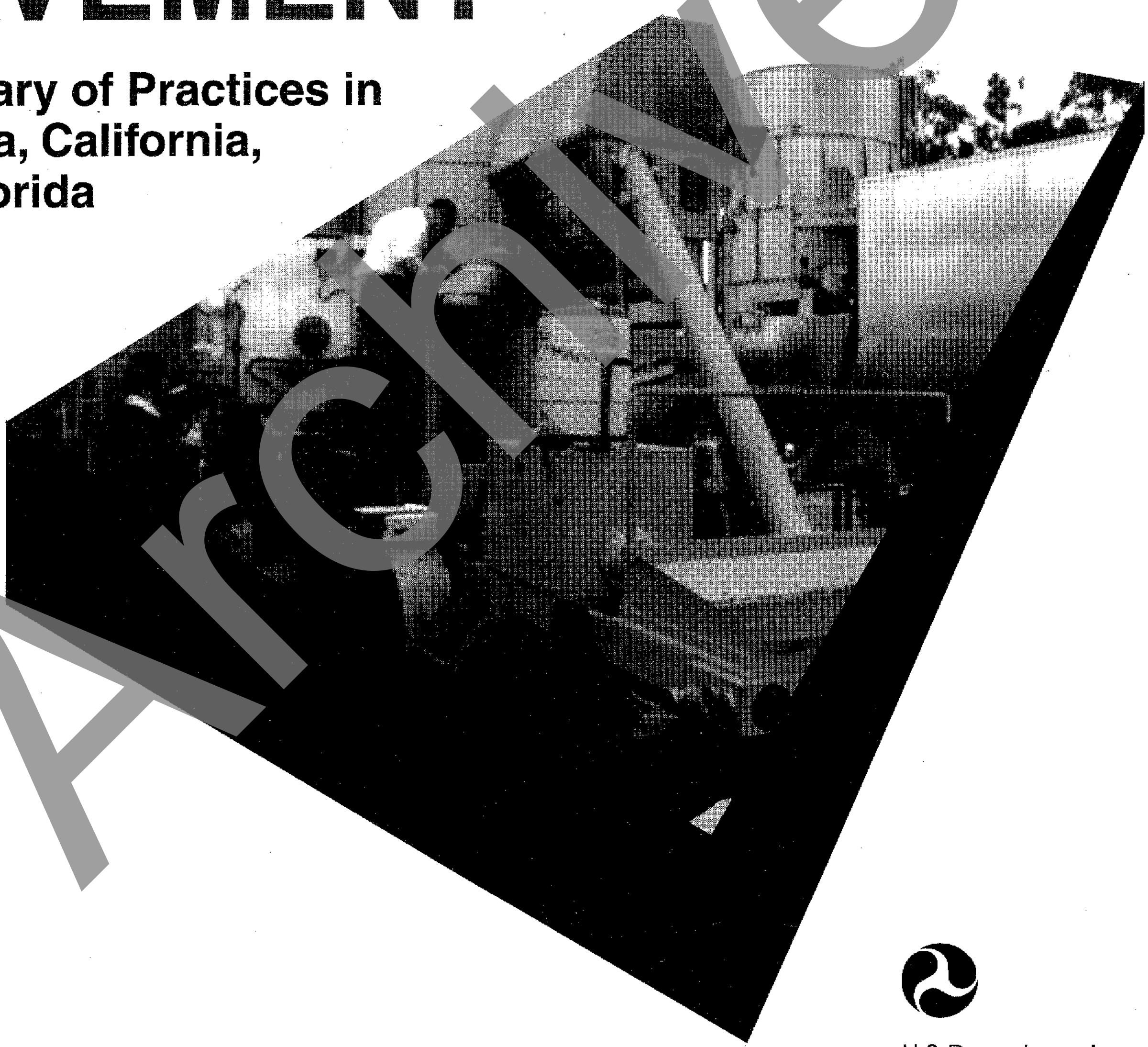
Crumb Rubber Modifier (CRM) in ASPHALT PAVEMENT

Summary of Practices in Arizona, California, and Florida



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16. Abstract

Highway agencies have been evaluating crumb rubber modifier (CRM) in hot mix asphalt (HMA) since the 1970's. Three agencies, Arizona, California, and Florida, currently use CRM in HMA at levels that would approach or exceed the mandate in Section 1038 of the Intermodal Surface Transportation Efficiency Act of 1991.

This report documents the use of CRM in HMA in these three States. In particular, it addresses issues including thickness design, materials and mix design, construction procedure, including quality control, and pavement performance. The report also addresses the following questions: (1) What processes are used? (2) Why are they used? (3) How are the products performing?

Significant findings include the following:

- CRM-HMA is used primarily as a functional overlay. Functional overlays are used to improve ride quality and skid resistance or pavement deterioration.
- The wet process is used exclusively in the three States in dense-, gap-, and/or open-graded mixes.
- The agencies use modified versions of the Marshall or Hveem mix design procedures.
- Cost for CRM-HMA ranges from 15 to 70± percent higher than conventional HMA.
- All agencies feel they are obtaining added value with CRM-HMA. However, there are inadequate data to quantify the benefits.

This report is one of several to be developed as a part of this FHWA study titled "Crumb Rubber Modifiers in Asphalt Pavements."

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Preface

Highway agencies have been evaluating crumb rubber modifier (CRM) technologies in hot mix asphalt (HMA) since the 1970's. Numerous technologies have been studied, with varying degrees of success. Three agencies have used CRM-HMA in quantities that meet or exceed the mandate specified in Section 1038 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. These agencies, which include Arizona, California, and Florida, use the wet process in dense-, gap-, or open-graded mixes.

To provide other agencies with information on the use of CRM-HMA, the Federal Highway Administration (FHWA) undertook a 5-year study titled "Crumb Rubber Modifiers (CRM) in Asphalt Pavements" in September 1994. The contract was awarded to a team headed by Oregon State University and includes the National Center for Asphalt Technology at Auburn University, University of California-Berkeley, University of Nevada-Reno, and Nichols Consulting Engineers. The overall objectives of the study are to:

- Develop guidelines for pavement structural and mix design and for pavement construction, including mix production and field quality control tests.
- Establish the long-term pavement performance of CRM mixes as well as the ability to recycle these mixes.

While there is also a need to consider all conceivable variables, there is also a need to focus the work early on to consider high payoff issues. This will result in a better definition, reduction, or elimination of process applications, materials, or other variables which, based on available data, are not important or significant.

This report is one of the early products of the study. The document summarizes the CRM-HMA practices in the States of Arizona, California, and Florida. The information was collected through visits with agency and industry personnel in each of the States. It is intended to provide information on pavement design, materials, mix design, construction (including costs and quality control), and pavement performance. Significant findings include the following:

- **Thickness design considerations.** Much of the use of CRM-HMA is as functional overlays. Only California utilizes a layer equivalency to reduce the thickness of the CRM-HMA.
- **Materials.** The different agencies generally use ambient-ground CRM with asphalts that will produce an asphalt-rubber binder with a certain viscosity. Dense-, open-, and gap-graded aggregates have been used.
- **Mix design considerations.** Arizona and Florida have modified the Marshall procedure to obtain their mix designs. California has modified the Hveem procedure. All have produced successful mixes.
- **Construction process.** The addition of CRM in HMA makes use of much of the equipment used for conventional mixes. However, there is an additional requirement for a blending/reaction vessel and some increases in mixing temperatures.
- **Costs.** The increased cost of the CRM-HMA (compared with conventional HMA) ranges from as little as 15 percent (in Florida) to 70± percent in Arizona/California, depending on the mix type.

- **Quality control.** This issue is an important one. The uniformity of the asphalt rubber is generally checked using viscosity tests; however, there is a definite need for improved procedures to evaluate the binder uniformity as well as the mix properties.

- **Performance.** All agencies feel they are obtaining an added value. However, inadequate data are available to quantify these benefits.

Acknowledgments

The Federal Highway Administration acknowledges the many contributions of both public and private sector individuals in the States of Arizona, California, and Florida in the preparation of this report. In addition, this report was prepared as part of the States' Planning and Research program study entitled "Evaluation of Crumb Rubber Modifier in Asphalt Pavements" SP&R-(2)166. The Federal Highway Administration would like to acknowledge the following states for supporting this pooled fund study effort: Alabama, Arizona, Arkansas, California, Connecticut, Delaware, Florida, Georgia, Illinois, Iowa, Kansas, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Tennessee, Utah, Virginia, Washington, Wisconsin, and Wyoming.

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CHAPTER 1

Introduction

Background

In June 1993, the Federal Highway Administration (FHWA) published a congressional report summarizing the state of the practice for incorporating recycled materials, including crumb rubber modifier (CRM), into highway pavements. The report, called the Phase I study, concluded that further research is necessary to assess the performance characteristics and recycling potential of CRM asphalt concrete (AC). In September 1994, the FHWA contracted with Oregon State University to resolve many of the outstanding technical issues identified in the congressional report. The research program is extensive in scope and designed to produce guidelines that can be used by State highway agencies (SHA's) to incorporate CRM into asphalt pavements. The goal of this study (termed the Phase II study) is to answer the following questions:

- What existing pavement design method is most suited for use with CRM?
- Can existing performance prediction models be applied to CRM technologies?
- What binder testing techniques are most suitable for use with CRM?
- How can mix design procedures be adapted to this technology?
- What construction equipment and production procedures are most effective for each of the CRM technologies?
- What are the expected performance characteristics of these materials? Does performance vary with construction process and environmental region?
- To what degree can these materials be recycled?

The overall objectives are to evaluate CRM technology as it relates to design, construction, recycling, and performance of asphalt-concrete pavements. Specifically, the project will develop guidelines for the mix and structural design and construction of CRM-asphalt pavements. Guidance will also be provided for the production control and quality assurance of CRM mixes. The project will also establish the long-term performance of CRM pavements and determine their recyclability.

If the Intermodal Surface Transportation Efficiency Act (ISTEA) mandate is implemented in October 1995, all State highway agencies must use 15 percent crumb-rubber-modified hot mix asphalt (CRM-HMA). At present, very few SHA's approach this level of utilization. The States that presently satisfy the ISTEA mandate include Arizona, California, and Florida. Each of these agencies has developed, over several years, a CRM infrastructure (tire recyclers, blenders, and contractors) that is capable of meeting the maximum mandate (20 percent utilization).

Objectives of Report

The purpose of this report is to clearly document clearly the use of CRM in the States of Arizona, California, and Florida to allow others to benefit from their experiences. The report addresses the following: thickness design, materials/mix design, construction procedures/costs, quality control/ quality assurance (QC/QA) considerations, and performance. Also included are a glossary of terms (appendix A) as well as typical specifications for the HMA applications used in these States.

History of Use

The uses of CRM in HMA in the three States has evolved over the years. The Arizona Department of Transportation (ADOT)/City of Phoenix initiated the use of CRM in HMA in the 1970's using test sections. While most of these test sections used the wet process, ADOT placed two sections using the dry process. Prior to that time, Arizona DOT's CRM use had been limited to stress-absorbing membranes (SAM's), stress-absorbing membrane interlayers (SAMI's), and sealants.

More extensive use of CRM in HMA began in 1985 using open- and gap-graded mixes. Only the wet process is used now. The open-graded mixes have been used in thicknesses less than 40 mm (1.6 in) over both asphalt and portland cement concrete pavements. The gap-graded mixes thicknesses less than 60 mm (2.4 in) are primarily used over asphalt-concrete pavements. The CRM in both mix types provides thicker films of binder and reportedly improves the durability and cracking resistance.

California has experimented with both wet and dry CRM processes for hot mixes since the 1970's. Currently, they primarily use the wet process in a gap-graded mix. In some instances (mountain passes), they have used a dense-graded wet process. They no longer utilize the dry process because of erratic pavement performance with these systems.

Florida Department of Transportation (Florida DOT) initiated the CRM-HMA work in 1988-1989. Their interest was sparked by State legislative interest. They primarily use CRM (5 percent by weight of binder) in dense-graded friction courses of 25 mm (1 in) thickness to improve the resistance to shoving/rutting, particularly at intersections. On their freeways, they use a thin 15 mm (0.6 in) open-graded friction course (containing 12 percent CRM by weight of binder) to improve the durability. Florida has developed a wet process that provides for the introduction of very fine rubber into the hot asphalt cement. The dry process is not used by Florida DOT.

Limitations

The agency practices documented here have been developed specifically for use in the States of Arizona, California, and Florida. The information contained in this report was obtained through interviews with agency and industry personnel in each State. Currently, all three agencies use the "wet" process exclusively. Much of this technology appears to be transferable to other public agencies in the United States.

CHAPTER 2 Thickness Design Considerations

There is significant variation in the use of CRM-HMA in the United States. As pointed out earlier, the three States selected for inclusion in this early technology transfer document have substantial experience with CRM materials, particularly the wet process. The bulk of this experience was gained through the use of CRM mixes in functional and structural overlays of existing HMA and, to a lesser degree, portland cement concrete (PCC) pavements. CRM-HMA has been used in new pavement construction in these States mainly as a wearing course. With these limitations in mind, the design procedures described here necessarily reflect the experience of these States, and may not be appropriate for designs of pavements utilizing dry process CRM mixes and for other environmental regions in the United States.

Typical Applications

Arizona, California, and Florida typically use CRM mixes in functional and some structural overlays of existing pavements. Florida uses mixes containing CRM as the surface friction course in new construction as well as rehabilitation. For purposes of this document, functional overlays are distinguished from structural overlays based on thickness and purpose.

Functional surfaces or resurfacings are generally less than 40 mm (1.6 in) thick and have as their main purposes the improvement of ride quality, skid resistance, or prevention of pavement deterioration. All overlays placed in California are expected to satisfy ride quality, structural adequacy, and reflection crack control for a 10-year design period. Thirty-mm (1.2-in) overlays are placed under the Capital Preventative Maintenance program and must satisfy a 5-year design. When ride quality is poor, California Department of Transportation (CALTRANS) uses a two-pass operation consisting of a 30-mm (1.2-in) cold plane followed by a 30-mm (1.2-in) inlay.

In contrast, structural overlays are generally greater than 40 mm (1.6 in) thick and increase the load-carrying capacity of the roadway, normally in anticipation of increasing future traffic or to extend the life of the pavement. Only California makes use of CRM-HMA as a structural overlay.

New Construction

CRM materials have been used in new construction to a limited degree in all three States. Florida and Arizona use the American Association of State Highway and Transportation Officials (AASHTO) methodology (1972 and 1986, respectively) for their new pavement designs. If CRM materials are to be used in the new design, the mixes are assigned the same layer equivalency as a comparable nonmodified mix except as noted below. Typically, the CRM materials are used only in the wearing course.

CALTRANS has drafted a suggested modification to their new pavement design procedure that allows a slight reduction in the overall structural thickness when CRM mixes are used as the surface course.

This modification is based on preliminary performance experience and results from early experimental lab tests. Long-term performance tests have not been considered. This preliminary design procedure is described below.

Functional and Structural Overlays

Florida has several years' experience with CRM as the final wearing courses. Florida DOT uses crumb rubber in three products: membrane interlayers (not discussed further), open-graded, and dense-graded friction courses. Open-graded friction courses (OGFC's) are required on all multilane facilities with design speeds equal to or greater than 73 km/h (50 mi/h). No structural value is typically assigned to the OGFC. Dense-graded friction courses (DGFC's) are used where an OGFC is not required, such as in urban areas with average daily traffic (ADT) in excess of 3,000.

Of the agencies included in this study, agencies in Arizona have the longest history with CRM materials, dating back to the mid-1960's. Much of the early experience was with stress-absorbing membranes (SAM's) and stress-absorbing membrane interlayers (SAMI's) when from 1974 to 1989, about 1,125 km (700 mi) of State highways were constructed using these materials. Asphalt rubber continues to be used in relatively thin, functional overlays of existing AC pavements. For example, the city of Phoenix places a gap-graded, wet process mix in thicknesses of approximately 30 mm (1.2 in) as part of a routine preventive maintenance program. The thickness design is based on experience and probably cannot be transferred to other agencies, due in part to the unique environmental conditions in Phoenix.

Arizona DOT uses asphalt-rubber mixes to reduce reflection cracking, improve surface course durability, and reduce noise in urban areas. Typical lift thicknesses for open-graded mixes are 12 to 25 mm (1/2 to 1 in) and 25 to 50 mm (1 to 2 in) for gap-graded mixes. The OGFC mixes are considered a functional overlay used to improve safety, aesthetics, and ride. The gap-graded mixes are used on low volume, badly cracked pavements; however, they have also been used on the interstate highways.

Design Methodologies

All three agencies base functional overlay thicknesses on agency experience. Two of the three agencies (Arizona and Florida) studied use older versions of the AASHTO overlay design procedures[1,2] to determine the thickness of structural overlays. California has modified their structural design approaches for overlays and new construction to accommodate CRM mixes. Following are details of each State's procedure:

Arizona

The city of Phoenix uses CRM materials in 30-mm (1.2-in) functional overlays without a documented design procedure. Arizona DOT does not have a documented procedure for thickness substitution of gap-graded CRM materials for nonmodified dense-graded mixes. Reduction in thickness is based primarily on engineering judgment. A typical substitution would be 37 mm (1.5 in) gap-graded CRM material for 64 mm (2.5 in) of nonmodified dense-graded mix. The selection of asphalt rubber over conventional mixes is based on pavement management system (PMS)-derived performance information. Specifically, CRM mixes have shown better crack reflection resistance and durability. CRM-HMA sections have been monitored through the Arizona PMS for nearly 10 years.

California

California is the only State among the three included in this report that has made significant modifications to their structural design procedure to accommodate CRM materials. The modific-ations were based on careful observations of a wide variety of CRM mixes (wet, dry-process with dense-, open-, and gap-graded aggregates) placed throughout the State beginning in 1978.[3,4] The implementation of reduced thickness overlays has been limited to selected applications. Investigations of CRM projects continue, and additional modifications to California Department of Transportation (CALTRANS) design procedures may be warranted, based on field performance. Although the procedure described below for new construction has not been formally implemented by CALTRANS, both rehabilitation and new pavements are considered. CALTRANS is currently conducting extensive laboratory and field testing. The early field-testing program makes use of accelerated pavement testing using the South African Heavy Vehicle Simulator (HVS).

California is working on a design procedure based on their standard methodology that would allow partial substitution of CRM mixes for conventional HMA as the wearing course in new construction. A draft of this procedure is shown graphically in figure 1. The draft procedure would allow substitution of up to 60 mm (2.4 in) of CRM material 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 CRM would require about 182 mm (7.2 in) of DGAC over class 2 aggregate base. As an alternative, 60 mm (2.4 in) of CRM mix could be placed over 75 mm (3 in) of DGAC over the same aggregate base, saving approximately 45 mm (1.8 in) of mix. **(It must be noted that this methodology is subject to change and does not constitute an accepted CALTRANS design standard.)**

The structural design of overlays is based on several assumptions as well as field observations. These assumptions were first described in a memo prepared in March 1992 and reviewed in October 1993. The assumptions follow in figure 1 on page 2-4 so that other agencies may judge the appropriateness of the CALTRANS procedure to their circumstances. The assumptions[5] include the following:

- The most promising form of CRM is asphalt-rubber hot mix-gap graded (ARHM-GG). Additional work with dense-graded asphalt-rubber mixes and dry process mixes is being undertaken to confirm this assumption.

- ARHM-GG is recyclable. CALTRANS successfully recycled CRM-HMA in 1994 and is considering recycling additional jobs in 1995.

- Cracking in overlays is caused by a combination of traffic loads and movement of the underlying pavement.

- Even thinner layers of asphalt rubber hot mix-gap graded (ARHM-GG) may be appropriate but, to limit risk, higher equivalencies should be considered experimental. Furthermore, construction considerations, such as heat retention and surface irregularities in the surface being covered, limit the minimum thickness of ARHM-GG to 30 mm (1.2 in).

- ARHM-GG may be little or no better than conventional dense-graded AC in preventing cold-weather-induced transverse cracking.

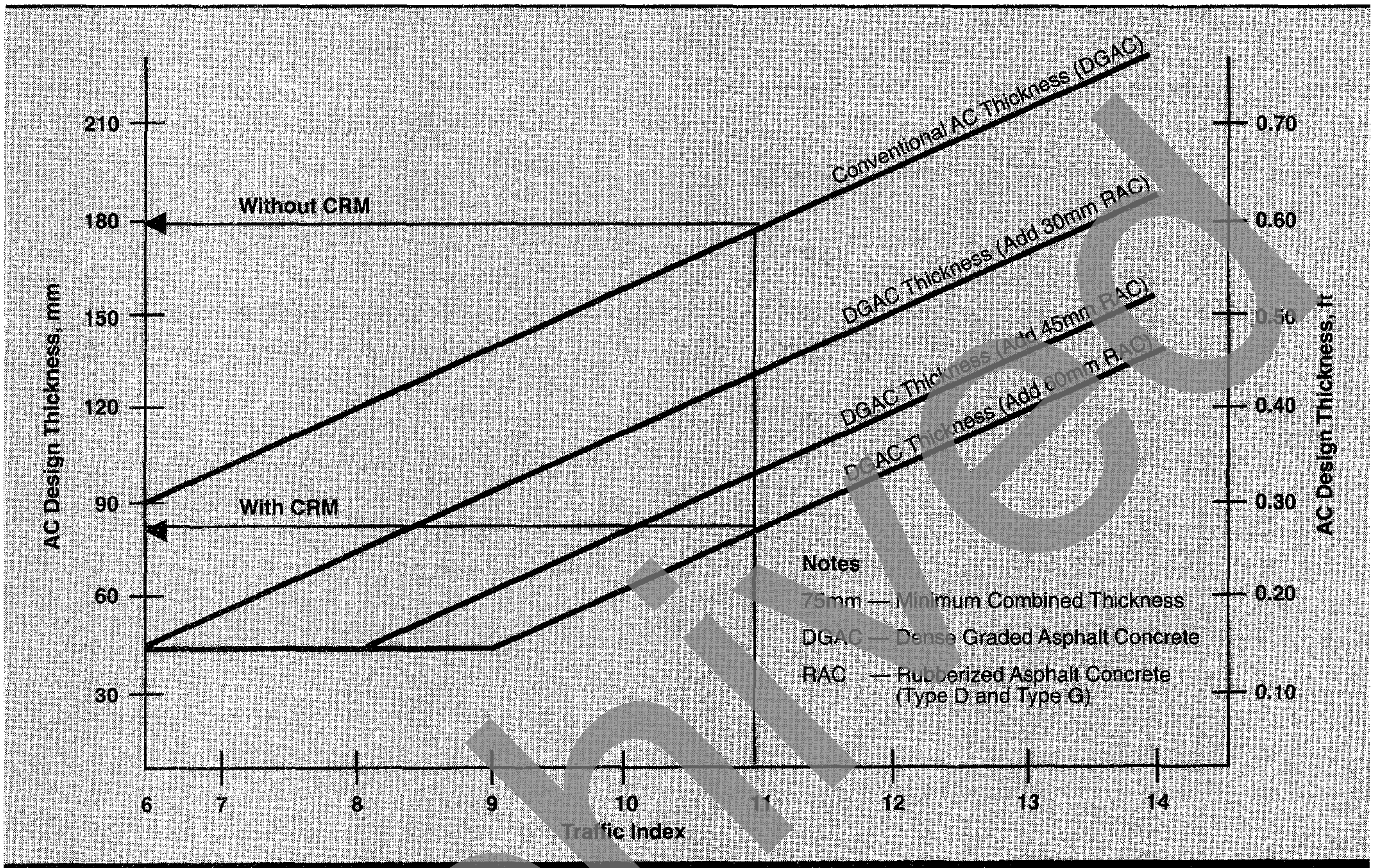
- The degree of stiffening provided by a specific thickness of ARHM-GG is less than the amount of stiffening provided by the same thickness of DGAC. Thus, the after-overlay ratio of tolerable deflection:actual deflection for ARHM-GG may become less favorable when the ARHM-GG thickness is greater than 60 mm (2.4 in).

- ARHM-GG can withstand considerably higher deflection than the same thickness of DGAC without cracking.

- The mild climate structural equivalency of ARHM-GG for nonexperimental work is less than or equal to twice that of DGAC. Some recent performance observations may allow the elimination of the "mild climate" from this assumption.

FIGURE 1

Preliminary Guidelines for New Construction Using Combinations of AC and Rubber-Modified AC Over Class 2 Aggregate Bases



- The mild climate structural equivalency of a SAMI is ≤15 mm (0.6 in) of ARHM-GG (i.e., ≤30 mm [1.2 in] of DGAC; assuming that the SAMI reduces that portion of the total overlay stress caused by reflection of underlying cracks/joints). Again, recent performance observations may allow the elimination of the "mild climate" from this assumption.

- The reflection crack retardation equivalency of ARHM-GG is considerably greater than that of DGAC.

- The reflection crack retardation equivalency of a SAMI is 30 mm (1.2 in) of ARHM-GG when used in conjunction with ARHM-GG, and equivalent to 30 mm (1.2 in) DGAC when used with a DGAC over an untreated aggregate base.

- There may be stability problems if ARHM-GG is placed thicker than 60 mm (2.4 in), even if multiple lifts are used.

California's overlay design procedure consists of the following basic steps:

1. Determine the thickness of conventional DGAC required for the structural needs of the existing pavement (based on deflections and structural section stiffening using current CALTRANS procedures).

2. Determine the thickness of conventional DGAC required to improve ride quality and retard reflection cracking (using current CALTRANS procedure).

3. Select a DGAC overlay thickness that satisfies the requirements of 1 and 2 above.

4. Use either table 1 or table 2 to determine the ARHM-GG equivalent sections, with and/or without SAMI's. Use table 1 if structural needs control and table 2 if reflection crack retardation controls.

5. If the ride score of the pavement to be rehabilitated is greater than or equal to the allowable ride score of 45 and there is no structural need per 1 above, use the following strategy, if reflective cracking per 2 above is satisfied:

   a) Place one 60-mm-thick (2.4-in) lift of ARHM-GG; or

   b) Cold plane to a depth of 30 mm (1.2 in), then place ARHM-GG as determined in steps 1 through 4 to satisfy a two-pass operation.

Florida

The bulk of the CRM mixes placed in Florida are the final surface and are placed to assure the friction characteristics of the roadway. DGFC's are specified at 25 mm (1 in) and OGFC's are specified at 15 mm (0.6 in). The AASHTO (1972) procedure is used with the DGFC layer receiving an assigned structural equivalency (a-value) of 0.22. This value is one-half that of their nonmodified dense-graded AC (e.g., 0.44). Their CRM DGFC is essentially the same as their nonmodified dense-graded mix, except for the CRM material and the use of polish-resistant aggregate.

TABLE 1
California Structural Equivalencies (in mm) (From CALTRANS memorandum dated February 28, 1992)

Dense-Graded Asphalt Concrete	Asphalt Rubber Hot Mix: Gap Graded[1-5]	Asphalt Rubber Hot Mix: Gap Graded on a Stress-Absorbing Membrane Layer
45 (1.8 in)	30[2] (1.2 in)	-
60 (2.4 in)	30 (1.2 in)	-
75 (3.0 in)	45 (1.8 in)	30 (1.2 in)
90 (3.6 in)	45 (1.8 in)	30 (1.2 in)
105 (4.2 in)	60 (2.4 in)	45 (1.8 in)
120 (4.8 in)	60 (2.4 in)	45 (1.8 in)
135 (5.4 in)	45[3] (1.8 in)	60 (2.4 in)
150 (6.0 in)	45[4] (1.8 in)	60 (2.4 in)
165 (6.6 in)	60[3] (2.4 in)	45[3] (1.8 in)
180 (7.2 in)	60[4] (2.4 in)	45[4] (1.8 in)

NOTES

1. The maximum allowable nonexperimental equivalency for ARHM-GG is 2:1.
2. The minimum allowable ARHM-GG lift thickness is 30 mm (1.2 in).
3. Place 45 mm (1.8 in) of new DGAC first.
4. Place 60 mm (2.4 in) of new DGAC first.
5. ARHM-GG may not prevent cold-weather-induced transverse cracks. ARHM-DG is used in lieu of ARHM-GG in areas subject to snow chain wear.

TABLE 2

Reflection Crack Retardation Equivalencies (in mm) (From CALTRANS memorandum dated February 28, 1992)

Dense-Graded Asphalt Concrete	Asphalt Rubber Hot Mix: Gap Graded[1,5]	Asphalt Rubber Hot Mix: Gap Graded on a Stress-Absorbing Membrane Layer
45 (1.8 in)	30[1] (1.2 in)	-
60 (2.4 in)	30 (1.2 in)	-
75 (3.0 in)	45 (1.8 in)	-
90 (3.6 in)	45 (1.8 in)	-
105[2] (4.2 in)	45 or 60[3] (1.8 or 2.4 in)	30[4] (1.2 in)

NOTES

1. The minimum allowable ARHM-GG lift thickness is 30 mm (1.2 in).
2. A DGAC thickness of 105 mm (4.2 in) is the maximum thickness recommended by CALTRANS for reflection crack retardation.
3. Use 45 mm (1.8 in) if the crack width is <3 mm (1/8 in) and 60 mm (2.4 in) if the crack width is ≥3 mm (1/8 in).
4. Use if the crack width is ≥3 mm (1/8 in). If <3 mm (1/8 in), use another strategy.
5. ARHM-GG may not prevent cold-weather-induced transverse cracks. ARHM-DG is used in lieu of ARHM-GG in areas subject to snow chain wear.

Summary

New Construction

CRM materials are routinely and successfully used by each of the three States. Only limited experience is available on the use of CRM mixes in new construction except as applied in wearing courses. California has drafted a trial modification to their pavement design procedure for new construction that would allow partial substitution of CRM.

Functional Overlays

Thin lift wearing courses are a common use of CRM material, particularly in Arizona and Florida. These would be considered functional overlays. Structural design, per se, is not used for this type of overlay. Instead, the agencies rely on experience to determine the layer thickness. Florida and Arizona have had good performances from both dense- and open-graded CRM mixes.

Structural Overlays

Structural overlays (>40 mm [1.6 in]) have been placed most commonly in Arizona and California. Arizona currently uses up to 65 mm (2.6 in) of gap-graded CRM mix on badly cracked, low volume roads and on interstate highways. Only California has made significant changes to their design procedures to accommodate CRM. Although often reported as a simple substitution of 25 mm (1 in) of CRM for 50 mm (2 in) of conventional mix, as shown before in table 2, the maximum allowable substitution rate is 1:2 for overlay construction after considering pavement age, condition, etc. Reduced overlay thickness is based on thickness requirements, applications, and engineering experience.

CHAPTER 3 Materials and Mix Design

Each agency has employed slightly different CRM technologies in HMA. Though Arizona and California use similar suppliers of CRM and asphalt rubber, there are differences in the CRM composition size and gradation. Florida experimented with one of the Arizona technologies, then made modifications that include smaller rubber particle size, lower amounts of rubber, and lower blending temperatures.

This chapter briefly describes the materials and mix design procedures. Additionally, it also summarizes accepted procedures used in the States by local agencies.

Materials

Crumb Rubber Modifier (CRM)

Tire rubber, the principal component of CRM, is primarily a composite of natural rubber, synthetic rubber, and carbon black. Historically, passenger tires contained approximately 20 percent natural and 26 percent synthetic rubber, whereas truck tires contained approximately 33 percent natural and 21 percent synthetic rubber.[6] Industry sources today indicate that passenger car tires typically contain approximately 16 percent natural and 31 percent synthetic rubber, whereas truck tires contain approximately 31 percent natural and 16 percent synthetic rubber.[7] Other sources of raw material for CRM include peel from over-the-road vehicles and buffings (a by-product of the retreading process).

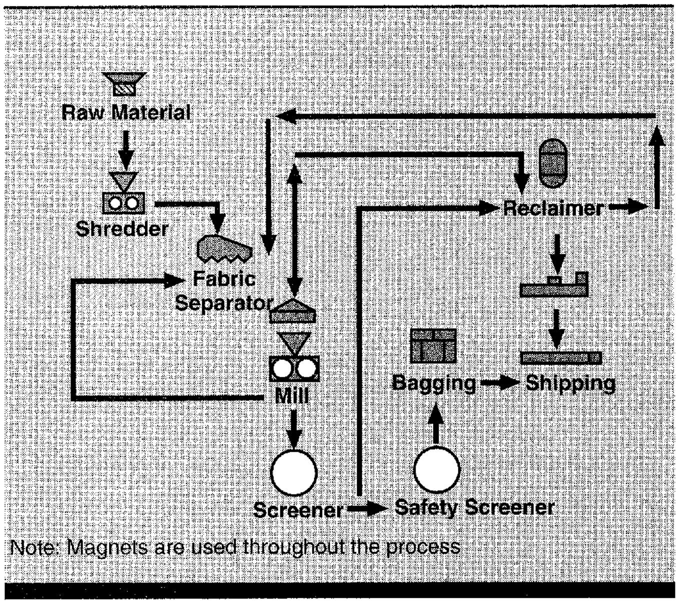
Raw material may be delivered to the processing plant as whole, cut, or shredded tires or buffing waste; the form depends on the capabilities of the processing plant. Whole tires require the least amount of preprocessing but are bulky and limit shipping capacity. Tires that have been minimally processed—typically cut, split, or sectioned—improve handling and shipping. Shredded tire rubber approximately 150 mm (6 in) square is the preferred form of raw material for producing CRM. Buffing waste, because of its small size and generally high quality, is typically diverted to other rubber manufacturing processes. The quality of the raw material is a critical factor in producing a "quality" CRM and is inevitably the responsibility of the CRM processor.

Although there are several methods for processing scrap tires, the primary goal of each is to reduce the size and separate the steel belting and fiber reinforcing from the rubber. Processing scrap tires into CRM may generally be divided into two general categories: ambient grinding/granulating and cryogenic grinding.

As the name implies, ambient grinding/granulating involves tearing and shearing at room temperature. The ambient process consists of a series of crackermills or granulators, screeners, conveyors, and various types of magnets to remove steel as necessary. A schematic of a typical crackermill grinding system is shown in figure 2. The crackermill process is currently the most common and productive method of producing CRM. The end product is usually an irregularly shaped particle with a large surface area, varying in size from 4.75 mm (.187 in) to 0.425 mm (0.017 in)

FIGURE 2

Basic Ambient Tire Grinding Process

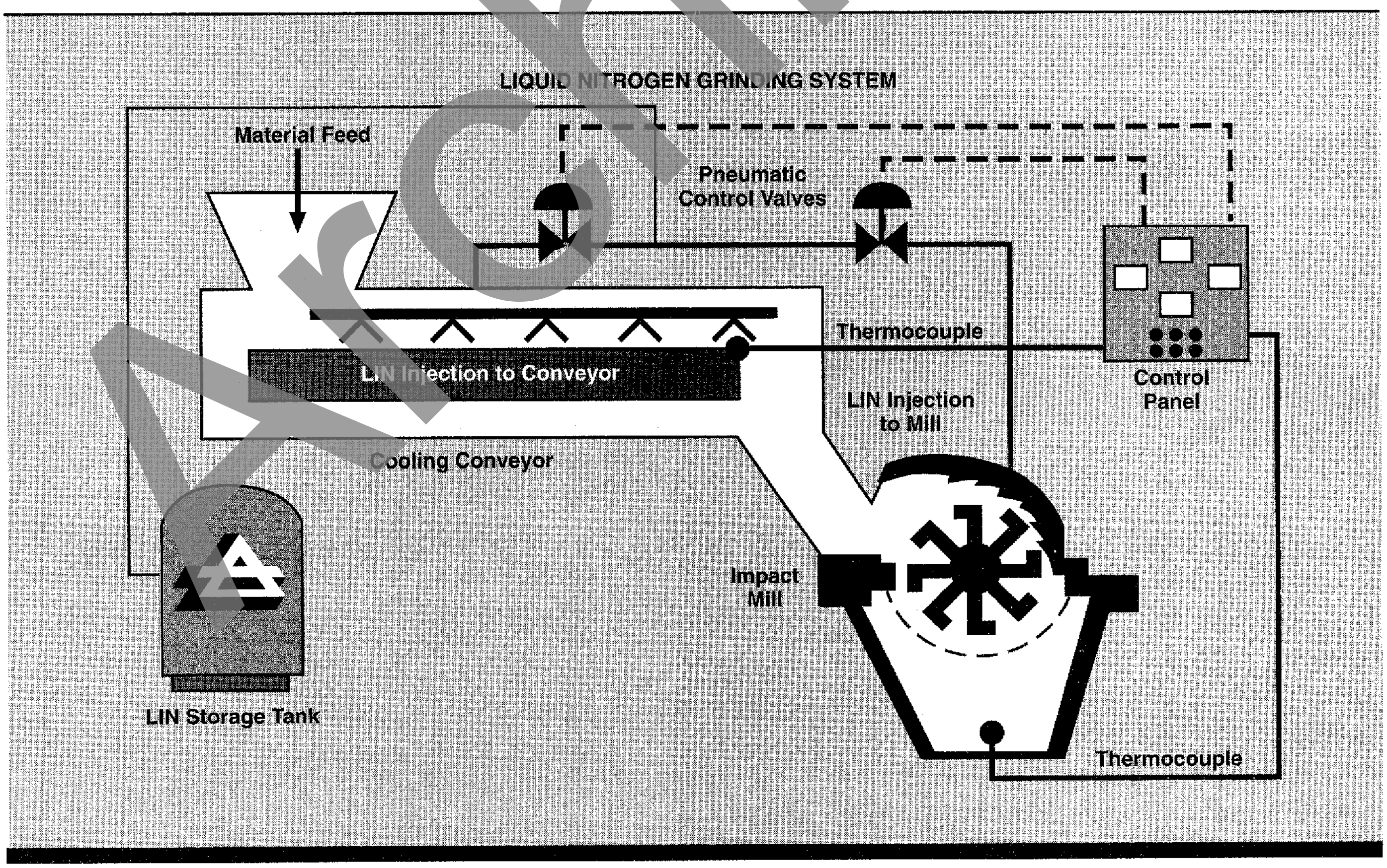


(i.e., the No. 4 to No. 10 sieve). These particles are typically referred to as *ground CRM*. The granulator produces a cubical, more uniformly shaped particle with lower surface area over a range of sizes, usually from 9.5 mm to 2 mm (i.e., 3/8 in to No. 10 sieve), called *granulated CRM*. Micro-milling, also an ambient and sometimes slurry process, yields finely ground particles ranging in size from 425 to 75 microns (i.e., No. 40 to No. 200 sieve).[8,9]

Cryogenic grinding (or separation) is accomplished at extremely low temperatures (−87°C to −198°C [−125°F to −325°F]) by submersing the scrap tire rubber in liquid nitrogen. Below the glass transition temperature (≅ −62°C [≅ −80°F]) the rubber is very brittle and easily fractured in a hammer mill to the desired size. Reportedly, the surface is glasslike, and thus has a much lower surface area than ambiently ground CRM of similar gradation. A schematic of the basic cryogenic grinding process appears in figure 3.[8,9]

FIGURE 3

Basic Cryogenic Grinding System



Specifying CRM may be done in terms of physical and/or chemical properties. The most commonly specified properties include the following: size/gradation, specific gravity, steel and fiber contents, acetone extract, ash, carbon black, rubber hydrocarbon, and natural rubber content. There may also be an upper limit set for moisture content to prevent problems when mixing the CRM at elevated temperatures routinely encountered at a hot-mix plant. A list of CRM producers/blenders used in the three States is shown in appendixes B and C.

Asphalt and CRM Interaction[10]

When CRM is added to asphalt cement at elevated temperatures, the rubber particles tend to swell. The extent and rate of swelling is dependent on a number of factors: chemical and physical properties of the asphalt cement and CRM; mixing conditions such as time, temperature, and degree of agitation; and additives. As the rubber particles swell, the interparticle distance between them is reduced, which results in an increase in viscosity of the CRM-asphalt blend. Preferential absorption of asphalt components by the rubber also contributes to the swelling. Asphalt cement is composed of a variety of petroleum fractions typically classified as asphaltenes, resins, cyclics, and saturates. The quantity of the fractions varies widely with crude source and refining process. Laboratory test data suggest that rubber is more likely to absorb the cyclic fraction than the asphaltene fraction. Therefore, in material selection, compatibility of the asphalt cement and CRM is a key consideration.

Many CRM characteristics affect the interaction with asphalt cement. They include the following: CRM size, gradation, quantity, surface area, and chemical composition; and contaminants such as water, fiber, mineral, and metal. Generally, as rubber content increases, the viscosity of the asphalt-rubber blend increases. Finer size CRM materials tend to "react" more quickly and produce higher viscosities than do CRM with larger particle sizes because of increased surface area. The major CRM compositional effect on asphalt-rubber physical properties is attributed to the total rubber hydrocarbon content and natural rubber content. Asphalt-rubber blends with high total rubber hydrocarbon tend to make the material more ductile because of the high natural rubber content. Preliminary research at Western Research Institute (WRI) suggests that asphalt crude source is the most important variable affecting physical properties of the asphalt-rubber blend.[11]

Contaminants may affect processing and/or physical properties of the blend. Excessive moisture causes foaming and may lead to overflow of production or storage vessels. Fiber contaminants tend to increase viscosity, softening point, and resilience, and decrease penetration and ductility. Metal contaminants tend to accelerate wear on pumps and other construction application equipment.

Extender oils may be added to asphalt-rubber blends to soften the asphalt and decrease the low temperature stiffness of the blend. The primary purpose of the addition of an extender oil is to minimize the absorption of the lighter asphalt fractions by the CRM. Generally, aromatic or naphthanic oils are specified.

Design Methodologies—DOT's

As mentioned earlier, an interview form that addressed critical issues affecting mix design was sent to State Highway Agency (SHA) personnel prior to the visits. Of particular interest were the following: type of CRM technology used; CRM source, composition, size, gradation and specification(s); and mix design procedures and criteria.

The general state-of-the-use of CRM for hot mix asphalt concrete in these three States may be summarized as follows:

- Currently, all three States use the "wet" process exclusively, and do so with open-, dense-, and/or gap-graded mixes. California terminated use of the "dry" process technology in 1992 because of erratic performance of the product and poor technical support from those marketing the technology.
- Maximum size of the CRM particles used in these "wet" process applications ranges from 2.36 mm to 0.18 mm (i.e., passing the No. 8 sieve to passing the No. 80 sieve).
- Ambiently ground CRM is much more widely used than is cryogenically ground CRM. One CRM supplier in California cryogenically separates the rubber from the steel, then grinds the material at ambient temperature.*
- Specifying the CRM is based primarily on gradation, although the California and Florida specifications do include some chemical properties as well as requirements for a minimum percentage of natural rubber. Rarely, however, do any of the States or CRM suppliers conduct tests to verify the CRM properties, physical or chemical.
- Only California specifies the use of extender oils.
- Laboratory preparation of asphalt rubber binders is reasonably consistent from State to State, as all reportedly blend at higher temperatures (≈150°C to 175°C [≈300°F to 350°F]) for 10 to 45 minutes to ensure adequate reaction of the CRM and asphalt cement. Furthermore, all the States use a minimum value or range of viscosity as a means of quality control. There is not, however, widespread agreement as to the need for agitation (i.e., initial, continuous, or intermittent) during laboratory blending or the length of time beyond which the material is unsuitable for use.
- In terms of mix design, two general approaches have been taken to select a total binder content for CRM mixes. Both Arizona and Florida, which use the Marshall method, adjust the unmodified mix binder content by formula or some preselected percentage, or select the CRM binder content that corresponds to a higher air void content (e.g., 5 percent air voids). Arizona typically uses 20 percent CRM (by weight of asphalt cement) for both open- and gap-graded mixes. Florida uses CRM mixes for both dense- and open-graded friction courses. The rubber contents are 5 and 12 percent (by weight of asphalt cement) for the dense- and open-graded mixes, respectively.

  Depending upon binder type, California uses 14 to 23 percent CRM in dense-, gap- and open-graded mixes. Using the Hveem method of mix design, California currently selects total binder content of CRM mixes at 3 to 4 percent air voids, depending on climate and traffic.
- Application of conventional mix design criteria varies from State to State. For its gap-graded mixes, Arizona has no minimum Marshall stability requirement. If the mix has low stability, engineering judgment is used to make appropriate changes in the job mix formula. Florida has a minimum Marshall stability requirement of 6.67 kN (1,500 lb) for its dense-graded mixes. There are additional criteria for Marshall flow, air void content, and voids in the mineral and effective asphalt content. Although California uses the Hveem method mix design for its conventional mixes, it does not specify a minimum stabilometer value.

Note: *Detailed specifications are given in appendix D.*

* It should be noted that early potential applications did not permit the use of cryogenically ground CRM.

Arizona

The Arizona SHA makes exclusive use of the "wet" process for both open- and gap-graded mixes where the maximum size of the CRM is 2.0 mm (passing the No. 10 sieve). For both the open- and gap-graded mixes, 20 percent CRM (by weight of asphalt cement) is blended with an AC-10. CRM is specified by gradation only and no extender oil is specified. The asphalt-rubber blend is evaluated in terms of viscosity, cone penetration, softening point, and resilience (ASTM D-297 test methods). Typical binder contents (by total weight of mix) for the open- and gap-graded mixes are 9 to 10 and 6.5 to 8.5 percent, respectively. Binder content for the gap-graded mixes is selected at 5 percent air voids. For the open-graded mix, binder content is selected based on the following formula:

$$\text{Binder content} = \left[.38(\text{ABS}) - 0.4 + 9.0 \left(\frac{2.620}{G_{sb}} \right) \right]$$

where: G_{sb} = bulk specific gravity of aggregate blend, and

ABS = water absorption of aggregate blend.

If Marshall stability of the gap-graded mix is less than 4.45 kN (1,000 lb), the job-mix formula is adjusted by reducing the binder content or adding an admixture such as hydrated lime or Type II portland cement. More detailed information on Arizona SHA's use of CRM technology is shown in table 3 on page 3-6.

California

Like Arizona, CALTRANS uses the "wet" process exclusively for open-, dense-, and gap-graded mixes. Most of the CRM-HMA applications, however, use the gap-graded mix. Because of poor performance and inadequate technical support, the State no longer uses the "dry" process. The 2.36 mm (passing the No. 8 sieve) CRM that CALTRANS requires is typically supplied by Atlos, Baker, and BAS Recycling, Inc. (see appendix B). Unlike Arizona, CALTRANS specifies the CRM in terms of gradation, production process, specific gravity, and rubber content. CRM content depends on binder type: Type 1 binder uses 14 to 20 percent CRM by weight of binder; while type 2 binder uses 17 to 23 percent CRM by weight of binder, with 2 to 6 percent extender oil by weight of binder permitted. The asphalt-rubber blend is specified in terms of viscosity. Base asphalt cements used, regardless of mix types, are AR-1000, AR-2000, and AR-4000. Typical binder contents (by weight of dry aggregate) for the gap-, dense-, and open-graded mixes are 8, 6.5, and 7.2 percent. Mix design for the gap- and dense-graded mixes is generally conducted in accordance with the Hveem procedure with modifications. For gap-graded mixes, the binder content is selected at 3 to 4 percent air voids in hot climates and 3 percent in mountain climates; and there is no requirement for a minimum Hveem stabilometer value. For CRM open-graded mixes, the binder content is 1.25 × binder content of the unmodified mix. More detailed information on CALTRANS use of CRM technology is shown in table 4.

Florida

The State of Florida uses "wet" process CRM technology for both open- and dense-graded friction courses. For dense-graded mixes, the nominal maximum size of the CRM is 0.18 mm (passing the No. 80 sieve); for open-graded friction courses, the nominal maximum size is either 0.425 mm or 0.18 mm (passing the No. 40 or No. 80 sieve). Typical CRM content is 5 percent and 12 percent (by weight of asphalt cement) for the dense- and open-graded mixes, respectively. An AC-30 is used for both open- and dense-graded mixes. Florida requires that final processing of the CRM be ambient grinding. Additionally, the CRM is specified in terms of specific gravity, moisture content, metal contaminants, acetone extract, hydrocarbon content, ash content, carbon black, and natural rubber content. Specifications for the asphalt-rubber blend include blending time, temperature, and minimum viscosity. Typical binder contents

TABLE 3

Arizona SHA CRM Technology

- Use the WET process exclusively.
- Aggregate gradations: OPEN and GAP.
- Maximum size of CRM used: 2 mm (passing the No. 10 sieve).
- CRM supplier: Baker.
- Typical CRM content—20% by weight of binder for OPEN- and GAP-graded mixes.
- Typical base asphalt cement: AC-10.
- CRM specified by GRADATION only; no requirement for a certain percentage of natural, synthetic rubber; no chemical requirement for CRM.
- CRM gradation used for both OPEN- and GAP-graded mixes:

Sieve Size Opening, mm	Sieve Number	Percent Passing
2.000	No. 10	100
1.180	No. 16	75-100
0.600	No. 30	25-100
0.300	No. 50	0-45
0.150	No. 100	0-10
0.075	No. 200	0

- No EXTENDER oils added.
- Preparing asphalt rubber in lab: blend at 175°C (350°F) for a minimum of 60 minutes; continuous agitation.
- Test conducted on asphalt rubber binder:
  - — Haake viscosity @ 175°C (350°F)—1,500 to 4,000 cP
  - — Cone pen @ 25°C (77°F)—minimum of 20
  - — Softening point—52°C (125°F) minimum
  - — Resilience @ 25°C (77°F)—15% minimum
- Mix design:
  - — OPEN—selected by formula.
  - — No draindown test is used.
  - — GAP—selected at 5% air void content
- Typical binder content (by total weight of mix):
  - — OPEN (9 to 10%)
  - — GAP (6.5 to 8.5%)
- Design criteria—method specification; no additional requirements for Marshall stability, flow, voids; asphalt absorption ≤ 1%; if Marshall stability ≤ 4.45 kN (1,000 lb), mix adjusted by reducing binder content or adding an admixture.
- Though moisture sensitivity evaluation is not part of CRM mix design, 1% lime or portland cement is generally used as an admixture in all mixes.
- AZ DOT does mix design.

TABLE 4

California SHA CRM Technology

- Use the WET process exclusively (last DRY process project in 1992).
- Aggregate gradations: OPEN, GAP, and DENSE.
- Maximum size of CRM used: 100% passing the 2.36 mm (#8 sieve) (for OPEN-, DENSE-, or GAP-graded).
- CRM supplier: typically Atlos, Baker, BAS.
- Typical CRM content:
  - — Type 1 binder (no extender oil)—14 to 20% CRM by weight of binder
  - — Type 2 binder (may contain 2 to 6% extender oil)—17 to 23% CRM by weight of binder
- Typical base asphalt cement: AR-1000, AR-2000, or AR-4000.
- CRM specified
  - — Gradation (100% passing No. 8 sieve):

Sieve Size Opening, mm	Sieve Number	Percent Passing
2.360	No. 8	100
2.000	No. 10	95-100
1.180	No. 16	40-80
0.600	No. 30	5-30
0.300	No. 50	0-15
0.075	No. 200	0-3

  - — Ambiently ground
  - — Specific gravity 1.1 to 1.2
  - — Type 1 binder may not contain CRM particles larger than 4.7 mm (.19 in)
  - — Type 2 binder may not contain CRM particles larger than 6.4 mm (.25 in) and must be 20 to 30% natural rubber
- EXTENDER oil used only in type 2 binder (2 to 6%); added at job site; no verification.
- Preparing asphalt rubber in lab:
  - — Type 1 & 2—blend at 175°C to 190°C (350°F to 375°F) for a minimum of 45 minutes; continuous agitation; shall not be held at temperature exceeding 163°C (325°F) for more than 4 hours
- Asphalt rubber binder specification
  - — Viscosity @ 175°C (350°F)—1,500 to 4,000 cP
- Mix design
  - — GAP-graded—kneading compaction at higher temperature (≅150°C [≅ 300°F]); to 2% voids, but may increase this to 3 to 4% voids. Select binder content at 3 to 4% air voids for hot climate and 3% for mountain climate.
  - — DENSE-graded—same as for gap-graded except compact to 3% voids;.
  - — OPEN-graded—draindown test binder content increased by 20% to account for CRM
- Moisture sensitivity evaluation with AASHTO T283 procedure; minimum tensile strength ratio (TSR) of 80%.
- CALTRANS does all mix designs.

(by total weight of mix) are 7.1 and 6.5 percent for the open- and dense-graded mixes, respectively. For dense-graded mixes, a minimum Marshall stability of 6.67 kN (1,500 lb) is required, as is flow in the range of 0.031 cm to 0.055 cm (8 to 14 [0.01 in]). Additional criteria include the following: minimum voids in the mineral aggregate (VMA) of 15.5 percent; air void content of 4 to 6 percent; and minimum effective asphalt content of 5.5 percent. More detailed information on Florida's use of CRM technology is shown in table 5.

A side-by-side summary of the individual SHA approaches to CRM mix design is shown in table 6.

Design Methodologies—Local Agencies

In addition to discussions with SHA personnel in Arizona, California, and Florida, major contractors and material suppliers in these States were also visited to obtain the industry perspective on CRM technology. Personnel from the larger cities and counties in these three States also provided input that is noteworthy.

Several contractors in Arizona, including International Surfacing, Inc. (ISI), FNF Construction, and Western Technologies, provided tours of their facilities and information with regard to CRM specifications, mix design, and plant operations. The city of Phoenix provided information on its specification for asphalt concrete overlays that require either polymer or rubber modification. Information provided by these groups is summarized in appendix E.

Similarly, visits with blending contractors (e.g., Manhole Adjusting and Granite Construction) also resulted in information on local agency experience in southern California. The specifications developed by American Public Works Association (APWA) for use in southern California are shown in appendix D and summarized in appendix E. Type A uses whole scrap tire rubber, while types B through D allow the use of natural rubber (often ground-up tennis balls). Type B is the process used by Manhole Adjusting.

Summary

Based on the interviews with SHA personnel, producers/suppliers, and paving contractors in Arizona, California, and Florida, CRM mix design issues may be divided into two general categories: CRM technology and specifications, and mix design procedures and criteria. Within the former there are specifications for not only the CRM, but also the asphalt-rubber blend, which vary in terms of degree and enforcement.

As noted earlier in this chapter, all three States make exclusive use of the "wet" process technology. This is logical from both historical and field performance perspectives. The wet process technology was developed by Charles H. McDonald, the Sahuaro Petroleum and Asphalt Co., and the Arizona Refining Co. In California, exclusive use of the wet process is largely the result of erratic performance and poor technical support of the dry process technology. The CRM used in all three States is primarily ambiently ground, and the maximum size varies from 2.36 mm to 0.18 mm (No. 8 sieve and No. 80 sieve). All States specify, at a minimum, the CRM gradation. California and Florida specify some chemical and physical properties for the CRM, as well. Interestingly, however, neither State *currently* verifies the CRM properties with any testing in-house. CRM content varies from a minimum of 5 percent in Florida to a maximum of 23 percent in California, depending on mix type.* Also, CRM has been used success-fully with dense-, gap-, and open-graded mixes. Laboratory preparation and specification of the asphalt-rubber blend are a bit

*Note that CRM content is expressed as percent by weight of asphalt cement.

TABLE 5

Florida SHA CRM Technology

- Use the WET process exclusively.
- Aggregate gradations: OPEN and DENSE.
- Maximum size of CRM used: depends on mix type (see below).
- CRM supplier: Baker, Rouse, ATR, TireGator.
- Typical CRM content:
  - — minimum 5% by weight of asphalt cement for DENSE-graded friction course
  - — minimum 12% by weight of asphalt cement for OPEN-graded friction course
- Typical base asphalt cement: AC-30.
- CRM specified by the following:
  - — final processing is ambient grinding
  - — gradation (type A and B)

Sieve Size Opening, mm	Sieve Number	Ground Tire Rubber Type A	Ground Tire Rubber Type B
2.000	No. 10		
0.850	No. 20		100
0.425	No. 40	100	85-100
0.180	No. 80	90-100	10-50
0.150	No. 100	70-90	5-30
0.075	No. 200	35-60	

NOTE: Type A used for DENSE-graded friction course.
Type A or B used for OPEN-graded friction course.

- Physical:
  - — specific gravity 1.10 ± 0.06
  - — moisture content ≤ 0.75%
  - — metal contaminants ≤ 0.01%
- Chemical:
  - — acetone extract ≤ 25%
  - — hydrocarbon content 40 to 55%
  - — ash content ≤ 8%
  - — carbon black 20 to 40%
  - — natural rubber 16 to 45%; type A ≥ 10%
- No EXTENDER oils added.
- Preparing asphalt rubber in lab:
  - — DENSE-graded friction course—blend at 150°C to 170°C (300°F to 335°F) for 10 minutes (type A)
  - — OPEN-graded friction course—blend at 150°C to 175°C (300°F to 350°F) for 10 (type A) or 15 minutes (type B)
  - — DENSE-graded friction course—minimum viscosity 400 cP @ 150°C (300°F) (type A)
  - — OPEN-graded friction course—minimum viscosity 1,000 cP @ 150°C (300°F) (type A or B)
- Asphalt rubber specification:

Asphalt Rubber Binder		
Binder type	ARB-5	ARB-12
Rubber type	A	B (or A)
Friction course	Dense	Open
Percent CRM (by weight of binder)	5	12
AC grade	AC-30	AC-30
Blending temperature	150°C to 170°C (300°F to 335°F)	150°C to 175°C (300°F to 350°F)
Minimum blending time	10	15
Minimum viscosity @150°C (300°F) (cP)	400	1,000

- Mix Design:
  - — DENSE-graded—binder content determined from Marshall procedure using AC-30; total binder content is unmodified binder content including 5% CRM
  - — OPEN-graded—binder content determined from FHWA OGFC procedure using AC-30; total binder content is unmodified binder content+12% CRM
  - — Typical total binder content (by total weight of mix):
    - OPEN-graded friction course—7.1%
    - DENSE-graded friction course—6.5%
- Design criteria:
  - — DENSE-graded
    Marshall stability ≥6.67 kN (≥1,500 lb)
    Marshall flow 0.031 cm to 0.055 cm (8-14 [0.01 in])
    Percent VMA ≥15.5
    Percent air voids 4-6
    Effective asphalt content ≥ 5.5 (percent by weight of mix)
- Moisture sensitivity is NOT routinely evaluated as part of CRM mix design, but would use modified Lottman (AASHTO T 283) if necessary. Liquid antistrip used on all surface course mixes.
- Florida DOT does OPEN-graded mix design. Contractor does DENSE-graded mix design; Florida DOT verifies design.

TABLE 6
Summary of State Highway CRM Technology

Technology Criteria	Arizona	California	Florida
Type of CRM Technology	wet	wet	wet
Aggregate Gradation(s)	open and gap	open, dense, and gap	open and dense
Maximum Size of CRM	2.0 mm (passing No. 10)	2.36 mm (passing No. 8)	dense—nominal max. No. 80 open—nominal max. No. 40 or No. 80
Typical CRM Content (percent by weight of asphalt cement)	20%	14 to 20% (type 1 binder) 17 to 23% (type 2 binder)	dense—5% open—12%
Based Asphalt Cement	AC-10	AR-1000, AR-2000, and AR-4000	AC-30
CRM specification(s):			
Physical			
gradation	yes	yes	yes
specific gravity		1.1 to 1.2	1.10 ± 0.06
moisture content			≤ 0.75%
metal contaminants			≤ 0.01%
Production			
ambient vs. cryogenic		ambient	ambient
Chemical			
natural rubber		20% minimum (type 2 binder)	16 to 45%
acetone extract			≤ 25%
hydrocarbon content			40 to 55%
ash content			≤ 8% (≤ 10% for type A)
carbon black			20 to 40%
Verification of CRM Specification(s)	sieve analysis only	no	no
Extender Oils	not permitted	required for type 2 binder	not permitted
Lab Blending of CRM and Asphalt Cement	blend at 175°C (350°F) for 60 minutes	blend at 175°C to 190°C (350°F to 375°F) for 45 minutes	blend at 150°C to 175°C (300°F to 350°F) for 10 to 15 minutes
Asphalt Rubber Binder Criteria			
viscosity	1,500 to 4,000 cP at 175°C (350°F)	1,500 to 4,000 cP at 175°C (350°F)	minimum 400 cP at 150°C (300°F) (ARB 5)
cone penetration	minimum of 20% at 25°C (77°F)		
softening point	52°C (125°F) minimum		minimum 1,000 cP at 150°C (300°F) (ARB 12)
resilience	minimum of 15% at 25°C (77°F)		
Mix Design			
Selection of binder contents			
dense		at 2% air voids	binder content of unmodified mix at 5% air voids
gap	at 5% air voids	at 3 to 4% air voids	
open	adjustment from 9% by formula	1.25 × binder content of unmodified mix	1.12 × binder content of unmodified mix
Mix Design Criteria			
Volumetric			
percent air voids	not specified	not specified	4 to 6%
percent VMA	not specified	not specified	≥ 15.5%
Mechanical			
Marshall stability	not specified	not specified	≥ 6.67 kN (1,500 lb)
Marshall flow	not specified	not specified	8 to 14
Hveem stability	not specified	not specified	
Moisture sensitivity evaluation	not part of mix design process	AASHTO T283; minimum TSR 80%	liquid antistrip used on all surface courses

more uniform as all States mix at somewhat higher temperatures (≅150°C to 175°C [≅300°F to 350°F]) and use viscosity as a measure of quality control. Only California requires the use of extender oils.

In terms of mix design, there are similarities as well. For both CRM dense- and gap-graded mixes, whether Marshall or Hveem design, binder content is selected at a particular void content.
For CRM open-graded mixes, binder content, including CRM, is determined by formula—usually by increasing the unmodified binder content by some predetermined factor. Application of mix design criteria is somewhat less consistent from State to State. Only Florida has minimum Marshall stability requirements. California, which uses the Hveem method, does not specify a minimum stabilometer value.

Ironically, some cities, counties, and producers/suppliers have far more comprehensive specifications for both the raw material, for example CRM, and the asphalt-rubber blend than do some of the State highway agencies. Enforcement of these specifications, however, varies dramatically.

CHAPTER 4

Construction Process/Costs

Although the construction procedures used by the various agencies are similar, there are distinct differences. This chapter discusses the procedures used in terms of handling the CRM, the construction process, including plant operations, placement, and compaction. The costs for the asphalt-rubber binders and asphalt-rubber-modified HMA mixes are summarized.

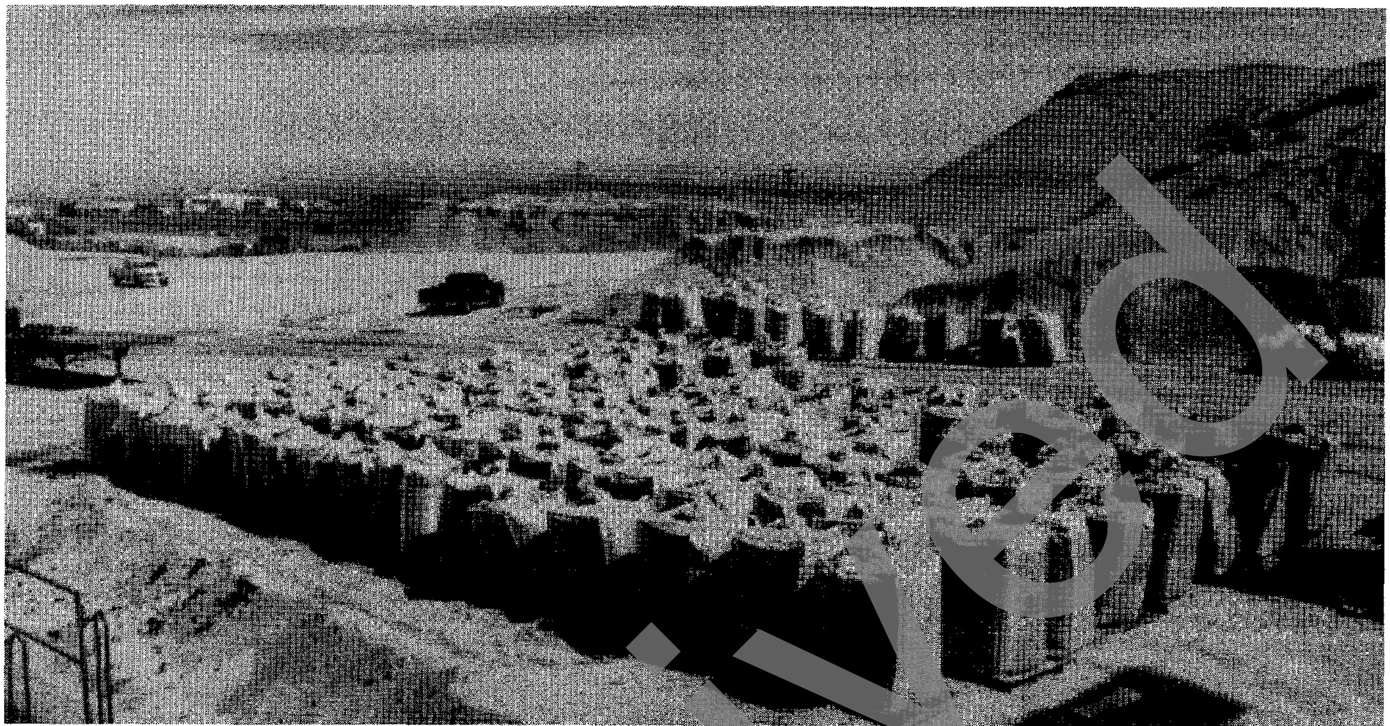
Shipping, Storage, and Handling of CRM Materials

The CRM is produced using one of the following processes or combination of processes: ambient grinding, ambient granulating, cryogenic grinding, or wet grinding. The feed stock may be buffings, whole truck or automobile tires and, in one case, reject tennis balls. The key for the contractor or agency purchasing the material is that it meets the specifications, be uniform, be free of metal, contain very little fiber, and be relatively dry. Uniformity is required because if the gradation or chemical makeup of the rubber changes, it may change the properties of the resultant asphalt-rubber binder, such as viscosity, softening point, reaction time, etc. The material must be free of metal particles because they can, and have, damaged the contractor's pumping equipment. An excessive amount of fibers may cause nozzles to clog. The material is shipped to the asphalt-rubber blending operations in either 453-kg to 907-kg (997-lb to 1,995-lb) gaylord boxes, supersacks (approximately 1 metric ton [2,200 lbs]), bulk tanker trucks (similar to cement or lime bulk trucks), or in bags weighing 11 kg to 27 kg (24 lb to 59 lb). Figure 4 shows the supersack storage area on a project in California. After shipment to the project site, the rubber must be kept dry because moisture in the rubber can cause foaming of the asphalt cement. Once the material is at the project site, it can be loaded directly into a crumb rubber hopper on the blending equipment or it can be blown from the bulk tanker truck into a silo from which it can be augured into the asphalt-rubber blending unit. There have been reported problems with the material clumping in the large containers such as the gaylord boxes or super-sacks. Some rubber suppliers (generally at the request of the asphalt-rubber blender) have added up to 2 to 4 percent calcium carbonate or talc to the CRM to prevent the CRM from sticking together and thus to improve its free flow characteristics.

Construction Process: Blending

The asphalt cement and the CRM are blended into a homogeneous asphalt-rubber system, which is reacted at elevated temperatures. Since the expiration of the patents on the asphalt-rubber process, there have been a number of different processes developed for blending the asphalt cement and the CRM. The time required to disperse, blend and react, or melt the CRM into the asphalt cement is dependent on a number of factors in the chemistry of the asphalt cement and

FIGURE 4
Photograph of Supersack Storage Yard on California Project



CRM, 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." Basically, for a given weight of CRM, the reaction time is directly proportional to the diameter squared of the CRM particles. Also, the reaction time is inversely proportional to the temperature of the material. The reaction time will double with every 10°C (18°F) decrease in asphalt-cement temperature.[12] Adding CRM to the asphalt drops the temperature of the asphalt cement due to the ambient temperature of the CRM. For example, the addition of 20 percent CRM material to an asphalt cement at about 204°C (400°F) will cause the combined temperature to drop to about 177°C (350°F).

The following paragraphs describe a multitude of blending systems that are now being used. Systems in use that were in the early stages of development or systems for which information was not available to the team are not discussed. Any system used for blending asphalt rubber should be evaluated for its ability to produce a uniform, fully "reacted" product.

Arizona

The CRM-HMA pavements built in Arizona require 17 to 23 percent of a 600 μm (30 mesh) CRM, and the specifications call for 30 to 60 minutes' reaction time after the rubber is blended with the asphalt cement. Therefore, the equipment consists of a mixing chamber and a reaction vessel to hold the material.

FNF Construction in Tempe uses a CRM blending system manufactured by CEI Enterprises in Albuquerque, New Mexico. The system consists of a portable asphalt-rubber mixing system and an agitation tank that is mounted on a trailer. It uses a mass flow asphalt-cement meter and a crumb rubber hopper that is equipped with a load cell. The load cell provides feedback to the computer to control the flow rate for the crumb rubber. The system is computer controlled to provide precise batch ratios. The computer also provides constant monitoring. The mixing tank is 1,135 liters (300 gallons) and is equipped with a twin-bladed shaft driven by a 3-hp vertical mixer. One mixing blade is positioned at the bottom, and the other blade is at the middle of the unit. The asphalt cement is introduced at 204°C (400°F). During the blending process the temperature of the blended material will drop to approximately 177°C (350°F). After the material is blended it is fed into a double-compartment, hot-oil-heated tank. The tank has a 56,781-liter (15,000-gallon) capacity, and each compartment is 28,390 liters (7,500 gallons). A turbine mixer is located in each compartment to keep the crumb rubber in suspension. Each tank compartment is equipped with independent heat coils. The asphalt rubber blend is held in the agitation tank for 45 minutes to an hour prior to use. This system can produce approximately 25 metric tons (28 tons) of asphalt-rubber binder per hour, or sufficient binder to allow a contractor to produce approximately 357 metric tons (400 tons) of rubber-modified HMA per hour.

International Surfacing Incorporated (ISI) in Chandler uses a blending system that they developed based on the original McDonald process. (See figure 5 on page 4-4 for a schematic of the system.) With the ISI system, the asphalt cement and CRM are combined and mixed together in a blender unit and pumped into an agitated storage/reaction tank, where it is reacted for 30 to 60 minutes. It is a batch process. The amount of CRM is determined by weight for each batch. The temperature of the asphalt cement at the time the CRM is added should be between 190°C (375°F) and 232°C (450°F). This allows for the temperature drop caused by adding the ambient temperature rubber. The asphalt-rubber blend is held at 162°C (325°F) to 190°C (375°F) during the reaction period. The asphalt rubber may be allowed to cool to between 149°C (300°F) and 176°C (350°F). After the material has been reacted for a period of 30 to 60 minutes, the asphalt rubber can be metered into the HMA mixing facility or pumped into an agitated holding tank. The material is blended in 15,142-liter (4,000-gallon) batches. This system can produce approximately 15.2 to 31.2 metric tons (17 to 35 tons) of asphalt-rubber per hour, or sufficient binder to allow a contractor to produce approximately 226 to 454 metric tons (250 to 500 tons) of rubber-modified HMA per hour.

California

The asphalt-rubber HMA pavements built in California are similar to those built in Arizona. They use about 17 to 22 percent 600 µm (30 mesh) CRM and require a reaction time of 30 to 60 minutes. Thus, there is a cross utilization of equipment and contractors between the two States.

Manhole Adjusting Contractors, Inc., of Monterey Park has developed a rubber blending system where the asphalt-CRM is generally blended at the HMA plant. This process is similar to the original Arizona Refining Co. process. They use a combination of scrap tires and natural rubber (from ground tennis balls), ground rubber buffings, and 1- to 6-percent asphalt modifier. The modifier is high resin, high flash point, aromatic hydrocarbon or extender oil. The rubber (1 part natural rubber and 3 parts rubber buffings) is fed into a mixing chamber where it is mixed at 90 gallons per minute. The mixing process is continuous. The asphalt cement and modifier are preblended and are between 190°C and 232°C (375°F and 450°F) when the CRM is added. The CRM is added using 27-kg (60-lb) bags. The asphalt-rubber mix is fed into a reaction trailer, where it is held a minimum of 30 minutes prior to use. After reaction the asphalt-rubber binder is fed into an agitated storage tank, where it is held until used. (See figure 6 for a photograph of the blending system.) The system produces sufficient asphalt-rubber binder to produce approximately 2,267 metric tons (2,500 tons) of HMA per day.

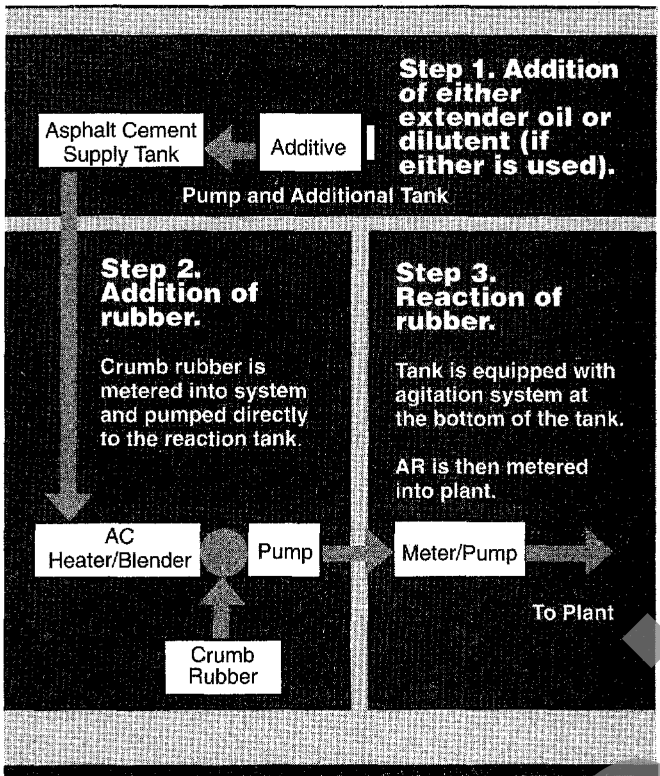
Granite Construction, Inc., of Palm Desert operates the same system that FNF Construction in Phoenix does. It is also built by CEI Industries, Albuquerque, New Mexico.

Florida

Florida specifications call for either a 180 µm or 425 µm (80 mesh or 40 mesh) CRM at 5 and 12 percent concentration rates. With the smaller material and lower concentrations the "reaction"

FIGURE 5

Schematic of ISI Blending System



time can be shorter and is generally about 15 minutes. Thus, much of the equipment consists of a wetting chamber and a mixing chamber from which the material is pumped into a holding tank prior to being used in the HMA mixing facility. Anderson-Columbia Construction Co. in Lake City has established a terminal-type operation at their HMA plant site. It is shown schematically in figure 7. The CRM is delivered to the plant in bulk tanker trucks and then blown into one of two 71-metric-ton (80-ton) storage silos. The asphalt cement is metered into a 45,425-liter (12,000-gallon) blending tank equipped with two propellers. The ground tire rubber (GTR) is then weighed into the tank, where it is blended for a minimum of 15 minutes at about 171°C (340°F). The blended asphalt rubber is pumped into 22,712-liter (6,000-gallon) transport trucks for delivery to an HMA mixing plant. These trucks are equipped with heating systems and high viscosity pumps for circulation.

HEATEC (a Division of Astec Industries) has built a trailer-mounted system. It is used by Martin Paving in Daytona Beach and by Bitcom in Coral Springs. The CRM is loaded into a crumb rubber hopper. (See figure 8 for a schematic.) It can be loaded from supersacks or from an auger. It is then augured into a 1,892-liter (500-gallon) prewet mixing tank. From there, the wetted material is pumped into another 1,892-liter (500-gallon) mixing tank for further blending. Heatec also manufactures a unit with one 3,028-liter (800-gallon) mixing tank rather than two 1,892-liter (500-gallon) tanks. From these mixing tanks, it is then pumped into an 11,356-liter (3,000-gallon) mixing tank where it is held until it is used. The tanks are vertical with two mixing paddles, one near the bottom and one near the middle of the tanks. The asphalt cement is heated to 204°C to 232°C (400°F to 450°F) prior to mixing with the CRM. Care must be taken to make sure the final temperature of the blend (asphalt cement plus crumb rubber) is not exceeded.

Blacklidge Emulsions has three different systems, one in Mobile, Alabama, one in Gulfport, Mississippi, and one in Tampa, Florida. The system in Tampa consists of two 26,497-liter (7,000-gallon) tanks that are trailer mounted. The tank is filled with asphalt cement, and then the CRM is weighed into the tank from a storage silo located on scales. The system in Mobile is a portable rig that was built as a coventure with Etinourer. This unit is fed from 22.6-kg (50-lb) sacks that are dumped into a hopper, and the CRM is augured into the blending unit.

Rouse Rubber Industries, Inc., of Vicksburg, Mississippi, has developed a portable blending and metering unit mounted on a trailer. (See figure 9 for a photograph of the system and figure 10 for a schematic of the system. Note in the photo the bag delivery system.) In this system the rubber is augured into the primary tank, where it is mixed with an asphalt cement that is supplied at 162°C (325°F). A secondary tank is used to increase the reaction time for the process. The primary and secondary tanks are 1,892-liter (500-gallon) tanks with an active space of about 1,514 liters (400 gallons). The pump from the heat tank feeds the asphalt cement at a rate of 264 L/min

FIGURE 6
Photograph of Asphalt-CRM Blending System Used by Manhole Adjusting

FIGURE 7
Schematic of Anderson-Columbia Blending System

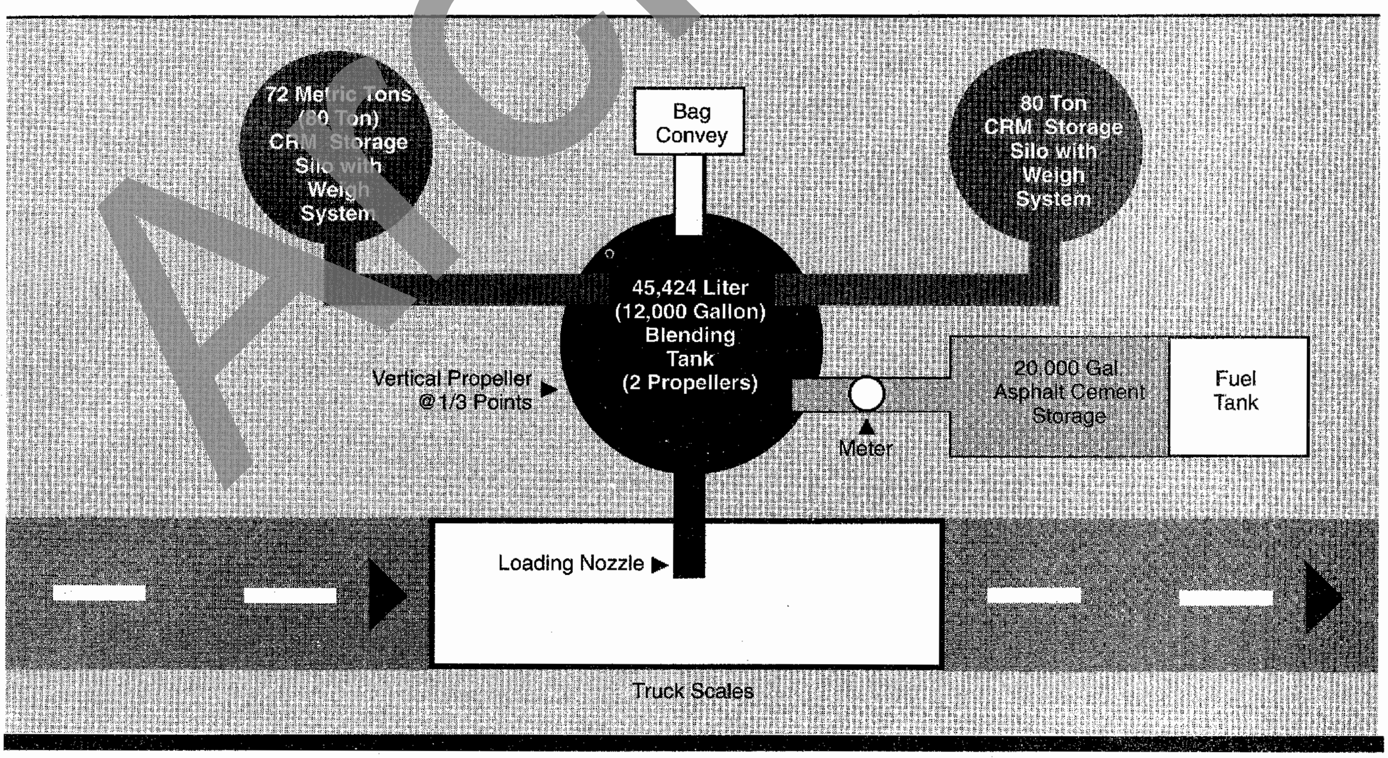
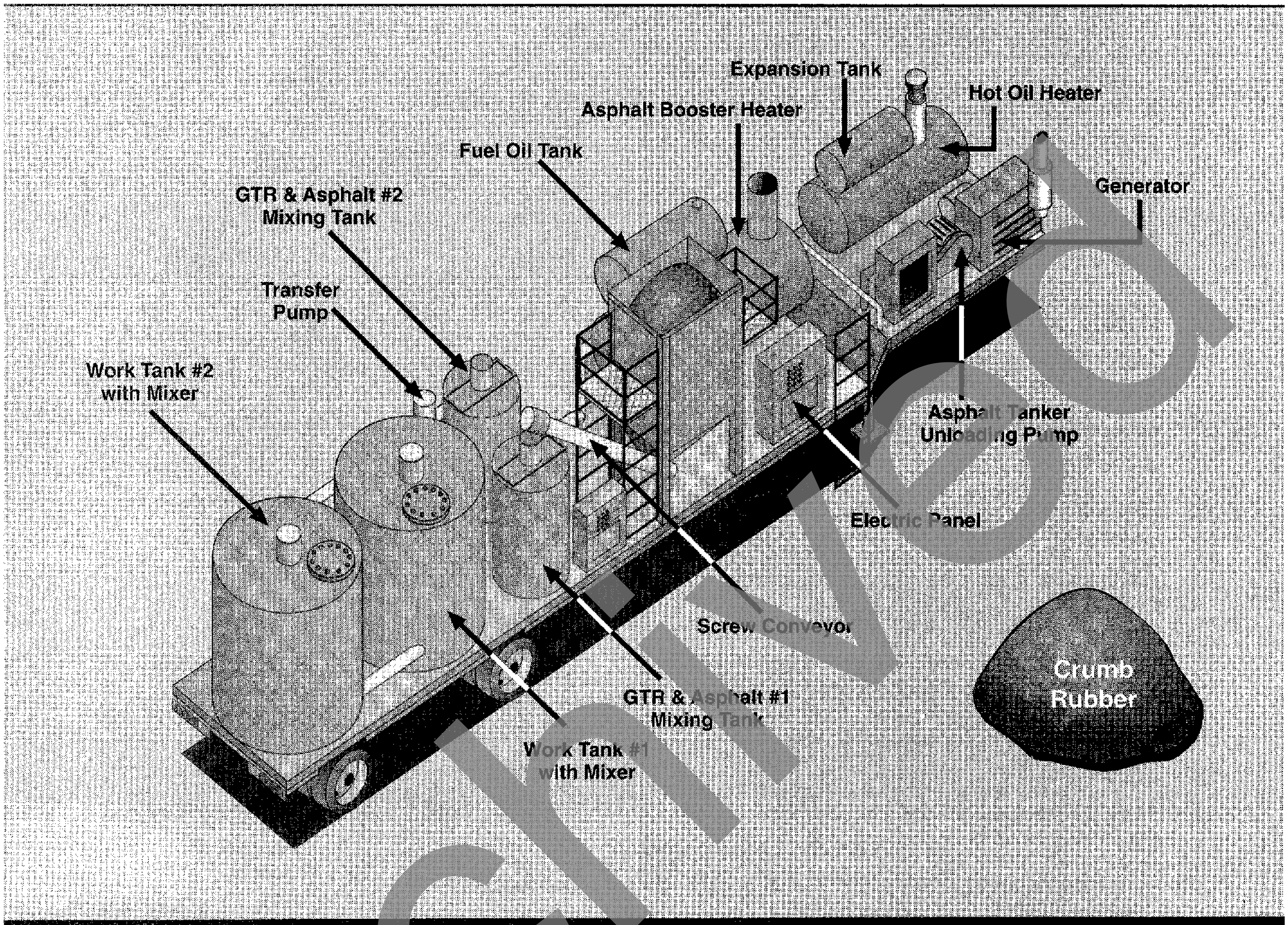


FIGURE 8

Schematic of HEATEC Crumb Rubber & Asphalt Mixing System



(70 gal/min). The percent rubber is controlled by adjusting the rate of the auger that feeds the rubber. The residence time for the asphalt-rubber blend in the mixing unit is approximately 15 minutes. The equipment can produce 22,704 liters (6,000 gallons) of reacted asphalt rubber in 1.5 hours.

Summary

Regardless of the type of blending operation used, the plant should be operated in such a way as to obtain a thorough and uniform mixture of the materials. This takes care and attention to details by the asphalt-rubber blender and the HMA contractor.

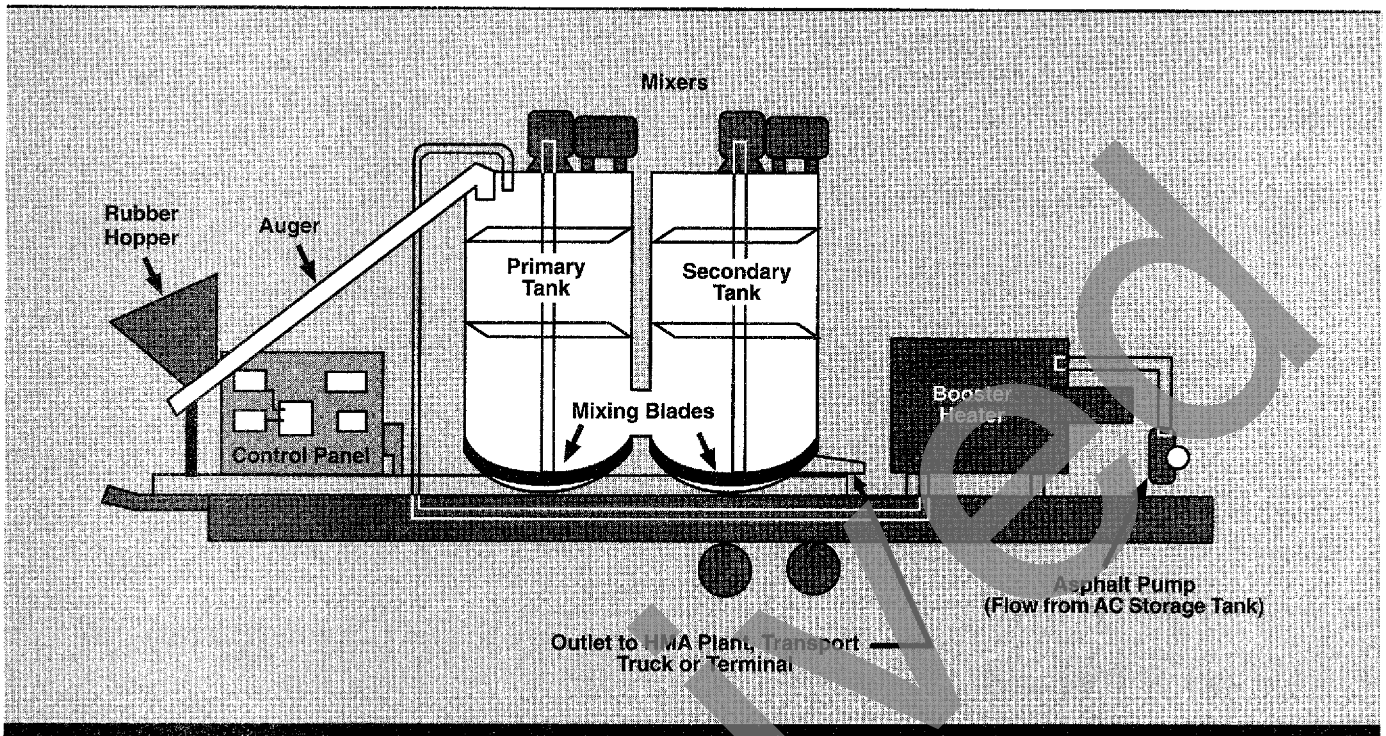
When an extended delay (greater than 6 hours) occurs before the binder can be used after the reaction has been achieved, the asphalt-rubber mix is normally allowed to cool to 110°C to 121°C (225°F to 250°F). It can be reheated slowly prior to its use to a temperature of between 150°C (300°F) and 190°C (375°F). It must be thoroughly mixed before pumping and metering into the HMA plant. The viscosity of the asphalt-rubber binder should be checked. If it is out of the desired range, the asphalt-rubber blend is adjusted by the addition of asphalt cement and/or ground tire rubber to provide the proper viscosity. The effect of extended delays (i.e., prolonged storage at elevated temperature) on performance is not well documented. If the asphalt-rubber blender uses a bin-type feed system for the CRM, steps must be taken to ensure that the material is free flowing. As was discussed earlier with regard to shipping, the rubber can clump and the chunks can plug up the gates and auger systems used to feed the mixing operation. Possible remedies include a vibrator on the bin or an individual who periodically sticks the material in the bin to keep it free flowing.

Operation of HMA Mixing Facility

The operation of the HMA mixing facility for the construction of wet-processed asphalt-rubber HMA mixes is unchanged from that used for conventional mixes, with the exception that the mix is produced at higher temperatures. The blending equipment or agitated nurse tanks can easily be hooked up to both the drum and batch plants. When a 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. The asphalt-rubber metering equipment is then attached to the valve to feed the asphalt-rubber accurately. When a batch plant is used, the valve is installed directly onto the supply line leading to the weigh bucket. Many times a separate supply line to the weigh bucket is installed. Separate pumps are used by the blending contractor to prevent damage to the HMA contractor's pumps. The asphalt rubber is generally more viscous than the asphalt cement; thus, these pumps are

FIGURE 9
Photograph of Rouse Blending System

FIGURE 10
Schematic of Rouse Blending System



generally larger than the standard pumps used on an HMA facility. Also, the pipes and supply lines need to be of sufficient diameter to allow the movement of a more viscous fluid. It may be necessary to employ jacketed and heated lines. There appears to be no problem with the asphalt-rubber material building up in lines or any requirements for unusual cleaning or flushing of equipment when asphalt-rubber HMA mixes are produced.

The transportation of the asphalt-rubber HMA mix can be accomplished in any truck typically used for the transportation of conventional HMA. During the visits, there was no indication of sticking or other problems associated with the trucking. Wetting agents for the truck beds should be either soapy water or silicone emulsions. Solvent-based wetting agents should not be used.

Placement/Handwork

The handling and placement of the CRM-HMA mix must be accomplished 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 of the surface on which it is placed should be warm. Arizona DOT requires that the surface be at least 26°C (80°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 an adverse effect upon the CRM-HMA mix.

The CRM-HMA mix delivered to the screed unit 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 tarpaulins, and/or dump the material directly into the paver rather than using pick-up devices. Pick-up devices have been used; but because of the temperature sensitivity of the material, they should be used with caution. One contractor suggested that the screed unit may need to be heated periodically to prevent buildup of the mix on the screed.

There can be pick-up of the HMA mix when the roadway is turned over to traffic. This can be addressed by lightly sanding the mix or by applying lime water to the surface.

Compaction

The viscosity and amount of asphalt binder in an HMA mix will affect the compactibility of the mix. The higher the viscosity of the binder, the stiffer the mix at a given temperature. Generally, the binder in an asphalt-rubber mix is stiffer than what the agency or the contractor is accustomed to. Asphalt-rubber mixes must be compacted while they are hot. Compaction is generally not a problem if the temperature is maintained. The criticality of the temperature increases as the rubber content increases. Arizona DOT requires that the temperature of the rubber-modified HMA be at least 135°C (275°F) just prior to compaction and that compaction be completed prior to the mix temperature reaching 104°C (220°F). A cautionary note: The presence of CRM may generate fumes and smoke at typical compaction temperatures.

The compaction can be accomplished with either vibratory or steel-wheel rollers. Pneumatic rollers should not be used, as the rubber-modified binder can pick up on the pneumatic wheels.

Costs of CRM Binder/Mix

The price of CRM asphalt cement and HMA varies from region to region. It will generally consist of the cost of the CRM material, the asphalt cement, and the costs of blending the material. As the CRM material is ground finer, the cost of the CRM will increase; and as the percentage of CRM in the asphalt cement increases, the cost of the asphalt-rubber binder will increase.

A survey of the suppliers of CRM material indicates that the approximate cost of the CRM at the CRM supplier's grinding plant varies with particle size. Typical costs are shown in table 7. Table 8 presents the typical cost of asphalt cement and asphalt rubber for each of the surveyed States. The prices described in table 8 reflect the reduction in the cost of asphalt-rubber binder since the patents expired. In Arizona in 1991 (the year before the patents expired), the average bid price was $400 per metric ton ($448 per ton). Florida

TABLE 7

Approximate Costs of the CRM at the CRM Supplier's Grinding Plant

Size	Cost
6.3 mm (1/4 in)	$0.18 to 0.31 per kg ($0.08 to 0.14 per lb)
2.0 mm (10 mesh)	$0.22 to 0.35 per kg ($0.10 to 0.16 per lb)
0.60/0.425 mm (30/40 mesh)	$0.37 to 0.46 per kg ($0.17 to 0.21 per lb)
0.180 mm (80 mesh)	$0.48 to 0.66 per kg ($0.22 to 0.30 per lb)

TABLE 8

Typical Cost of Asphalt Cement and Asphalt Rubber in Each of the Surveyed States

State	Asphalt Cement	5% 0.180 mm (80 mesh)	12% 0.425 mm (40 mesh)	17-22% 2 mm (10 mesh)
FL	$99/tonne ($110/ton)	$211/tonne ($233/ton)	—	—
	$99/tonne ($110/ton)	—	$197/tonne ($218/ton)	—
AZ	$108/tonne ($120/ton)	—	—	$245/tonne ($271/ton)
CA	$113/tonne ($125/ton)	—	—	$366/tonne[1] ($403/ton)

NOTE

1. Asphalt-rubber binder used for chip seals may be higher than AR binder used for HMA.

TABLE 9

Cost of the Various Asphalt-Rubber Mixes Used in Each of the Three Surveyed States

State	Type of Mix	Cost	
		Conventional	Asphalt Rubber
FL	Dense-graded friction course	$\$2.40/m^2$ ($\$2.06/yd^2$)	$\$2.71/m^2$ ($\$2.32/yd^2$)
	Open-graded friction course	$\$1.23/m^2$ ($\$1.05/yd^2$)	$\$1.47/m^2$ ($\$1.26/yd^2$)
AZ	Open-graded friction course	$\$1.68/m^2$ ($\$1.44/yd^2$)	$\$2.91/m^2$ ($\$2.50/yd^2$)
	Gap-graded mix	$\$.58/m^2/mm$ ($\$1.27/yd^2/in$)	$\$1.20/m^2/mm$ ($\$2.62/yd^2/in$)
CA	Dense-graded mix	$\$.91/m^2/mm$ ($\$1.98/yd^2/in$)	$\$1.22/m^2/mm$ ($\$2.66/yd^2/in$)
	Gap-graded mix	—	$\$1.44/m^2/mm$ ($\$3.14/yd^2/in$)
	Open-graded mix	$\$1.57/m^2$ ($\$1.35/yd^2$)	$\$2.79/m^2$ ($\$2.39/yd^2$)

reports that the cost of blending, etc., by the asphalt-rubber supplier is approximately \$4.50 per tonne (\$5.00 per ton).

Table 9 presents the cost of the various asphalt-rubber mixes used in each of the three surveyed States.The cost figures presented in table 9 should be used only as a guide for large quantities of asphalt-rubber binder. On projects that contain small amounts of asphalt-rubber binder (which reflects many of the projects being built), the prices can, and will, probably be considerably higher due to the cost of mobilization of the blending equipment. Also, it should be noted that the potential decrease in cost of CRM-HMA due to the use of thinner sections has not yet been addressed.

Summary

This chapter presented procedures used to blend the CRM with the asphalt, as well as mixing and placement procedures. Also presented are typical costs for the CRM, the asphalt-rubber binder, and the finished mix.

CHAPTER 5

Quality Control/Quality Assurance (QC/QA) Considerations

The purchasing agency (DOT or city or county) can use its standard HMA acceptance procedures with a few modifications. The source acceptance for the asphalt cement and the mineral aggregates will remain the same. Good volumetric quality control procedures should be followed. Some modifications will need to be made for the rubber, the asphalt-rubber binder, and the CRM-HMA mix.

In all three States surveyed, the purchasing agencies (cities, counties, or DOT's) require that the CRM supplier furnish the engineer-certified test results covering each shipment of material to each project. They also require that the certification include the manufacturer's batch or lot number. Some agencies do verification testing on the rubber gradation. They also require that the supplier furnish the agency with binder formulation and samples of all the materials to be used, at least 15 working days before construction. This binder formulation should include the following:

- The source and paving grade of the asphalt cement.
- The source and grade of any additives to the asphalt cement; for example, antistripping agents, extender oils, etc.
- The percentages of the asphalt cement and additives being used by total weight of the asphalt-rubber blend.
- The source and grade of CRM.
- The percentage of CRM by total weight of the asphalt-rubber blend.
- Brookfield (or Haake) viscosity of the blended material.

Asphalt Rubber

The production of asphalt rubber should be closely monitored. In each of the three States surveyed, the public agencies (and many of the contractors in those States) monitor the production of the asphalt-rubber blend using a portable viscometer. (See figure 11 for a photograph of a portable viscometer in operation in the field.) For batch-type processes, this test is run on each batch. In Arizona, and with some contractors in California, the trend is to run the ring and ball softening point (AASHTO Test Method T53-89), and cone penetration and resilience tests (ASTM Test Method D3407) on the blended asphalt rubber. The key to running the viscosity tests in the field is good temperature control during the tests. A small variation in the temperature could cause inaccurate test results that may result in changes in the process that are not required.

Insufficient data exist at this time to be able to quantify the variation in the test results from projects.

FIGURE 11
Photograph of Portable Viscometer in Operation

Asphalt-Rubber Content

Arizona and California utilize a nuclear asphalt content gauge that has been properly calibrated to monitor and control the asphalt-rubber binder content. They all reported problems with calibration. The Florida DOT conducted a study to evaluate the use of the extraction test to determine the binder content in an asphalt-rubber mix. They concluded that since a percentage of the rubber passes through the filter (the amount cannot be determined), the calculated binder content from the extraction test is not accurate.[13] Therefore, the Florida DOT determines asphalt rubber binder content based on certified meter readings at the HMA facility.

Aggregate Gradation

Standard extraction procedures (using either chlorinated or biodegradable solvents) can be used to determine the gradation of the aggregate. The Florida DOT found that even though some rubber particles are left in the extracted aggregate, their weight contribution to any particular sieve is small.[13]

CHAPTER 6

Performance

Arizona, California, and Florida all have several years' experience with CRM materials. In particular, Arizona and California placed numerous CRM-HMA overlays beginning in the late 1970's. Many of the early, experimental placements included SAM or SAMI layers and/or proprietary products. Florida DOT's work with CRM mixes began in 1989. CRM performance from each State is summarized below. Only performance history considered relevant to the use of CRM-HMA and currently available technologies are included.

Arizona

Arizona, arguably, has the longest sustained experience with CRM mixes of any State. Though many of their older projects used SAM's or SAMI's exclusively to mitigate reflection cracking, these products were expressly excluded from study in the current project, which focuses on traditional HMA sections and applications. Much of the CRM-HMA performance information available is from projects initiated in the late 1980's.[17]

Currently, the city of Phoenix uses significant quantities of gap-graded CRM mixes in overlays of residential streets. Prior to 1992, the CRM mixes used a patented asphalt-rubber binder. During the 1995 construction season about 26 km (16 mi) of CRM mix will be placed. Typical overlay thicknesses are 30 mm. Overall, performance is reported to be better than conventional mixes. Recently, some early reflection cracking has been reported.

Arizona DOT uses both open- and gap-graded mixes on existing rigid and flexible pavements. Open-graded mix overlays are generally less than 25 mm, whereas the gap-graded mixes are placed in thicknesses of about 50 mm. Since 1989, approximately 40 projects have been placed using open-graded mixes. All are reported to be in excellent condition. Of the 16 gap-graded mix projects placed since 1989, all are performing satisfactorily. Some bleeding (presumably due to over-asphalting) and premature reflective cracking has been reported on gap-graded mix projects.

California

California has performance history on CRM materials dating back to 1978. Both wet and dry process mixes have been placed over existing flexible and rigid pavements with and without SAMI's. Evaluation of these projects has led CALTRANS to use only asphalt-rubber (wet process) gap-graded and dense-graded mixes in nonexperimental work. Investigation of other CRM mix types is continuing; however, this work is limited.

Performance of dry mixes has been variable with potholing in some projects. The potholing was attributed to variation in rubber content. Older, wet-process mixes sometimes raveled or cracked prematurely. Some of this distress was associated with low binder contents, or, in one case, with overlay placement on an existing pavement that was too flexible. Rutting and bleeding has been reported on some newer gap-graded projects. The cause of these problems is being investigated.

It should be noted that although distresses have been reported (rutting, bleeding, and raveling), the majority of projects are performing well. CALTRANS reports improved durability, reflection crack control, and resistance to chain wear when asphalt-rubber hot mixes are used. Side-by-side performance comparison of thinner CRM and conventional overlays led CALTRANS to reduce required overlay thickness when CRM is used, as described in chapter 2.

Florida

Although Florida first placed CRM material in the 1970's, the bulk of their performance experience is limited to projects placed since 1989. Both open- and dense-graded friction course mixes are used. To date, performance has been good. Beginning in January 1994, all OGFC's and DGFC's require an asphalt-rubber binder. Florida DOT expects improved durability and better temperature susceptibility performance from the CRM mixes.

Summary

Performance of CRM mixes in these three States has generally been good overall. California and Arizona have longer performance records, particularly with wet process mixes. Occasional problems have been reported as being attributed to mix design problems (over- or under-asphalting), lack of contractor experience, and use of newer processes. The continued use of wet process CRM materials is perhaps the strongest indication of their satisfaction with CRM performance. (See table 10.)

TABLE 10
History of CRM-HMA Projects in Arizona, California, and Florida

Agency	First Use of HMA	Type of Mix	Estimated Total Number of Projects	Approximate Tonnage Since First Use	Proposed Tonnage in 1995
Arizona	1989	Gap-graded	16	212,000	50,000
	1975	Open-graded	41	470,000	150,000
California	1978	Gap-graded	76	820,000	200,000
		Dense-graded	35	180,000	15,000
Florida	1989	Dense-graded	255	726,000	400,000
		Open-graded	306	766,000	500,000

CHAPTER 7

Summary

This report summarizes the current CRM practices in HMA for the States of Arizona, California, and Florida. The major items addressed were:

- *Thickness design considerations.* Much of the use of CRM-HMA is as functional overlays. Only California utilizes a layer equivalency to reduce the thickness of the CRM-HMA.

- *Materials.* The different agencies generally use ambiently ground CRM with asphalts that will produce an asphalt-rubber binder with a certain viscosity. Dense-, open-, and gap-graded aggregates have been used.

- *Mix design considerations.* Arizona and Florida have modified the Marshall procedure to obtain their mix designs. California has modified the Hveem procedure. All have produced successful mixes.

- *Construction process.* The addition of CRM in HMA makes use of much of the equipment used for conventional mixes. However, there is an additional requirement for a blending/reaction vessel and some increases in mixing temperatures.

- *Costs.* The increased cost of the CRM-HMA (compared with conventional HMA) ranges from as little as 15 percent (in Florida) to 70± percent in Arizona, depending on the mix type.

- *Quality control.* This issue is an important one. The uniformity of the asphalt rubber is generally checked using viscosity tests; however, there is a definite need for improved procedures to evaluate the binder uniformity as well as the mix properties.

- *Performance.* All agencies feel they are obtaining an added value. However, inadequate data are available to quantify these benefits.

APPENDIX

A Glossary

Terms associated with waste tires and crumb rubber modifier have been defined by the Federal Highway Administration (FHWA),[14] ASTM, Lagrone,[15] and Witczak.[16] These terms as defined by these authors are given below in a consolidated glossary.

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. Diluents are not used routinely.

Asphalt rubber—asphalt cement modified with crumb rubber modifier.

Asphalt-rubber blend—a blend of ground tire rubber (generally finely 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 26 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. The "blend" can be used as the binder in chip seals, seal-slurry coats, and dense- or open-graded asphalt hot-mix construction. When used in this manner, the aggregate gradation can generally conform to typical gradings used with conventional asphaltic concrete mixes. Asphalt-rubber blends can be produced directly at the plant site by adding ground rubber (18 to 26 percent) to the appropriate asphalt cement, and applying heat (190°C to 218°C [375°F to 425°F]) for 1 to 2 hours. Special equipment in the form of mixing chambers, reactor and blending tanks, and oversized pumps are needed. Two types of commercially available asphalt-rubber blends are used frequently: McDonald-Sahuaro (Crafco) process, and ARCO-ARM-R-SHIELD (Arizona refining process).

Asphalt-rubber concrete—implies the use of an asphalt-rubber blend (binder) with dense-graded aggregates 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 which is a byproduct from the conditioning of tire carcasses in preparation for retreading.

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.

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.

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).

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.

Rubber-modified friction course—a hot-mix asphalt mixture with open-graded aggregates using a rubber-modified asphalt.

Rubber-modified hot-mix asphalt—hot-mix asphalt mixture that incorporates crumb rubber modifier primarily as rubber aggregate.

Rubberized asphalt—same meaning as **wet process.**

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 6 and 9 mm (1/4 and 3/8 in).

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.

TLS—the abbreviation for three-layer system. It was 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 between 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. Early in the development of this system, other asphaltic mixes (e.g., dense-graded asphaltic concrete) were used in lieu of the open-graded 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.

APPENDIX B

CRM Suppliers for Arizona, California, and Florida

Arizona/California

Atlos Rubber, Inc.
1522 Fishburn Avenue
Los Angeles, CA 90063
213-266-4570

Baker Rubber Southwest
11400 E. Pecos Road
Queen Creek, AZ 85242
602-987-3006

BAS Recycling Inc.
1400 N. "H" St.
San Bernardino, CA 92405
909-383-7050

Florida

American Tire Recyclers, Inc.
302 N. Lane Ave.
Jacksonville, FL 32254
904-786-5200

Rouse Rubber Industries, Inc.
1000 Rubber Way
Vicksburg, MS 39182-0369
601-636-7141

APPENDIX C

List of CRM Blenders for Arizona, California, and Florida

Arizona

Cox Paving Company, Inc.
P.O. Box 519
Blanco, TX 78606
210-833-4547

FNF Construction
P.O. Box 5005
Tempe, AZ 85280-5005
602-784-2910

International Surfacing, Inc. (ISI)
6751 W. Galveston
Chandler, AZ 85226
602-268-0874

California

FNF Construction
P.O. Box 5005
Tempe, AZ 85280-5005
602-784-2910

Granite Construction Co.
38,000 Monroe St.
Indio, CA 92203
619-775-7500

Manhole Adjusting Contractors, Inc.
P.O. Box 250
Monterey Park, CA 91754
213-725-1387

Silvia Construction, Inc.
2209 Arrow Route
Upland, CA 91786
909-949-1127

Florida

Anderson Columbia Co., Inc.
P.O. Box 1829
Lake City, FL 32056-1829
904-752-7585

Bitcom
3111 University Drive
Suite 1000
Coral Springs, FL 33065
305-753-6501

Blacklidge Emulsions
P.O. Box 76799
Tampa, FL 33675
813-247-5699

Martin Paving
1801 S. Nova Rd.
South Daytona, FL 32119
904-752-7585

APPENDIX

D Typical Specifications

Arizona Department of Transportation

Item 4070040—Asph. Conc. Friction Course (Asphalt-Rubber):

Description:

Asphaltic Concrete Friction Course (Asphalt-Rubber), hereinafter asphaltic concrete, shall consist of furnishing all materials, mixing at a plant, hauling, and placing a mixture of aggregate materials, mineral admixture if required, and bituminous material (asphalt-rubber) to form a pavement course or to be used for other specified purposes, in accordance with the details shown on the project plans and the requirements of these specifications, and as directed by the Engineer.

The contractor shall be responsible for all adjustments to his equipment necessary to properly accommodate the use of asphalt-rubber as a bituminous material.

Asphaltic Concrete Mix Design Criteria:

Mix designs will be performed in accordance with Arizona Test Method 814, modified as necessary for Asphaltic Concrete Friction Course (Asphalt-Rubber). The allowable range of percent absorbed asphalt-rubber shall be 0-1.0, when tested in accordance with the applicable section of Arizona Test Method 815.

Materials:

For comparative purposes, quantities shown in the bidding schedule have been calculated based on the following data:

Asphaltic Concrete

Spread Rate, Pounds per Square Yard	xxx
Percent, Bituminous Material	xxx

The spread rate specified includes XX percent for leveling to provide a minimum 1/2-inch thickness; however, the exact spread rate will be determined by the Engineer.

Mineral Aggregate Source:

There is no Department-furnished source of mineral aggregate. The contractor shall provide a source in accordance with the requirements of Section 1001 of the Standard Specifications.

When the contractor selects a source or sources, he shall notify the Engineer. The contractor shall be solely responsible for assuring that the mineral aggregate meets all requirements and, when processed, is fully capable of providing asphaltic concrete which meets all the requirements of these specifications.

Mineral Aggregate:

Coarse mineral aggregate shall consist of crushed gravel, crushed rock, or other approved inert materials with similar characteristics, or a combination thereof, conforming to the requirements of these specifications.

Fine mineral aggregate shall be obtained from crushed gravel or crushed rock. All uncrushed material passing the No. 4 sieve shall be removed prior to the crushing, screening, and washing operations necessary to produce the specified gradation. The contractor shall notify the Engineer a minimum of 48 hours in advance of crushing the material to be used as mineral aggregate, so all crushing operations are inspected. Existing stockpile material which has not been inspected during crushing will not be permitted for use. Any material inspected by the Department as crushed material shall be separated from the contractors other stockpiles and reserved for use by the Department.

Mineral aggregate shall be separated into two stockpiles. The Engineer may approve changes to the specified stockpile gradations, provided he determines that a suitable composite gradation is obtainable. The gradation of each stockpile shall conform to the requirements in Table 1.
The proportions of mineral aggregate material from each stockpile necessary to provide a mixture which is expected to provide a suitable composite gradation are as follows:

Mineral Aggregate	Percent
Coarse	95
Fine	5

TABLE 1

Mineral Aggregate Stockpile Grading Limits

Stockpile	Sieve Size	Percent Passing
Coarse	3/8"	100
	1/4"	45-80
	No. 4	25-45
	No. 8	0-10
	No. 200	0-1.5
Fine	1/4"	100
	No. 8	80-100
	No. 40	15-35
	No. 200	0-4.0

NOTE

1. In order to meet this gradation, washing of the fine material may be required.

The exact percentage of material from each stockpile will depend upon the actual gradation of the mineral aggregate in each stockpile and may vary from the amount indicated. No additional payment will be made for changes in proportional use of mineral aggregate stockpiles from the targets specified.

Mineral aggregate shall conform to the requirements in Table 2 when tested in accordance with the applicable test methods.

Tests on aggregates outlined in Table 2, other than abrasion, shall be performed on materials furnished for mix design purposes and composited to the mix design gradation. Abrasion shall be performed separately on samples from each source of mineral aggregate. All sources shall meet the requirements for abrasion.

Mineral Admixture:

Where the average elevation of the project is over 3500 feet, an approved mineral admixture will be required. The amount shall be one percent, by weight of the mineral aggregate and shall be either portland cement type II or hydrated lime, conforming to the requirements of Table 3.

TABLE 2

Mineral Aggregate Characteristics

Characteristic	Test Method	Requirement
Combined Bulk Specific Gravity	Arizona Test Method 814	2.35-2.85
Combined Water Absorption	Arizona Test Method 814	0-2.5
Sand Equivalent	Arizona Test Method 242	Minimum 55
Crushed Faces	Arizona Test Method 212	Minimum 70%
Flakiness Index	Arizona Test Method 233	Maximum 25
Percent Carbonates in Aggregate	Arizona Test Method 238	Maximum 30%
Abrasion	AASHTO T-96	100 Rev., Max. 9% 500 Rev., Max. 40%

TABLE 3

Mineral Admixture

Material	Requirement
Portland Cement, Type II	ASTM C-150
Hydrated Lime	ASTM C-1097

Bituminous Material:

Bituminous material shall be asphalt-rubber (vulcanized) conforming to the requirements of Section 1009 of the Standard Specifications, except for the following:

The rubber shall conform to the following gradation:

Sieve Size	Percent Passing
No. 10	100
No. 16	75-100
No. 30	25-100
No. 50	0-45
No. 100	0-10
No. 200	0-5

The asphalt-rubber shall conform to the following:

Parameter	Requirement
Viscosity, Haake, 350°F	1500-4000 centipoise
Cone Penetration, 77°F (ASTM D-1191)	minimum of 20
Softening Point, °F (ASTM D-36)	125° F minimum
Resilience, 77°F (ASTM D-3407)	15% minimum

The asphalt cement shall be modified by the addition of a minimum of 20 percent of granulated rubber, by weight of the asphalt, unless otherwise approved by the Department's Central Laboratory.

During the production of asphalt-rubber, the contractor shall maintain at the plant site equipment necessary to measure the viscosity. The asphalt-rubber shall be maintained between 1500 and 4000 centipoise at 350°F. The viscosity shall be checked at the direction of the Engineer.

In no case shall the asphalt-rubber be diluted with extender oil, kerosene, or other solvents. Any asphalt-rubber so contaminated shall be rejected.

Any kerosene or other solvents used in the cleaning of equipment shall be purged from the system prior to any subsequent use of that equipment.

The asphalt cement and rubber shall be blended for a period of at least one hour prior to mixing with the mineral aggregate and mineral admixture; however, the mixture of asphalt cement and rubber shall not be held at temperatures over 350°F for a period over 10 hours. The temperature of the asphalt cement shall be between 350 and 400°F at the addition of the granulated rubber. Temperature of the asphalt-rubber shall be maintained between 325 and 375°F during the one-hour reaction period.

At the end of each shift, the contractor shall provide the Engineer with documentation on the production of asphalt-rubber, which includes the following:

1. The amount and temperature of the asphalt cement prior to the addition of rubber.
2. The amount (bags) of rubber added.
3. The viscosity of the asphalt-rubber just prior to the mixing with the aggregate and mineral admixture.
4. The time of the rubber additions and viscosity tests.

Mix Design:

Approximately 200 pounds of produced mineral aggregate, in proportion to the anticipated percent usage, shall be obtained by the contractor and witnessed by the Engineer so that both parties are satisfied that samples are representative of the mineral aggregate to be utilized in the asphaltic concrete production.

The contractor shall also furnish one full bag (as packaged by the supplier) of the granulated rubber proposed for use, one gallon of asphalt cement from the intended supplier, two gallons of the proposed mixture of asphalt and rubber, and, if mineral admixture is required, a one-gallon can of the mineral admixture to be used in the asphaltic concrete.

Along with the samples furnished for mix design testing, the contractor shall submit a letter explaining in detail his methods of producing mineral aggregate including wasting, washing, blending, proportioning, etc., and any special or limiting conditions he may propose. His letter shall also state the source(s) of mineral aggregate, the source of asphalt cement and granulated rubber, the asphalt-rubber supplier, and, if required, the source and type of mineral admixture.

Within 10 working days of receipt of all samples and the contractor's letter in the Central Laboratory, the Department will provide the contractor with the percentage of asphalt-rubber to be used in the mix, the percentage to be used from each of the stockpiles of mineral aggregate, the composite mineral aggregate gradation, and any special or limiting conditions for the use of the mix.

Mix Design Revisions:

The contractor shall not significantly change his methods of crushing, screening, or stockpiling from that used during production of material used for mix design purposes without approval of the Engineer, or requesting a new mix design. Significant changes may include changes in the amount or type of materials rejected or wasted, changes in the amount of materials crushed, or reduction in the amount of crushed fines.

During production of asphaltic concrete, the contractor, on the basis of field test results, may request a change to the approved mix design. The Engineer will evaluate the proposed changes and notify the contractor of his decision within two working days of the receipt of the request.

If, at any time, unapproved changes are made in the source of bituminous material, source(s) of mineral aggregate, or proportional changes in violation of approved mix design stipulations, production shall cease until a new mix design is developed, or the contractor complies with the approved mix design.

At any time after the mix design has been approved, the contractor may request a new mix design.

The costs associated with the testing of materials in the developing of mix designs after a mix design acceptable to the Department has been developed shall be borne by the contractor.

If, during production, the Engineer on the basis of testing, determines that a change in the mix design is necessary, he will issue a revised mix design. Should these changes require revisions to the contractor's operations which result in additional cost to the contractor, he will be reimbursed for these costs. However, the Engineer reserves the right to modify the asphalt-rubber content without compensation being made to the contractor involving additional operation costs.

Acceptance of Materials:

General:

The contractor's attention is directed to the requirements of the Standard Specifications under Subsection 105.12—Removal of Unacceptable and Unauthorized Work.

If the production of asphaltic concrete is stopped either for failure to meet the requirements specified hereinafter under Asphaltic Concrete, or because changes are made in the mix design, samples will be taken for calculating new consecutive averages either after production resumes or after the changes in the mix design have been made. The acceptance of the mineral aggregate gradation and the bituminous material content will be determined on the basis of the tests as hereinafter specified under Asphaltic Concrete. The Engineer reserves the right to increase the frequency of sampling and testing upon the resumption of asphaltic concrete production.

Mineral Aggregate:

Aggregate shall be free of deleterious materials, clay balls, and adhering films or other material that prevent the thorough coating with the bituminous material.

At the direction of, and witnessed by an authorized representative of the Engineer, the contractor shall secure one representative sample of each day's production from each stockpile. These samples will be tested for conformance with the mineral aggregate gradation in accordance with the requirements of Arizona Test Method 201. These samples will also be composited to the specified stockpile percentages by the Engineer and tested for sand equivalent in accordance with Arizona Test Method 242, the percent of crushed faces in accordance with the requirements of Arizona Test Method 212, and flakiness index in accordance with the requirements of Arizona Test Method 233.

Should testing indicate results not meeting the requirements of Table 1 for gradation, and Table 2 for sand equivalent, crushed faces, and flakiness index, material represented by failing test results will be rejected.

Asphaltic Concrete:

(A) Mineral Aggregate Gradation:

For each approximate 500 tons of asphaltic concrete, at least one sample of mineral aggregate will be taken. *Samples will be taken in* accordance with the requirements of Arizona Test Method 105 on a random basis, by means of a sampling device which is capable of producing samples which are representative of the mineral aggregate. The device, which shall be approved by the Engineer, shall be furnished by the contractor. In any shift when the production of asphaltic concrete is less than 500 tons, at least one sample will be taken.

Samples will be tested for conformance with the mix design gradation in accordance with the requirements of Arizona Test Method 201. If mineral admixture is required, and the sample does not include mineral admixture, the gradation results will be adjusted to reflect the addition of mineral admixture.

The gradation of the mineral aggregate, including mineral admixture if required, will be considered to be acceptable, unless the average of any three consecutive tests or the result of any single test varies from the mix design gradation percentages as follows:

Passing Sieve	Acceptable Variation in Test(s) (Percent) Avg. of 3 Consecutive	Single
No. 4	± 4	± 6
No. 8	± 3	± 4
No. 200	± 1.0	± 1.5

One hundred percent of the material shall pass the largest sieve size shown in Table 1.

At any time that test results indicate that the gradation of the mineral aggregate, including mineral admixture if required, does not fall within all of the limits indicated, the production of asphaltic concrete shall cease immediately and shall not begin again until a calibration test indicates that the gradation is within the three consecutive test limits indicated.

(B) Asphalt-Rubber Content:

During production of asphaltic concrete, the contractor shall maintain at the plant site a nuclear asphalt content gauge calibrated in accordance with the gauge manufacturer's recommendations, on the material being tested. Asphalt-rubber content shall be measured by the contractor by means of the *nuclear asphalt content gauge a* minimum of four times per full shift. Production of asphaltic concrete shall cease immediately and the plant re-calibrated if the Engineer determines the percent of asphalt-rubber has varied by an amount greater than ±0.5 percent from the amount directed by the Engineer.

Construction Requirements:

Quality Control:

Quality control shall be the responsibility of the contractor. The Engineer reserves the right to obtain samples of any portion of any material at any point of the operations for his own use.

Stockpiling:

The contractor will not be allowed to feed the hot plant from stockpiles containing less than two full days of production unless only two days production remain to be done or special conditions exist where the Engineer deems this requirement waived.

Mineral aggregate shall be separated and stockpiled so that segregation is minimized. An approved divider of sufficient size to prevent intermingling of stockpiles shall be provided.

Proportioning:

The contractor shall provide documentation by calibration charts or other approved means that the mineral aggregate, asphalt-rubber, and mineral admixture if required, are being proportioned in accordance with the approved mix design.

Changes in stockpile use in excess of five percent from the approved mix design will not be permitted without the approval of the Engineer.

Mineral admixture, if required, shall be mechanically mixed with the mineral aggregate prior to combining the mineral aggregate and asphalt-rubber. The Engineer may direct a spray of water be applied either to control the loss of the mineral admixture or to comply with any mix design requirements for wet mixing of the aggregate and admixture.

If a drum mix plant is used, the mineral admixture shall be added and thoroughly mixed by means of a mechanical mixing device prior to the mixture entering the drum drier. The mineral admixture shall be weighed across a weigh belt or an approved alternative weighing system, with a weight totalizer prior to entry into the mechanical mixing device. The mechanical mixing device shall be a pugmill type mixer consisting of at least two motorized shafts with mixing paddles. The mixing device shall be designed such that the mixture of aggregate and admixture is moved in a near horizontal direction by the mixing paddles without the aid of conveyor belts for a distance of at least 3 feet. Mixing devices which permit the mixture of aggregate and admixture to fall through mixing blades onto a belt or chute are not acceptable. The mixing devices' rated capacity in tons per hour shall not be exceeded by the rate of material feed to the mixer. The mixer shall be constructed to prevent the leakage of the contents. The mixer shall be located in the system at a location where the mixed material can be readily inspected on a belt prior to entry into the drum. The mixing device shall be capable of effective mixing in the full range of asphaltic concrete production rates.

A positive signal system and a limit switch device shall be installed in the plant at the point of introduction of the admixture. The positive signal system shall be placed between the metering device and the drum drier, and utilized during production whereby the plant shall automatically be stopped if the admixture is not being introduced into the mixture.

If a batch plant is used, the mineral admixture shall be added and thoroughly mixed in the pugmill prior to adding asphalt-rubber.

The contractor shall furnish daily documentation to the Engineer that the required amount of mineral admixture has been incorporated into the asphaltic concrete.

No fine material which has been collected in the dust collection system shall be returned to the mixture unless the Engineer, on the basis of tests, determines that all or a portion of the collected fines can be utilized. If the Engineer so determines, he will authorize in writing the utilization of a specific proportion of the fines; however, authorization will not be granted unless the collected fines are uniformly metered into the mixture.

Mineral aggregate, mineral admixture, and asphalt-rubber shall be proportioned by volume, by weight, or by a combination of volume and weight.

When mineral aggregate, mineral admixture, and asphalt-rubber are proportioned by weight, all boxes, hoppers, buckets, or similar receptacles used for weighing materials, together with scales of any kind used in batching materials, shall be insulated against the vibration or movement of the rest of the plant due to the operation of any equipment so that the error in weighing with the entire plant operating shall not exceed two percent for any setting nor one and one half percent for any batch. Bituminous material shall be weighed in a heated, insulated bucket suspended from a springless dial scale system.

When mineral aggregate, mineral admixture, and asphalt-rubber are proportioned by volume, the correct portion of each mineral aggregate size introduced into the mixture shall be drawn from the storage bins by an approved type of continuous feeder which will supply the correct amount of mineral aggregate in proportion to the bituminous material and so arranged that the proportion of each mineral aggregate size can be separately adjusted. The continuous feeder for the mineral aggregate shall be mechanically or electrically actuated.

The introduction of asphalt-rubber shall be controlled by an automated system fully integrated with the controls for mineral aggregate and mineral admixture.

Drying and Heating:

A recording pyrometer or other approved recording thermometric instrument sensitive to a rate of temperature change not less than 10°F per minute shall be so placed at the discharge chute of the drier in order to record automatically the temperature of the asphaltic concrete or mineral aggregate. A copy of the recording shall be given to the Engineer at the end of each shift.

The moisture content of the asphaltic concrete immediately behind the paver shall not exceed one percent. The moisture content will be determined in accordance with Arizona Test Method 406. Drying and heating shall be accomplished in such a manner as to preclude the mineral aggregate from becoming coated with fuel oil or carbon.

Mixing:

The production of the plant shall be governed by the rate required to obtain a thorough and uniform mixture of the materials. Mixing shall continue until the uniformity of coating, when tested in accordance with the requirements of AASHTO T-195, is at least 95 percent.

A positive signal system shall be provided to indicate the low level of mineral aggregate in the bins. The plant will not be permitted to operate unless this signal system is in good working condition. Each bin shall have an overflow chute or a divider to prevent material from spilling into adjacent bins.

The temperature of asphaltic concrete upon discharge from the mixer shall not exceed 350°F. If the asphaltic concrete is discharged from the mixer into a hopper, the hopper shall be constructed so the segregation of the asphaltic concrete will be minimized.

Placing and Finishing:

(A) General Requirements:

The handling of asphaltic concrete shall at all times be such as to minimize segregation. Any asphaltic concrete which displays segregation shall be removed and replaced.

Before asphaltic concrete is placed, the surface to be paved shall be cleaned of all objectionable material and tacked in accordance with the requirements of Section 404 of the Standard Specifications. The cleaning of the surface, the tacking of the surface, and the amount and grade of asphalt cement used shall be as directed by and acceptable to the Engineer.

Unless otherwise specified on the project plans, asphaltic concrete shall not be placed on the two foot widened section where guard rail is to be installed.

Dates and Surface Temperature:

Asphaltic concrete shall be placed between the dates shown as applicable to the average elevation of the project and within these dates only when the temperature of the surface on which the asphaltic concrete is to be placed is at least 80°F.

Despite a surface temperature of 80°F, the Engineer, at any time, may require that the work cease or that the work day be reduced in the event of weather conditions either existing or expected which would have an adverse effect upon the asphaltic concrete.

Average Elevation of Project, feet	Beginning and Ending Dates
0 - 3499	February 15-May 31
0 - 3499	September 1-December 15
3500 - 4999	April 1-October 31
5000 and over	May 1-September 30

Delivery to Screed Unit:

Asphaltic concrete delivered to the screed unit shall be a free flowing, homogeneous mass in which there is no segregation, crusts, lumps, or migration of the asphalt-rubber.

Should any one or more of such conditions be evident in the material delivered to the screed unit, and which cannot be eliminated by one or more of the following methods, the Engineer will order the work to be stopped until conditions are conducive to the delivery of the material in the condition as hereinbefore required:

1) Covering hauling units with tarpaulins.
2) Dumping material directly into the paver.
3) Moving the hot plant nearer to the point of delivery.

Other measures proposed by the contractor which will deliver asphaltic concrete meeting the above requirements will be considered by the Engineer.

(B) Loading Asphaltic Concrete into the Paving Machine:

If the asphaltic concrete is dumped from the hauling vehicles directly into the paving machine from trucks, care shall be taken to avoid jarring the machine or moving it out of alignment. No vertical load shall be exerted on the paving machine by the trucks. Trucks, while dumping, shall be securely attached to the paving machine.

If the asphaltic concrete is dumped upon the surface being paved and subsequently loaded into the paving machine, it shall not be dumped at a distance greater than 150 feet in front of the paving machine. The loading equipment shall be self-supporting and shall not exert any vertical load on the paving machine. Substantially all of the asphaltic concrete shall be picked up and loaded into the paving machine.

(C) Placing and Finishing Asphaltic Concrete by Means of Self-Propelled Paving Machines:

All courses of asphaltic concrete shall be placed and finished by means of self-propelled paving machines except under certain conditions or at certain locations where the Engineer deems the use of self-propelled paving machines impractical.

In order to achieve, as far as practical, a continuous operation, the speed of the paving machine shall be coordinated with the production of the plant. If the paving machine is stopped for more than three minutes, or there is a three minute or longer interval between the completion of delivery by one truck and the beginning of delivery by the next truck, the paving machine shall be pulled away from the mat in order for the rollers to compact this area in accordance with the temperature limitations given hereinafter under Compaction, (C) Rolling Procedure. A transverse construction joint shall be made by a method approved by the Engineer.

Self-propelled paving machines shall spread the mixture without segregation or tearing within the specified tolerances, true to the line, grade, and crown indicated on the project plans. Pavers shall be equipped with hoppers and augers which will distribute the mixture uniformly in front of adjustable screeds.

Screeds shall include any strike-off device operated by tamping or vibrating action which is effective without tearing, shoving, or gouging the mixture and which produces a course with a uniform texture and density for the full width being paved. Screeds shall be adjustable as to height and crown and shall be equipped with a controlled heating device for use when required.

Tapered sections not exceeding eight feet in width, or widened sections not exceeding four feet in width may be placed and finished by other means approved by the Engineer.

(D) Automatically Actuated Control System:

Except under certain conditions or at certain locations where the Engineer deems the use of automatic controls impracticable, all courses of asphaltic concrete shall be placed and finished by means of self-propelled paving machines equipped with an automatically actuated control system.

The control system shall control the elevation of the screed at each end by controlling the elevation of one end directly and the other end indirectly either through controlling the transverse slope or alternately when directed, by controlling the elevation of each end independently.

The control system shall be capable of working with the following devices, which shall be furnished with the machine:

Ski-type device at least 30 feet in length, supported throughout its entire length.

Short ski.

Failure of the control system to function properly shall be cause for the suspension of the asphaltic concrete operations.

Joints:

The contractor shall schedule his paving operations to minimize exposed longitudinal edges. Unless otherwise approved by the Engineer, the contractor shall limit the placement of asphaltic concrete courses, in advance of adjacent courses, to one shift of asphaltic concrete production. The contractor shall schedule his paving operations in such a manner to eliminate exposed longitudinal edges over weekends or holidays.

Longitudinal joints shall be located within one foot of the centerline between two adjacent lanes.

Before a surface course is placed in contact with a cold traverse construction joint, the cold existing asphaltic concrete shall be trimmed to a vertical face by cutting the existing asphaltic concrete back for its full depth and exposing a fresh face. After placement and finishing of the new asphaltic concrete, both sides of the joint shall be dense and the joint shall be well sealed. The surface in the area of the joint shall conform to the requirements hereinafter specified for surface tolerances when tested with the straightedge placed across the joint.

Compaction:

(A) General Requirements:

The temperature of asphaltic concrete just prior to compaction shall be at least 275°F.

The wheels of compactors shall be wetted with water or, if necessary, soapy water to prevent mix pick-up during rolling. The Engineer may change the rolling procedure if in his judgement the change is necessary to prevent picking up of the asphaltic concrete.

(B) Equipment:

A minimum of three static steel wheel compactors shall be provided. The drums shall be of sufficient width that when staggered, two compactors can cover the entire width of the ribbon with one pass.

The compactors shall weigh not less than eight tons.

The compactors shall be self-propelled and shall be operated with the drive wheel in the forward position. Vibratory rollers may be used in the static mode only. All rollers shall be equipped with pads and a watering system to prevent sticking of the asphaltic concrete mix to the steel wheels.

(C) Rolling Procedure:

Two compactors shall be used for initial breakdown and be maintained no more than 300 feet behind the paving machine. The remaining compactor shall follow as closely behind the initial breakdown as possible. As many passes as is possible shall be made with the compactors before the temperature of the asphaltic concrete falls below 220°F.

Pavement Smoothness Requirements and Tolerances:

(A) General:

Asphaltic concrete shall be compacted as required, smooth and reasonably true to the required lines, grades, and dimensions.

The final pavement surface shall be evaluated for smoothness by testing.

Past experiences have shown that the following practices have contributed to smooth pavements:

> Keeping a constant head of hot mix material in front of the screed. Not letting the truck bump the paver. Running the paver continuously at a speed which matches the asphalt delivery. Avoid stopping the paver. Exercising care in making transverse joints. Using a uniform, consistent mix, and avoiding segregation at any point.

Some newer techniques and systems for placing the material that can improve pavement smoothness are:

> Precision controls to maintain a proper head of material, maintaining uniformity in both consistency and volume. Infinitely variable auger-conveyer speeds to match paver speed and thickness requirements. Power adjustable auger height to provide "on-the-go" control. Ultrasonic sensing systems to check automatically for material height and signal the auger and conveyer drive to keep correct head of material. Three-point suspension systems and hydraulic drives. Mix temperatures maintained within a narrow range.

Some compaction techniques and systems for improving smoothness include:

> Edge compactors to compact mat edges more efficiently. Edge cutters to trim mat edges in preparation for paving additional lanes, thereby promoting smoother longitudinal joints. Heavier/larger rollers to "break down" thicker lifts. Solid state controls for speed, direction, frequency, and amplitude to promote more efficient compaction and smoother surfaces. Use of higher frequency ranges and the ability to match amplitude and frequency to production densification at higher production rates.

However, the contractor may need to adopt innovative or state-of-the-art techniques to achieve an incentive payment.

The U.S. Army Corps of Engineers distributes the *Handbook of Hot-Mix Asphalt Paving*, which presents some advanced pavement techniques the contractor may elect to use to achieve greater smoothness. The handbook was jointly prepared by the American Association of State Highway and Transportation Officials (AASHTO), the Federal Aviation Administration (FAA), Federal Highway Administration (FHWA), National Asphalt Pavement Association, U.S. Army Corps of Engineers, American Public Works Association (APWA), and National Association of County Engineers. A copy is available for reference at the ADOT Materials Section, 1221 North 21st Avenue, Phoenix, Arizona 85009-3740.

This document is available from the Federal Aviation Administration Advisory Circular AC 150/5370-14 and from the U.S. Army Corps of Engineers Publication UN-13 (CEMP-ET). In addition, the National Asphalt Pavement Association has available information on pavement smoothness, including *Information Series 111, Pavement Smoothness.*

(B) Testing:

Testing will be performed by the Department in accordance with the provisions of Arizona Test Method 829. At the completion of mainline paving, the contractor shall notify the Engineer in writing that the pavement is ready for testing. The Engineer will then evaluate the roadway. If the Engineer determines that additional roadway preparation is required, the contractor shall perform such preparation as directed by the Engineer. The contractor shall ensure that the road can be driven safely at the design speed. If requested by the Engineer, the contractor shall broom the pavement immediately prior to testing. No measurement or direct payment will be made for preparing the roadway, the cost being considered as included in the price of contract items.

The testing will be performed within seven days after the Engineer has accepted the roadway for testing. The Engineer will notify the contractor of the test results no later than 7 days after the testing has been performed.

Testing will be done on mainline traffic lanes only, and will include the full length of the pavement placed under the contract. Distress lanes, shoulders, ramps, tapers, cross roads, and frontage roads will not be tested. Testing will not be performed on any portions that cannot be made safe for testing at the design speed, or on any lanes of less than 0.30 mile in length.

Testing will not be done when the ambient air temperature is less than 40°F or during rain or other weather conditions determined to be inclement by the Engineer.

The existing roadway has the following smoothness values (Mays-Meter inches per mile):

****Substitute Headings and 0.1 Mile Profilometer*****
****Survey Data if Available*****

	XXXXXbound	XXXXXbound
High	XX	XX
Low	XX	XX
Average	XX	XX

Any 0.1 lane-mile increment having an Actual Smoothness (AS) equal to or greater than the Correction Value (CV) shall be repaired. Upon completion of the repairs, the 0.1 lane-mile increment containing the repaired area will be re-tested.

The Correction Value (CV) for this contract is 100 inches per mile.

If repairs are required, the contractor shall prepare a written repair proposal detailing corrective actions and submit the proposal to the Engineer within 10 working days after the contractor's receipt of test results. Within three working days, the Engineer will review the submitted proposal and either accept it or reject it and ask for a new proposal. If rejected, the contractor shall prepare a new proposal for corrective action, within 10 working days, based on discussions with the Engineer.

If, after the first attempt to repair the pavement, the Actual Smoothness (AS) is still equal to or greater than the Correction Value (CV), additional repairs and testing shall be performed as directed by the Engineer.

The contractor shall perform remedial work, including furnishing materials, required to correct pavement smoothness deficiencies such that the correction value (CV) is less than 100 inches per mile. Remedial work shall be performed by the contractor at no additional cost to the Department.

Traffic control costs during the initial smoothness testing period will be reimbursed under the provisions of Section 701 of the Specifications. Any additional traffic control costs incurred, outside the normal scope of work, due to pavement repairs and subsequent pavement smoothness measurements shall be borne solely by the contractor.

In addition to the smoothness requirements, asphaltic concrete shall not vary more than 1/8 inch from the lower edge of a ten-foot straightedge when the straightedge is placed parallel to the center line of the roadway.

Acceptance:

Asphaltic concrete will be accepted complete in place if, in the judgement of the Engineer, the asphaltic concrete reasonably conforms to the requirements specified herein. Asphaltic concrete that is not acceptable and is rejected shall be replaced to the satisfaction of the Engineer and at no expense to the Department.

Method of Measurement:

Asphaltic concrete will be measured by the ton for the mixture actually used, which will include the weight of mineral aggregate, mineral admixture if required, and asphalt-rubber. Measurement will include any weight used in construction of intersections, turnouts, or other miscellaneous items or surfaces.

Asphalt-rubber will be measured by the ton in accordance with the requirements of Section 1009 of the Standard Specifications.

Mineral admixture will be measured by the ton.

Basis of Payment:

The accepted quantities of asphaltic concrete, measured as provided above, will be paid for at the contract unit price per ton, which price shall be full compensation for the work, complete in place, as specified herein.

Payment for the asphalt-rubber will be made by the ton, including asphalt cement and granulated rubber.

Payment for mineral admixture will be made by the ton.

An Incentive/Disincentive Value will be added or subtracted from the contract monies due the contractor based on the following:

The Incentive Disincentive Value (IDV), plus or minus, for each 0.1 lane-mile shall be determined from the following formulas:

When AS < **XX**.0:

Incentive Value = ((**XX** - AS) / (**XX** + 2)) * 2500

When AS > **YY**.0:

Disincentive Value = ((**YY** - AS) / (**XX** + 2)) * 1000

The Actual Smoothness Value (AS) shall be determined in accordance with Arizona Test Method 829.

The Incentive Base for this contract is $2,500.00 for each 0.1 lane-mile increment or fraction thereof. The Disincentive Base for this contract is $1,000.00 for each 0.1 lane-mile increment or fraction thereof.

The total Incentive/Disincentive Value, plus or minus, for the contract shall be the summation of the individual Incentive/Disincentive Values for the respective 0.1 lane-mile segments.

Incentive/Disincentive Value will not be applied to pavement in distress lanes, shoulders, ramps, tapers, cross roads, or frontage roads.

For projects where pavement is removed and replaced to grade, followed by an ACFC overlay, no smoothness measurements will be made for the following areas:

Pavement placed within 35 feet of the termini of the project.

Pavement placed within 35 feet of the approaches and departures for bridge structures not being overlain as part of the project.

For projects where pavement is removed and replaced to grade, followed by an overlay, followed by an ACFC overlay, no smoothness measurements will be made for the following areas:

Pavement placed within 100 feet of the termini of the project.

Pavement placed within 100 feet of the approaches and departures for bridge structures not being overlain as part of the project.

Bridges and their approaches and departures which are overlain with this project will be subject to the smoothness requirements.

California Department of Transportation

California Special Provision—Gap-Graded Asphalt Rubber (12-13-94)

10-1. RUBBERIZED ASPHALT CONCRETE (TYPE G-ASPHALT RUBBER).-Rubberized asphalt concrete (Type G-Asphalt Rubber) shall be asphalt rubber hot mix-gap graded (ARHM-GG) and shall consist of furnishing and mixing gap graded aggregate and asphalt-rubber binder and spreading and compacting the mixture. Type G rubberized asphalt concrete shall conform to the requirements specified for Type A asphalt concrete in Section 39, "Asphalt Concrete," of the Standard Specifications and these special provisions.

The last sentence of the first paragraph in Section 39-2.01, "Asphalts," of the Standard Specifications and the fifth, sixth, seventh and eighth paragraphs of Section 39-3.03, "Proportioning," of the Standard Specifications shall not apply to Type G rubberized asphalt concrete. The swell, moisture vapor susceptibility, and stabilometer value requirements in Section 39-2.02, "Aggregate," of the Standard Specifications shall not apply to Type G rubberized asphalt concrete.

The second paragraph in Section 39-3.05, "Asphalt Concrete and Asphalt Concrete Base Storage," of the Standard Specifications is amended to read:

> Storage silos shall be equipped with a surge-batcher sized to hold a minimum of 4,000 pounds of material. A surge-batcher consists of equipment placed at the top of the storage silo which catches the continuous delivery of the completed mix and changes it to individual batch delivery and prevents the segregation of product ingredients as the completed mix is placed into storage. The surge-batcher shall be center loading and shall be thermally insulated or heated or thermally insulated and heated to prevent material buildup. Rotary chutes shall not be used as surge-batchers.
>
> The surge-batcher shall be independent and distinct from conveyors or chutes used to collect or direct the completed mixture being discharged into storage silos and shall be the last device to handle the material before it enters the silo. Multiple storage silos shall be served by an individual surge-batcher for each silo. Material handling shall be free of oblique movement between the highest elevation (conveyor outfall) and subsequent placement in the silo. Discharge gates on surge-batchers shall be automatic in operation and shall discharge only after a minimum of 4,000 pounds of material has been collected and shall close before the last collected material leaves the device. Discharge gate design shall prevent the deflection of material during the opening and closing operation.

GENERAL. Binder for Type G rubberized asphalt concrete shall be, at the Contractor's option, either Type 1 or Type 2 asphalt-rubber binder conforming to the requirements of these special provisions.

The amount of asphalt-rubber binder to be mixed with the aggregate for Type G rubberized asphalt concrete will be determined by the Engineer using the samples of aggregates furnished by the

Contractor in conformance with Section 39-3.03, "Proportioning," of the Standard Specifications. The Engineer will determine the amount of asphalt-rubber binder to be mixed with the aggregate in accordance with California Test 367, except as follows:

The specific gravity used in Section B. "Voids Content of Specimen" of California Test 367 will be determined using California Test 308, Method A.

Section C. "Optimum Bitumen Content" of California Test 367 shall be as follows:

1. Using Figure 2, record in Step 1 of the pyramid the asphalt content of the four specimens with the maximum asphalt content used in the square farthest to the right.

2. Plot asphalt content versus void content for each specimen on Form TL-306 (Figure 3), and connect adjacent points with straight lines.

3. From Figure 3, select the theoretical asphalt content that has 3.0 percent voids. Record this amount in Step 4 of the pyramid.

4. Record the asphalt content in Step 4 as the Optimum Bitumen Content (OBC).

5. To establish a recommended range, OBC as the high value and 0.3 percent less as the low value.

The temperature of the aggregate at the time the asphalt-rubber binder is added shall be not more than 325°F.

[Editor's Note: All figures and forms referred to here can be found in California Test 367, published by the California Department of Transportation.]

ASPHALT-RUBBER BINDER. The grade of paving asphalt to be used in asphalt-rubber binder will be either grade AR-1000, AR-2000, or AR-4000, as determined by the Engineer from recommendation by the asphalt-rubber binder supplier.

The reclaimed vulcanized rubber shall be produced primarily from the processing of automobile and truck tires. The rubber shall be produced by ambient temperature grinding processes only.

The specific gravity of reclaimed vulcanized ground rubber shall be not less than 1.10 nor more than 1.20, and shall conform to the following gradation when tested in accordance with ASTM Designation C 136:

Sieve Size	Percent Passing
No. 8	100
No. 10	95-100
No. 16	40-80
No. 30	5-30
No. 50	0-15
No. 200	0-3

Rubber for use in asphalt-rubber binder shall be free of loose fabric, wire and other contaminants except that up to 4 percent (by weight of rubber) calcium carbonate or talc may be added to prevent caking or sticking of the particles together. The rubber shall be sufficiently dry so as to be free flowing and not produce foaming when blended with the hot paving asphalt.

At least two weeks before its intended use, the Contractor shall furnish samples of the asphalt-rubber binder proposed for use on the project. The samples shall consist of 4 one-quart size cans of the asphalt-rubber binder, together with the formulation and the grade of paving asphalt used.

The method and equipment for combining the rubber and paving asphalt shall be so designed and accessible that the Engineer can readily determine the percentage by weight for each material being incorporated into the mixture.

Equipment utilized in the production and proportioning of asphalt-rubber binder shall include the following:

An asphalt heating tank with hot oil heat transfer to heat the paving asphalt to the necessary temperature before blending with the granulated rubber. This unit shall be equipped with a thermostatic heat control device.

A mechanical blender for proper proportioning and thorough mixing of the paving asphalt and rubber. This unit shall have both an asphalt totalizing meter (gallons or liters) and a flow rate meter (gallons per minute or liters per minute).

An asphalt-rubber binder storage tank equipped with a heating system to maintain the proper temperature of the binder and an internal mixing unit capable of maintaining a homogeneous mixture of asphalt and rubber.

The asphalt-rubber mixture shall not be used as a binder after it has been retained for more than 48 hours.

TYPE 1 BINDER. Type 1 asphalt-rubber binder shall be a uniform and reacted mixture of compatible paving grade asphalt and reclaimed vulcanized rubber. The length of the individual rubber particles shall not exceed 3/16 inch.

Type 1 asphalt-rubber binder shall contain not less than 14 percent nor more than 20 percent rubber, by weight, of the total asphalt-rubber binder.

The temperature of the paving asphalt shall be between 350°F and 425°F at the time the rubber is blended with the paving asphalt. The paving asphalt and rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the rubber is added to the paving asphalt. The asphalt-rubber binder shall be maintained at a temperature of not less than 325°F nor more than 375°F during the reaction period.

The viscosity of the asphalt-rubber binder after the reaction period, when tested in accordance with ASTM Designation D 2196, shall be not less than 1,500 centipoise nor more than 3,000 centipoise at 350°F (Brookfield).

The asphalt-rubber binder, after reaching the desired consistency, shall not be held at temperatures over 325°F for more than 4 hours.

TYPE 2 BINDER. Type 2 asphalt-rubber binder shall be a uniform and reacted mixture of compatible paving grade asphalt, extender oil, natural rubber and reclaimed vulcanized rubber.

Extender oil shall be a resinous, high flash point, aromatic hydrocarbon conforming to the following:

Test	ASTM Designation	Requirement
Viscosity, SSU, at 100°F	D 88	2,500 min.
Flash Point, COC, °F	D 92	390 min.
Molecular Analysis:		
Asphaltenes, percent by weight	D 2007	0.1 max.
Aromatics, percent by weight	D 2007	55 min.

The paving asphalt and extender oil, when combined, shall form a material that is chemically compatible with the rubber.

The extender oil shall be added to the paving asphalt at a rate of not less than 2 percent nor more than 6 percent by weight of the paving asphalt, the exact amount to be as determined by the Engineer from recommendation by the asphalt-rubber binder supplier. The asphalt shall be at a temperature of not less than 350°F nor more than 425°F when the extender oil is added.

Rubber for use in Type 2 asphalt-rubber binder shall consist of reclaimed vulcanized rubber and shall contain not less than 20 percent nor more than 30 percent, by weight, natural rubber, when tested in accordance with ASTM Designation D 297. The rubber shall contain no particles longer than 1/4 inch in length.

The paving asphalt-extender oil blend and rubber shall be combined and mixed together in the blender unit to produce a homogeneous mixture.

The amount of rubber to be added to the paving asphalt-extender oil blend shall be not less than 17 percent nor more than 23 percent by weight of the combined mixture of paving asphalt, extender oil, and rubber. The exact amount will be as determined by the Engineer from recommendation by the asphalt-rubber binder supplier. The paving asphalt-extender oil blend shall be at a temperature of not less than 350°F nor more than 425°F when the rubber is added.

The asphalt-rubber binder shall be reacted for a minimum of 45 minutes from the time the rubber is added to the paving asphalt-extender oil blend. The asphalt-rubber binder shall be maintained at a temperature between 375°F and 425°F during the reaction period.

The viscosity of the asphalt-rubber binder after the reaction period, when tested in accordance with ASTM Designation D 2196, shall be not less than 1,500 centipoise nor more than 3,000 centipoise at 375°F (Brookfield).

The asphalt-rubber binder, after reaching the desired consistency, shall not be held at temperatures over 375°F for more than 4 hours.

AGGREGATE. The aggregate for Type G rubberized asphalt concrete shall conform to the following grading and shall meet the quality requirements specified for Type A asphalt concrete in Section 39-2.02, "Aggregate," of the Standard Specifications, except the loss at 500 revolutions from the Los Angeles Rattler test shall be 40 percent maximum.

The symbol "X" in the following table is the gradation which the Contractor proposes to furnish for the specific sieve.

Aggregate Grading Requirements
Percentage Passing
1/2" maximum

Sieve Size	Limits of Proposed Gradation	Operating Range	Contract Compliance
3/4"		100	100
1/2"		90-100	90-100
3/8"	79-87	X±5	X±7
No. 4	32-40	X±5	X±7
No. 8	18-24	X±4	X±5
No. 30	9-12	X±4	X±5
No. 200		2-7	0-8

The symbol "X" in the following table is the gradation which the Contractor proposes to furnish for the specific sieve.

Aggregate Grading Requirements
Percentage Passing
3/4" maximum

Sieve Size	Limits of Proposed Gradation	Operating Range	Contract Compliance
1"		100	100
3/4"		90-100	90-100
3/8"	60-68	X±5	X±7
No. 4	32-40	X±5	X±7
No. 8	18-24	X±4	X±5
No. 30	9-12	X±4	X±5
No. 200		2-7	0-8

CONSTRUCTION. After the material has reacted for at least 45 minutes, the asphalt-rubber binder shall be metered into the mixing chamber of the asphalt concrete production plant at the percentage determined by the Engineer.

When batch type asphalt concrete plants are used to produce Type G rubberized asphalt concrete, the asphalt-rubber binder and mineral aggregate shall be proportioned by weight.

When continuous mixing type asphalt concrete plants are used to produce Type G rubberized asphalt concrete, the asphalt-rubber binder shall be proportioned by an asphalt meter of the mass flow, coriolis effect type. The meter shall be calibrated in accordance with California Test 109.

Type G rubberized asphalt concrete shall be spread at a temperature of not less than 275°F nor more than 325°F, measured in the hopper of the paving machine.

Pneumatic tired rollers shall not be used to compact Type G rubberized asphalt concrete. Alternative compacting equipment as specified in Section 39-6.03, "Compacting," of the Standard Specifications shall be used to compact the Type G rubberized asphalt concrete.

Traffic shall not be allowed on the Type G rubberized asphalt concrete for at least one hour after final rolling operations have been completed.

When ordered by the Engineer to prevent tracking by public traffic from the surface of Type G rubberized asphalt concrete, prior to opening a traffic lane, sand shall be spread on the surface at the approximate rate of from one to two pounds per square yard. Sand shall be free from clay or organic material and shall be of such gradation that at least 90 percent will pass the No. 4 sieve and not more than 5 percent will pass a No. 200 sieve. When ordered by the Engineer, excess sand shall be removed from the pavement surface by sweeping.

MEASUREMENT AND PAYMENT. Rubberized asphalt concrete (Type G-asphalt rubber) will be measured and paid for by the ton in the same manner specified for asphalt concrete in Section 39-8, "Measurement and Payment," of the Standard Specifications.

Full compensation for furnishing, spreading, and sweeping sand cover shall be considered as included in the contract price paid per ton for rubberized asphalt concrete (Type G-asphalt rubber), and no separate payment will be made therefor.

California Special Provision—Dense-Graded Asphalt Rubber (12-13-94)

10-1. RUBBERIZED ASPHALT CONCRETE (TYPE D-ASPHALT RUBBER).—Rubberized asphalt concrete (Type D-Asphalt Rubber) shall be asphalt rubber hot mix-dense graded (ARHM-DG) and shall consist of furnishing and mixing dense graded aggregate and asphalt-rubber binder and spreading and compacting the mixture. Type D rubberized asphalt concrete shall conform to the requirements specified for Type A asphalt concrete in Section 39, "Asphalt Concrete," of the Standard Specifications and these special provisions.

The last sentence of the first paragraph in Section 39-2.01, "Asphalts," of the Standard Specifications and the fifth, sixth, seventh and eighth paragraphs of Section 39-3.03, "Proportioning," of the Standard Specifications shall not apply to Type D rubberized asphalt concrete. The swell, moisture vapor susceptibility, and stabilometer value requirements in Section 39-2.02, "Aggregate," of the Standard Specifications shall not apply to Type D rubberized asphalt concrete.

The second paragraph in Section 39-3.05, "Asphalt Concrete and Asphalt Concrete Base Storage," of the Standard Specifications is amended to read:

> Storage silos shall be equipped with a surge-batcher sized to hold a minimum of 4,000 pounds of material. A surge-batcher consists of equipment placed at the top of the storage silo which catches the continuous delivery of the completed mix and changes it to individual batch delivery and prevents the segregation of product ingredients as the

completed mix is placed into storage. The surge-batcher shall be center loading and shall be thermally insulated or heated or thermally insulated and heated to prevent material buildup. Rotary chutes shall not be used as surge-batchers.

The surge-batcher shall be independent and distinct from conveyors or chutes used to collect or direct the completed mixture being discharged into storage silos and shall be the last device to handle the material before it enters the silo. Multiple storage silos shall be served by an individual surge-batcher for each silo. Material handling shall be free of oblique movement between the highest elevation (conveyor outfall) and subsequent placement in the silo. Discharge gates on surge-batchers shall be automatic in operation and shall discharge only after a minimum of 4,000 pounds of material has been collected and shall close before the last collected material leaves the device. Discharge gate design shall prevent the deflection of material during the opening and closing operation.

GENERAL. Binder for Type D rubberized asphalt concrete shall be, at the Contractor's option, either Type 1 or Type 2 asphalt-rubber binder conforming to the requirements of these special provisions.

The amount of asphalt-rubber binder to be mixed with the aggregate for Type D rubberized asphalt concrete will be determined by the Engineer using the samples of aggregates furnished by the Contractor in conformance with Section 39-3.03, "Proportioning," of the Standard Specifications. The Engineer will determine the amount of asphalt-rubber binder to be mixed with the aggregate in accordance with California Test 367, except as follows:

The specific gravity used in Section B, "Voids Content of Specimen" of California Test 367 will be determined using California Test 308, Method A.

Section C, "Optimum Bitumen Content" of California Test 367 shall be as follows:

1. Using Figure 2, record in Step 1 of the pyramid the asphalt content of the four specimens with the maximum asphalt content used in the square farthest to the right.

2. Plot asphalt content versus void content for each specimen on Form TL-306 (Figure 3), and connect adjacent points with straight lines.

3. From Step 1 of the pyramid, select the three highest asphalt contents that do not exhibit moderate or heavy surface flushing, and record these asphalt contents in Step 2. See Note 1.

4. From Figure 2, select the theoretical asphalt content that has 3.0 percent or more voids and is within the asphalt range listed in Step 2 of the pyramid. Always stay as close to 3.0 percent voids as possible. Record this amount in Step 4 of the pyramid.

5. Record the asphalt content in Step 4 as the Optimum Bitumen Content (OBC).

6. To establish a recommended range, use the Optimum Bitumen Content (OBC) as the high value and 0.3 percent less as the low value.

The temperature of the aggregate at the time the asphalt-rubber binder is added shall be not more than 325°F.

ASPHALT-RUBBER BINDER. The grade of paving asphalt to be used in asphalt-rubber binder will be either grade AR-1000, AR-2000, or AR-4000, as determined by the Engineer from recommendation by the asphalt-rubber binder supplier.

The reclaimed vulcanized rubber shall be produced primarily from the processing of automobile and truck tires. The rubber shall be produced by ambient-temperature grinding processes only.

The specific gravity of reclaimed vulcanized ground rubber shall be not less than 1.10 nor more than 1.20, and shall conform to the following gradation when tested in accordance with ASTM Designation C 136:

Sieve Size	Percent Passing
No. 8	100
No. 10	95-100
No. 16	40-80
No. 30	5-30
No. 50	0-15
No. 200	0-3

Rubber for use in asphalt-rubber binder shall be free of loose fabric, wire and other contaminants except that up to 4 percent (by weight of rubber) calcium carbonate or talc may be added to prevent caking or sticking of the particles together. The rubber shall be sufficiently dry so as to be free flowing and not produce foaming when blended with the hot paving asphalt.

At least two weeks before its intended use, the Contractor shall furnish samples of the asphalt-rubber binder proposed for use on the project. The samples shall consist of 4 one-quart size cans of the asphalt-rubber binder, together with the formulation and the grade of paving asphalt used.

The method and equipment for combining the rubber and paving asphalt shall be so designed and accessible that the Engineer can readily determine the percentage by weight for each material being incorporated into the mixture.

Equipment utilized in the production and proportioning of asphalt-rubber binder shall include the following:

An asphalt heating tank with hot oil heat transfer to heat the paving asphalt to the necessary temperature before blending with the granulated rubber. This unit shall be equipped with a thermostatic heat control device.

A mechanical blender for proper proportioning and thorough mixing of the paving asphalt and rubber. This unit shall have both an asphalt totalizing meter (gallons or liters) and a flow rate meter (gallons per minute or liters per minute).

An asphalt-rubber binder storage tank equipped with a heating system to maintain the proper temperature of the binder and an internal mixing unit capable of maintaining a homogeneous mixture of asphalt and rubber.

The asphalt-rubber mixture shall not be used as a binder after it has been retained for more than 48 hours.

TYPE 1 BINDER. Type 1 asphalt-rubber binder shall be a uniform and reacted mixture of compatible paving grade asphalt and reclaimed vulcanized rubber. The length of the individual rubber particles shall not exceed 3/16 inch.

Type 1 asphalt-rubber binder shall contain not less than 14 percent nor more than 20 percent rubber, by weight, of the total asphalt-rubber binder.

The temperature of the paving asphalt shall be between 350°F and 425°F at the time the rubber is blended with the paving asphalt. The paving asphalt and rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the rubber is added to the paving asphalt. The asphalt-rubber binder shall be maintained at a temperature of not less than 325°F nor more than 375°F during the reaction period.

The viscosity of the asphalt-rubber binder after the reaction period, when tested in accordance with ASTM Designation D 2196, shall be not less than 1,500 centipoise at 350°F (Brookfield).

The asphalt-rubber binder, after reaching the desired consistency, shall not be held at temperatures over 325°F for more than 4 hours.

TYPE 2 BINDER. Type 2 asphalt-rubber binder shall be a uniform and reacted mixture of compatible paving grade asphalt, extender oil, natural rubber and reclaimed vulcanized rubber.

Extender oil shall be a resinous, high flash point, aromatic hydrocarbon conforming to the following:

Test	ASTM Designation	Requirement
Viscosity, SSU, at 100°F	D 88	2,500 min.
Flash Point, COC, °F	D 92	390 min.
Molecular Analysis:		
Asphaltenes, percent by weight	D 2007	0.1 max.
Aromatics, percent by weight	D 2007	55 min.

The paving asphalt and extender oil, when combined, shall form a material that is chemically compatible with the rubber.

The extender oil shall be added to the paving asphalt at a rate of not less than 2 percent nor more than 6 percent by weight of the paving asphalt, the exact amount to be as determined by the Engineer from recommendation by the asphalt-rubber binder supplier. The asphalt shall be at a temperature of not less than 350°F nor more than 425°F when the extender oil is added.

Rubber for use in Type 2 asphalt-rubber binder shall consist of reclaimed vulcanized rubber and shall contain not less than 20 percent nor more than 30 percent, by weight, natural rubber, when tested in accordance with ASTM Designation D 297. The rubber shall contain no particles longer than 1/4 inch in length.

The paving asphalt-extender oil blend and rubber shall be combined and mixed together in the blender unit to produce a homogeneous mixture.

The amount of rubber to be added to the paving asphalt-extender oil blend shall be not less than 17 percent nor more than 23 percent by weight of the combined mixture of paving asphalt, extender oil, and rubber. The exact amount will be as determined by the Engineer from recommendation by the asphalt-rubber binder supplier. The paving asphalt-extender oil blend shall be at a temperature of not less than 350°F nor more than 425°F when the rubber is added.

The asphalt-rubber binder shall be reacted for a minimum of 45 minutes from the time the rubber is added to the paving asphalt-extender oil blend. The asphalt-rubber binder shall be maintained at a temperature between 375°F and 425°F during the reaction period.

The viscosity of the asphalt-rubber binder after the reaction period, when tested in accordance with ASTM Designation D 2196, shall be not less than 1,500 centipoise nor more than 3,000 centipoise at 375°F (Brookfield).

The asphalt-rubber binder, after reaching the desired consistency, shall not be held at temperatures over 375°F for more than 4 hours.

AGGREGATE. The aggregate for Type D rubberized asphalt concrete shall conform to the 3/4" maximum, medium grading and shall meet the quality requirements specified for Type A asphalt concrete in Section 39-2.02, "Aggregate," of the Standard Specifications, except the loss at 500 revolutions from the Los Angeles Rattler test shall be 40 percent maximum.

CONSTRUCTION. After the material has reacted for at least 45 minutes, the asphalt-rubber binder shall be metered into the mixing chamber of the asphalt concrete production plant at the percentage determined by the Engineer.

When batch type asphalt concrete plants are used to produce Type D rubberized asphalt concrete, the asphalt-rubber binder and mineral aggregate shall be proportioned by weight.

When continuous mixing type asphalt concrete plants are used to produce Type D rubberized asphalt concrete, the asphalt-rubber binder shall be proportioned by an asphalt meter of the mass flow, coriolis effect type. The meter shall be calibrated in accordance with California Test 109.

Type D rubberized asphalt concrete shall be spread at a temperature of not less than 275°F nor more than 325°F, measured in the hopper of the paving machine.

Pneumatic tired rollers shall not be used to compact Type D rubberized asphalt concrete. Alternative compacting equipment as specified in Section 39-6.03, "Compacting," of the Standard Specifications shall be used to compact the Type D rubberized asphalt concrete.

Traffic shall not be allowed on the Type D rubberized asphalt concrete for at least one hour after final rolling operations have been completed.

When ordered by the Engineer to prevent tracking by public traffic from the surface of Type D rubberized asphalt concrete, prior to opening a traffic lane, sand shall be spread on the surface at the approximate rate of from one to two pounds per square yard. Sand shall be free from clay or organic material and shall be of such gradation that at least 90 percent will pass the No. 4 sieve and not more than 5 percent will pass a No. 200 sieve. When ordered by the Engineer, excess sand shall be removed from the pavement surface by sweeping.

MEASUREMENT AND PAYMENT. Rubberized asphalt concrete (Type D-asphalt rubber) will be measured and paid for by the ton in the same manner specified for asphalt concrete in Section 39-8, "Measurement and Payment," of the Standard Specifications.

Full compensation for furnishing, spreading, and sweeping sand cover shall be considered as included in the contract price paid per ton for rubberized asphalt concrete (Type D-asphalt rubber), and no separate payment will be made therefor.

California Special Provision—Open-Graded Asphalt Rubber (12-13-94)

10-1. RUBBERIZED ASPHALT CONCRETE (TYPE O-ASPHALT RUBBER). Rubberized asphalt concrete (Type O-Asphalt Rubber) shall be asphalt rubber hot mix-open graded (ARHM-OG) and shall consist of furnishing and mixing open graded aggregate and asphalt-rubber binder and spreading and compacting the mixture. Type O rubberized asphalt concrete shall conform to the requirements specified for open graded asphalt concrete in Section 39, "Asphalt Concrete," of the Standard Specifications and these special provisions.

The last sentence of the first paragraph in Section 39-2.01, "Asphalts," of the Standard Specifications and the fifth, sixth, seventh, and eighth paragraphs of Section 39-3.03, "Proportioning," of the Standard Specifications shall not apply to Type O rubberized asphalt concrete.

The second paragraph in Section 39-3.05, "Asphalt Concrete and Asphalt Concrete Base Storage," of the Standard Specifications is amended to read:

Storage silos shall be equipped with a surge-batcher sized to hold a minimum of 4,000 pounds of material. A surge-batcher consists of equipment placed at the top of the storage silo which catches the continuous delivery of the completed mix and changes it to individual batch delivery and prevents the segregation of product ingredients as the completed mix is placed into storage. The surge-batcher shall be center loading and shall be thermally insulated or heated or thermally insulated and heated to prevent material buildup. Rotary chutes shall not be used as surge-batchers.

The surge-batcher shall be independent and distinct from conveyors or chutes used to collect or direct the completed mixture being discharged into storage silos and shall be the last device to handle the material before it enters the silo. Multiple storage silos shall be served by an individual surge-batcher for each silo. Material handling shall be free of oblique movement between the highest elevation (conveyor outfall) and subsequent placement in the silo. Discharge gates on surge-batchers shall be automatic in operation and shall discharge only after a minimum of 4,000 pounds of material has been collected and shall close before the last collected material leaves the device. Discharge gate design shall prevent the deflection of material during the opening and closing operation.

GENERAL. Binder for Type O rubberized asphalt concrete shall be, at the Contractor's option, either Type 1 or Type 2 asphalt-rubber binder conforming to the requirements of these special provisions.

The amount of asphalt-rubber binder to be mixed with the aggregate for Type O rubberized asphalt concrete will be determined by the Engineer using the samples of aggregates furnished by the Contractor in conformance with Section 39-3.03, "Proportioning," of the Standard Specifications. The Engineer will determine the amount of asphalt-rubber binder to be mixed with the aggregate in accordance with California Test 368, except the test temperature in Section D, "Test Procedure," shall be 325°F.

The temperature of the aggregate at the time the asphalt-rubber binder is added shall be not more than 325°F.

ASPHALT-RUBBER BINDER. The grade of paving asphalt to be used in asphalt-rubber binder will be either grade AR-1000, AR-2000, or AR-4000, as determined by the Engineer from recommendation by the asphalt-rubber binder supplier.

The reclaimed vulcanized rubber shall be produced primarily from the processing of automobile and truck tires. The rubber shall be produced by ambient temperature grinding processes only.

The specific gravity of reclaimed vulcanized ground rubber shall be not less than 1.10 nor more than 1.20, and shall conform to the following gradation when tested in accordance with ASTM Designation C 136:

Sieve Size	Percent Passing
No. 8	100
No. 10	95-100
No. 16	40-80
No. 30	5-30
No. 50	0-15
No. 200	0-3

Rubber for use in asphalt-rubber binder shall be free of loose fabric, wire, and other contaminants except that up to 4 percent (by weight of rubber) calcium carbonate or talc may be added to prevent caking or sticking of the particles together. The rubber shall be sufficiently dry so as to be free flowing and not produce foaming when blended with the hot paving asphalt.

At least two weeks before its intended use, the Contractor shall furnish samples of the asphalt-rubber binder proposed for use on the project. The samples shall consist of 4 one-quart size cans of the asphalt-rubber binder, together with the formulation and the grade of paving asphalt used.

The method and equipment for combining the rubber and paving asphalt shall be so designed and accessible that the Engineer can readily determine the percentage by weight for each material being incorporated into the mixture.

Equipment utilized in the production and proportioning of asphalt-rubber binder shall include the following:

An asphalt heating tank with hot oil heat transfer to heat the paving asphalt to the necessary temperature before blending with the granulated rubber. This unit shall be equipped with a thermostatic heat control device.

A mechanical blender for proper proportioning and thorough mixing of the paving asphalt and rubber. This unit shall have both an asphalt totalizing meter (gallons or liters) and a flow rate meter (gallons per minute or liters per minute).

An asphalt-rubber binder storage tank equipped with a heating system to maintain the proper temperature of the binder and an internal mixing unit capable of maintaining a homogeneous mixture of asphalt and rubber.

The asphalt-rubber mixture shall not be used as a binder after it has been retained for more than 48 hours.

TYPE 1 BINDER. Type 1 asphalt-rubber binder shall be a uniform and reacted mixture of compatible paving grade asphalt and reclaimed vulcanized rubber. The length of the individual rubber particles shall not exceed 3/16 inch.

Type 1 asphalt-rubber binder shall contain not less than 14 percent nor more than 20 percent rubber, by weight, of the total asphalt-rubber binder.

The temperature of the paving asphalt shall be between 350°F and 425°F at the time the rubber is blended with the paving asphalt. The paving asphalt and rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the rubber is added to the paving asphalt. The asphalt-rubber binder shall be maintained at a temperature of not less than 325°F nor more than 375°F during the reaction period.

The viscosity of the asphalt-rubber binder after the reaction period, when tested in accordance with ASTM Designation D 2196, shall be not less than 1,500 centipoise nor more than 3,000 centipoise at 350°F (Brookfield).

The asphalt-rubber binder, after reaching the desired consistency, shall not be held at temperatures over 325°F for more than 4 hours.

TYPE 2 BINDER. Type 2 asphalt-rubber binder shall be a uniform and reacted mixture of compatible paving grade asphalt, extender oil, natural rubber, and reclaimed vulcanized rubber.

Extender oil shall be a resinous, high flash point, aromatic hydrocarbon conforming to the following:

Test	ASTM Designation	Requirement
Viscosity, SSU, at 100°F	D 88	2,500 min.
Flash Point, COC, °F	D 92	390 min.
Molecular Analysis:		
Asphaltenes, percent by weight	D 2007	0.1 max
Aromatics, percent by weight	D 2007	55 min.

The paving asphalt and extender oil, when combined, shall form a material that is chemically compatible with the rubber.

The extender oil shall be added to the paving asphalt at a rate of not less than 2 percent nor more than 6 percent by weight of the paving asphalt, the exact amount to be as determined by the Engineer from recommendation by the asphalt-rubber binder supplier. The asphalt shall be at a temperature of not less than 350°F nor more than 425°F when the extender oil is added.

Rubber for use in Type 2 asphalt-rubber binder shall consist of reclaimed vulcanized rubber and shall contain not less than 20 percent nor more than 30 percent, by weight, natural rubber, when tested in accordance with ASTM Designation D 297. The rubber shall contain no particles longer than 1/4 inch in length.

The paving asphalt-extender oil blend and rubber shall be combined and mixed together in the blender unit to produce a homogeneous mixture.

The amount of rubber to be added to the paving asphalt-extender oil blend shall be not less than 17 percent nor more than 23 percent by weight of the combined mixture of paving asphalt, extender oil, and rubber. The exact amount will be as determined by the Engineer from recommendation by the asphalt-rubber binder supplier. The paving asphalt-extender oil blend shall be at a temperature of not less than 350°F nor more than 425°F when the rubber is added.

The asphalt-rubber binder shall be reacted for a minimum of 45 minutes from the time the rubber is added to the paving asphalt-extender oil blend. The asphalt-rubber binder shall be maintained at a temperature between 375°F and 425°F during the reaction period.

The viscosity of the asphalt-rubber binder after the reaction period, when tested in accordance with ASTM Designation D 2196, shall be not less than 1,500 centipoise nor more than 3,000 centipoise at 375°F (Brookfield).

The asphalt-rubber binder, after reaching the desired consistency, shall not be held at temperatures over 375°F for more than 4 hours.

AGGREGATE. The aggregate for Type O rubberized asphalt concrete shall conform to 1/2 inch maximum open graded asphalt concrete aggregate specified in Section 39-2.02, "Aggregate," of the Standard Specifications.

CONSTRUCTION. After the material has reacted for at least 45 minutes, the asphalt-rubber binder shall be metered into the mixing chamber of the asphalt concrete production plant at the percentage determined by the Engineer.

If the Contractor selects the batch mixing method, asphalt concrete shall be produced by the automatic batch mixing method as provided in Section 39-3.03A(1b), "Automatic Proportioning," of the Standard Specifications.

When batch type asphalt concrete plants are used to produce Type O rubberized asphalt concrete, the asphalt-rubber binder and mineral aggregate shall be proportioned by weight.

When continuous mixing type asphalt concrete plants are used to produce Type O rubberized asphalt concrete, the asphalt-rubber binder shall be proportioned by an asphalt meter of the mass flow, coriolis effect type. The meter shall be calibrated in accordance with California Test 109.

Type O rubberized asphalt concrete shall be spread at a temperature of not less than 275°F nor more than 325°F, measured in the hopper of the paving machine. Type O rubberized asphalt concrete shall be placed only when the atmospheric temperature is above 45°F.

The area to which paint binder has been applied shall be closed to public traffic. Care shall be taken to avoid tracking binder material onto existing pavement surfaces beyond the limits of construction.

In addition to the requirements in Section 39-5.01, "Spreading Equipment," of the Standard Specifications, asphalt paving equipment shall be equipped with automatic screed controls and a sensing device or devices.

When paving contiguously with previously placed mats, the end of the screed adjacent to the previously placed mat shall be controlled by a sensor that responds to the grade of the previously placed mat and will reproduce the grade in the new mat within a 0.01-foot tolerance.

Should the methods and equipment furnished by the Contractor fail to produce a layer of asphalt concrete conforming to the requirements, including straightedge tolerance, of Section 39-6.03, "Compacting," of the Standard Specifications, the paving operations shall be discontinued and the Contractor shall modify his equipment or furnish substitute equipment.

Should the automatic screed controls fail to operate properly during any day's work, the Contractor may use manual control of the spreading equipment for the remainder of that day; however, the equipment shall be corrected or replaced with alternative automatically controlled equipment conforming to the requirements in this section before starting another day's work.

Traffic shall not be allowed on the Type O rubberized asphalt concrete for at least one hour after final rolling operations have been completed.

When ordered by the Engineer to prevent tracking by public traffic from the surface of Type O rubberized asphalt concrete, prior to opening a traffic lane, sand shall be spread on the surface at the approximate rate of from one to two pounds per square yard. Sand shall be free from clay or organic material and shall be of such gradation that at least 90 percent will pass the No. 4 sieve and not more than 5 percent will pass a No. 200 sieve. When ordered by the Engineer, excess sand shall be removed from the pavement surface by sweeping.

MEASUREMENT AND PAYMENT. Rubberized asphalt concrete (Type O-asphalt rubber) will be measured and paid for by the ton in the same manner specified for asphalt concrete in Section 39-8, "Measurement and Payment," of the Standard Specifications.

Full compensation for furnishing, spreading, and sweeping sand cover shall be considered as included in the contract price paid per ton for rubberized asphalt concrete (Type O-asphalt rubber), and no separate payment will be made therefor.

Florida Department of Transportation

Florida Department of Transportation

I. Asphalt Rubber Binder. (FA 9-12-94) (REV 8-25-94)

SECTION 336 (Pages 42-46) of the Supplemental Specifications is deleted and the following substituted:

Section 336 Asphalt Rubber Binder

336-1 Description.

This specification governs the production of asphalt rubber binder for use in Asphaltic Concrete Friction Courses and Asphalt Rubber Membrane Interlayers.

336-2 Materials.

336-2.1 Asphalt Cement: The particular grade of asphalt cement as specified in Table 336-1 for the respective uses shall meet the requirements of Section 916.

336-2.2 Ground Tire Rubber: The type of ground tire rubber shall meet the requirements of Section 919.

336-3 Asphalt Rubber Binder.

The asphalt cement and ground tire rubber shall be thoroughly mixed and reacted in accordance with the requirements of Table 336-1. The rubber type shall be in accordance with the approved design mix. Blending of the asphalt cement and ground tire rubber will be accomplished at the asphalt supplier's terminal or at the project site.

336-4 Equipment.

The blending equipment for asphalt rubber binder shall be designed for that purpose and shall be capable of producing a homogeneous mixture of ground tire rubber and asphalt cement meeting the requirements of Table 336-1. The blending unit may be a batch type or continuous type and shall provide for sampling of the blended and reacted asphalt rubber binder material during normal production. The accuracy of the meter used to determine the asphalt rubber binder content of bituminous mixtures shall be certified once every six months. Such certification shall be furnished by an approved scale technician, and the Contractor shall be responsible for obtaining this certification.

In order to meet specification requirements specialized equipment will be necessary to handle and keep the asphalt rubber uniformly blended while in storage. Storage tanks shall be equipped with a sampling device.

336-5 Testing and Certification Requirements.

336-5.1 Blending at Project Site: The ground tire rubber content in the asphalt rubber binder will be monitored by the Department on a daily basis based on the following: (1) the weight of the ground tire rubber used, and the gallons of asphalt rubber binder used (The weight per gallon for the various types of asphalt rubber binder shown in Table 336-1 are to be used for these calculations.) or (2) the weight of the ground tire rubber used and the number of gallons of asphalt cement used.

336-5.2 Blending at Asphalt Supplier's Terminal: Where the asphalt rubber binder is blended at the asphalt supplier's terminal, each load delivered to the project site shall be certified that the asphalt rubber binder has been produced in accordance with and meets the requirements of 336-3. In addition, the certification shall include the certification requirements for the asphalt cement and ground tire rubber, as specified in 916-1.2 and 919-6, respectively.

336-5.3 Testing of Asphalt Rubber Binder:

336-5.3.1 Quality Control Requirements: The asphalt rubber binder shall be tested for the viscosity requirement of Table 336-1 by the Contractor at the following frequencies and situations:

(1) One per batch (for batch blending) or two per day (for continuous blending) during blending at the project site.

(2) Each load delivered to the project site when blended at the asphalt supplier's terminal.

(3) Beginning of each day from the storage tank when the asphalt rubber binder is stored at the project site.

The viscosity testing equipment specified in FM 5-548 shall be obtained by the Contractor and made available to the Department for acceptance purposes.

In the event that the Quality Control and Acceptance samples are being tested simultaneously, the Acceptance Test results can be used for quality control.

336-5.3.2 Acceptance Requirements: The Department will test the asphalt rubber in accordance with FM 5-548 to assure conformance with the minimum viscosity requirement as specified in Table 336-1. Specific frequencies and situations are as follows:

(1) One per batch (for batch blending) or two per day (for continuous blending) during blending at the project site.

(2) Beginning of each day from the storage tank when the asphalt rubber binder is stored at the project site.

If the asphalt rubber binder does not meet the minimum viscosity requirement, the Contractor shall make the appropriate adjustments in order to (1) correct the viscosity of the blended material, and (2) correct the blending operation. These corrective actions may include increasing the GTR content, lowering the blended temperature, or increasing the reaction time. In the event that the corrective actions taken by the Contractor fail to

TABLE 336-1

Asphalt Rubber Binder

Binder Type	ARB-5	ARB-12	ARB-20
Rubber Type	Type A	Type B (or A)	Type C (or B or A)
Min. % Ground Tire Rubber (by weight of asphalt cement)	5	12	20
AC Grade	AC-30	AC-30	AC-20
Min. Temperature, °F	300	300	335
Max. Temperature, °F	335	350	375
Min. Reaction Time (minutes)	10	15 (for Type B)	30 (for Type C)
Unit Weight at 60°F[2] (lb/gal)	8.6	8.7	8.8
Min. Viscosity[3] (Poises)	4.0 @ 300°F	10.0 @ 300°F	15.0 @ 350°F

NOTES

1 Use of finer rubber could result in the reduction of the minimum reaction time.

2 Conversions to standard 60°F are as specified in 300-8.3.

3 FM 5-548, Viscosity of Asphalt Rubber Binder by use of the Rotational Viscometer.

NOTE:

The minimum reaction time may be adjusted if approved by the State Materials Office depending upon the temperature, size of the ground tire rubber, and viscosity measurement determined from the asphalt rubber binder material prior to or during production. The asphalt rubber binder for use in membrane interlayers shall be applied within a period of six hours unless some form of corrective action such as cooling and reheating is approved by the State Materials Office.

correct the problem, or the material consistently fails to meet the minimum viscosity requirement, all asphalt rubber production operations shall be stopped until the problem has been solved. Production operations shall not resume until approval is granted by the District Bituminous Engineer. Any mix placed with low viscosity asphalt rubber binder shall be subject to an engineering evaluation to determine if it should be removed and replaced. In the event that the viscosity of the asphalt rubber binder increases to the extent that paving operations of the mixture are adversely affected (i.e., density or texture problems occur), plant operations shall be stopped until the problem has been resolved.

336-6 Use of Excess Asphalt Rubber.

Excess asphalt rubber may be utilized in other asphaltic concrete mixtures requiring the use of an AC-30 by blending with straight AC-30 so that the total amount of GTR in the binder is less than 2.0 percent. Asphalt rubber blended with any asphalt material that is used as a recycling agent in a recycled mixture must be blended in such proportions that the total amount of GTR in the recycling agent is less than 1.0 percent.

337 Asphaltic Concrete Friction Courses. (FA 10-24-94) (REV 5-25-94)

SECTION 337 (Pages 265-271) is deleted and the following substituted:

Section 337 Asphaltic Concrete Friction Courses (Asphalt Rubber Binder)

337-1 Description.

This Section specifies the materials, composition, mix design and compensation for Asphaltic Concrete Friction Courses containing asphalt rubber binder. The requirements for plant and equipment for this pavement are specified in Section 320. General construction requirements for all asphaltic concrete pavements as specified in Section 330 are applicable to this Section subject to any exceptions contained herein.

The work will be accepted on a LOT by LOT basis in accordance with the applicable requirements of Sections 5, 6, and 9. The size of the LOT for the bituminous mix accepted at the plant will be as specified in 331-5 and for the material accepted on the roadway as stipulated in 330-10 and 330-12.

The mixes covered by this Section are designated as Friction Course 2 (FC-2) and Friction Course 3 (FC-3).

337-2 Materials.

337-2.1 General: The materials used shall conform with the requirements specified in Division III as modified herein.

337-2.2 Asphalt Rubber Binder: The asphalt rubber binder material for friction courses shall be an ARB-12 for FC-2 and an ARB-5 for FC-3, both meeting the requirements of Section 336. In addition, the asphalt rubber binder shall contain 0.5 percent heat stable anti-stripping additive from an approved source. This amount may be varied based on tests performed by the State Materials Office. When the amount is varied in excess of the 0.5 percent, the Contractor will be compensated at the invoice price for the additive. When the amount is varied less than 0.5 percent, the Department shall be reimbursed at the invoice price of the additive.

The heat stable anti-stripping additive shall be introduced and mixed into the asphalt cement at the asphalt terminal during loading or by the Contractor at the asphalt plant in a manner satisfactory to the Engineer. Addition of the additive at the asphalt terminal shall be certified by the supplier.

337-2.3 Coarse Aggregate: Except as modified herein, all coarse aggregate shall meet the requirements of Section 901.

337-2.4 Fine Aggregate: Fine aggregates shall meet all applicable requirements of Section 902.

337-3 General Composition of Mixes.

337-3.1 General: The bituminous mix shall be composed of a combination of aggregate (coarse, fine, or a mixture thereof), mineral filler if required, and asphalt rubber binder. The several aggregate fractions shall be sized, uniformly graded and combined in such proportions that the resulting mix will meet the grading and physical properties of the approved job mix formula.

337-3.2 Aggregate Components: The aggregate components of the various mixes set out in this Section shall be as follows:

FC-2 — The coarse aggregate component of FC-2 shall be either crushed granite, crushed slag, or lightweight aggregates (that have been approved for this use). Crushed limestone from the Oolitic formation will also be permitted if the coarse aggregate contains a minimum of twelve percent non-carbonate material as determined by FM 5-510 and approval of the source is granted by the State Materials Office prior to its use. In addition, use of aggregates other than those listed above may be permitted if approved by the State Materials Office.

FC-3 — The coarse aggregate components of the FC-3 mixture shall be either crushed gravel, crushed granite, crushed slag, or crushed limestone from the Oolitic formation as specified for use in FC-2. In addition, use of aggregates other than these listed above may be permitted if approved by the State Materials Office.

The fine aggregate components shall consist of crushed screenings or a combination of crushed screenings and local materials. The crushed screenings shall be composed of hard, durable particles resulting from the crushing or processing of coarse aggregate as specified above. In addition, screenings from other approved sources may be used provided that the total of these screenings along with silica sand or local materials does not exceed 40 percent. The gradation requirements of the screenings shall be as specified in 902-5.1.

Not more than 20 percent by weight of the total aggregate used shall be silica sand or local materials as defined in Section 902.

Continuing approval of all sources of material for use in FC-2 and FC-3 will be based on field performance.

337-3.3 Grading Requirements: The job mix formula, as established by the Contractor and approved by the Department, shall be within the design range specified in Table 331-1 for all friction courses.

337-3.4 Stability for FC-3: The constituents for FC-3 shall be combined in such proportions as to produce a mix having Marshall properties within the limits shown in Table 331-2.

337-4 Mix Design.

The mix design shall conform to the requirements of 331-4.3 of these specifications except that Item No. 7 in 331-4.3.1 shall not apply to FC-2. For FC-3, data shall be submitted showing that the mix design meets the requirements of Table 331-2 using conventional AC-30. The asphalt rubber will then be substituted at the optimum conventional binder content for production and shall be shown as the optimum binder content on the approved mix design.

337-5 Contractor's Quality Control.

The Contractor shall provide the necessary quality control of the friction course mix and construction in accordance with the applicable provisions of 6-8.4 and 331-4.4. After the mix design has been approved, the Contractor shall furnish the material to meet the approved mix design in accordance with the provisions of 331-4.4.2 and Table 331-3. Plant calibration shall comply with the provisions of 331-4.4.3 and Table 331-3.

337-6 Acceptance of Mix.

337-6.1 Acceptance at the Plant: The bituminous mix shall be accepted at the plant with respect to gradation in accordance with the applicable requirements of 331-5. Acceptance determinations for asphalt rubber binder content for mixtures produced by batch, drum, or continuous mix plants are as follows:

337-6.1.1 Batch Plants: All batch plants producing friction course mixtures containing asphalt rubber shall be equipped with an automatic printer system which is capable of printing either the individual bin weights or total aggregate weight, as well as the amount of asphalt rubber binder, that is delivered to the pugmill. Each batch of asphaltic concrete mixture produced shall have an individual printout.

The asphalt rubber binder content for acceptance purposes shall be based on the calculated binder content from the printout of the batch that is selected based upon the random number. Payment shall be based on the provisions of Table 331-6, using the Asphalt Cement Content (printout) characteristic.

The batch scales and the accuracy of the automatic printer system shall be certified at least once every six months. Such certification shall be furnished by an approved certified scale technician and the Contractor shall be responsible for obtaining this certification. The automatic printer system shall maintain an accuracy of one percent for the asphalt rubber binder and aggregate.

337-6.1.2 Drum-Mix Plants: All drum-mix plants producing friction course mixtures containing asphalt rubber shall be equipped with a metering/printer system that is capable of one of the following:

1) Printing an instantaneous reading, upon demand, of dry aggregate and asphalt rubber binder being delivered to the drum (in TPH). The asphalt rubber binder content for acceptance purposes will then be based on the calculated binder content from the printout that is obtained based upon the random number.

2) Printing an instantaneous reading, at a regular frequency of no longer than 5 minutes, of dry aggregate and asphalt rubber binder that is delivered to the drum (in TPH). The asphalt rubber binder content for acceptance purposes will then be based upon the calculated binder content from the printout obtained that is nearest to the random number.

The instantaneous readings of asphalt rubber binder and dry aggregate shall be synchronized such that the readings are representative of the proportions of asphalt rubber binder and dry aggregate at the instant that they are combined.

Payment shall be based on the provisions of Table 331-6, using the Asphalt Cement Content (printout) characteristic.

The metering/printer system shall be certified at least once every six months. Such certification shall be furnished by an approved certified scale technician and the Contractor shall be responsible for obtaining this certification. The metering/printer system shall maintain an accuracy of one-half percent for the asphalt rubber binder and one percent for the aggregate.

337-6.1.3 Continuous-Mix Plants: All continuous-mix plants producing friction course mixtures containing asphalt rubber binder shall be equipped with a metering/printer system as approved by the District Bituminous Engineer. The asphalt rubber binder content for acceptance purposes will then be based on the calculated binder content from the metering/printer system that is obtained based upon the random number.

Payment shall be based on the provisions of Table 331-6, using the Asphalt Cement Content (printout) characteristic.

The metering/printer system shall be certified at least once every six months. Such certification shall be furnished by an approved certified scale technician and the Contractor shall be responsible for obtaining this certification. The metering/printer system shall maintain an accuracy of 1/2% for both the asphalt rubber binder and aggregate.

337-6.2 Acceptance on the Roadway: The bituminous mix will be accepted on the roadway with respect to density and surface tolerance in accordance with the applicable provisions of 330-10 and 330-12. There will be no density requirements for FC-2.

337-6.3 Additional Tests: The provisions of 331-5.5 shall apply to the friction courses FC-2 and FC-3.

337-7 Special Construction Requirements.

337-7.1 Temperature Requirements for FC-2:

337-7.1.1 Air Temperature at Laydown: The mixture shall be spread only when the air temperature (the temperature in the shade away from artificial heat) is at or above 60°F.

337-7.1.2 Temperature of the Mix: The asphalt rubber binder and aggregates shall be heated and combined in such a manner as to produce a mix having a temperature, when discharged from the pugmill, of 290°F. The tolerance from this established temperature shall be as specified in Table 330-1. All other requirements of 330-6.3 shall apply to FC-2.

337-7.2 Temperature Requirements for FC-3:

337-7.2.1 Air Temperature at Laydown: The mixture shall be spread only when the air temperature (the temperature in the shade away from artificial heat) is at or above 45°F.

337-7.2.2 Temperature of the Mix: The asphalt rubber binder and aggregates shall be heated and combined in such a manner as to produce a mix having a temperature, when discharged from the pugmill, of 310°F. The tolerance from this established temperature shall be as specified in Table 330-1. All other requirements of 330-6.3 shall apply to FC-3.

337-7.3 Compaction of FC-2: Only seal rolling will be required; this rolling will be accomplished using a tandem steel-wheel roller. The weight of the steel-wheel roller shall not exceed 135 pounds per linear inch (PLI) of drum width.

$$PLI = \frac{\text{Total Weight of Roller (pounds)}}{\text{Total width of Drums (inches)}}$$

Rolling shall be accomplished with a single coverage and with a nominal amount of overlap. Where the lane being placed is adjacent to a previously laid mat, the longitudinal joint will not be pinched in a manner with the roller on the cold mat. The longitudinal joint will be pinched with the roller on the mat being rolled, overlapping onto the cold mat by no more than three inches.

In no case shall a roller be allowed on the mat after the seal rolling has been completed.

337-7.4 Prevention of Adhesion: In order to minimize adhesion to the drum during the rolling operations, a small amount of liquid detergent may be added to the water in the roller.

At intersections and in other areas where the pavement may be subjected to cross-traffic before it has cooled, the approaches shall be sprayed with water in order to wet the tires of the approaching vehicles before they cross the pavement.

337-7.5 Thickness of Friction Courses: The thickness of the friction course shall be designated in the plans. This is the minimum desirable thickness for FC-3 and the maximum desirable thickness for FC-2. The minimum spread rate for FC-2 shall be 25 pounds per square yard when lightweight aggregates are used and 40 pounds per square yard when conventional aggregates are used.

337-7.5.1 Thickness Requirements—Tonnage Payment: For FC-2 mixes where payment is on a tonnage basis, the rate of application shown on the plans shall be considered approximate. The intent is to achieve the maximum thickness of the friction course shown in the plans. Particular care must be exercised to avoid exceeding the established rate of application for FC-2 mixes.

337-7.5.2 Thickness Requirements—Square Yard Payment: The thickness shall be determined in accordance with 330-15.1 except that the average thickness will not be calculated. Cores will not be taken in areas where the friction course is being transitioned in thickness to tie into an existing surface. The maximum allowable deficiency from the thickness specified in the plans shall be 1/4 inch. If any area is deficient in thickness by more than the allowable tolerance, the Contractor shall correct the deficiency by removing and replacing the friction course at the proper thickness. Thickness deficiencies may be corrected by overlaying if approved by the Engineer. The overlay shall extend 50 feet either side of the deficient area and shall extend across the full width of the roadway.

As an exception to the foregoing, if the Engineer determines that the friction course will satisfactorily perform its intended function without corrective work, the friction course may be left in place without compensation. The area for which no payment will be made shall be the product of the total distance between cores indicating thickness within tolerances and the width of the lane which was laid in the particular pass in which the deficient thickness occurred. Additional cores will be taken as necessary to define the limits of a deficiency. Open-graded friction courses will not be cored for thickness determinations.

337-7.6 Hot Storage of FC-2 Mixes: When surge or storage bins are used in the normal production of FC-2, as with the drum mixer plants, the maximum time the mix is allowed to remain in the surge or storage bin shall not exceed one hour.

337-7.7 Longitudinal Grade Controls for Open-Graded Friction Courses: On open-graded friction courses, the use of the longitudinal grade control (skid, ski, or traveling stringline) is prohibited. The use of the joint matcher is required.

337-7.8 Transportation Requirements of Friction Course Mixtures: All loads of friction course mixtures shall be covered with a tarpaulin as specified in 320-6.4.

337-8 Method of Measurement.

337-8.1 Payment Based on Area: When the plans indicate that the friction course is to be paid for on an area basis, the area to be paid for shall be plan quantity subject to 9-3.2. The pay area shall include entire areas of transitions to tie into existing pavement but excluding areas for which no payment is to be made due to deficient thickness as defined in 337-7.5. No adjustment to the area to be paid for will be made for extra thickness.

337-8.2 Payment Based on Weight: When the plans indicate that the friction course is to be paid for by weight, the weight shall be determined as provided in 320-2 (including provisions for the automatic recordation system).

For FC-2 mixes, in the event the actual rate of application exceeds the rate established by the DOT Lab (as provided in 337-7.5.1) by in excess of ten pounds per square yard, the weight to be paid for shall be reduced to a theoretical quantity computed as the product of the actual area covered by the friction course and the established rate of application plus ten pounds per square yard.

337-8.3 Bituminous Material: The provisions of 331-6.4 apply to bituminous materials used in friction course mixes.

337-9 Basis of Payment.

337-9.1 Asphalt Rubber Binder: The bid price for the friction course mix shall include the cost of the asphalt cement, ground tire rubber, anti-stripping agent and blending and handling of the asphalt rubber binder in the friction course mix. The bid price for the friction course shall be based on the following asphalt rubber binder contents:

Mix Type	Asphalt Rubber Binder Content (%) by weight of total mix
FC-2	7.1[1]
FC-3	6.5

NOTE:
1 13.8 for FC-2 with lightweight aggregate.

If the asphalt rubber binder content in the approved mix design increases or decreases from the foregoing percentages, the bid price of the mix will be adjusted based on the invoice price of the asphalt rubber binder material plus ten percent of the invoice price. When the asphalt rubber binder is blended at the asphalt plant, the invoice price will be a combination of the invoice price for the asphalt cement, the ground tire rubber and the blending of the asphalt rubber binder.

$$\text{Adjustment } (\$ / sy) = t \frac{(ARBC_{Design} - ARBC_{Table}) \ 100 \ lb/sy\text{-}in}{8.6 \ lb/gal} (IP) \ 1.10$$

where

$ARBC_{Table}$ = Asphalt Rubber Binder Content (%) from above table,

$ARBC_{Design}$ = Asphalt Rubber Binder Content (%) in the mix design, as issued by the Materials Office,

t = Design Thickness (inches),

IP = Invoice Price.

As an example, when the asphalt rubber binder content for a FC 3 mix is determined to be 7.0 percent, the adjustment shall be calculated as follows:

$ per square yard = *t* x (*.005* x *100 lb/sy -in / 8.6 lb/gal*) x *Invoice Price* x 1.10

where $ARBC_{Design} - ARBC_{Table}$ = *.070–.065* = *.005*, and other variables are defined above.

*For FC-2 the *lb/sy-inch* will be based on the average spread rate for the project, and the thickness will not be needed.

The contract unit price per square yard for Asphaltic Concrete Friction Course shall be full compensation for all the work specified under this Section.

Payment shall be made under:

Item No. 337-5	—	Asphaltic Concrete Friction Course
	—	per square yard.

I. Ground Tire Rubber for Use in Asphalt Rubber Binder. (FA 9-12-94) (REV 5-25-94)

SECTION 919 (Pages 253-255) of the Supplemental Specifications is deleted and the following substituted:

Section 919 Ground Tire Rubber for Use in Asphalt Rubber Binder

919-1 Description.

This specification governs ground tire rubber for use in asphalt rubber binders for use in a variety of paving applications.

919-2 General Requirements.

The ground tire rubber shall be produced from tires such that the final processing is an ambient grinding method. The rubber shall be sufficiently dry so as to be free flowing and to prevent foaming when mixed with asphalt cement. The rubber shall be substantially free from contaminants including fabric, metal, mineral, and other non-rubber substances. Up to four percent (by weight of rubber) of talc or other inert dusting agent may be added to prevent sticking and caking of the particles.

919-3 Physical Requirements.

The physical properties of the ground tire rubber shall be determined in accordance with FM 5-559 and shall meet the following requirements:

Specific Gravity—1.10 ± 0.06

Moisture Content—Maximum 0.75%

Metal Contaminants—Maximum 0.01%

Gradation—The gradation shall meet the limits shown in Table 919-1 for the type of rubber specified.

TABLE 919-1
Gradations of Ground Tire Rubber

Sieve Size % Passing	Type A	Type B	Type C
10	—	—	100
20	—	100	85-100
40	100	85-100	20-60
80	90-100	10-50	5-20
100	70-90	5-30	—
200	35-60	—	—

919-4 Chemical Requirements.

The chemical composition of the ground tire rubber shall be determined in accordance with ASTM D 297 and shall meet the following requirements:

Acetone Extract—Maximum 25 percent.

Rubber Hydrocarbon Content—40 to 55 percent.

Ash Content—Maximum 8 percent.

Carbon Black Content—20 to 40 percent.

Natural Rubber—16 to 45 percent.
10 percent for Type A rubber.

919-5 Packaging and Identification Requirements.

The ground tire rubber shall be supplied in moisture resistant packaging such as either disposable bags or other appropriate bulk containers. Each container or bag of ground tire rubber shall be labeled with the manufacturer's designation for the rubber and the specific type, maximum nominal size, weight and manufacturer's batch or lot designation.

919-6 Certification Requirements.

The manufacturer of the ground rubber shall furnish the Engineer certified test results covering each shipment of material to each project. These reports shall indicate the results of tests required by this specification. They shall also include a certification that the material conforms with all requirements of this specification, and shall be identified by manufacturer's batch or lot number.

Standard Specifications for Public Works Construction—1994 ("Green Book")*

PART 6

Section 600—Modified Asphalts, Pavements and Processes

600-1 Requirements.

600-1.1 General. Section 600 covers various processes for both wet and dry crumb rubber materials and methods. Other products may be added as they are developed. The types of methods all utilize whole scrap tire crumb rubber. These specifications were developed to provide quality products that should produce reasonable results. While the specifications have been developed, the engineering properties are still being evaluated. The Engineer should evaluate the various methods and specify those to be considered for bidding in the project Specifications.

600-1.2 Mix Designs and Certifications. The Contractor shall furnish to the Engineer a mix design and samples of all materials to be used at least 15 working days before construction is scheduled to begin. The mix design and certifications shall include, but are not limited to, the following information:

1) **Mix Design**:
   a) Combined aggregate gradation.
   b) Individual bin gradations (hot for batch, cold for drum plant).
   c) Percentage of each component (asphalt, CRM, and bins).
   d) Source and paving grade of asphalt.
   e) Density.
   f) Air voids.
   g) Voids and Mineral Aggregate (VMA).
   h) Stability.
2) CRM:
   a) Source of CRM.
   b) Identification of Grade of CRM.

600-1.3 Definitions.

Asphalt—A dark brown to black cementitious material in which the predominating constituents are bitumins which occur in nature or are obtained in petroleum processing.

Asphalt Modifier (extender oil)—An aromatic oil used to supplement the asphalt/crumb rubber modifier reaction.

Asphalt-Rubber (AR)—Asphalt cement modified with crumb rubber modifier.

Buffings—High-quality scrap tire rubber which is a byproduct from the conditioning of tire carcasses in preparation for retreading.

Crackermill—A process at ambient temperature 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.

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Crumb Rubber Modifier (CRM)—A general term for scrap tire rubber that is reduced in size and is used as a modifier in asphalt paving materials.

Cryogenic Separation—An initial process that freezes the scrap tire rubber for the separation of steel and fabric from used tire rubber.

Diluent—A lighter petroleum product (typically kerosene) added to asphalt rubber binder just before the binder is spray applied to 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 process only applies to hot-mix asphalt production.

Granulated CRM—Cubical, uniformly shaped, cut crumb rubber particles with a low surface area which are 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 size of the rubber to a crumb particle.

Ground CRM—Irregularly shaped, torn crumb rubber particles with a large surface area which are generally produced by a crackermill.

Hot-Mix Asphalt (HMA)—HMA is used generically to include many different types of mixes produced at elevated temperatures in an asphalt plant. Three types of HMA are dense-graded, open-graded, and gap-graded.

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.

Rubber Aggregate—That portion of the crumb rubber modifier added to a hot-mix asphalt mixture using the dry process which retains its physical shape and rigidity.

Rubber Modified Hot-Mix Asphalt (RUMAC)—A dry process of hot-mix asphalt mixtures which incorporate crumb rubber modifier primarily as rubber aggregate.

Shredding—The initial process that reduces the whole scrap tires into pieces.

Asphalt-Rubber and Aggregate Membrane (ARAM [SAM])—surface treatment using an asphalt-rubber spray application and cover aggregate.

Asphalt-Rubber and Aggregate Membrane Interlayer (ARAMI [SAMI)])—A membrane beneath an overlay designed to resist the stress/strain of reflective cracks and delay the propagation of the cracks through the new overlay. The membrane is a spray application of asphalt-rubber binder and cover aggregate.

Wet Process—Any method that blends crumb rubber modifier with the asphalt cement prior to incorporating the binder in the asphalt paving project.

600-2 Crumb Rubber Modified (CRM) Binders and Pavements—Wet Process.

600-2.1 Asphalt-Rubber.

600-2.1.1 General. Asphalt-rubber shall consist of a mixture of paving asphalt and crumb rubber modifier (CRM) and shall conform to Type A, B, C, or D or as specified or contained in the Contract Documents.

600-2.1.2 Type A. Asphalt-rubber shall be a combination of whole scrap tire CRM, paving asphalt, and diluent (when required for spray applications) conforming to 600-2.

600-2.1.3 Type B. Asphalt-rubber shall be a combination of whole scrap tire CRM, natural

CRM, paving asphalt, and asphalt modifier conforming to 600-2.

600-2.1.4 Type C. Asphalt-rubber shall conform to all of the requirements for Type A asphalt-rubber, but may substitute a maximum of 3 percent total binder weight of natural rubber in lieu of any whole scrap tire CRM quantities.

600-2.1.5 Type D. Asphalt-rubber shall be a combination of whole scrap tire CRM, natural CRM (slightly less than Type B), paving asphalt, and asphalt modifier conforming to 600-2.

600-2.2 Materials. The Contractor shall submit test reports and certificates of compliance for the asphalt, CRM's, diluent, or modifier to be used. In addition, when requested by the Engineer, the Contractor shall submit samples of the tested material along with the certificates of compliance.

600-2.2.1 Paving Asphalt. The asphalt used for asphalt-rubber shall be AR 2000 or AR 4000 conforming to 203-1. Any proposed change to the viscosity grade, as specified, shall be submitted to the Engineer by the Contractor 48 hours prior to beginning work. The asphalt for Type B or Type D asphalt-rubber shall be modified with an asphalt modifier meeting the requirements of Table 600-2.2 (B).

600-2.2.2 Crumb Rubber Modifier (CRM). The material shall be whole scrap tire crumb rubber or other crumb rubber products meeting the requirements of this subsection. Steel and fiber separation may employ any method. Cryogenic separation shall be performed separately from and prior to grinding or granulating. All CRM shall be ground or granulated at ambient temperature. CRM may contain a maximum of 0.01 percent of wires and all other contaminants, except fabric which shall not exceed 0.5 percent by weight of CRM. CRM used in spray applications shall have less than 0.1 percent, by weight of CRM, of wires and fabric. CRM for use in spray applications may be produced all or in part from tire tread buffings in order to meet the maximum fabric requirements of this subsection. CRM shall be dry and free-flowing. Calcium carbonate or talc may be added up to a maximum of 4 percent by weight of CRM to prevent CRM particles from sticking together. The CRM shall have a specific gravity range from 1.1 minimum to 1.2 maximum as determined by ASTM D 297. Whole scrap tire CRM shall be derived from whole scrap tires generated within the State boundaries of the user agencies. Whole scrap tire CRM material shall conform to the following chemical analysis in Table 600-2.2.2 (A):

TABLE 600-2.2.2 (A)

Test	ASTM Test Method	Min.	Max.
Acetone Extract	D 297	11.0%	19.0%
Ash Content	D 297	—	8.0%
Carbon Black Content	D 297	28.0%	38.8%
Rubber Hydrocarbon	D 297	42.0%	52.0%
Natural Rubber Content	D 297	16.0%	34.0%

The natural CRM used in Type B and Type C asphalt-rubber shall meet the following chemical analysis in Table 600-2.2.2 (B):

TABLE 600-2.2.2 (B)[1]

Text	ASTM Test Method	Min.	Max.
Acetone Extract	D 297	4%	10%
Ash Content	D 297	35%	—
Carbon Black Content	D 297	—	15%
Natural Rubber Content	D 297	40%	—

NOTE

1. Tennis ball manufacturing scrap rubber is the primary known source for this material.

The combined whole scrap tire CRM and natural rubber CRM material used in Type D asphalt-rubber shall conform to the combined chemical analysis in Table 600-2.2.2 (C). Whole scrap tire CRM shall meet the chemical analysis in Table 600-2.2.2 (A). The natural CRM shall conform to the chemical analysis in Table 600-2.2.2 (B) or Table 600-2.2.2 (D).

Type D CRM shall conform to the requirements of 600-2.2.2. Type D CRM shall conform to the combined gradation, Table 600-2.2.4 (A). The asphalt modifier shall meet the requirements of Table 600-2.2.5 (B).

TABLE 600-2.2.2 (C)

Test	ASTM Test Method	Min.	Max.
Acetone Extract	D 297	9.5%	17.5%
Ash Content	D 297	—	18.5%
Carbon Black Content	D 297	20.0%	38.0%
Rubber Hydrocarbon	D 297	30.0%	55.0%
Natural Rubber Content	D 297	21.0%	42.0%

TABLE 600-2.2.2 (D)

Test	ASTM Test Method	Min.	Max.
Acetone Extract	D 297	5%	10%
Ash Content	D 297	—	10%
Carbon Black Content	D 297	25%	33%
Rubber Hydrocarbon	D 297	45%	65%
Natural Rubber Content	D 297	45%	65%

600-2.2.3 Formulations and Certifications. The Contractor shall supply to the Engineer for approval a binder formulation and samples of all materials to be used, at least 15 working days before construction is scheduled to begin. The binder formulation shall consist of the following information:

Paving Asphalt.

1) Source of paving asphalt and grade of asphalt cement.

2) Source and grade of additives used.

3) Percentage of asphalt cement and additives by total weight of the asphalt-rubber blend.

CRM.

1) Source of CRM.

2) Identification or grade of CRM.

3) Percentage of CRM by total weight of the asphalt-rubber blend.

   If CRM from more than one source is used, the above information will be required for each CRM used.

   Minimum Brookfield viscosity using a Number 3 rotor.

   Laboratory test results of the proposed blend per the test parameters for the type of asphalt-rubber selected including the minimum mixing reaction time.

When permitted by the Engineer, asphalt-rubber material, not used on another agency's project, may be used by another agency if the initial using agency certifies the following:

1) The total gallons and type of material being held over.

2) The amount of CRM contained within the holdover load on a percentage basis.

3) The grade of paving asphalt used and its source.

4) Date of original mixing.

5) Number of reheat cycles.

The Contractor shall notify the Agency at least 4 hours in advance of the need for a holdover load certificate. If, through no fault of the Contractor, the Agency is not able to provide the Contractor with a holdover certificate before the end of the shift which resulted in the holdover material, the Contractor and the asphalt-rubber supplier shall, under the penalty of perjury, certify to the above criteria. The maximum percentage of material held over shall not exceed 33 percent of the total amount of finished blended material contained in any vessel. In no case will more than 20 tons of holdover asphalt-rubber material be allowed to be transferred from one project to another. In all cases, the holdover asphalt-rubber material blended with new asphalt-rubber binder shall meet the viscosity requirements of the type being used.

Holdover material shall meet all of the following:

1) It shall be certified.

2) It shall not exceed the 33 percent blending requirements set forth above.

TABLE 600-2.2.4 (A)[1]

	Percentage Passing Sieve[2]		
Sieve Size	Type I	Type II	Type III
No. 8	100	100	100
No. 10	95-100	100	—
No. 16	40-60	70-100	45-85
No. 30	0-20	25-60	5-35
No. 50	0-10	0-20	0-15
No. 100	—	—	0-10
No. 200	0-5	0-5	0-1

NOTES

1. CRM from more than one source may be used provided the combined CRM gradation meets the specified limits. No particles shall exceed a length of 1/4 inch as measured on any axis.

2. CRM gradations shall be determined per ASTM C 136 with the following modifications: To a 100 gram sample of CRM add 5.0 grams of talc. Mix the CRM and talc for a minimum of 1 minute in a sealed pint size jar and shake by hand or stir until particle agglomerates/clumps are broken and the talc is uniformly mixed. After sieving the combined materials for 10 minutes, sum the total weight of the contents of each sieve, including the pan, and subtract 100. The remainder is to be subtracted from the bottom pan contents. This is the adjusted bottom pan contents, accounting for the talc used. If the sum of the weights is less than 103.5 grams or greater than 105.0 grams, the test shall be repeated with a new sample. The procedure is not applicable to CRM's with greater than 30% passing the No. 50 sieve.

TABLE 600-2.2.4 (B)[1]

Property	ASTM Text Method	Min.	Max.
Flash Point, COC, °F	D 92	130	—
Initial Boiling Point, °F	D 86	340	—
Dry Point, °F	D 86	390	415

NOTE

1. Caution: Not all kerosene will meet these requirements.

TABLE 600-2.2.5 (A)[1]

Sieve Size[2]	Percentage Passing Sieve Minimum-Maximum
No. 8	100
No. 10	98-100
No. 16	50-85
No. 30	5-30
No. 50	0-15
No. 100	0-10
No. 200	0-1

NOTES

1. Type B CRM shall contain 25±2 percent (by total weight of CRM) natural rubber. No particles shall exceed a length of 1/4 inch as measured on any axis.

2. ASTM C 136 modified per Table 600-2.2.4 (A).

TABLE 600-2.2.5 (B)

Property	ASTM Test Method	Value	
Viscosity, SUS @ 100°F	D 88	2,500	Min.
Flash Point, COC, °F	D 92	390	Min.
Molecular Asphaltenes, % by wt.	D 2007	0.1	Min.
Aromatics, % by wt.	D 2007	55	Min.

3) It shall be a maximum of 20 tons.

4) When blended with new asphalt-rubber material it shall meet the requirements of the type being used.

600-2.2.4 Type A. Type A CRM shall conform to the requirements of 600-2.2.2 and conform to the combined gradations for either Type I or Type II in Table 600-2.2.4 (A). The asphalt-rubber diluent (kerosene) shall be compatible with all other materials and meet the requirements in Table 600-2.2.4 (B).

600-2.2.5 Type B. Type B CRM shall conform to the requirements of 600-2.2.2 and shall conform to the combined gradations in Table 600-2.2.5 (A). The asphalt-rubber modifier shall meet the requirements in Table 600-2.2.5 (B).

600-2.3 Mixing.

Mixing of the asphalt and CRM shall be accomplished as specified herein for the type being furnished.

600-2.3.1 Type A Asphalt-Rubber. The proportions of the two materials, by weight, shall be 80 ± 3 percent asphalt and 20 ± 3 percent Type A CRM. For spray application, the minimum CRM content shall be 20 percent. The asphalt-rubber binder shall meet the physical parameters in Table 600-2.3.1 (A) for the climate specified when reacted at 350°F ± 25°F for 30 to 60 minutes in the laboratory and at the time of use on the project. If diluent is used, the sample shall be obtained prior to the addition of diluent when testing for conformance with the physical parameters in Table 600-2.3.1 (A).

TABLE 600-2.3.1 (A)[1]

Climate Type		Hot	Moderate
Avg. monthly max. temp. (a) (Hottest Month)		≥ 110°F	≤ 100°F
Avg. monthly min. temp. (b) (Coldest Month)		≥ 30°F	≤ 15°F
Test Parameter			
Brookfield Viscosity, 350°F, No. 3 Rotor, 20 RPM: Centipoise (ASTM D 2669)	Min.	1,500	1,500
	Max.	6,500	6,000
Needle Penetration, 77°F, 100g, 5 sec.: 1/10 mm (ASTM D 5)	Min.	25	25
	Max.	75	75
Penetration, 39.2°F, 200g, 60 sec.: 1/10 mm (ASTM D 5)	Min.	10	15
Softening Point: °F (ASTM D 36)	Min.	135	130
Resilience, 77°F: % (ASTM D 3407)	Min.	25	20

NOTE

1. Properties specified are to be measured before the addition of diluent. The amount of allowable diluent shall be determined by prior testing in advance of use.

The temperature of the asphalt shall be between 375°F minimum and 450°F maximum at the addition of the CRM. The temperature shall not exceed 10°F below the actual flash point of the mixture. The CRM shall be combined and mixed together in an asphalt-rubber mechanical blender meeting the requirements of 600-2.4. The combined asphalt and CRM shall be pumped into a storage/reaction tank or distributor truck meeting the requirements of 600-2.4 and allowed to react for a period of time as required by the Engineer, which shall be based on laboratory testing by the asphalt-rubber supplier. The required mixing/reaction time shall be 30 minutes minimum to 60 minutes maximum. The temperature of the asphalt-rubber mixture shall be between 325°F minimum to 375°F maximum during the reaction period.

For spray applications, after the full reaction has occurred, the mixture may be diluted with a diluent per 600-2.2.4. The amount of diluent used shall be 0 percent minimum to 5 percent maximum, by volume, of the asphalt-rubber mixture as required for adjusting viscosity for spraying or better wetting of the screenings. The temperature of the mixture shall not exceed 350°F at the time the diluent is added. The asphalt-rubber material may be utilized immediately following reaction. The application temperature shall be between 325°F minimum and 400°F maximum. The application temperature shall not be higher than 10°F below the actual flash point of the mixture.

If the material is not to be used within 6 hours of mixing, the heat shall be discontinued. The material shall be uniformly reheated to a temperature between 325°F minimum and 400°F maximum at time of use. Additional diluent, asphalt, and/or CRM, meeting the requirements of this subsection, may be added as needed. The cumulative amount of additional diluent shall not exceed 3 percent of total binder weight. The cumulative amount of additional CRM shall not exceed 10 percent of total binder weight. The cumulative amount of additional asphalt shall be such that the resulting asphalt-rubber binder conforms to the minimum CRM content as required in 600-2.3.1. The maximum number of reheating cycles shall not exceed three. Any time the material cools to below 300°F or is held above 375°F for more than 6 hours after mixing shall constitute a reheat cycle. Reheated asphalt-rubber binder shall conform to the requirements of the approved blend formulation as required in Table 600-2.3.1 (A).

600-2.3.2 Type B Asphalt-Rubber. Shall consist of the following:

1) Paving asphalt conforming to AR 4000 grade in 600-2, crumb rubber modifier (CRM) conforming to 600-2.2.2 and Table 600-2.2.5 (A), and asphalt modifier conforming to Table 600-2.2.5 (B).

2) The percent of asphalt modifier shall be 1 percent minimum to 6 percent maximum by volume of paving asphalt. The exact amount to be added shall be the amount in the binder formulation submitted and approved by the Engineer.

3) The proportions of the two materials, by weight, shall be 80 ± 2 percent paving asphalt with modifier and 20 ± 2 percent CRM. The CRM shall contain a minimum of 75 percent ± 2 percent crumb rubber derived from whole scrap tire rubber with the balance of the crumb rubber obtained from natural rubber sources conforming to Table 600-2.2.2 (B).

The temperature of the blended asphalt and modifier shall be between 375°F minimum and 450°F maximum when the CRM is added. The temperature shall not exceed 10°F below the actual flash point of the mixture. The CRM shall be added and mixed with the asphalt-modifier blend in an asphalt-rubber blender conforming to 600-2.4. The combined materials shall be pumped into a storage/reaction tank or distributor truck meeting the requirements of 600-2.4. The combined materials shall be allowed to react for a period of 30 minutes minimum after incorporation of all the CRM. The temperature of the combined materials shall be maintained between 375°F minimum and 425°F maximum during the mixing period. Agitation or recirculation shall be adequate to provide good mixing and dispersion of the combined materials. The asphalt-rubber material may be utilized immediately following reaction. The application temperature at the time of use on the project shall be between 375°F minimum and 425°F maximum.

After reaction, the AR 4000, asphalt modifier, and CRM, the asphalt-rubber binder shall conform to the requirements in Table 600-2.3.2 (A).

If the material is not to be used within 6 hours of mixing, the heat shall be discontinued. The material shall be uniformly reheated to a temperature between 375°F minimum and 425°F maximum at time of use. Additional CRM meeting the requirements of 600-2.2.2 may be added as needed. The cumulative amount of additional CRM shall not exceed 10 percent of total binder weight. The maximum number of reheating cycles shall not exceed three. Anytime the material cools to below 300°F or is held above 375°F for more than 6 hours after mixing, it shall constitute a reheat cycle. Reheated asphalt-rubber binder shall conform to the requirements in Table 600-2.3.2 (A).

TABLE 600-2.3.2 (A)

Test Parameter	Test Method	Specification Limit Min.	Specification Limit Max.
Brookfield Field Viscosity @ 375°F, No. 3 Rotor, 20 RPM, Centipoise	ASTM D2669	1,150	3,050
Cone Penetration @ 77°F, 1/10 mm	ASTM D 217	25	70
Resilient @ 77°F, % Rebound	ASTM D 3407	15	—
Field Softening Point, °F	ASTM D 36	125	165

600-2.3.3 Type D Asphalt-Rubber. Asphalt modifier conforming to Table 600-2.2.5 (B) shall be 2 percent minimum to 6 percent maximum, by volume of the paving asphalt. The exact amount to be added shall be the amount submitted in the binder formulation and approved by the Engineer.

The proportions of the two materials, by weight, shall be 80 ± 2 percent paving asphalt and modifier and 20 ± 2 percent CRM. The CRM shall contain a minimum of 77 percent crumb rubber derived from whole scrap tire (CRM) with the balance of the crumb rubber obtained from natural rubber sources. The combined CRM shall meet the chemical analysis in Table 600-2.2.2 (C).

The temperature of the blended asphalt and modifier shall be between 350°F minimum and 450°F maximum when CRM is added. The temperature shall not exceed 10°F below the actual flash point of the mixture. The CRM shall be added rapidly and be mixed and reacted with the asphalt-modifier blend for a period of 30 minutes minimum after incorporation of all the CRM. The temperature of the combined materials shall be maintained between 350°F minimum and 425°F maximum during this period. Agitation or recirculation shall be adequate to provide thorough mixing and dispersion of the combined materials.

Following reaction, the paving asphalt, asphalt modifier, and CRM, the asphalt-rubber binder shall conform to the requirements in Table 600-2.3.3 (A) at the time of use on the project.

TABLE 600-2.3.3 (A)

Test Parameter	Test Method	Spec. Limit Min.	Spec. Limit Max.
Brookfield Field Viscosity @ 400°F, No. 3 Rotor, 20 RPM	ASTM D 2669 Modified #1	600	2000
Cone Penetration @ 77°F, 10 mm	ASTM D 217	25	70
Resilient @ 77°F, % Rebound	ASTM D 3407	15	—
Softening Point, °F	ASTM D 36	125	165

The asphalt-rubber binder material may be utilized immediately following reaction. The application temperature shall be 350°F minimum and 425°F maximum. However, if the material is not to be used within 6 hours of mixing, the heating shall be discontinued.

The material shall be uniformly reheated to a temperature between 350°F minimum and 425°F maximum at the time of use. Additional CRM meeting the requirements of 600-2.2.2 may be added as needed. The cumulative amount of additional CRM shall not exceed 10 percent of total binder weight. The maximum number of reheating cycles shall not exceed three. Anytime the material cools below 300°F or is held above 375°F for more than 6 hours after mixing, it shall constitute a reheat cycle. Reheated asphalt-rubber binder shall conform to the requirements in Table 600-2.3.3 (A).

600-2.4 Equipment. Equipment utilized in preparing, distributing, and storing asphalt-rubber shall include the following:

1) **Asphalt Heating Tank.** An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature

for blending with the CRM. This unit shall be capable of heating a minimum of 2,500 gallons of asphalt.

2) **Blender Equipment Types.** All blending materials shall be measured using devices approved by the Engineer:

(a) **Blender I:** The blender shall consist of a mixing chamber within a 400-gallon tank. A mixer head assembly consisting of a shear plate and double suction cones shall be used for mixing, and shall be located on a shaft within the mixing chamber. The RPM's of this shaft shall be maintained between 2,500 and 3,500 during the mixing process. Auger-style mixing shall not be used. The internal mixing chamber shall have a 3/4-inch mesh screen at the bottom that all asphalt-rubber material shall exit through after being subjected to the mixing process. The mix process shall be continuous and shall produce a homogeneous mixture of asphalt and CRM that conforms to the specified ratios of the approved blend formulation. An asphalt-totalizing meter, CRM feed-system meter, and a blend-ratio meter shall be used to maintain component percentages during the mixing process. The blending unit shall have a separate asphalt-feed pump and finished-product pump.

(b) **Blender II:** The blender shall have a two-stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and CRM at the mix design specified ratios of the approved blend formulation. This unit shall be equipped with separate feed systems for CRM and asphalt cement, and be capable of properly proportioning all the materials in a continuous blending operation. It shall be capable of fully and uniformly blending the individual rubber particles with the asphalt. A separate asphalt-cement feed pump and finished-product pump are required. This unit shall have both an asphalt-totalizing meter in gallons and a flow-rate meter in gallons per minute, unless other devices are approved by the Engineer.

(c) **Blender III:** Blending equipment shall produce a homogeneous blend and uniform product, conforming to the physical properties of the type being used, as verified by consistent viscosity testing using a Brookfield viscometer and approved by the Engineer.

3) **Storage/Reaction Tank.** The asphalt-rubber storage/reaction tank shall be equipped with a heating system to maintain a storage/reaction temperature of 425°F maximum during the reaction period. This unit shall be capable of sustaining thorough agitation to maintain a uniform mixture of asphalt and CRM.

4) **Distributor Truck.** Distributor trucks shall meet the requirements for distributing equipment of 203-2.5 and be equipped with an internal heating device capable of evenly heating the material to a temperature of 425°F.

In addition, this unit shall have an internal agitation device capable of sustaining thorough agitation to maintain a uniform mixture of asphalt and CRM. The agitation device in the distributor truck and storage/reaction tank shall have an indicator to verify its rotation. The Contractor shall provide a suitable sampling outlet in the line connecting the asphalt-rubber storage tank to the binder weighing system or spray bar in an asphalt concrete mixing plant or to a distributor truck. The sampling valve shall be placed in a readily accessible and nonhazardous location. A drainage receptacle

TABLE 600-2.5.4 (A)

Sieve Size	Class		
	ARHM-GG-B Min. - Max.	ARHM-GG-C Min. - Max.	ARHM-GG-D Min. - Max.
1"	100	—	—
3/4"	90-100	100	—
1/2"	—	90-100	100
3/8"	60-75	78-92	78-92
No. 4	28-42	28-42	28-42
No. 8	15-25	15-25	15-25
No. 30	5-15	5-15	5-15
No. 200	0-5	2-7	2-7
% Asphalt-rubber Binder by Weight of Dry Aggregate	7.5-8.4	7.5-8.7	7.5-8.7
Air Voids % Calif. Test 367	2-5	2-5	2-5
Stabilometer Value Min. Calif. Test 304 and 366	25	25	25
Voids in Mineral Agg. Percent Min.	18	18	18

shall be provided for flushing the valve prior to sampling. One gallon shall be drawn from the sampler prior to taking the sample.

All equipment used in heating, curing, and distributing the asphalt-rubber shall be equipped with a thermostatic heat control device and an easily accessible, functional, and readable thermometer.

5) **Viscometers.** The Contractor shall supply a Brookfield viscometer for use by the Engineer to verify the viscosity of the asphalt-rubber on all projects where a field laboratory is used. All asphalt concrete batch plants are required to have a field laboratory for use by the Engineer per 8-3.

600-2.5 Crumb Rubber Modified Hot-Mix Asphalt (CRM-HMA) Wet Process.

600-2.5.1 General. CRM-HMA shall be the product of mixing mineral aggregate, asphalt binder, and CRM at a central-mixing plant and shall conform to 4-1-4, 203-6, and 600-1.2, Asphalt Concrete, except as modified herein.

600-2.5.2 Wet Process. A wet-process mix is defined as any process which incorporates CRM into the hot paving asphalt by mixing and blending (asphalt-rubber) prior to incorporating the binder with the aggregate at the central-mixing plant.

600-2.5.3 Materials. The asphalt-rubber binder shall conform to 600-2.1. Subsection 203-6.2.1 shall not apply.

600-2.5.4 Composition and Grading. Asphalt-rubber hot-mix—gap-graded (ARHM-GG) will be designated by class, i.e., ARHM-GG-C, and shall conform to the requirements of this subsection and Table 600-2.5.4 (A).

600-2.5.5 Mix Designs and Certifications. The optimum binder content for ARHM-GG mixes shall be determined by California Test Method 367 except that Step 2 regarding surface flushing shall not be used. Voids shall be substituted in selecting the optimum binder content between 2 percent minimum to 5 percent maximum as approved by the Engineer. Compaction shall be in accordance with California Test Method 304 except for the following:

Mixing Temperatures:

Asphalt-rubber = 340°F - 360°F

Aggregate = 290°F - 310°F

Compaction Temperature = 290°F - 300°F

In addition to the formulations and certifications required in 600-2.2.3 for asphalt-rubber, the Contractor shall furnish to the Engineer a mix design and samples of all materials to be used at least 15 working days before construction is scheduled to begin. The mix design and certifications shall include, but are not limited to, the following:

1) Combined aggregate gradation.

2) Individual bin gradations (hot for batch, cold for drum plant).

3) Percentage of each bin.

4) Asphalt-rubber formulation per 600-2.2.3.

5) Density.

6) Air Voids.

7) Voids in Mineral Aggregates (VMA).

8) Stability.

600-2.5.6 Miscellaneous Requirements. Miscellaneous requirements shall conform to 203-6.8 except that the temperature of the asphalt-rubber binder shall be 300°F minimum to 400°F maximum for Type A, C, and D asphalt-rubber; and 375°F minimum to 425°F maximum for Type B asphalt-rubber when added to the aggregate. The temperature of the aggregate at the time of adding the asphalt-rubber binder shall be 300°F minimum to 350°F maximum.

600-2.6 Asphalt-Rubber Hot-Mix—Gap-Graded (ARHM-GG).

600-2.6.1 General. ARHM-GG shall conform to the specifications for 302-5 except ARHM-GG shall consist of one or more courses of an asphalt-rubber binder and graded aggregate conforming to 600-2.5 placed upon a prepared roadbed or base, or over existing pavement. The courses shall conform to the requirements as shown on the Plans or in the Specifications.

600-2.6.2 Distribution and Spreading. Distribution and spreading shall conform to 302-5.5 except that at the time of delivery to the work site, the temperature of the ARHM-GG shall be 285°F minimum to 325°F maximum. At the direction of the Engineer, this maximum temperature may be raised to 350°F during cold climatic conditions. Atmospheric temperature shall be 50°F and rising.

600-2.6.3 Rolling. Rolling shall conform to 302-5.6 except that a vibratory roller using the vibratory mode shall be used for initial breakdown rolling unless otherwise directed by the Engineer. The initial breakdown rolling shall be completed before the ARHM-GG temperature falls below 275°F measured immediately in front of the roller. Pneumatic rollers shall not be used.

600-2.6.4 Rock Dust Blotter. At the option of the Engineer, when traffic conditions warrant, a rock dust blotter may be required to avoid tracking. Rock dust blotter shall conform to 200-1.2 and be uniformly applied using a mechanical spreader at a rate of 2 pounds minimum to 4 pounds maximum per square yard. When the ARHM-GG pavement has cooled to below 150°F, the rock dust blotter may not be required. Rock dust blotter placement and sweeping shall be included in the price bid for other items of work and no additional compensation will be allowed therefor.

600-2.7 Asphalt-Rubber and Aggregate Membrane (ARAM) Surfacing or Interlayer.

600-2.7.1 Screenings. Screenings when used as a cover aggregate for ARAM shall be crushed rock conforming to the following gradations in Table 600-2.7.1 (A):

TABLE 600-2.7.1 (A)

Sieve Size	Percentage Passing Sieve Coarse 1/2"	 Medium 3/8"	 Fine 3/8"
3/4"	100	100	—
1/2"	90-100	95-100	100
3/8"	50-80	70-85	85-100
No. 4	0-15[1]	0-15[1]	5-20[1]
No. 8	0-5	0-5	0-5
No. 16	—	—	—
No. 200	0-1	0-1	0-1

NOTE

1. Lower percentages are desirable.

Screenings shall be medium 3/8 inch unless otherwise specified. Screenings shall be preheated between 260°F to 300°F and adequately coated with 0.70 percent to 1 percent viscosity Grade AR 4000 asphalt at the central mixing plant to prevent free dust. The exact amount of asphalt shall be recommended by the Contractor and approved by the Engineer. Screenings shall conform to the requirements of Table 200-1.2 (B).

600-2.7.2 General. ARAM surfacing or interlayer shall involve cleaning and preparing the existing surface, spreading asphalt-rubber and cover aggregate, rolling, and sweeping.

The construction sequence of an ARAM shall be as follows:

1) The surface, when specified or as directed by the Engineer, shall be cold planed and repaired.

2) The surface shall be cleaned.

3) Asphalt-rubber shall be applied.

4) Cover aggregate shall be placed, rolled, and loose material removed. Only then will the ARAM surface be opened to traffic. A minimum of 48 hours shall elapse after placement of the screenings before a slurry seal conforming to 302-4 may be applied, unless otherwise directed by the Engineer.

Certified volume or weight slips shall be delivered to the Engineer for all materials supplied.

600-2.7.3 Pavement Preparation. Unless otherwise specified, all cracks 1/4 inch or greater in width shall be cleaned and sealed with an approved hot-applied crack sealant. Holes, spalls, and cracks greater than 1 inch in width shall be filled and compacted with an F-AR-4000 asphalt concrete mix. The pavement shall then be cleaned with a power broom.

600-2.7.4 Asphalt-Rubber Construction.

(a) **General.** Asphalt-rubber shall conform to 600-2.3. The Contractor shall submit a manufacturer's certificate of compliance for the asphalt and crumb rubber.

(b) **Application.** Asphalt-rubber shall be placed upon a clean dry surface. The pavement surface temperature shall be a minimum of 55°F in shaded areas; the atmospheric temperature shall be a minimum of 60°F; the wind shall not adversely affect spray distribution; and all necessary equipment shall be in position and ready to commence placement operations. The contractor shall take temperature readings with a temperature measuring device approved by the Engineer.

Asphalt-rubber shall be applied by distributor equipment meeting the requirements of 600-2.4 and the following:

1) The distributor shall have a platform on the rear of the vehicle and an observer shall accompany the distributor.

2) The observer shall ride in a position so that all spray bar tips are in full view and readily accessible for unplugging if a plugged tip should occur.

3) Material shall be applied at a rate between 0.55 to 0.65 gallons per square yard as directed by the Engineer.

4) Material spreading shall not be in excess of that which can be covered with aggregate within 15 minutes maximum.

The asphalt-rubber mixture may be applied to the roadway immediately following mixing, and reacting at temperature between 350°F minimum to 400°F maximum for Type A and C, and 375°F minimum to 425°F maximum for Type B. However, if the material is not to be used within 6 hours of mixing, the mixture shall be allowed to cool below 300°F for 12 hours maximum, or to ambient temperature for longer periods, and shall be uniformly reheated to a temperature between 300°F minimum to 425°F maximum at time of placement and conform to the viscosity requirements of the types specified.

When joining edges against areas with cover aggregate, the joint shall be swept clean of excess aggregate prior to the adjacent application of asphalt-rubber material. Transverse joints of this type shall be constructed by placing building paper across and over the end of the previous asphalt-rubber application. Once the spraying has progressed beyond the paper, the paper shall be removed immediately.

Joints between areas of asphalt-rubber without cover aggregate shall be made by overlapping asphalt-rubber distributions. The excess material shall be dispersed by spreading with a squeegee or rake over a larger area of freshly applied asphalt-rubber. The longitudinal joint between adjacent applications of screenings shall coincide with the line between designated traffic lines. All longitudinal joints shall be overlapped for complete coverage. The overlap shall not exceed 4 inches. At longitudinal joints, the edge shall be broomed back and blended so there are no gaps and the elevations are the same, free from ridges and depressions.

The application of asphalt-rubber to areas not accessible with the distributor bar on the truck shall be accomplished by using pressurized hand wands or other means approved by the Engineer.

Application of asphalt-rubber shall be discontinued sufficiently early in the workday to permit completion of initial sweeping prior to the termination of traffic control.

600-2.7.5 Cover Aggregate. Following the application of asphalt-rubber, cover aggregate conforming to 600-2.7.1, Screenings, shall be placed over all areas receiving asphalt-rubber. Cover aggregate shall be applied (within a maximum of 15 minutes) at a temperature between 260°F minimum to 300°F maximum at a rate of 28 to 40 pounds per square yard as directed by the Engineer.

The Contractor shall prevent any vehicle, including construction equipment, from driving on the uncovered asphalt-rubber. Cover aggregate shall be placed with a self-propelled, aggregate-spreading machine that can be adjusted to accurately spread the specified amounts per square yard. Trucks for hauling cover material shall conform to 302-2.3.

Initial rolling shall commence within 90 seconds following the placement of cover aggregate. Rolling shall be accomplished by three self-propelled, pneumatic-tired rollers meeting the requirements of 302-5.6.1 except that the tires shall be inflated to 100 pounds per square inch. The operating weight of each roller shall be a minimum of 20,000 pounds. If in the opinion of the Engineer, complete coverage may be provided by two rollers in one pass, then two pneumatic-tired rollers are sufficient. The initial rolling equipment shall maintain a distance of not more than 200 feet behind the cover-aggregate spreader on the first pass. There shall be at least four complete coverages (single pass in one direction) by the pneumatic-tired rollers before final roller coverage. A steel-drum roller weighing 8 tons minimum to 10 tons maximum shall complete the final roller coverage.

Sweeping shall be a multi-step operation following final rolling of the aggregate. A power broom shall be used to remove loose material without dislodging aggregate set in the asphalt-rubber. The initial sweeping shall be a light brooming on the same day as ARAM placement. The ARAM shall be maintained free of loose cover aggregate for a minimum of 5 working days following placement. During this period, the surface shall be swept as necessary to remove any loose cover material as directed by the Engineer. Final sweeping shall be done and all loose aggregate shall be removed prior to acceptance. The sweeping operations shall be accomplished without the use of gutter brooms or steel-tined brooms.

Immediately upon opening the street to traffic, the Contractor shall start removing loose aggregate from parkways, sidewalks, and intersecting streets. Both operations shall continue until all excess or loose aggregate is removed from the roadway surface and abutting adjacent areas.

At the option of the Engineer, rock dust blotter material shall be applied immediately after the initial pass of the rollers or after sweeping, but prior to opening to traffic, to prevent bleeding and pickup of the asphalt-rubber material. Rock dust blotter conforming to 200-1.2 shall be uniformly applied using a mechanical spreader at a rate of 2 pounds minimum to 4 pounds maximum per square yard. The Contractor shall include in the bid price for ARAM the full cost of applying rock dust blotter to all areas of ARAM, as directed by the Engineer.

The Contractor shall protect all existing manhole, valve, survey monument, and other miscellaneous frames and covers. The Contractor shall cooperate with the owners of any frames and covers and shall cover and completely protect them with heavy roofing paper or other suitable material. Petroleum-based release agents shall not be used for this purpose.

600-2.7.6 Public Convenience and Traffic Control. The Contractor shall prohibit traffic on the street until the initial sweeping is complete. Prior to opening the streets to traffic, "Loose Gravel," C6 signs, and appropriate speed-reduction signs conforming to local, State, and Federal regulations shall be posted and maintained by the Contractor. These signs shall remain in place until there is no further dislodging of the cover aggregate.

600-2.7.7 Measurement and Payment. ARAM including asphalt-rubber and cover aggregate will be paid for at the contract unit price per square yard. Unless otherwise specified, such price shall include full compensation for pavement preparation, furnishing and placing materials required, including rock dust blotter, and for all labor, equipment, sweeping, tools, and incidentals needed to complete the work in place.

APPENDIX E

Summary of Selected Local Agency Specifications

TABLE E-1

CRM Information Provided by the City of Phoenix

Type II Ground Tire Rubber Gradation:

Sieve Size Opening, mm	Sieve	% Passing
2.000	No. 10	100
1.180	No. 16	75-100
0.600	No. 30	25-60
0.300	No. 50	0-20
0.075	No. 200	0-5

Asphalt Rubber Specification (Hot Climate)

Test Description	Spec. Limits Min.	Max.
Virgin Binder		
Viscosity, Haake, 350°F, P2000 spindle 3, 20 rpm	2000	6000
Penetration, @ 25°C (77°F), dmm 100 g, 5 sec	25	75
Penetration, @ 4°C (39.2°F), dmm 200 g, 60 sec	15	—
Cone Penetration, @ 25°C (77°F), dmm 150 g, 5 sec	30	—
Resilience, @ 25°C (77°F), %	25	—
Softening Point, °C	57	—
Flash Point, °C	232	—
Ductility, @ 4°C (39.2°F), 1 cpm	5	—
Aged Binder (RTFO)		
Penetration Retention, @ 4°C (39.2°F), %	75	
Ductility Retention, @ 4°C (39.2°F), %	50	—
Ground Tire Rubber		
% of total asphalt binder by weight	17	—

Asphalt Rubber Mixing and Reaction Procedure:

1. **Asphalt Cement Temperature:** The temperature of the asphalt cement shall be between 204°C and 218°C (400°F and 425°F) at the addition of the granulated rubber.

2. **Blending and Reacting:** The asphalt and granulated rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage reaction tank, and then reacted for a minimum of 60 minutes from the time the granulated rubber is added to the asphalt cement. Temperature of the asphalt-rubber mix shall be a minimum of 190°C (375°F) during the reaction period. The mix of asphalt cement and rubber shall not be held at temperatures over 175°C (350°F) for a period over 10 hrs. The asphalt rubber may be allowed to cool to between 148°C and 175°C (300°F and 350°F) after it has reacted for the specified period.

3. **Transfer:** After the material has reacted for at least 60 minutes and the required viscosity is verified, the asphalt-rubber shall be metered into the mixing chamber of the asphalt concrete production plant at the percentage required by the engineer.

4. **Delays:** When a delay occurs in binder use after its full reaction, the asphalt-rubber shall be allowed to cool. The asphalt-rubber shall be reheated slowly just prior to a temperature between 140°C and 204°C (300°F and 400°F), and shall also be thoroughly mixed before pumping and metering into the hot plant for combination with the aggregate. The viscosity of the asphalt-rubber shall be checked by the supplier and verified by the Engineer. If the viscosity is out of the range specified, the asphalt-rubber shall be adjusted by the addition of asphalt cement or granulated rubber to produce a material with the appropriate viscosity and within the previously specified percent ground rubber range.

TABLE E-2

CRM Information Provided by International Surfacing

Recommended binder grades:

	ASPHALT CEMENT GRADE*	
Climate	**Viscosity Graded**	**Penetration Graded**
Cold	AC-2.5, AC-5, AC-10, AR-1000, or AR-2000	120-150 or 200-300
Moderate	AC-5, AC10, AR-1000, or AR-2000	85-100 or 120-150
Hot	AC-10, AC-20, AR-2000, or AR-4000	60-70 or 85-100

* The exact grade of asphalt cement shall be determined by the asphalt-rubber supplier dependent on the specific project requirements and conditions (climate and traffic).

Crumb Rubber Modifier:
The crumb rubber modifier (CRM) shall be produced primarily from processing automobile and/or truck tires by ambient grinding methods. The CRM shall be substantially free from contaminants including fabric, metal, mineral, and other nonrubber substance. The CRM shall be sufficiently dry to be free flowing and not produce a foaming problem when added to hot asphalt cement. Up to 4% by weight of talc or other appropriate blocking agent can be added to reduce agglomeration of the rubber particles.

Physical Requirements of CRM:

CRUMB RUBBER MODIFIER (CRM) GRADATION LIMITS

Sieve Size Opening, (mm)	Sieve Size	Percent Passing Type I	Percent Passing Type II
2.360	No. 8	100	—
2.000	No. 10	95-100	100
1.180	No. 16	40-60	70-100
0.600	No. 30	0-20	25-60
0.300	No. 50	0-10	0-20
0.075	No. 200	—	0-5
	Max. Particle Length	0.476 cm (.1875 in)	0.476 cm (.1875 in)

Fiber Content: The CRM shall be designated Grade A or Grade B. For Grade A CRM, the fiber content shall be less than 0.1% by weight. For Grade B CRM, the fiber content shall be less than 0.5% by weight.

Moisture Content: For each CRM type and grade the moisture content shall be less than 0.75% by weight.

Mineral Contaminants: For each CRM type and grade the mineral contaminant amount shall not be greater than 0.25% by weight.

Metal Contaminants: The CRM shall contain no visible metal particles as indicated by thorough stirring of a 50 gram (minimum) sample with a magnet.

Specifications for Asphalt Rubber Binder:

		Climate Type		
Test	**Spec Limits**	**Hot (a)**	**Moderate (b)**	**Cold (c)**
Apparent Viscosity, 176°C (350°F)	Min	1500	1500	1500
Spindle 3, 20 rpm, cP, (ASTM D 2196)[1]	Max	5000	5000	5000
Penetration, 25°C (77°F), 100 g, 5 sec	Min	25	25	50
1/10 mm, (ASTM D 5)	Max	75	75	100
Penetration, 4°C (39.2°F), 200 g, 60 sec 1/10 mm, (ASTM D 5)	Min	10	15	25
Softening Point, °C: (ASTM D 36)	Min	57	54	52
Resilience, 25°C (77°F), %, (ASTM D 3407)	Min	25	20	15
TFOT Residue, (ASTM D 1754) Penetration Retention, 4°C (39.2°F), %	Min	75	75	75

(a) Hot Climate	Average monthly maximum 43°C (110°F) or greater Average monthly minimum 1 °C (30°F) or greater
(b) Moderate Climate	Average monthly maximum 43°C (110°F) or lower Average monthly minimum -9°C (15°F) or greater
(c) Cold Climate	Average monthly maximum 18°C (80°F) or lower Average monthly minimum -9°C (15°F) or lower

NOTE

1. Either digital or dial reading viscometers may be used —record peak measurement. For LV series models, use spindle 3 at 12 rpm. For RV and HA series models, use spindle 3 at 20 rpm. Haake-type viscometers may be substituted, particularly for field control.

TABLE E-2

CRM Information Provided by International Surfacing (continued)

Asphalt Extender Oil: An asphalt extender oil may be added, if necessary, to meet the requirements of the asphalt rubber binder specification shown above. Extender oil shall be a resinous, high flash point, aromatic hydrocarbon meeting the following test requirements:

Viscosity, SUS, at 38°C (100°F) (ASTM D 88)	2500 min
Flash Point, COC, °C (ASTM D 92)	199 min
Molecular Analysis (ASTM D 2007):	
— Asphaltenes, Wt. %	0.1 max
— Aromatics, Wt. %	55.0 min

Asphalt-Rubber Binder Design:

The binder design shall be performed on the asphalt-rubber. The proportion of CRM shall be between 15 and 23% by total weight.

Asphalt-Rubber Mixing and Reaction Procedure:

Asphalt Cement Temperature: The temperature of the asphalt cement shall be between 191°C (375°F) and 232°C (450°F) at the addition of the CRM.

Blending and Reacting: The asphalt and CRM shall be combined and mixed together in a blender unit, pumped into the agitated storage/reaction tank, and then reacted for minimum of 30 minutes from the time all the CRM is added to the asphalt cement. The quantity of CRM added shall be determined by weight for each batch. Temperature of the asphalt-rubber mix shall be maintained at not less than 325°F during the reaction period. The asphalt-rubber may be allowed to cool to between 148°C and 175°C (300°F and 350°F) after it has reacted for the specified period.

TABLE E-3

CRM-Related Specifications Provided by the American Public Works Association (Southern California Chapter)

CRUMB RUBBER MODIFIED (CRM) BINDERS AND PAVEMENTS—WET PROCESS

Asphalt-Rubber. Asphalt-rubber shall consist of a mixture of paving asphalt and crumb rubber modifier (CRM) and shall conform to Type A, B, C, or D.

Type A. Asphalt-rubber shall be a combination of whole scrap tire CRM, paving asphalt, and diluent.

Type B. Asphalt-rubber shall be a combination of whole scrap tire CRM, natural CRM, paving asphalt, and asphalt modifier.

Type C. Asphalt-rubber shall conform to all of the requirements for Type A asphalt-rubber, but may substitute a maximum of 3 percent total binder weight of natural rubber in lieu of any whole scrap tire CRM quantities.

Type D. Asphalt-rubber shall be a combination of whole scrap tire CRM, natural CRM (slightly less than Type B), paving asphalt, and asphalt modifier.

Paving Asphalt. The asphalt used for asphalt-rubber shall be AR 2000 or AR 4000.

Crumb Rubber Modifier (CRM). The material shall be whole scrap tire crumb rubber or other crumb rubber products meeting the requirements shown below. Steel and fiber separation shall be performed separately from and prior to grinding or granulating. All CRM shall be ground or granulated at ambient temperature. CRM may contain a maximum of 0.01 percent of wires and all other contaminants, except fabric which shall not exceed 0.5 percent by weight of CRM. Calcium carbonate or talc may be added up to a maximum of 4 percent by weight of CRM to prevent CRM particles from sticking together. The CRM shall have a specific gravity range from 1.1 minimum to 1.2 maximum.

Whole scrap tire CRM material shall conform to the following chemical analysis:

E-3-1

Test	Min. (%)	Max. (%)
Acetone Extract	11.0	19.0
Ash Content	—	8.0
Carbon Black Content	28.0	38.8
Rubber Hydrocarbon	42.0	52.0
Natural Rubber Content	16.0	34.0

The natural CRM used in Type B and C asphalt-rubber shall meet the following chemical analysis:

E-3-2

Test	Min. (%)	Max. (%)
Acetone Extract	4	10
Ash Content	35	—
Carbon Black Content	—	15
Natural Rubber Content	40	—

The combined whole scrap tire CRM and natural rubber CRM material used in Type D asphalt-rubber shall conform to the combined chemical analysis shown below:

E-3-3

Test	Min. (%)	Max. (%)
Acetone Extract	9.5	17.5
Ash Content	—	18.5
Carbon Black Content	20.0	38.0
Rubber Hydrocarbon	30.0	55.0
Natural Rubber Content	21.0	42.0

Whole scrap tire CRM shall meet the chemical analysis in E-3-1. The natural CRM shall conform to the chemical analysis in E-3-2 or E-3-4.

E-3-4

Test	Min. (%)	Max. (%)
Acetone Extract	5	10
Ash Content	—	10
Carbon Black Content	25	33
Rubber Hydrocarbon	45	65
Natural Rubber Content	45	65

TABLE E-3

CRM-Related Specifications Provided by the American Public Works Association (Southern California Chapter) (continued)

Type D CRM shall conform to the combined gradation shown below:

E-3-5[1]

Sieve Size Opening (mm)	Sieve Size	Percentage Passing Sieve[2] Type I	Type II	Type III
2.360	No. 8	100	100	100
2.000	No. 10	95-100	100	—
1.180	No. 16	40-60	70-100	45-85
0.600	No. 30	0-20	25-60	5-35
0.300	No. 50	0-10	0-20	0-15
0.150	No. 100	—	—	0-10
0.075	No. 200	0-5	0-5	0-1

NOTES

1. CRM from more than one source may be used provided the combined CRM gradation meets the specified limits. No particles shall exceed a length of 1/4 inch as measured on any axis.

2. CRM gradations shall be determined per ASTM C 136 with the following modifications: To a 100 gram sample of CRM add 5.0 grams of talc. Mix the CRM and talc for a minimum of 1 minute in a sealed pint size jar and shake by hand or stir until particle agglomerates/clumps are broken and the talc is uniformly mixed. After sieving the combined material for 10 minutes, sum the total weight of the contents of each sieve, including the pan, and subtract 100. The remainder is to be subtracted from the bottom pan contents. This is the adjusted bottom pan contents, accounting for the talc used. If the sum of the weights is less than 103.5 grams or greater than 105.0 grams, the test shall be repeated with a new sample. The procedure is not applicable to CRMs with greater than 30% passing the No. 50 sieve.

Type A. Type A CRM shall conform to the combined gradations for either Type I or Type II in E-3-5.

Type B. Type B CRM shall conform to the combined gradations in E-3-6.

E-3-6[1]

Sieve Size Opening, mm	Sieve Size[2]	Percentage Passing Sieve Minimum - Maximum
2.360	No. 8	100
2.000	No. 10	98-100
1.180	No. 16	50-85
0.600	No. 30	5-30
0.300	No. 50	0-15
0.150	No. 100	0-10
0.075	No. 200	0-1

1. Type B CRM shall contain 25±2 percent (by total weight of CRM) natural rubber. No particles shall exceed a length of 1/4 inch as measured on any axis.

2. ASTM C 136 modified per E-3-5.

Type A Asphalt-Rubber. The proportions of the two materials, by weight, shall be 80 ± 3 percent asphalt and 20 ± 3 percent Type A CRM. The asphalt-rubber binder shall meet the physical parameters in E-3-7 for the climate specified when reacted at 176°C ± 14°C (350°F ± 25°F) for 30 to 60 minutes in the laboratory and at the time of use on the project. If diluent is used, the sample shall be obtained prior to the addition of diluent when testing for conformance with the physical parameters in E-3-7.

E-3-7[1]

Climate Type		Hot	Moderate
Avg. monthly max. temp. (a) (Hottest Month)		≥ 110°F	≤ 110°F
Avg. monthly min. temp. (b) (Coldest Month)		≥ 30°F	≤ 15°F
Test Parameter			
Brookfield Viscosity, 176°C (350°F), No. 3 Rotor, 20 rpm, Centipoise (ASTM D 2669)	Min. Max.	1500 6500	1500 6000
Needle Penetration, 25°C (77°F), 100 g, 5 sec.; 1/10 mm (ASTM D 5)	Min. Max.	25 75	25 75
Penetration, 4°C (39.2°F), 200 g, 60 sec.; 1/10 mm (ASTM D 5)	Min.	10	15
Softening Point °C (ASTM D 36)	Min.	57	54
Resilience, 25°C (77°F.) % (ASTM D 3407)	Min.	25	20

1. Properties specified are to be measured before the addition of diluent. The amount of allowable diluent shall be determined by prior testing in advance of use.

TABLE E-3

CRM-Related Specifications Provided by the American Public Works Association (Southern California Chapter) (continued)

Type B Asphalt-Rubber. Shall consist of the following:

1) Paving asphalt conforming to AR 4000, crumb rubber modifier (CRM) conforming to E-3-1, E-3-2, E-3-3, or E-3-4 and E-3-6.

2) The percent of asphalt modifier shall be 1 percent minimum to 6 percent maximum by volume of paving asphalt.

3) The proportions of the two materials, by weight, shall be 80 ± 2 percent paving asphalt with modifier and 20 ± 2 percent CRM. The CRM shall contain a minimum of 75 percent ± 2 percent crumb rubber derived from whole scrap tire rubber with the balance of the crumb rubber obtained from natural rubber sources conforming to E-3-2.

The resulting asphalt-rubber blend shall conform to the requirements shown below:

E-3-8

	Specification Limit	
Test Parameter	**Minimum**	**Maximum**
Brookfield Field Viscosity @ 191°C (375°F), No. 3 Rotor, 20 rpm, Centipoise	1150	3050
Cone Penetration @ 25°C (77°F), 1/10 mm	25	70
Resilient @ 25°C (77°F), % Rebound	15	—
Field Softening Point, °C	52	74

Type D Asphalt-Rubber. Asphalt modifier shall be 2 percent minimum to 6 percent maximum, by volume of the paving asphalt.

The proportions of the two materials, by weight, shall be 80 ± 2 percent paving asphalt and modifier and 20 ± 2 percent CRM. The CRM shall contain a minimum of 77 percent crumb rubber derived from whole scrap tire (CRM) with the balance of the crumb rubber obtained from natural rubber sources. The combined CRM shall meet the chemical analysis in E-3-3.

The resulting asphalt rubber blend shall conform to the requirements shown below:

E-3-9

	Specification Limit	
Test Parameter	**Minimum**	**Maximum**
Brookfield Field Viscosity @ 204°C (400°F), No. 3 Rotor, 20 rpm	600	2000
Cone Penetration @ 25°C (77°F), 10 mm	25	70
Resilience @ 25°C (77°F), % Rebound	15	—
Softening Point °C	52	74

Crumb Rubber Modified Hot-Mix Asphalt (CRM-HMA) Wet Process

Composition and Grading. Asphalt-rubber hot-mix—gap-graded (ARHM-GG) will be designated by class, i.e., ARHM-GG-C, and shall conform to the requirements shown below:

E-3-10

		Class		
Sieve Size Opening (mm)	**Size**	**ARHM-GG-B Min.- Max.**	**ARHM-GG-C Min.- Max.**	**ARHM-GG-D Min.-Max.**
25.4	1"	100	—	—
19.0	3/4"	90-100	100	—
16.0	1/2"	—	90-100	100
9.51	3/8"	60-75	78-92	78-92
4.75	#4	28-42	28-42	28-42
2.36	#8	15-25	15-25	15-25
0.60	#30	5-15	5-15	5-15
0.075	#200	0-5	2-7	2-7
% Asphalt-rubber Binder by Weight of Dry Aggregate		7.5-8.4	7.5-8.7	7.5-8.7
Air Voids % Calif. Test 367		2-5	2-5	2-5
Stabilimeter Value Min. Calif. Test 304 and 366		25	25	25
Voids in Mineral Agg. Percent Min.		18	18	18

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