Temperature Considerations

The blending temperature normally used is between 176-204°C (350-400°F) for Type 1 binders and 190-218°C (375-425°F) for Type 2 binders. Higher temperatures often result in excess fumes and/or smoke. Lower temperatures means the reaction may not fully develop and take longer (1 hour) to react. It is important that the asphalt rubber be reacted at the specified time and temperatures.

5.1.2 Hold-Over Loads

Whatever the type of blending operation used, the plant must be operated as necessary to obtain a thorough and uniform mixture of materials. For example, when the use of the reacted asphalt rubber may be delayed by more than 4 hours, the binder should be allowed to cool. It can then be reheated slowly prior to the use to a temperature between 176-204°C (350-400°F) for Type 1 and 190-218°C (375-425°F) for Type 2. It must be thoroughly mixed before pumping/metering into the HMA plant and the viscosity of the asphalt rubber must be verified within limits. If it is out of the desired range, the AR blend can be adjusted by adding additional asphalt cement and/or ground tire rubber to produce the desired viscosity. This is commonly done with good and consistent results.

5.2 HOT MIX PRODUCTION

5.2.1 Operation of Facility

The operation of a hot mix facility for the construction of asphalt rubber is essentially the same as that for conventional mixes, with the exception that the mix is produced at higher temperatures. The blending equipment (or agitated nurse trucks) can easily be hooked up to both the drum and batch plants to supply the AR binder for the job. However, production rates are influenced by the use of AR binders. The hot plant must run slower due to the higher binder contents. Also, the production capacity of the asphalt rubber plant will limit the hot plant production rate (only about 25-30 tons of binder per hour depending on the output of the AR blending operation).

5.2.2 Plant Types and Space Requirements

Either batch plants or continuous drum dryer plants can be used to produce asphalt rubber hot mix. In both cases extra equipment is required, requiring extra space. The added equipment includes:

- CRM storage and handling
- Blending tanks
- Metering systems

When the drum plant is used, a two- or three-way valve is installed in the existing feed line on the output side of the asphalt pump. When a batch plant is used, the valve is installed directly onto the supply line. To handle the high viscosity binder and to prevent damage to the hot mix contractor’s pumps, the blending contractor normally provides separate pumps. Since the asphalt rubber is generally more viscous than neat asphalt, these pumps are generally larger. Also the pipes and supply lines need to be of sufficient diameter to allow the movement of a more
viscous fluid. Also, line losses need to be minimized by using 45-degree bends. This may require the use of jacketed and heated lines.

Typical space requirements for asphalt rubber hot mix operations are shown in Figure 5.1. The additional equipment need for the AR operations is discussed below.

- For a rubber plant setup directly at the hot plant, the agitated tank (footprint is about 80 × 15 ft) needs to be located within a few feet of the coater.
- The blending tank (footprint of about 50 × 15 ft) needs to be located next to the agitated tank.
- An additional tank (footprint of about 80 × 15 ft) is placed next to the blending tank.
- A small trailer (30 × 15) containing the extender oil is also required.

The total additional space requirement can vary from contractor to contractor, but generally falls in the range of an additional 15 to 20%, but can vary depending on the equipment used.

5.2.4 Air Quality Permits

Asphalt rubber hot mix (like any other mix) may produce smoke and fumes if heated to high temperature. As a result, air quality permits are often required. The following steps should be taken to assure the air quality issues are properly addressed:

- Produce the mix at the lowest possible temperature (e.g., < 163°C or 325°F). Cooler temperatures can be used with tarped loads, shorter windrows with belly dumps, or use of end dumps.
- Ensure the flights in drum plants are in good working order. The veil of aggregate falling in front of the flame retards/minimizes the chances for smoke.
- Lower rates of production reduce visible emissions. Also, there are commercial deodorants available to help mitigate the operational odor.

5.3 HOT MIX TRANSPORT AND PLACEMENT

5.3.1 Transport to the Job

The transportation of the asphalt rubber hot mix can be accomplished in any truck typically used for the transport of conventional hot mix (e.g., dump trucks or belly dumps). Release agents for the truck beds should be either soapy water or silicone emulsions. Under no circumstances should solvent-based release agents (e.g., diesel) be used. Except for extremely short hauls, it is necessary to tarp the trucks so that the mix does not cool below the placement and compaction temperatures (e.g., 143°C or 290°F and 135°C or 275°F, respectively).

As the trucks deliver the mix, the inspector should look for the following signs which reflect potential problems:

- **Blue smoke** – indicating an overheated mix
- **Stiff appearance** – indicating a cool mix
- **Slumped mix** – indicating excess asphalt rubber binder or moisture
- **Dull appearance** – indicating too little asphalt rubber binder
- **Rising steam** – indicating excess moisture

5.3.2 Laying the Mix

The handling and placement of the asphalt rubber mix must be accomplished in such a way to minimize segregation. It should be placed only when the surface temperature and weather conditions are optimum. Since the material is more viscous than
conventional HMA, the temperature on the prepared surface should be at or above 13°C or 55°F. Even if the surface temperature requirement is met, it may be necessary to cease work due to existing or expected weather conditions that could have a negative effect on the placement and compaction of the AR mixture. A cold surface or a cold day will cause the mat to cool too quickly, making it difficult to achieve compaction. Use of insulated tarped loads, live bottom trailers, and material transfer devices will help keep the mixture hot.

The mixture delivered to the paver must be a free flowing, homogeneous mass in which there is no segregation, crusts, lumps, or migration of the asphalt rubber. It may be necessary to cover the hauling units with tarp and/or dump the material directly into the paver to minimize heat loss. Bottom dump trucks (and pick-up devices) can be used in warm weather if the windrows are kept close to the paver.

The materials must be delivered at a rate that allows the paver to operate continuously because when the paver stops, the mix below the screed compacts and cools. As paving resumes, a permanent depression (or bump) is left on the mat.

When a lane is finished, the contractor should construct a bulkhead or a paper transverse joint. In either case, the purpose is to provide a compacted vertical joint to begin the next day. Longitudinal joints in a paving operation are also generally cold joints. To ensure good bond at the joint, it should be tacked prior to paving the adjacent lane. The screed should overlap the previously paved mat slightly and should be set at the exact height above the mat to allow for compaction.

5.3.5 Lift Thickness

As previously mentioned, lift thickness is important for a number of reasons. Two of the most important include:

- **Cooling of the Mix** – The thinner the lift thickness, the faster the mat cools.
- **Maximum Aggregate Size** – The minimum lift thickness must be 2-3 times the maximum aggregate size. For a 12.5 mm (1/2 in.) maximum aggregate, this means its lift thickness should be 25 to 37.5 mm (1 to 1 1/2 in.). If it is less, the coarse aggregate may tear the mat or break down under the vibratory roller.

5.4 COMPACTION AND FINISHING

The viscosity and amount of the asphalt rubber binder will affect the compactability of the mix. The higher the viscosity, the stiffer the mix at a given temperature. Generally, the binder in asphalt rubber mixes is stiffer than conventional mixes. Therefore, asphalt rubber mixes must be compacted while they are hot. Good performance is achieved from mixes compacted to 5-8% air voids.

Aggregate grading can also have an impact on the compaction of the AR mix. Minor changes in aggregate grading may allow the mix to compact more easily. The grading curve should be uniform without humps or dips. Also, the mix should have sufficient fines to assist with compaction.

5.4.1 Equipment and Procedures

Compaction can be accomplished with either vibratory or static steel-wheel rollers; however open-graded mixes are not vibrated. Pneumatic rollers are not used as the asphalt rubber binder is sticky and can pick up on the pneumatic wheels.

Breakdown compaction should begin while the mix is hot (144°C or 290°F) and be completed before the mat cools to 130°F (265°F). If the contractor is not compacting the mix to the required density or the mix temperature is too low, the operation should be stopped until the problem is fixed. Final compaction should be completed by the time the temperature reaches 115°F (240°F).

5.4.2 Temperature Considerations
Lift thickness, pavement surface temperature, ambient temperature, and wind all impact the time available for compaction. Compacting the mix at the proper temperature is the key to a successful job. Thin lifts cool faster and cool surfaces, low ambient temperatures, and wind cause the mix to cool more quickly.

5.4.3 Finishing

Traffic allowed on a new lift may pick-up surface material. This can be corrected by applying a light application of sand. If necessary, excess sand may need to be removed by a pick-up broom. For open-graded mixes, an application of water after rolling can be applied to address the pick-up. There can be pick up of the asphalt rubber mix when the roadway is turned over to traffic.

5.5 QUALITY CONTROL

Quality control is the responsibility of the contractor. In the absence of industry standards, the following summary of best practices is recommended.

5.5.1 Ingredients

Recommended testing and testing frequency for the AR ingredients are as follows:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Sampling Frequency</th>
<th>Test</th>
<th>Testing Frequency</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt cement</td>
<td>Every truck load</td>
<td>Viscosity</td>
<td>Every truck load</td>
<td>Certification must be provided</td>
</tr>
<tr>
<td>CRM</td>
<td>Every shipment</td>
<td>Gradation</td>
<td>2 tons</td>
<td>Certification must be provided</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical Composition</td>
<td>125 tons</td>
<td>Certification must be provided</td>
</tr>
</tbody>
</table>

As indicated, samples are taken frequently, but not always tested unless a problem arises. AR binder producers need to assure themselves that the ingredients are the ones ordered. Certifications of all ingredients should be required.

5.5.2 AR Binder

Considerable variation currently exists in the industry in terms of sampling/testing frequency as well as test temperature. Binders should be tested at the specification temperature and the variation in test temperature should conform as closely with ASTM recommendations as possible. Suggested QC guidelines for testing AR binder are as follows:

<table>
<thead>
<tr>
<th>Property</th>
<th>Sampling Frequency</th>
<th>Testing Frequency</th>
<th>Test Temperature</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haake viscosity</td>
<td>Every batch</td>
<td>Every batch</td>
<td>Spec ± 2.5°C</td>
<td>Certification must be provided</td>
</tr>
<tr>
<td>Resilience</td>
<td>Every batch</td>
<td>Once/project</td>
<td>ASTM spec</td>
<td>Test performed in certified lab</td>
</tr>
<tr>
<td>Cone penetrometer</td>
<td>Every batch</td>
<td>Once/project</td>
<td>ASTM spec</td>
<td>Test performed in certified lab</td>
</tr>
<tr>
<td>Softening point</td>
<td>Every batch</td>
<td>Once/project</td>
<td>ASTM spec</td>
<td>Test performed in certified lab</td>
</tr>
</tbody>
</table>

Pre-job testing (binder design) can be utilized to establish the standard to which field tests can be compared. It is recommended that the binder design yield a viscosity in the mid-range of the specification and that it is maintained by adjusting the reaction time and temperature. Experience has shown viscosity to be a good indicator of compliance with the other parameters.

5.5.3 Mixtures

Testing of the completed AR mixture is also important. The following guidelines are suggested for quality control of mixtures.
<table>
<thead>
<tr>
<th>Property</th>
<th>Sampling Frequency</th>
<th>Testing Frequency</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate absorption, crushed faces, abrasion gradation, sand equivalent, AR binder content CRM content in binder Volumetric properties (voids, VMA)</td>
<td>Part of mix design process</td>
<td>500 to 4000 tons</td>
<td>500 to 4000 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 to 4000 tons</td>
<td>500 to 4000 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>As needed</td>
<td>500 to 4000 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample taken for mix design</td>
<td></td>
</tr>
</tbody>
</table>

### 5.5.4 Summary

For all QC processes, summaries showing variations in the property being monitored should be developed (e.g., control charts). Control charts are necessary for effective QC since they graphically illustrate variation in the specified binder and mix properties. This information will assure the contractor and the owner that the project is within specifications.

### 5.6 QUALITY ASSURANCE

The owner agency is responsible for quality assurance. The level of testing will vary from owner to owner and whether the work is for a public or private owner. All owners should be encouraged to develop a QA program for their own protection. The types of tests would include those used for QC, only the frequency of the testing would be less.
Asphalt rubber chip seals are widely used for pavement maintenance and/or rehabilitation. The primary reasons for their use include:

- prevent water intrusion into the base and subgrade
- reduce the oxidation of the existing surface
- bind the existing surface together
- reduce spalling around reflection cracks

They are routinely used in a variety of applications including:

- preventive maintenance to extend the life of a pavement
- corrective maintenance over cracked or raveled pavements or to improve skid resistance
- new or reconstruction to waterproof the pavement surface or prevent reflection cracking from stabilized bases
- as an interlayer to delay reflection cracking from below

### 6.1 PRODUCTION OF MATERIALS

The materials used in chip seals include the AR binder and the aggregate. The AR binder is spray applied to the pavement surface and then covered with a clean one-sized aggregate.

#### 6.1.1 Binder

The AR binder used in chip seals is the same as that used in hot mix except the CRM is often increased by 1-2%. It consists of a blend of asphalt cement, crumb rubber, and in some cases an asphalt modifier (extender oil), usually an aromatic compound. Normally, the raw materials (asphalt and CRM) are delivered to the job site (with a certificate of compliance) and blended and reacted prior to application.

#### 6.1.2 Aggregate

Chip seals are constructed with a variety of rock sizes, shapes, and gradings. Several factors influence the choice of the chip seal rock:

- **Surface Texture** – Coarse surface textures are obtained with 12.5 mm (1/2 in.) aggregates.
- Finer textures are achieved with 9 mm (3/8 in.) maximum size aggregates.
- **Volume of Traffic** – This can influence the aggregate size choice. High traffic volume conditions favor the use of smaller top size rock, which is easier to stick and less likely to break windshields and headlights.
- **Uniform Appearance** – This is achieved using aggregates with few fines. It also produces the best nonskid characteristics and reduces rock loss.
- **Durability** – The durability of the seal is affected by the hardness of the seal rock. It is desirable to have a rock which will not crush or degrade during construction or under traffic.
- **Dust and Moisture** – The cover aggregate should not have a dust coat. Better results are obtained if the aggregate is dry.

Typical aggregates for AR chip seals are either 9 to 12 mm (3/8 to 1/2 in.) top size. In most cases, the chips are preheated and precoated so they can be placed in day or night. The heating helps drive off the moisture and the coating promotes good chip retention.

### 6.2 APPLICATION AND PLACEMENT

The equipment required to place a chip seal includes a distributor, chip spreader, trucks, roller(s), and hand tools (broom, shovels, etc.). A power broom and equipment to apply a flush coat are optional, but desirable, equipment.

#### 6.2.1 Asphalt Rubber Applications

It is most important that the distributor be properly adjusted and operated to apply the proper amount of asphalt uniformly over the surface. 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 is too cold or when its viscosity is too high.

The distributor should start and finish each application on paper. This ensures uniformity for the entire application. The application rate should be adjusted so the longitudinal joint (meet-line) is on the center-line 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.
From this, the gallons/square yard can be calculated to assure that the proper application rate has been met.

6.2.2 Chip Application

The rock application should follow as rapidly as possible, preferably within three minutes. The asphalt rubber binder will never be as fluid as when it first leaves the distributor. The asphalt must be fluid so the rock will be embedded by the displacement of the asphalt, preferably to 50 to 70% embedment.

Trucks should back into the spreader box. The trucks should not cross over any exposed asphalt rubber binder. The speeds and loads of the trucks hauling the chip rock 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. Areas that receive an aggregate cover that is too light should be covered with additional aggregate (normally by hand).

6.2.3 Rolling

Pneumatic rollers are normally used for rolling chip seals because they will not fracture the rock and will roll into the depressions. Rolling of a chip seal is done to orient the rock (get the flat sides down). Rollers should be operated at slow speeds (4-6 mph) so that the rock is set, not displaced. The number of rollers required depends on the speed of operation, as it takes 2-4 passes of the roller to set the rock.

6.2.4 Brooming

Brooming is done at the completion of seal coat to remove surplus aggregate from the surface of the new chip seal and to reduce the opportunity for flying rocks. Brooming can be done shortly after application, usually within 30 minutes. It is desirable to broom during the cool period of the day using a rotary power broom.

6.2.5 Traffic Control

Some form of traffic control is required to keep the initial traffic speed below about 25 mph. Flaggers 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.

6.3 QUALITY CONTROL (QC)

The contractor is responsible for the QC on the project. Items which need to be carefully controlled include the following:

- **AR Binder** – The binder viscosity needs to be evaluated periodically for specification compliance.
- **Aggregate** – The aggregate needs to be evaluated periodically for specification compliance.
- **Application Rates** – Both the asphalt and aggregate application rates need to be checked daily to ensure they are within specification.
- **Weather Conditions** – Weather can have a marked effect on the quality of a chip seal. Cool weather makes the asphalt less sticky and may not be able to retain the rock. Seal coating must be postponed if there is rain or the threat of rain. In many areas there are seasonal restrictions during which chip seals cannot be applied.

6.4 QUALITY ASSURANCE (QA)

The owner agency should obtain and retain samples of the asphalt rubber binder and aggregates in the event there is a problem with the finished chip seal. The types of tests would be the same as those used in the QC process but the frequency would be less.

A good post-seal inspection is to determine the embedment of the aggregate into the asphalt a day or so after the construction of the chip seal. By removing several of the largest stones, one can determine if the 50-70% embedment has been obtained.
7.0 PRE-CONSTRUCTION MEETING

Prior to the beginning of any construction project, it is recommended that a pre-construction meeting be held to discuss a number of technical and non-technical issues. This is intended to provide a good understanding of the issues that face both the contractor and the owner agency. Both the AR binder supplier and the hot mix producer should attend this meeting along with the resident engineer and inspectors.

7.1 TECHNICAL ISSUES

7.1.1 Materials

The selection and design of materials used on the job are extremely important. Both parties should understand the need for the importance of the following:
- Certification of all materials used
- Binder design
- Mix design
- Properties of the mixture to be achieved (voids, stability, etc.)
- Moisture sensitivity of the mixture

7.1.2 Temperature

Asphalt rubber products are more temperature sensitive. This means that they maybe more difficult to place and compact in cool conditions. The mixing and compaction temperatures must be followed carefully to ensure success. Most of the compaction is achieved during breakdown rolling, so the timing and number of rollers applied is very important.

The viscosity and amount of the AR binder also affects the compactability of the mix. The higher the binder viscosity, the stiffer the mix at a given temperature. Since asphalt rubber binders are high viscosity materials, they must be compacted while they are hot. Compaction is generally not a problem if the compaction temperatures are followed. Compaction can be accomplished with either a vibratory or static steel wheel roller. Pneumatic rollers should not be used as the AR binder can be picked up on the pneumatic wheels.

7.1.3 Finishing

Hand work with asphalt rubber mixes is more difficult than with conventional mixes because the material tends to be stiffer and stickier at lower temperatures.

There can be pick-up of the AR mixture after the pavement is opened to traffic. This can be addressed by lightly sanding the pavement surface as discussed earlier.

7.1.4 Night Work

Because of the cooler temperatures at night, mixing and compaction temperatures must be strictly adhered to. In addition, because of the poorer lighting conditions, hand work becomes more difficult. Other issues associated with night work include the following:
- **Noise** – It is important to inform local residents of the night work to mitigate any negative effects of noise.
- **Safety** – This is a major concern at night. Equipment must be lighted to avoid potential accidents.
- **Striping** – Once the work is completed it is important to place temporary markers on the pavement to delineate lanes and edge of pavement.
- **Traffic control** – It is extremely important to have effective traffic control procedure for night work

7.2 PRODUCTION ISSUES

It is important to ensure there will be balance and uniformity in all aspects of production and placement. For AR mixes, if the plant produces mix faster than it can be placed, trucks queue behind the paver and the mix will get cold. If the plant produces less than the capacity of the paver, then the paving operation is stopped frequently leading to the potential of bumps. The same consideration for balance and uniformity also applies for chip seals.
7.2.1 Production Rates

Typical production rates for the various operations for hot mix and chip seals are as follows:

<table>
<thead>
<tr>
<th>Type of Product</th>
<th>Production Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR Binders (tons/hour)</td>
<td>25-30</td>
</tr>
<tr>
<td>AR Hot Mix (tons/hour)</td>
<td>200-400*</td>
</tr>
<tr>
<td>AR Chip Seals (lane-miles/day)</td>
<td>5-7</td>
</tr>
</tbody>
</table>

*Running above 300 tons/hour would require the binder supplier to provide extra tankage for the AR binder.

7.2.2 Staging

Because most AR projects are related to maintenance and rehabilitation of existing roadways, it is important they be properly staged to:

- minimize disruption to users, particularly at intersections
- improve safety to all – contractor and public alike
- minimize costs to owner
- Because of pick-up problems, provide adequate areas for cleaning trucks before they enter the traffic stream.

Staging plans should be developed prior to commencing project work which shows how these issues will be addressed.

7.2.3 QC/QA

The role of the contractor and owner agency need to be clearly defined in order to eliminate questions with respect to the responsibility of each party. The contractor is normally responsible for the QC on the job while the owner agency provides the inspection and QA. The type and frequency of the QC/QA tests need to be clearly spelled out.

7.3 UTILITIES

Utilities pose a problem during construction and after the construction is complete. This problem has been further complicated with the deregulation of many of the utility providers causing more cuts in the roadways – both planned and unplanned.

7.3.1 Protection During Construction

All structures from which manhole frames and covers are removed prior to paving need to be covered temporarily with a steel plate by the contractor. When this procedure is impractical, remodeling or reconstruction of the utilities need to be completed prior to paving.

Paving rings can also be used. These are placed in front of the paver to allow the manholes to be raised easily. Some agencies also allow the paver to pave over the manhole, then clean out the mix above the manhole prior to compaction.

7.3.2 Utility Cuts Afterwards

With proper coordination with the utilities, cuts immediately after construction should not be necessary. However, cuts may eventually be required in the AR pavements and patching materials would not likely be an AR product. It is desirable that the patching material has more or less the same gradation so that the surface texture matches. However, it may be necessary to increase the structural layer thickness because of the 2:1 equivalency and assuming the availability of AR mix to replace the cut material may not be good.

7.4 CLEAN-UP

Asphalt rubber mix can be spilled/tracked along the haul routes or in the vicinity of the job. Every effort must be made by the contractor to minimize these impacts. The public and owner agency do not want to see AR product tracked on other streets or roadways.
8.0 ENVIRONMENTAL CONSIDERATIONS

8.1 ENVIRONMENTAL BENEFITS

California is faced with the challenge of diverting or safely managing more than 30 million scrap tires generated annually. In addition, this number appears to be increasing by approximately one-half million tires each year. Additionally, there are an estimated three million tires stockpiled across the state.

There are two separate, but interrelated, aspects that are key to sound scrap tire management. The first aspect is dealing with the newly generated scrap tires by putting them into a secondary use such as: incorporation into asphalt rubber pavement, civil engineering applications, retreading, or tire-derived fuel. The second problem is dealing with the legal and illegal stockpiles of tires, which are the residue of past (and some current) methods of handling scrap tires. Tire stockpiles can become breeding grounds for mosquitoes and other pests (rodents, snakes, etc.).

There are unique challenges associated with remediating stockpiled tires, as they are generally exposed to the elements and therefore can be dried out, dirty, or contain contaminants such as vectors or chemicals. This means that the longer they remain stockpiled, the less economic value they retain. The costs associated with remediation are considerable and property owners and business operators are many times reluctant to expend the money for major cleanup operations. The legal process to compel cleanup is quite lengthy and expensive and is initiated only after the tire piles are located on economically undesirable land and cleanup costs exceed the value of the land itself, making land seizure a hollow threat. In other cases the property owners are victims of unscrupulous operators (tire collectors) and do not have the necessary resources to pay for cleanup. In any case, the rationale for clean up of the site is a simple one – due to the fire threat. Waste tire sites pose a significant threat to public health and safety and it costs less to clean up a site before a tire fire than it does afterwards.

Assembly Bill 1843 (Statutes 1989, Chapter 974) established the Tire Recycling Management Act (Act). The Act initiated a tire recycling program administered by the California Integrated Waste Management Board (Board), to promote and develop markets for waste tires. The Board has provided more than $3 million to support the use of rubberized asphalt concrete (RAC) since 1991 when it entered into an agreement with the California Department of Transportation (CalTrans) to purchase testing equipment for RAC research efforts. In addition to funding the cost of RAC projects with several local governments, the Board has also funded the establishment and operation of two Rubberized Asphalt Concrete Technology Centers (RACTC) that provide statewide technology transfer for RAC use. These two centers provide technology transfer to local governments through direct consultation, conducting local and regional workshops, providing informational materials and an Internet website. Current RAC projects use more than 2 million scrap tires per year (excluding buffings from retread operations). Future use of RAC technology could consume 5 to 6 million tires per year.

The Board’s tire program also addresses the storage of tires in stockpiles and cleanup of illegal waste tire stockpiles where public health and safety and the environment may be at risk. Since 1990, landfilling and stockpiling of “new” scrap tires has been reduced 30 percent, from 66 percent of scrap tires generated in 1990 (before the program began), to 35.5 percent of scrap tires generated in 1999. Legacy stockpiles have been reduced by 93 percent, from 45 million tires stockpiled in 1990 to an estimated 3 million tires stockpiled in 1999.

8.2 SOCIAL BENEFITS

There are numerous other social benefits of using ground tires in asphalt pavements. These include, but are not limited to, the following:

- **Noise Abatement** – Use of tire rubber in gap- or open-graded asphalt rubber mixes reduces tire noise by 3 to 5 db compared with the pre-overlaid pavement. Appendix I presents the results of a noise study conducted by Sacramento County.
- **Longer Lives** – When properly designed and constructed, asphalt rubber pavements normally result in longer lives than pavements constructed with conventional binders. Longer lives means less interruptions for maintenance and/or rehabilitation work and less delays to the user.
- **Improved Safety** – Asphalt rubber pavements provide skid resistant surfaces and excellent color contrast for striping and marking. This also improves nighttime visibility.
- **Splash and Spray** – AR pavements reduce the splash and spray effect resulting in clearer visibility while driving in the rain.
- **Traffic Issues** – Thin AR overlays are less disruptive to traffic because they can be used
in reduced thickness and construction in less time.

- **Energy Usage.** AR mixes used in reduced thickness use less energy and natural resources.

### 8.3 HEALTH CONCERNS

As with any new product, health concerns often become an issue. Two of the issues which have been evaluated by Caltrans and others include the following:

- **Fumes** – Caltrans reported some health problems in the early 1990s with the use of asphalt rubber. Caltrans and other agencies and industries conducted studies to evaluate the potential health hazards of fumes from both asphalt rubber and conventional asphalt binders. In the early 1990’s, Caltrans conducted extensive testing and monitoring on their AR projects. The data from these studies were included in the project reports. Caltrans continues to use asphalt rubber mixes and to monitor them for health concerns. To date, Caltrans has not reported any further health issues.

  NIOSH also evaluated the potential increase in environmental and human health effects associated with the use of crumb rubber modified asphalt. Site evaluations were performed at seven sites (Michigan, Indiana, Florida, Arizona, Massachusetts, and California). A report documenting overall conclusions, risk assessment, or recommendations has not yet been issued.

- **Smoke** – When mixed at elevated temperatures, asphalt rubber mixes, or for that matter conventional mixes, have a tendency to cause smoke that is in violation of most air quality opacity standards. The smoke is initiated by excess heat to the binder that can be caused by poorly maintained mixing equipment or operating at excess temperatures. In recent (2000) projects in the Bay area, smoke has become an issue and it is being addressed jointly by Caltrans and industry. Smoke or air quality impacts can be reduced if the mix temperature is maintained at 325°F or less and the production rates are lowered.

### 8.4 RECYCLABILITY

Like most asphalt materials, they are often recycled at the end of their life for use as aggregate or in new asphalt mixes. This section addresses potential problems with recycling and identifying projects that have recycled asphalt rubber mixes or chip seals.

#### 8.4.1 Potential Problems

In the early 1990s, recycling of asphalt rubber products was a concern because of potential fumes and smoke problems. A number of agencies (Ontario MOC, Texas DOT) conducted field demonstration projects to evaluate these concerns. California has limited experience with recycling AR mixes. (See Appendix I.)

#### 8.4.2 Results from Field Studies

The results from the limited studies are still inconclusive. Additional work is still need to confirm whether AR mixes and chip seals can be recycled without problems.
9.0 CURRENT/FUTURE DEVELOPMENTS

This chapter presents a brief overview of some of the current/future developments in California that may have an impact on asphalt rubber usage.

9.1 QC/QA SPECIFICATIONS

Many agencies, including Caltrans, are adopting QC/QA specifications. In these type specifications, the following responsibilities are defined:

- **Quality Control (QC)** – All quality control is the responsibility of the contractor. In some cases the mix designs are also performed by the contractor.
- **Quality Assurance (QA)** – Quality assurance of asphalt products are performed either by the agency or by an independent organization working for the agency. The use of QC/QA specifications shifts more of the responsibility for quality to the producer and away from the owner agency. Caltrans uses this concept for conventional mixes, but not for asphalt rubber mixes.

Several agencies have used a pay incentive/disincentive program where a contractor is given additional compensation for work exceeding expectations and deductions for work not meeting targets (e.g. density, gradation, binder content). Typically, the maximum incentive is 5% of the bid price and the maximum disincentive is 25%. If it drops below this value the pavement is removed and replace with spec material.

9.2 SUPERPAVE

Based on the products resulting from a 5-year Strategic Highway Research Program on asphalt binders and mixes, the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have been implementing the products throughout the USA. The products include, but are not limited to, the following:

- a suite of binder tests which can be related to cracking and permanent deformation. Most SHAs are currently using or plan to use these tests to specify asphalt binders within their agency.
- a suite of mixture tests which are related to field performance. These are tests associated with fatigue cracking, thermal cracking, and moisture sensitivity
- an initial performance related specification for conventional (hot modified) binders including appropriate criteria to insure the binders relate to field performance.

The initial products are all undergoing continuous evaluation to ensure they work not only for conventional, but also for modified binders. Asphalt rubber is one of the many modified binders still being evaluated using both the binder and mixture tests.

Caltrans is still evaluating the use of these tests for specifying asphalt products. However, many states have already adopted the use of the tests and specifications for all asphalt products. The use of PG graded asphalt is common in many western states, including Arizona and Nevada.

9.3 PERFORMANCE-BASED BINDER SPECIFICATIONS

The Pacific Coast Conference on Asphalt Specifications (PCCAS) is currently working on the development of performance-based binder specifications for both asphalt rubber and for terminal blends of asphalt and crumb rubber. Caltrans led the initial effort in the development of their modified binder (MB) specifications which included the following:

- measuring performance-related properties of the binder using the modified Superpave binder tests
- relating the binder properties to performance-related mixture tests and to field performance
- developing criteria for the binder tests to ensure good pavement performance in terms of resistance to cracking and deformation

The MB specifications are still under evaluation by Caltrans. A total of 10 projects placed throughout the state are still being monitored. A performance report is expected on the 10 projects in 2002.

In the author’s opinion, the initial version of the MB specification apparently precluded some of the good performing AR products. However, in a follow-up study by Hicks and Epps (1999), they pointed out several other problems with the proposed specification. As a result, the PCCAS is also working on the development of performance-related specifications for both MB and AR binders. This is due in large part to the differences in binder properties and contents between the two products.
Since the long term goal should be to have one set of performance-based specifications for all modified binders, improvements to the current binder testing protocols and mix tests are continuing.

9.4 WARRANTY SPECIFICATIONS

Warranty specifications are now being used by many agencies to guarantee minimum performance out of paving products. Typical warrantee periods may range from 1 to 5 years or more. Caltrans has embraced this concept is now using warranty specifications on “5 pilot projects” scheduled to be placed in 2002 (see Appendix J for typical warranty specifications). They will be monitoring the projects during the 5-year warranty period.

9.5 MAINTENANCE

Maintenance treatments used for AR hot mixes and chips seals are essentially the same as those used for conventional materials. The only exception is that the frequency of the maintenance treatment is not as great with the AR products.

9.6 OTHER PROCESSES

In recent years, specifications for a new dry process, crumb rubber modified asphalt concrete gap-graded (CRUMAC_GG) and a terminal blend process, Tire modified asphalt concrete (TMAC) have been developed and included in part 6 of the Greenbook (2000 Edition). These processes have been used in southern California for the past 5 years and appear to be performing satisfactorily. Since extensive laboratory or field-testing of these new materials has not yet been conducted, it is premature to say whether they will perform as well as pavements constructed using the wet process.
10.0 REFERENCES


