Rubberized Asphalt Concrete

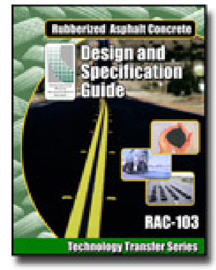
Design and Specification Guide

INTEGRATED WASTE MANAGEMENT BOARD

RAC-103

Technology Transfer Series

Design and Specification Guide
RAC-103



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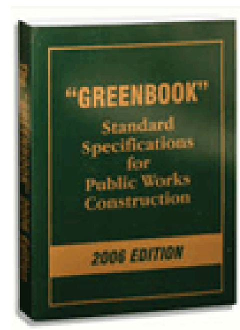
DESIGN AND SPECIFICATION GUIDE

Pavement design has two aspects. The first is structural design, to determine the thickness of asphalt concrete pavement needed to support the anticipated traffic loadings over the design period, and the types of materials to be used in each layer of the pavement structure.

The second aspect is volumetric mixture design, which is a family of laboratory procedures used to determine the appropriate “recipe”, i.e. composite aggregate gradation and binder content of a specific asphalt concrete mixture. Mix designs are developed based on volumetric analysis of mixture specimens fabricated with the designated component materials at a range of binder contents.

There are some differences when crumb rubber modifiers (CRM) are included, but the fundamental concepts are essentially the same as for conventional asphalt concrete materials. This module presents common factors and identifies the primary differences.

BEHAVIOR OF RUBBERIZED ASPHALT CONCRETE (RAC) HOT MIXES



Hot mixes made with wet process high viscosity asphalt-rubber binders are relatively low modulus materials compared to conventional dense-graded asphalt concrete (DGAC). RAC mixes made with high viscosity asphalt-rubber binders perform through flexibility and resistance to permanent deformation by elastic recovery, rather than stiffness like DGAC. How well RAC mixes perform is a function of how much binder is included.

High viscosity asphalt-rubber binders have a thick consistency that allows significant increases in binder content (up to 2% by total mix weight) compared to conventional asphalt concrete mixes with similar aggregate gradations, while minimizing potential for binder drain down. The high binder content is a primary cause of the documented performance benefits of asphalt-rubber hot mixes (also called ARHM) which include improved resistance to permanent deformation, fatigue and reflective cracking, aging, and environmental damage, and improved durability. However to capitalize on this feature, the aggregate matrix or skeleton must provide sufficient void space to accommodate the CRM particles and a sufficient quantity of high viscosity binder to modify mix behavior. Gap and open aggregate gradations are used to provide the necessary void space.

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

Dense-graded mixes are not appropriate for use with high viscosity binders because there is not sufficient void space available. However dense aggregate gradations are well suited for use with no agitation binders such as Caltrans MB or Greenbook MAC-10TR, and should provide similar structural capacity to conventional DGAC mixes

STRUCTURAL DESIGN

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

If ride and structure are satisfactory and traffic conditions allow, an asphalt-rubber chip seal may be used for maintenance or preservation instead of a thin overlay. However, chip seal surfaces are generally noisier than hot mixes, and noise considerations may influence strategy selection.

Thin overlay for maintenance or preservation: To restore ride and surface friction, reduce noise, and provide a pleasing appearance and long-lasting contrast with pavement markings. Such overlays may be gap-graded or open-graded. Gap-graded RAC mixes act as a structural layer in the pavement and are most effective at compacted thicknesses ranging from 1.2 inches (30 mm) to 2.4 inches (60 mm) according to recent structural analysis and modeling. This supports and corresponds to current Caltrans practice based on empirical experience and economic considerations. No structural credit is allowed for open-graded mixes, but these have served very effectively as thin maintenance and/or preservation overlays in Arizona.

Overlay procedures for flexible over existing flexible pavement

- *Structural adequacy*
- *Reflective cracking*
- *Ride quality*

Rehabilitation: For structurally sound pavements for which resistance to reflective cracking governs overlay thickness design, gap-graded asphalt rubber hot mixes (RAC-G or ARHM) can provide performance equivalent to a conventional DGAC overlay at one-half the required thickness of DGAC. Where cracking in the existing pavement is severe, a stress absorbing membrane interlayer-rubberized (SAMI-R) or asphalt-rubber aggregate membrane (ARAM) interlayer may be applied as a crack interruption layer prior to overlaying. In such cases, Caltrans allows a small structural credit for the effectiveness of SAMI-R at reducing crack reflection, although other agencies do not. If more than 2.4 inches of additional structure is required, a layer of dense-graded asphalt concrete should be placed prior to the RAC-G (and over the SAMI-R if used) to make up the difference in required thickness.

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

Structural design may be performed using a variety of methods such as Caltrans, AASHTO, or Asphalt Institute. Recent research indicates that RAC-G has a gravel factor similar to DGAC but slightly lower, which indicates similar structural capacity in spite of the relatively low modulus of RAC materials. For purely structural considerations, RAC-G may be considered equivalent to DGAC, which corresponds to experience and successful practice in Arizona and Texas. However, structural models indicate that RAC-G is most effective in the upper 2.5 inches of the pavement structure while use at lower levels provides no added benefit. Since RAC is more expensive than DGAC, it should be used where it provides the greatest benefit.

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

INFO

Caltrans

Caltrans Highway Design Manual (HDM)

Caltrans Flexible Pavement Rehabilitation Manual (FPRM)

AASHTO

SELECTION OF MIX TYPES

The designer specifies the type(s) of mixture(s) to be used in the respective layers of the flexible pavement structure. If high viscosity asphalt-rubber binders are to be used, the options are gap-graded for structure and/or open-graded for surface characteristics. Wet or dry process mixes may be used. No agitation binders may serve best for dense-graded mixes, which are not suitable for use with high viscosity binders.

Dry process mixes are typically gap-graded to provide space in the aggregate matrix for the CRM particles, which are added as a substitute for 1 to 3% of the fine aggregate. Some open-graded dry process mixes have also been used. The asphalt cement is not considered to be modified by the dry process, although there may be some limited interaction of the CRM with the asphalt cement during mixing in the AC plant, silo storage, hauling, placement and compaction.

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

Open-graded mix choices include RAC-O and RAC-O-HB (high binder). RAC-O is free draining and significantly reduces splash, spray and hydroplaning in wet conditions. The high binder content mix (RAC-O-HB) is not free draining, but still drains better than do gap-graded or DGAC mixes. Either RAC-O or RAC-O-HB may be used as a non-structural surface or wearing course, to restore surface friction, improve surface drainage, and to reduce tire noise. Both RAC-O and RAC-O-HB are highly resistant to reflective cracking and fatigue, as a function of binder content. Open-graded mixes are not appropriate for arterial streets, mill and fill sections, or parking areas. They serve best as surfaces for relatively free-flowing roadways and can be placed in layers less than one inch thick if 3/8-inch aggregate is used.

RAC MIX DESIGN

Mix designs for RAC-G materials are performed in general conformance with conventional volumetric asphalt concrete mix design methods such as Hveem and Marshall, with some relatively minor modifications. Mix design methods for open-graded mixes are quite different, and existing standard methods are used with some modifications. The primary difference in the asphalt concrete mix design procedure is the addition of the high viscosity asphalt-rubber binder design for wet process RAC mixes, which is developed first for use in the mix design.

There are two families of wet process binders, high viscosity and no agitation, which are set apart by a viscosity threshold of 1,500 centipoises (cPs, 1.5 Pa•sec). These two families represent very different ranges of physical properties and behavior that should never be considered to be equivalent or interchangeable, particularly for use in hot mixes. Neither type should be directly substituted for the other; adjustments in binder content of hot mixes or to spray application rate of surface treatments will be required.

High Viscosity Binder Design

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

- Asphalt Cement Source and Grade
- Rubber Type
- Rubber Source
- Amount of Rubber
- Gradation of Rubber
- Interaction Time
- Interaction Temperature

Therefore, an appropriate asphalt-rubber binder design must be developed using the designated sources and grades of asphalt, asphalt modifier if used, and CRM materials (scrap tire and, if used, high natural) that will be used for the subject project(s). The binder design should include testing to develop and present a design profile of each specification property value measured from samples taken at intervals over a 24-hour interaction period. The profile should include, at a minimum, results after an initial interaction period of 45 minutes, 4 hours later, and simulated over night cool down by reducing oven temperature to 275ºF for a period of 14 hours starting at 6 hours after CRM addition to 22 hours after CRM addition. After the cool down, the binder should be reheated to the appropriate temperature for viscosity testing after the 24-hour interaction is completed. Viscosity should also be measured and recorded at 2 and 3 hours after addition of the CRM to identify the expected trends for field production. The design profile must identify the specific component materials (source or supplier and grade) and proportions thereof used in the design. Gradation of the individual CRM components shall also be included for information. If any of the components are changed, the design profile would no longer apply.

The design profile indicates the compatibility of the components and the quality and stability of the resulting asphalt-rubber binder properties. Viscosity and resilience are the most meaningful indicators of performance and are expected to vary as the asphalt-rubber interaction proceeds. Viscosity should remain above the minimum 1,500 cPs value throughout the interaction and should not manifest drastic drops. There is no maximum value for resilience; high resilience typically indicates that the binder should perform well. MACTEC recommends that submittal of the high viscosity binder design profile should be required for both hot mix and spray applications.

Physical Properties Requirements
Type 1 and Type 2 Asphalt-Rubber Binder

Test Parameter	ASTM Test Method	Requirement	
		Min.	Max.
Cone Penetration @ 77ºF, 1/10 mm	D 217	25	70
Resilience @ 77ºF, Percent rebound	D 5329	25	—
Field Softening Point, °F	D 36	125	165
For Type 1 Binder: Viscosity @ 350ºF, Pa-s (x10-3)	See Note	1500	4000
For Type 2 Binder: Viscosity @ 375ºF, Pa-s (x10-3)	See Note	1500	4000

NOTE: The viscosity test shall be conducted using a hand held high range analog or digital rotational viscometer such as Rion Model VT-04, Haake Model VT-02 or VT-02 plus with Rotor 1, 24 mm in depth x 53 mm in height, or equivalent. The accuracy of the viscometer shall be verified by comparing the viscosity results obtained with the hand held viscometer to 3 separate calibration fluids of known viscosities ranging from 1000 to 5000 Pa-s (x10-3) or centipoises (cPs). The viscometer will be considered accurate if the values obtained are within 300 Pa-s (x10-3) (300 cPs) of the known viscosity. The known viscosity value shall be based on the fluid manufacturers standard test temperature or the test temperature versus viscosity correlation table provided by the fluid manufacturer. Viscometers used on the project shall be verified to be accurate. The accuracy verification results shall be provided to the Engineer.

No Agitation Binders

No agitation binders are wet process CRM-modified binders that do not require constant agitation to keep discrete rubber particles uniformly distributed in the hot asphalt cement. The term “terminal blend” is often used to describe such materials, which include rubber-modified asphalt materials such as Caltrans MB and Greenbook MAC-10TR. However such binders may be produced in the field or at an asphalt concrete plant as well, so calling them terminal blends may be misleading and is unnecessarily restrictive. The preferred description for this type of binder is therefore “wet process-no agitation”.

No agitation binders are often proprietary blends for which some of the components may be classified as trade secrets and thus may not be identified by the respective suppliers. However, the supplier should be willing and able to certify how much scrap tire and/or other waste rubber products are included. Design profiles have not typically been required or provided for such binders, as they are considered to be relatively stable during storage. Quality and stability of no agitation binders can be monitored over time by testing for specification compliance, and for separation according to ASTM D 7173-05.

Gap-Graded RAC

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

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

Standard Hveem and Marshall mix design methods have been successfully used for RAC-G mixes. Typical modifications have been to increase the mixing and compaction temperatures. Mixing temperatures for the aggregates range from 290ºF to 325ºF, and for high viscosity binders, from 325ºF to 400ºF. Compaction temperature is 290ºF to 300ºF. Protocols for applying Superpave gyratory compaction of mixes with high viscosity asphalt-rubber binders have not been standardized.

Another pending change in Caltrans specifications for RAC-G is to implement field compaction requirements based on maximum theoretical specific gravity and density (California Test 309) rather than Hveem laboratory density, with acceptance based on pavement cores

Caltrans is in the process of revising its standard special provisions for RAC-G, which will further modify the Hveem mix design method (California Test 367) for these materials. Proposed revisions include fabricating and testing three mix briquettes at each asphalt-rubber binder content tested and using the average of each set of results to evaluate volumetric properties. Minimum requirements for 18% VMA provide space to accommodate sufficient high viscosity binder, and a maximum of 23% is proposed. Minimum binder content requirements range from 7.0% (Caltrans) to 7.5% (Greenbook) by weight of dry aggregate based on pavement performance experience. The Greenbook sets a maximum binder content of 8.7% by weight of dry aggregate, but Caltrans is considering eliminating their upper limit. Minimum Hveem stability is 23, which reflects the lower modulus of RAC-G materials. Target air voids content ranges from 3 to 6%, depending on traffic index and climate, although an upper design limit of 5% has been proposed. Given the minimum binder content and VMA requirements, 6% air voids has been shown to be impracticably high for some sources of aggregate materials. High viscosity asphalt-rubber binders are less likely to flush or bleed than other types of asphalt binders, so it is not necessary to require 6% air voids.

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

Open-Graded RAC

Mix design methods for RAC-O and RAC-O-HB are much simpler. California Test 368 is used to determine the optimum conventional PG asphalt content for the proposed aggregate gradation as a starting point. For RAC-O, the high viscosity asphalt-rubber binder content is calculated as 1.2 times the optimum PG asphalt content. This factor compensates for the amount of CRM in the binder without increasing the amount of asphalt cement used and is intended to provide a free-draining mix. For RAC-O-HB, a multiplier of 1.6 is used, and the specified range for high viscosity asphalt-rubber binder content is 8.5 to 10% by weight of dry aggregate.

After determining the target high viscosity asphalt-rubber binder content, fabricate additional specimens at that content for binder drainage evaluation at 300ºF to verify that drain-down is not excessive.

No agitation binders may be used in open-graded mixes, and should be expected to behave similar to polymer-modified asphalt cement during the mix design. However, the optimum binder content will be limited by drain down and will likely fall between the optimum contents for PG asphalt and RAC-O made with high viscosity binder. It is extremely unlikely that an open-graded mix could hold enough no agitation binder to meet requirements for RAC-O-HB, without adding fibers or fillers.

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.

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Dry Process Mixes

Standard Hveem mix design procedures can also be applied to dry process mixes, with some minor modifications. Although the asphalt cement is not considered to be modified by the dry process, the amount of CRM in a Caltrans RUMAC mix is proportioned as18 ± 2% by mass of asphalt binder. In the mix design, the rubber is thoroughly mixed with dry heated aggregate (300-325ºF) before the asphalt cement is mixed in. The combined mixture is then compacted at a temperature between 290°F and 300°F.

It appears that there is some limited interaction of the CRM with the asphalt cement during AC plant mixing, silo storage, hauling, placement and compaction. There are also anecdotal indications that some level of interaction may continue after construction is completed, which may have pronounced effects on subsequent pavement performance. Use of Hveem the mix design method, with its extended curing period, should generally account for most of the long term asphalt absorption by the CRM particles and allow selection of an appropriate target asphalt content. If long term aging and absorption are not considered in the mix design procedure, target binder content may be too low and early raveling of the resulting pavement may occur. Care must also be taken during the mix design to make appropriate adjustments for the low specific gravity of the CRM (1.15 ± 0.05) compared to the aggregate specific gravity (range of 2.35-2.85) to assure proper volumetric analysis.

Mix Design Submittals

The Contractor shall submit the following information for each rubberized asphalt concrete mixture proposed:

Aggregate and supplemental fine aggregate (including lime, if used):

- Aggregate gradation ("X" values) for percent passing each sieve size for the aggregate blend, including supplemental fine aggregate
- Results of quality tests for coarse aggregate, fine aggregate, and aggregate blend
- Source of each aggregate to be used, including producer, location and California Mine Identification number
- Percentage of each aggregate cold feed or hot bin and supplemental fine aggregate used in the mix design
- Typical gradation of each aggregate cold feed or hot bin to be used
- For RAC-G, Calculations for VMA
- Material Safety Data Sheet for lime if used

Crumb Rubber Modifier (CRM):

- Supplier and identification (or type) of scrap tire and, if used, high natural CRM
- Typical gradation of each type of CRM material used in the asphalt rubber binder design

- Percentage of scrap tire and, if used, high natural CRM by total mass of the asphalt-rubber blend
- If CRM from more than one supplier is used, the above information will be required for each CRM supplier used
- Laboratory test results for specified test parameters
- Material Safety Data Sheets

Asphalt Rubber Binder:

- Base asphalt PG binder grade and supplier and Certificate of Compliance
- Percentage of the combined blend of asphalt and, if used, asphalt modifier by total mass of asphalt-rubber binder to be used
- If used, asphalt modifier type, supplier and identification and test results demonstrating conformance to these special provisions
- Percentage of asphalt modifier (if used) by mass of asphalt
- Selected asphalt rubber content as determined by California Test 367 (Gap-graded) or California Test 368 (Open-graded), modified as appropriate for high viscosity binders
- Design profile
- Minimum interaction time and temperature
- Material Safety Data Sheets

Antistrip additives, when applicable:

- Name of product, manufacturer, manufacturer's designation and proposed rate, location, and method of addition; and Material Safety Data Sheets

GLOSARY

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.

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 m2) 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.

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.

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.

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 (375ºF to 435ºF, 190ºC to 224ºC) and holding the resulting blend at elevated temperatures (375ºF to 425ºF, 190ºC to 218ºC) 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 375ºF (190ºC) 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 375ºF (190ºC) 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 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 375ºF (190ºC), 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 375ºF (190ºC) over the interaction period should be described as “wet process–high viscosity” binders to distinguish their physical properties from those of wet process-no agitation materials. These binders require agitation to keep the CRM particles evenly distributed. They may be manufactured in large stationary tanks or in mobile blending units that pump into agitated stationary or mobile storage tanks. Wet process-high viscosity binders include asphalt rubber materials that meet the requirements of ASTM D6114. Wet process-high viscosity binders typically require at least 15% scrap tire rubber to achieve the threshold viscosity. Caltrans requires a minimum total CRM content of 18%.

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

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

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.

- 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

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.

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

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 pre vent. 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