

# Rubberized Asphalt Concrete



# Production and Construction Guide



## RAC-104

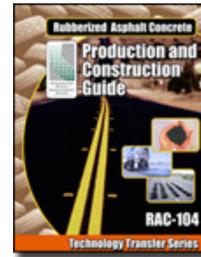
## Technology Transfer Series



# Production & Construction Guide

## Technology Transfer **RAC-104**

### Production and Construction Guide RAC-104



### Index

<b>Asphalt-Rubber Binder Production</b> .....	2
Holdover and Reheating .....	4
Documentation .....	5
Sampling and Testing Requirements .....	5
<b>Production of AR Hot Mixes (RAC)</b> .....	8
Mix Production .....	8
Inspection and Troubleshooting of the RAC Mixture .....	9
Importance of Temperature .....	9
Safety .....	11
<b>Hot Mix (RAC) Paving Equipment</b> .....	11
Haul Trucks .....	11
Material Transfer Vehicle (MTV) .....	12
Pavers .....	12
Rollers .....	12
<b>Final Preparations for Paving</b> .....	13
Tack Coat .....	13
<b>Hot Mix Delivery</b> .....	14
Coordinating Mix Delivery and Placement .....	14
Release Agents .....	15
Loading Haul Trucks .....	15
Unloading Hot Mix Into a Paver Hopper .....	15
Unloading Hot Mix Into a Material Transfer Vehicle .....	15
Load Tickets .....	16
<b>Hot Mix Placement</b> .....	16
Paver Operations .....	17
Raking and Handwork .....	17
Joints .....	17
<b>Hot Mix Compaction</b> .....	18
Temperature Requirements .....	19
Factors that Affect AC Compaction .....	19
Test Strips and Rolling Patterns .....	20

# Production & Construction Guide

## *Technology Transfer RAG-104*

Opening New Pavement to Traffic .....	20
<b>Examples Of Good Paving Practices</b> .....	21
<b>Asphalt Rubber Spray Applications</b> .....	22
Chip Seal Construction .....	22
Chip Seal Equipment .....	23
Asphalt Rubber Spray Application .....	23
Aggregate Application .....	24
Rolling Asphalt Rubber Chip Seals .....	25
Sweeping .....	25
Flush Coat .....	25
Fog Seals .....	25
Sand Cover .....	26
Traffic Control .....	26
<b>Emissions</b> .....	26
Air Quality .....	26
FHWA/USEPA .....	26
AC Plant Emissions Tests .....	27
Worker Health and Safety .....	28
National Institute for Occupational Safety and Health (NIOSH) .....	28
Industry Studies in California .....	29
Summary .....	30
Water Quality .....	30
<b>Glosary</b> .....	31
Types of CRM .....	31
CRM Preparation Methods .....	32
CRM Processing Equipment .....	32
Aggregates for Asphalt Concrete .....	36
Asphalt .....	38
Mix Design Methods .....	39
Mix Design Characteristics .....	39
Mix Design Properties .....	40
Typical Asphalt Paving Failures .....	42

# Production & Construction Guide

## Technology Transfer RAG-104

### ASPHALT-RUBBER BINDER PRODUCTION

Production methods for wet process high viscosity asphalt-rubber binders (minimum viscosity of 1,500 centipoises (cPs) or 1.5 Pascal-seconds) are essentially the same for both hot mix and spray applications. The primary difference is the importance of coordination of asphalt-rubber and hot mix production to assure that enough asphalt-rubber binder is available to provide the desired AC production rate. Binders for spray applications are typically produced close to the job site, not necessarily at an AC plant, and their production must be coordinated with application operations.

The Greenbook allows two types of high viscosity binders, Type 1 and Type 2. Type 2 Asphalt Rubber Binder includes the same components specified by Caltrans (asphalt cement, asphalt modifier (extender oil), and both scrap tire and high natural crumb rubber modifiers (CRM)) but allows more variation in the relative proportions of the two types of CRM. Caltrans currently uses Type 2 exclusively. Type 1 Asphalt Rubber Binder includes only asphalt cement and scrap tire CRM, the same composition routinely used for asphalt-rubber binders in Arizona, Texas, and Florida. These two types of high viscosity wet process binders are based on the two original patents for asphalt-rubber binders that expired years ago.

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

Type 2 asphalt-rubber binder must be interacted with agitation for a minimum of 45 minutes at temperatures from 375 to 425°F to achieve the desired interaction between asphalt and rubber. In order to maintain adequate reaction temperature, temperature of the asphalt cement and extender oil (if used) must be at least 400°F before the design proportions of scrap tire and high natural CRM are



Binder Production Overview



Asphalt Storage Tank



Crumb Rubber Super Sacks



Weigh Hopper



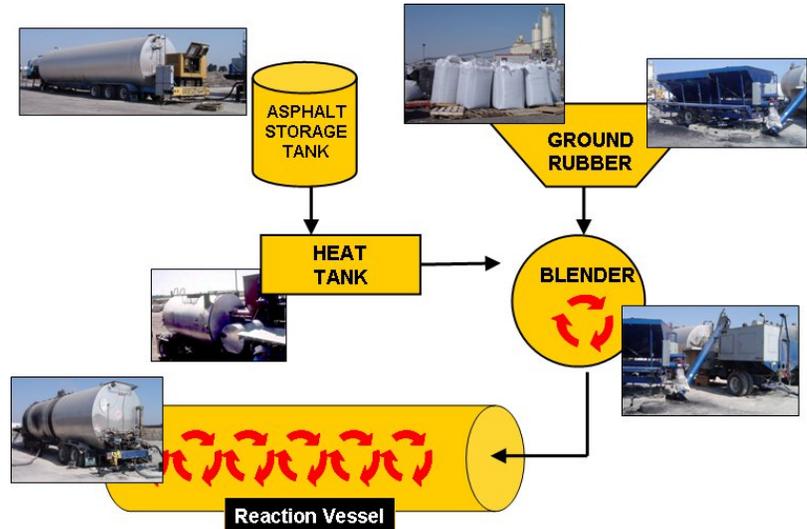
CRM Bins

# Production & Construction Guide

## Technology Transfer **RAG-104**

added at ambient temperature. Type 1 binders are routinely interacted at temperatures from 350 to 375°F and tested for viscosity at 350°F; the minimum viscosity limit remains at 1,500 cPs. Type 1 binders must meet the same property requirements as Type 2 binders.

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



Asphalt Binder Production

AR Binder Design Profile						
Test Performed	Minutes of Reaction					45 minutes Specification Limits***
	45	90	240	360	1,440	
Viscosity, Haake at 190°C, Pa.s, (10-3), or cP (*See Note)	2400	2800	2800	2800	2100	1500 – 4000
Resilience at 25°C, % Rebound (ASTM D5329)**	27	--	33	--	23	18 Minimum
Ring & Ball Softening Point, °C (ASTM D36)	59.0	59.5	59.5	60.0	58.5	52 – 74
Cone Pen. at 25°C, 150g, 5 sec., 1/10 mm (ASTM D217)	39	--	46	--	50	25 – 70

Crumb rubber modifier (CRM) is typically packaged in one ton super sacks that should be clearly labeled and stored to prevent loss or damage. The CRM is fed into a weigh hopper for proportioning along with the asphalt cement and other additives such as extender oil, if used.

# Production & Construction Guide

## Technology Transfer **RAG-104**

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

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

Hand held rotational viscometers (Haake, Rion, or equivalent) are used to monitor the viscosity of the asphalt rubber interaction over time for quality control and assurance. Before any asphalt rubber binder can be used for hot mix production or spray application, compliance with the minimum viscosity requirement must be verified using an approved viscometer. As long as the viscosity is in compliance and the interaction has proceeded for at least 45 minutes, the asphalt rubber may be used.

### Holdover and Reheating

If an asphalt rubber material is not used within 4 hours after the 45-minute reaction period, both Caltrans and the Greenbook require that heating be discontinued. Sometimes the binder must be held overnight. The rate of cooling in an insulated tank varies, but reheating is required if the temperature drops below 375°F for a Type 2 binder or 350° to 375°F for a Type 1 binder. A reheat cycle is defined as any time that an asphalt rubber binder cools below its designated viscosity measurement temperature and is reheated. Two reheat cycles are allowed, but the asphalt rubber binder must continue to meet requirements, including the minimum viscosity.

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



Hopper to blender feed



Blender Units



Reaction Vessels



AR Binder Product

# Production & Construction Guide

## Technology Transfer **RAG-104**

viscosity requirement before it can be used. The Greenbook has specific requirements for transferring holdover binder material between projects and Agencies

### **Documentation**

A Certificate of Compliance (COC) is required for every binder constituent as well as for the finished asphalt rubber binder. The COCs must include test results that show conformance of the materials to the respective special provisions, including chemical composition of the scrap tire and high natural CRM materials and asphalt modifier (extender oil) as applicable. COCs for the component materials delivered to site of the asphalt rubber blending operation should be provided to the Engineer, inspector and/or project staff. Representatives of the Owner typically sample the individual components and blended asphalt rubber materials at the blending site for testing and acceptance.

A copy of the approved asphalt rubber Binder Design Profile that includes results of specified laboratory tests and proportions of each component must be available at the asphalt rubber blending site.

A Log of Asphalt Rubber Binder Production shall also be maintained for each project. For each batch of asphalt rubber produced, the log should list the weights of each component used, the reaction start time, and results of each viscosity test performed, including the time and asphalt rubber binder temperature and the time when the batch was metered into the AC plant. The production log should also include all holdovers and reheat cycle information including the time that heating was discontinued, the time that reheating began and corresponding asphalt rubber binder temperature, CRM addition weight and time if applicable, and subsequent viscosity test results. The figure below presents an example of an asphalt rubber binder production log; other formats that clearly present the required information may also be used.

### **Sampling and Testing Requirements**

Frequency of sampling and testing may vary depending on the nature of the materials, project size, and available resources. Aside from minimum requirements, additional sampling is recommended whenever changes in any material or its behavior are observed. Sampling during production and construction is relatively easy and inexpensive, and it is rarely necessary to test every sample obtained.

# Production & Construction Guide

## Technology Transfer **RAG-104**

Suggested minimum requirements for quality control (QC) and quality assurance (QA) or acceptance sampling and testing are presented in the table below.

Minimum Sampling and Testing Requirements		
Material	QC Sampling & Testing	QA Sampling & Testing
CRM	Chemical composition each 250 tons	Once per project for compliance
CRM	Gradation & physical properties each 10,000 pounds	Once per project for compliance
Paving Asphalt	Once per project for compliance	Once per project for compliance
Asphalt Modifier	Once per project for compliance	Once per project for compliance
Asphalt Rubber Binder	Viscosity every hour One gallon per batch and after each reheat cycle	Sample one gallon per batch and after each reheat cycle Test one gallon per day for compliance
RAC Mixture	Morning and afternoon daily Gradation, binder content For Gap-Graded mixes, measure Rice and lab compacted air voids	One sample daily Gradation, binder content For Gap-Graded mixes, measure Rice and lab compacted air voids
RAC Mixture Lifts $\geq 1.5$ " thick	In-place compaction	Record pavement cores taken per day

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



**Go- No Go Test**



*Binder Viscosity Test*

# Production & Construction Guide

## Technology Transfer **RAG-104**

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

EXAMPLE TEST REPORT FORM  
ASPHALT RUBBER BINDER ROTATIONAL VISCOSITY

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

ASPHALT RUBBER BINDER FORMULATION	Blend Proportions
Asphalt Cement PG Grade and Supplier	
Asphalt Modifier Type and Supplier	% by AC mass:
Asphalt Cement and Modifier	% by Asphalt Rubber Binder mass:
Scrap Tire CRM Type & Supplier	% by Asphalt Rubber Binder mass:
High Natural CRM Source & Description	% by Asphalt Rubber Binder mass:

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

*Cycle Start Date & Time	AR Batch #	Temperature In ARB Tank (°F)	Temp. During Viscosity Test (°F) (375 $\pm$ 3°F)	Measured Viscosity** Pa-s( $\times 10^{-3}$ )	Date and Time Sampled	Date and Time Tested	Comments

Viscometer Make, Model and Serial #: \_\_\_\_\_  
Rotor Designation: \_\_\_\_\_

Test Operator: \_\_\_\_\_

\* The cycle begins when the asphalt rubber tank is fully loaded and temperature in the tank is 375 $\pm$ 3°F.  
\*\* Measure viscosity at 375 $\pm$ 3°F according to Caltrans LP-10X. Viscometer may read in units of centipoises (cPs) or dPa-s. Unit conversions are as follows:  
1 Pa-s = 1,000 cPs  
1 dPa-s = 0.1 Pa-s = 100 cPs  
1 mPa-s = 0.001 Pa-s = 1 cPs



Rotational viscosity is the go/no-go field test that governs use of the asphalt rubber binder. One-gallon cans are used to provide adequate clearance from the sides and bottom of the container, and should be 75-85% filled with the binder. There are currently two methods for testing rotational viscosity of high viscosity asphalt-rubber binders. One is described in Section 203-11.4.1 of the Greenbook. The Caltrans Asphalt Rubber Usage Guide includes a description of the unpublished Caltrans field method using the old style analog gauges,

# Production & Construction Guide

## Technology Transfer RAG-104

and suggested revisions. It is similar to the Greenbook method but does not include a correction factor. Either method can be used with similar results, but neither addresses the new style digital readout gauges or how to control binder temperature during viscosity measurement. Test equipment such as a hot plate, gas burner or stove, should be added for temperature control. The Caltrans method is being revised and updated to serve as a standard Caltrans Laboratory Procedure (LP) which can also be performed at the blending site, but it has not yet been approved. An ASTM method is in development which is based on the proposed Caltrans LP.

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



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

## PRODUCTION OF AR HOT MIXES (RAC)

### Mix Production

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

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

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

RAC production rates may be reduced somewhat from DGAC rates due to higher binder content (increased mixing time) and asphalt rubber binder production rate. However, planning and



*An AC Plant production rate of 375 Tons/hr using 18% by weight of RAC Mix will require 27 Tons/hr of RAC binder*

# Production & Construction Guide

## Technology Transfer **RAC-104**

coordination between the asphalt rubber binder producer and the AC plant operator can be used to minimize impacts on RAC production. The binder supplier can in many cases arrange to use more or larger storage and interaction tanks, and schedule materials deliveries and asphalt rubber blending operations to expedite production of asphalt rubber binder and mix.

### Inspection and Troubleshooting of the RAC Mixture

The primary change to the Plant Inspector's normal duties is the addition of monitoring the asphalt rubber production and viscosity results and sampling the asphalt rubber binder and its components. The Asphalt Rubber Binder Production Log and Testing Log should contain the pertinent information, and should be available for inspection. The Inspector should obtain at least one one-gallon sample from each batch of asphalt rubber binder produced for the project to test for compliance with specification limits, and additional samples if any changes in appearance or behavior are observed.

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

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



*Plant material sampling*

### Importance of Temperature

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

- Asphalt rubber binder manufacture
- RAC hot mix production
- RAC delivery



*Handheld thermometers*

# Production & Construction Guide

## Technology Transfer **RAC-104**

- RAC placement
- RAC compaction.

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

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

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

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

**Segregation:** Particle size segregation may be difficult to identify in some coarse gap-graded mixtures. There are few fines present and that can sometimes make the RAC appear segregated even if it is not. Identify the affected truckloads and corresponding placement areas, take samples and test gradation and binder content to verify. It is also recommended that, if possible, samples of RAC that do not appear segregated should be taken from the same truckload, for comparison. Temperature segregation (hot or cold spots) may be checked with a heat gun or with an infrared camera. The primary concern is differences rather than exact values.

**Blue smoke:** Mix is too hot.

**White smoke:** Steam, not smoke, which indicates too much moisture in the mix. This means that the aggregate was not dried enough prior

# Production & Construction Guide

## Technology Transfer **RAC-104**

to mixing with asphalt rubber binder. This may cause the RAC mix to become tender and may contribute to compaction problems.

**Stiff appearance:** Mix may be too cool – check temperature.

**Dull, flat appearance:** Indicates low asphalt rubber binder content and/or excessive fines (minus 0.075 mm (No. 200) sieve size). Localized areas of dullness may indicate insufficient mixing of the asphalt rubber binder and aggregates, or mix segregation. Take samples and test for gradation and binder content.

**Slumped and shiny:** High asphalt rubber binder content. RAC-O, and especially RAC-O (HB) mixtures, may look this way and still meet SSP requirements, so this is not always a problem. An old descriptive term for this is “wormy,” because the mix seems to almost crawl when watched. Look in the truck bed for binder drain down, take and test samples for asphalt rubber binder content and gradation.

### Safety

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



## HOT MIX (RAC) PAVING EQUIPMENT

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

### Haul Trucks

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

### Material Transfer Vehicle (MTV)

Use of this type of equipment is optional. MTVs (also called shuttle buggies) have been described as “surge bins on wheels” and are most often used when smoothness, segregation (particle size or temperature) or mixture delivery rate are concerns.



MTV

### Pavers

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

### Rollers

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



RAC-G mixtures are likely to require more compaction effort than DGAC due to the relatively coarse nature of the aggregate skeleton. Minimum recommended roller weight is 8 tons; pup rollers cannot provide sufficient compaction. The types of rollers include:

- Breakdown roller with vibratory capability: It is strongly recommended that two breakdown rollers be used to keep up with the paver, especially if paving width exceeds 12 feet.
- Intermediate roller: If not of equal or greater width than the breakdown roller(s), two intermediate rollers should be required.
- Finish roller: May be vibratory or static, but use the static mode for finishing
- Standby roller: One with vibratory capability should be on site and shall be required if only one breakdown roller is available.

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



# Production & Construction Guide

## Technology Transfer **RAC-104**

### FINAL PREPARATIONS FOR PAVING

Surface preparation must be completed prior to RAC production or spray application. This includes customary items such as removal and replacement of failed pavement and pothole repair (patching), milling or grinding for smoothness and/or to restore or adjust profile, crack filling and/or sealing.

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



Surface prep

#### Tack Coat

A tack coat should be uniformly applied to lightly cover the entire pavement surface to be overlaid. Tack coat may consist of paving grade asphalt or emulsified asphalt. Area of tack application should be limited to what will be paved over on that day. However, tack coat is not required when an asphalt rubber interlayer will be placed prior to overlaying, and is not usually recommended when RAC will be placed directly on a new pavement.

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



Tack coat truck



Poor tack coat

**Emulsified Asphalt:** Recommended application rate is 0.05 to 0.1 gal/square yard residual, depending on the condition of the existing surface. Caution should be used when ambient and pavement temperatures are marginally cool and emulsion tack coats are used. Emulsion must “break” (i.e. turn from dark brown to black as the

# Production & Construction Guide

## Technology Transfer **RAC-104**

suspended asphalt droplets separate from the water) and the water must evaporate prior to paving. Otherwise, the remaining water in the emulsion will turn to steam and rise up through the mat. This prevents the tack from establishing the intended bond with the new pavement and the excess moisture may also cause a tender spot in the mix during compaction. Water trapped between pavement layers may cause stripping and delamination. Cold or damp site conditions and lack of sun slow evaporation and may delay paving operations.

### HOT MIX DELIVERY

The same good practices recommended for conventional hot mix delivery should be applied to RAC materials, along with special attention to temperature. Any type of conventional AC haul truck can be used to transport RAC. However, use of bottom dumps and windrows is not recommended when air and pavement surface temperatures are marginally cool. It is critical that the RAC does not cool below the minimum laydown temperature (280°F to 300°F, depending on owner agency and temperature at paving site) during transport. Tarps are needed to maintain acceptable mixture shipment temperatures ranging from 290° to 325°F.



AR Delivery Equipment

### Coordinating Mix Delivery and Placement

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

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

# Production & Construction Guide

## Technology Transfer RAG-104

### Release Agents

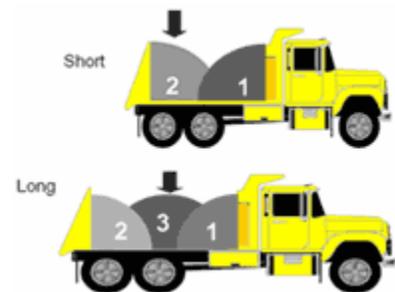
No solvent based release agents or diesel fuel should be used in haul truck beds because of adverse effects on the asphalt rubber binder. Soapy water (dish or laundry soap) is recommended; it is effective and cheap. Dilute silicone emulsions may also be used.



Warning sign

### Loading Haul Trucks

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



Truck Loading Practices for End Dumps

### Unloading Hot Mix into a Paver Hopper

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



Truck Loading Practices for Belly Dumps

### Unloading Hot Mix into a Material Transfer Vehicle

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

### Load Tickets

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

### HOT MIX PLACEMENT

Placement of asphalt rubber materials or any AC materials requires good paving practices. Temperature is critical for proper placement of all AC materials. Asphalt rubber binders are stiffer than conventional paving asphalt at the customary placement and compaction temperatures, so time available for compaction of modified materials is typically shorter than for conventional DGAC mixtures.

How much shorter depends on a number of variables that are discussed in the section on Compaction.



*RAC paver*

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

Caltrans special provisions for RAC-G specify minimum atmospheric and pavement surface temperatures of 55°F and rising for mixture placement. When atmospheric and pavement surface temperatures are between 55°F and 64°F, spread (lay down) temperature for RAC-G is specified as 290 to 325°F. For site temperatures greater than 64°F, the lower limit of RAC-G spread temperature drops to 280°F. The Greenbook allows a slightly lower ambient temperature of 50°F and rising for placement, but requires that breakdown compaction start before the mat temperature drops below 290°F. Placement at minimum ambient temperatures is not recommended, because time available for compaction is very limited and leaves no margin for circumstance or error, resulting in inadequate compaction. When feasible, it is recommended that the minimum ambient temperature requirement for placement be increased to 65°F. Because of the importance of temperature in achieving adequate RAC compaction, operating in the mid to upper end of specified temperature ranges is strongly recommended.

# Production & Construction Guide

## Technology Transfer **RAC-104**

### Paver Operations

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

A consistent paver speed, even if relatively slow, helps maintain a uniform head of material and to control thickness. Care should be taken to dump (fold) the paver wings before mix collected in the corners cools enough to form chunks. However, wings should never be dumped into an empty hopper. Slat conveyors should not be allowed to run empty or nearly so.

### Raking and Handwork

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



Handwork

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

### Joints

AC joints are typically defined as longitudinal or transverse, cold or hot.

Longitudinal joints are most likely to be cold joints. Butt joints are most typical and the practices presented apply to those. Some agencies

# Production & Construction Guide

## Technology Transfer **RAC-104**

have adopted wedge joints and/or skewed joints that are not discussed in this Guide; there may be some issues with using wedge joints for RAC mixes.

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

Compacted thickness of RAC is generally between about 1 inch and 2.5 inches, which typically yields height differences between adjacent paver passes of about 0.3 to 0.65-inch. Since lack of fines makes it difficult to feather the coarse-graded RAC-G mixtures, some raking may be unavoidable, but should be kept to the minimum necessary. Extra material should be raked onto the hot side, not the cold.

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

Transverse joints may be hot or cold. Hot joints should be treated the same as for conventional DGAC, but the RAC mix will stiffen more quickly. Cold joints should be treated as described for longitudinal joints. Most often, transverse joints are constructed at the end of the paving day or when a lane is finished, using a bulkhead or Kraft paper to provide a vertical butt joint. If the paver runs out the mix, the joint should be constructed where the full compacted thickness is available, and the rest of the mix placed past that point should be removed and wasted. Ideally, transverse joints should be rolled in a transverse direction, but this is usually not practical and rarely done. Transverse joints are generally rolled longitudinally.

## HOT MIX COMPACTION

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

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

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

### Temperature Requirements

According to Caltrans Special Provisions for RAC-G, when atmospheric and pavement surface temperatures are less than 64°F, breakdown compaction must be completed before the mat temperature drops below 260°F. For site temperatures with temperatures of 64°F and greater, breakdown compaction must be completed before the mat temperature drops below 250°F. The Greenbook calls for starting RAC-G breakdown compaction before mix temperature drops below 290°F. If ambient temperature is above 85°F, the starting temperature for breakdown rolling drops to 280°F. Regardless of the specification used, it is strongly recommended that breakdown compaction of RAC-G should be completed before the temperature of the RAC mat drops below 280°F.

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

### Factors That Affect AC Compaction

Compaction is affected by many factors including:

- Layer thickness,
- Air temperature,
- Pavement/ base temperature,
- Mix temperature,



Vibratory Roller



Paving rollers



*Temperature management is the key to achieving RAC compaction*

# Production & Construction Guide

## Technology Transfer **RAC-104**

- Wind velocity, and
- Sunlight or lack thereof.



Thin lifts, cool temperatures and wind reduce the time available for compaction because of temperature loss. Therefore, it is often easier to compact thick lifts (more than 2 inches thick) than thin ones. The rule of thumb is that the compacted thickness should be at least twice the maximum aggregate size, or three times the nominal maximum aggregate size. Otherwise, there may be problems with compaction due to a tendency for stones to stack and to catch under the screed and be dragged through the mat. When stones stack, they tend to reorient with each paver pass, or to break.

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

### *Compaction Best Practice*

- *Drive wheel forward  
Low side to high side  
Hot side to cold side  
Direction changes*
- *Sequence:  
1) Transverse joints  
2) Longitudinal joints*
- *Breakdown passes  
(vibrator on)*

### **Test Strips and Rolling Patterns**

Test strips for RAC-G materials are recommended when feasible to indicate what level of compaction effort is needed to achieve adequate in-place density. However, if California Test 113 is used for RAC-G, the temperature ranges for the test must be modified. During test strip compaction, both Contractor and agency representatives should correlate their respective nuclear gauge(s) on the test strip according to CT 375. Gauge data should then be correlated with core results in order for nuclear density to provide accurate data for quality control during paving.

### **Opening New Pavement to Traffic**

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



*Sand Spreader*

# Production & Construction Guide

## Technology Transfer **RAC-104**

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

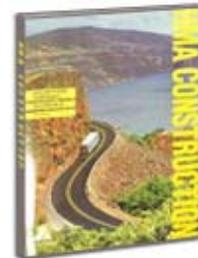
Any approved spreader with uniform distribution capabilities to provide a sand blotter for opening the RAC surface to traffic.

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

## EXAMPLES OF GOOD PAVING PRACTICES

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

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



### ASPHALT RUBBER SPRAY APPLICATIONS

The binders used for asphalt rubber chip seals and interlayers are generally the same as those used to make RAC mixes, using the equipment previously described. Chip seals are also called Stress Absorbing Membranes (SAMs) or Asphalt Rubber and Aggregate Membrane (ARAM) and may be used on the surface or as crack resistant interlayers under a conventional hot mix or RAC overlay. The primary difference in construction is that a flush coat is not applied to the surface of an interlayer prior to overlaying it.

#### Chip Seal Construction

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



Surface texture

Temperature is critical to successful chip seal construction whether the binder is conventional paving grade asphalt or high viscosity asphalt rubber. Clean or precoated chips are also critical and, for use with asphalt rubber binders, are required to be hot (260 to 325°F). Embedment and adhesion of the chips must be accomplished by rolling while the asphalt rubber membrane is still hot. Both Caltrans and the Greenbook indicate that the higher temperatures of the asphalt rubber binder and the use of hot precoated chips allow placement of asphalt rubber chip seal at cooler temperatures than do emulsion binders and at night. However, is not advisable to place chip seals when ambient or pavement temperature is less than 60°; such cool conditions leave little margin for variability in materials, application or site temperature conditions.

# Production & Construction Guide

## Technology Transfer **RAG-104**

### Chip Seal Equipment

The equipment required to place a chip seal includes:

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

### Asphalt Rubber Spray Application

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



*Spray application*

Each spray application should start and end on paper (tar paper or roofing felt if possible) to ensure uniformity for the entire application. The application width should be adjusted so that the longitudinal joint (meet-line) is not in the wheel path, but on the centerline or in the center or edge of the driving lanes. After each application, the distance, the width, and the amount of asphalt rubber should be determined to verify the application rate.

# Production & Construction Guide

## Technology Transfer **RAG-104**

### Aggregate Application

Aggregate application rates can be determined in the laboratory prior to the start of construction. The easiest method is to simply lay the aggregate one-stone deep on a measured area, weigh the amount of stone required to cover that area and convert to appropriate units.

Typical rates range from about 28 to 44 pounds per square yard, with the exact rate to be determined by the Engineer. To verify if application rates for binder and chips are appropriate, also check the embedment of the cover aggregate. Individual chips should be embedded to a depth of about 50-70 percent after seating in the lab or by rollers and traffic in the field.

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

The chip spreader should follow within 65 to 100 feet of the asphalt rubber distributor and must keep up. The asphalt rubber binder must be fluid so the rock will be embedded by the displacement of the asphalt. A chip seal train consisting of binder distributor truck, chip spreader, and roller is shown below.

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

The chip spreader should be operated at a speed that will prevent the cover aggregate from being rolled as it is being applied. The aggregate supply should be controlled to assure a uniform distribution across the entire box. If an excess of aggregate is spread in some areas, it should be distributed on the adjacent roadway surface or picked up. However, excess application usually interferes with embedment and adhesion and may lead to future problems with chip loss. Areas that do not get enough aggregate cover (about 85 percent of the total membrane area is a reasonable target) should be covered with additional



Aggregate application

# Production & Construction Guide

## Technology Transfer **RAC-104**

aggregate (normally by hand), but problems with adhesion may occur, because by then the asphalt rubber has cooled.

### Rolling Asphalt Rubber Chip Seals

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



Chip seal rolling

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



*Chip seals are the only asphalt rubber application in which rubber tire rollers can be utilized*

### Sweeping

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

### Flush Coat

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

### Fog Seals

Fog Seals are applied over chip seals to help retain the cover aggregate and provide a more uniform appearance. Fog seals are not applied over SAMI-R because it will be covered with an overlay. Fog seals typically consist of grade CSS-1, CSS-1h, or CQS-1 asphalt emulsion diluted with 50 percent added water. The standard

# **Production & Construction Guide**

## *Technology Transfer* **RAG-104**

application rate over asphalt rubber chip seals is about 0.05 to 0.1 gallon per square yard, or as determined by the Engineer.

### **Sand Cover**

Sand cover is applied immediately after application of the fog seal to prevent pick up and tracking of the chip seal material by vehicle tires. The sand must be clean, i.e., free of clay fines or organic material. It is spread in a single application of about 2 to 4 pounds per square yard, or at a rate determined by the Engineer.

### **Traffic Control**

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

## **EMISSIONS**

### **Air Quality**

Concerns have been expressed regarding the effects of CRM-modified paving materials on air quality, particularly related to HMA plant emissions and worker health and safety. CRM consists mostly of various types of rubber and other hydrocarbons, carbon black, extender oils, and inert fillers. Most of the chemical compounds in CRM are also present to some extent in paving grade asphalt, although the proportions are likely to differ. CRM does not include exotic chemicals that present any new health risks. Although a number of stack emissions and worker exposure studies have been performed throughout the U.S. that have not indicated any increased risk due to CRM-related emissions, concerns seem to persist. Findings of selected Federal, state, and private studies are presented herein.

### **FHWA/USEPA**

In June 1993, FHWA and the US Environmental Protection Administration (EPA) issued a report on the "Study of The Use of Recycled Paving Material - Report to Congress" which described an

# Production & Construction Guide

## Technology Transfer **RAG-104**

analysis of the results of seven studies to compare the relative threats/risks to human health and the environment of conventional asphalt paving to CRM asphalt paving. The report discussed some of the variables that influenced the health and environmental comparison. Conclusions indicated that the data evaluated contained no obvious trends to indicate a significant increase or decrease in emissions attributed to the use of CRM. The FHWA/USEPA report recommended further study of this issue. Subsequent studies have been conducted but have not provided sufficient evidence to change the original conclusions.

### **AC Plant Emissions Tests**

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

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

- Cal ARB Method 429 - Polyaromatic Hydrocarbons (PAH)
- Cal ARB Modified Method 5 – Determination of Particulate (BTEX)
- Test during production of Conventional AC and RAC in triplicate at two hot plants
- Testing during normal production runs

For this study, the County of Sacramento Public Works Agency conducted stack emission tests at two production facilities, a batch

# Production & Construction Guide

## Technology Transfer **RAC-104**

plant and a drum mix plant, to compare emissions during production of RAC and DGAC mixes. The asphalt rubber conformed to Caltrans requirements for wet process high viscosity binder. Although results at the batch plant were influenced by benzene exhaust from haul truck tailpipes in the truck load-out shed (other possible sources were evaluated and ruled out), measured emissions of particulate and specified toxic air contaminants were consistently lower than EPA AP-42 emission factors for production of both types of mixes and both types of plants. The conclusions of the Public Works Agency letter report on Results of Stack Emission Testing Asphalt Rubber and Conventional Asphalt Concrete, dated Feb 5, 2002, were as follows:

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

### **Worker Health and Safety**

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

### **National Institute for Occupational Safety and Health (NIOSH)**

NIOSH in cooperation with FHWA has performed evaluations of possible differences in the occupational exposures and potential health effects of CRM and conventional HMA. NIOSH Health Hazard Evaluations were performed at seven paving projects located in Michigan, Indiana, Florida, Arizona, Massachusetts, and California (2) from 1994 through 1997. The purposes of the multiple studies were to assess site-specific information relative to each project to compile

# **Production & Construction Guide**

## *Technology Transfer* **RAG-104**

results and compare the effects of exposure due to CRM and conventional materials.

The assessments included an evaluation of collected area air samples in order to characterize the asphalt fume emission, personal breathing zone (PBZ) air samples to evaluate worker exposures, and a medical component including questionnaires and lung function tests.

The NIOSH studies showed that the various exposure measurements evaluated for both conventional AC and CRM asphalt paving were below the NIOSH recommended exposure limits. Based upon the results of the individual studies, NIOSH did not draw any definitive conclusions regarding the potential health effects of CRM asphalt compared to conventional asphalt. These reports indicate that increases in plant emissions were related to the elevated operating temperatures, not the presence of the CRM.

### **Industry Studies in California**

A 2.5-year study was performed in Southern California to assess the effects of "Exposure of Paving Workers to Asphalt Emissions (When Using Asphalt Rubber Mixes)". The study began in 1989 and results were published in 1991 (Rinck, Napier and Null), before fume exhaust ventilation and capture devices were implemented on paving equipment. The study monitored a number of individual paving workers in direct contact with fumes during hot mix paving operations as well as spray applications. The researchers found that emission exposures in asphalt rubber operations did not differ statistically from those of conventional asphalt operations. Based on results of this study, "there is no evidence to indicate that persons who are involved in the application of asphalt rubber products are at risk from asphalt rubber emissions."

A worker exposure study of CRM HMA was conducted during highway construction near Holtville (Caltrans Contract No. 11-172504) from November 30 through December 1, 1994. Personal exposures were reportedly well under the existing Cal-OSHA limits. However, measured concentrations of fumes did not vary consistently with respect to mix temperature as has typically been noted in such studies.

# **Production & Construction Guide**

## *Technology Transfer* **RAG-104**

### **Summary**

The literature review indicated that numerous studies of worker exposure to potentially hazardous compounds in asphalt rubber fumes have been performed. Fumes generated by CRM-modified materials at elevated temperatures often have increased concentrations of a number of compounds of interest compared to conventional asphalt materials, but these rarely exceed established permissible exposure limits. Thus, there is no pattern of evidence that asphalt rubber materials present greater health hazards than conventional asphalt materials.

### **Water Quality**

Water quality is another area of concern regarding the use of CRM. Southwestern Laboratories tested leachate from stockpiles of reclaimed CRM pavement milled from IH10 in San Antonio, Texas, to evaluate the potential for contamination of surface runoff and groundwater.

Simulated precipitation leachates were prepared to represent the cumulative effects of acid rainwater leaching and were analyzed for the presence of trace metals, volatile organic compounds (VOCs) and semivolatile organic compounds. The only compound of interest that was present at a level above the analytical detection limit was mercury, but levels detected were below EPA limits (Crockford et al, 1995). The report concluded that levels of detectable leachates were too low to be environmentally significant or dangerous.

## GLOSSARY

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

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

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

### Types of CRM

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

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

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

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

# Production & Construction Guide

## Technology Transfer **RAG-104**

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

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

### CRM Preparation Methods

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

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

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

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

### CRM Processing Equipment

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

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

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

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

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

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

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

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

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

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

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

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

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

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

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

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

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

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

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

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

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

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

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

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

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

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

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

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

# Production & Construction Guide

## Technology Transfer **RAG-104**

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

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

## Aggregates for Asphalt Concrete

### Classification of Rock

- Sedimentary
- Igneous
- Metamorphic

### Aggregate Sources

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

# Production & Construction Guide

## Technology Transfer **RAG-104**

### Maximum Particle Size and Gradation

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

### Specific Gravity

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

### Cleanliness

- Free of unsuitable material
- Toughness
- Abrasion resistant

### Particle Shape

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

### Surface Texture

- Asphalt tends to strip from smooth surfaces.

### Absorptive Capacity

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

### Affinity to Asphalt

- Ability of the aggregate to bond with the asphalt binder

### Asphalt

#### Characteristics

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

#### Classifications

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

#### Physical Properties

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

#### Testing of Asphalts

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

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

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

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

# Production & Construction Guide

## Technology Transfer **RAG-104**

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

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

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

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

### Mix Design Methods

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

### HVEEM Mix Design Method

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

### Mix Design Characteristics

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

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

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

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

### **Design Asphalt Content**

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

### **Mix Design Properties**

#### **Stability**

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

#### **Durability**

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

# Production & Construction Guide

## Technology Transfer **RAC-104**

### **Impermeability**

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

### **Workability**

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

### **Flexibility**

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

### **Fatigue Resistance**

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

### **Skid Resistance**

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

# **Production & Construction Guide**

## *Technology Transfer* **RAG-104**

### **Typical Asphalt Paving Failures**

#### **Edge Failure**

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

#### **Weathered or Dry Surface**

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

#### **Pot Holes**

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

#### **Alligator (Fatigue) Cracking**

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

#### **Bleeding and Instability**

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

#### **Raveling**

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

# **Production & Construction Guide**

## *Technology Transfer* **RAG-104**

### **Slipping**

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

### **Stripping**

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

### **Surface Erosion**

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

### **Longitudinal or Transverse Cracking**

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