TOPS
Targeted Overlay Pavement Solutions

Asphalt Rubber Gap-Graded Mixtures

How-To Document

February 2024

U.S. Department of Transportation
Federal Highway Administration

Every Day Counts
Innovation for a Nation on the Move

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This document highlights FHWA's Every Day Counts initiative, Targeted Overlay Pavement Solutions. TOPS integrates innovative overlay procedures into practices to improve performance, lessen traffic impacts, and reduce the cost of pavement ownership.
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16. Abstract
Asphalt rubber gap-graded mixtures are durable pavement layers with resistance to reflective cracking, rutting, and oxidation and have frictional characteristics due to the gapped grading of the aggregate.

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LIST OF ACRONYMS

ARGG	Asphalt rubber gap-graded
AASHTO	American Association of State Highway Transportation Officials
ADOT	Arizona Department of Transportation
ASTM	American Society for Testing and Materials
Caltrans	California Department of Transportation
CRM	Crumb rubber modifier
GTR	Ground tire rubber
DSR	Dynamic shear rheometer
MassDOT	Massachusetts Department of Transportation
ME	Mechanistic-empirical
NMAS	Nominal maximum aggregate size
OGFC	Open-graded friction course
VMA	Voids in mineral aggregate

INTRODUCTION

Asphalt rubber gap-graded (ARGG) mixtures consist of an asphalt rubber binder mixed with a gap-graded aggregate blend. Combining the aggregate gradation with its stone-on-stone contact, in conjunction with the higher volume of asphalt rubber binder, can result in more durable mixtures with better resistance to reflective and thermal cracking, rutting, and oxidation than conventional asphalt mixtures. Gap-grading also can provide good pavement frictional resistance. Frictional characteristics are dependent on the aggregate used.

ARGG mixtures are designed to facilitate stone-on-stone contact between the coarse aggregate particles, which provides additional room for the undissolved asphalt rubber particles. The stone-on-stone contact also can increase resistance to rutting. Gap grading can create a greater amount of void space between the aggregate particles. The gap is filled with asphalt rubber, rubber particles, fine aggregate, and mineral filler. Consequently, these mixtures typically have a higher binder content than conventional dense-graded mixtures, resulting in greater durability. Another factor contributing to improved durability is the digestion of a portion of the rubber particles into the asphalt binder. This creates a higher viscosity binder resulting in thicker binder films and reduced oxidation. The carbon black component of ground tire rubber (GTR) also helps provide superior nighttime visibility.

Figure 1. ARGG mixture in California. (Source: NCAT)

The compacted lift thickness of ARGG mixtures depends on the nominal maximum aggregate size (NMAS) used and typically ranges from 1.25 to 2.25 inches (Heitzman 1992). The performance of ARGG mixtures makes it a viable overlay solution to cost-effectively extend the life of existing pavements without underlying structural issues.

The Federal Highway Administration (FHWA) developed this how-to document to help State Departments of Transportation (State DOTs), contractors, and material suppliers understand, adopt, and use this technology.

BACKGROUND

History

Rubber modification in asphalt pavements started in the 1840s with a study involving natural rubber in bitumen (Heitzman 1992). Over the years, there have been several studies (Lewis et al. 1954, Baker et al. 2003) and various marketing efforts, but rubber-modified asphalt did not significantly progress until the 1960s and 1970s. At that time, a Phoenix, Arizona, Materials Engineer blended asphalt binder and scrap tire rubber. This resulted in a material that could be used to patch cracked pavement surfaces. The process involved reacting asphalt binder and ground-up tire rubber at high temperatures.

In the mid-1960s, asphalt rubber chip seals were developed and served as the primary method of maintenance and preservation on arterial highways in the Phoenix area until the early 1970s when higher traffic volumes necessitated a change to thin asphalt overlays. Gap-graded asphalt rubber mixtures were developed and found to be a successful substitute (Caltrans 2006). In the mid-1970s, the Arizona Department of Transportation (ADOT) sponsored several rubber research projects and ultimately adopted the use of GTR in pavement interlayers, chip seals, and later as a binder modifier used in open- and gap-graded mixes. GTR in these applications proved effective for pavement maintenance and rehabilitation activities (Gonsalves 1979; Huffman 1980). Based on Arizona's success, several other States such as California, Florida, and Texas began evaluating rubber-modified asphalt mixtures.

In 1991, Section 1038(d) of the Intermodal Surface Transportation Efficiency Act (Pub. L. No. 102–240) required States to use a minimum amount of "crumb rubber" in asphalt surfacing each year, beginning in 1994. The mandate caused an increased interest in GTR. The National Highway System Designation Act of 1995 (Pub. L. No. 104–59) amended the law by eliminating the crumb rubber mandate (109 Stat. 577 Sec. 205). Although the mandate was lifted, many national research efforts to evaluate GTR were underway. Some State DOTs ceased their research efforts; others, including Arizona, California, Florida, Rhode Island, and Texas, continued using GTR in different asphalt pavement applications, primarily open-graded and gap-graded mixtures (Caltrans 2006). The California Department of Transportation (Caltrans) still uses ARGG mixtures extensively. As of 2023, ARGG mixtures make up approximately 35 percent of Caltrans' annual tonnage placed.

Additional background on the use of GTR can be found in the April 2020 FHWA publication entitled "Resource Responsible Use of Recycled Tire Rubber in Asphalt Pavements (FHWA-HIF-20-043)." https://www.fhwa.dot.gov/pavement/asphalt/hif20043.pdf

Terminology

ARGG mixtures contain asphalt binder, GTR, and, in some cases, an extender oil or binder modifier blended with a gap-graded aggregate blend. Since each of these components has unique attributes and plays a vital role in the performance of the mixture, here is a review of basic terminology.

Asphalt Rubber

According to the American Society for Testing and Materials (ASTM) D8, Standard Terminology Relating to *Materials for Roads and Pavements*[1] , 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" (ASTM, 2022). Blends with less than 15 percent reclaimed tire rubber are generally called rubberized asphalt or sometimes rubber-modified asphalt (Caltrans 2006).

Recycled Tire Rubber

Recycled tire rubber is obtained from processing highway tires such as automobile, truck, or bus tires. Chemical limitations are sometimes included in GTR specifications to eliminate unsuitable sources of rubber, such as solid tires and other non-automotive tires. GTR is also called crumb rubber modifier (CRM) and recycled tire rubber. The tires are ground to different sizes depending on the application and the specification requirements.

[1] ASTM specifications referenced herein are optional and not Federal requirements.

Tire Processing Methods

Tires are most commonly reduced in size by ambient or cryogenic grinding. In ambient grinding, scrap tires are ground or processed at or above a room temperature of 77 degrees Fahrenheit.

The cryogenic grinding process uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber to the desired particle size.

The main difference between the two-processing methods is the surface texture of the rubber particles. Ambient grinding produces an irregular, rough texture with an increased surface area due to the tearing process. In contrast, cryogenic grinding produces a smoother surface with a relatively small surface area to particle size. The increased surface area resulting from the ambient process tends to increase the interaction with the asphalt binder compared to the cryogenic process. Figure 2 shows the surface texture of two different types of particles at a 120x magnification level. The image on the left, with a reasonably smooth fracture surface, was obtained by the cryogenic process; the image on the right, with an irregular, rough shape, was obtained by the ambient process (Lee et al. 2007).

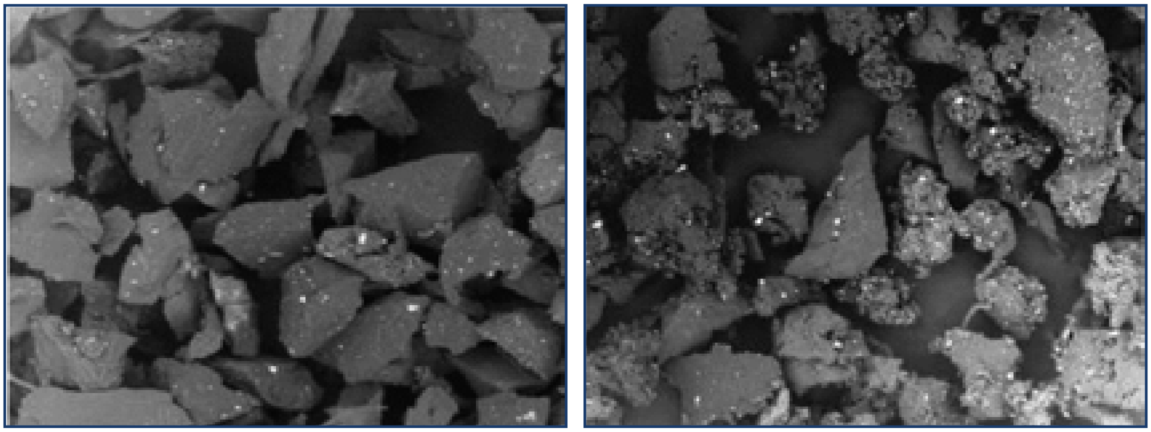

Figure 2. Cryogenic GTR (left) and ambient GTR at 120x magnification (right). (Source: Lee et al. 2007)

Gap-Graded Asphalt Mixtures

Gap-graded asphalt mixtures contain aggregate that is not continuously graded on all size fractions. These mixtures are typically missing or contain low amounts of the finer-sized material—passing the No. 8 sieve 2.36 mm or finer (Caltrans 2006).

Gap-graded mixtures typically comprise two parts—a coarse aggregate skeleton and a mortar. The coarse aggregate skeleton comprises approximately 70 to 80 percent crushed coarse aggregate particles. In contrast, the mortar consists of asphalt or asphalt rubber binder, fine aggregate, and mineral filler, which fills the voids in the coarse aggregate skeleton (National Academies 2011). Typical gradations for ARGG, an open-graded friction course (OGFC), and a 12.5 mm dense-graded Superpave surface course mixture of 12.5 mm are plotted in Figure 3.

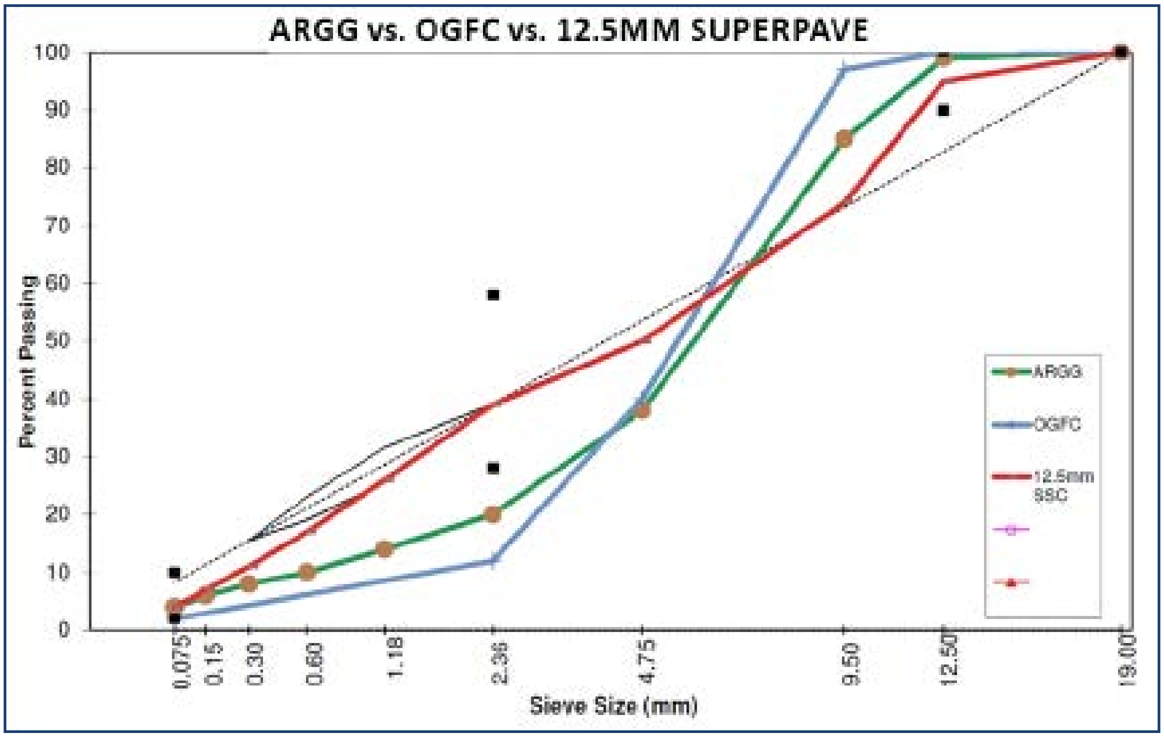

Figure 3. 0.45 Power chart for ARGG, OGFC, and 12.5 mm Superpave mixtures. (Source: MassDOT)

Blending Methods

A dry or wet process can blend GTR with asphalt binder. The original dry process focused on using GTR as an aggregate substitute. GTR, coarser than what is used in the wet process, was blended with heated aggregate before adding the asphalt binder into the mix, typically at a rate of 1 to 5 percent by the overall weight of the mixture (Huang et al. 2002). Historically, according to Huang, this process has not been very successful. New methods have been developed for the dry process where the rubber particles are pre-treated and coated with additives or polymers to act as processing aids before adding the rubber into the mixture. Compared to the original dry process, the new methods also use smaller particle sizes. The intention behind the use of smaller GTR size is to modify the binder during the asphalt mix production process (Clark et al. 2014).

In the wet process, GTR is blended with asphalt binder at a specific temperature and is slowly agitated while in storage for a given amount of time to facilitate the reaction before mixing with the aggregate. Depending on the amount and size of the GTR added to the binder, wet-process blending can be on-site or blended at a terminal.

- *On-Site Blending*: This type of wet-process blending is used for asphalt rubber binders, with rubber contents in the range of 15 to 22 percent by weight of the total binder. The maximum size of GTR particles used in this process is typically 100 percent passing No. 20 mesh[2]. The blended asphalt rubber binder may add other components or additives, such as extender oil or natural rubber. Extender oils are generally added to reduce binder viscosity, improve the workability of the asphalt rubber mixture, and increase the compatibility between the asphalt binder and the GTR (Shatnawi 2011). Natural rubber is sometimes required when truck tires are ground with automobile tires.

[2] 20 mesh screen has twenty openings in one square inch of screen. For comparison, a No. 8 sieve is a 20.0937 mesh.

- *Terminal Blending*: This type of wet-process blending is generally used for rubber-modified binders with less than 15 percent GTR. For these binders, blending occurs at the refinery or stationary asphalt terminal (hence the term “terminal blend”). This process typically uses finer GTR particles than those used in asphalt rubber binders (< 30 mesh) (Caltrans 2006).

DESIGN

Project Selection Criteria

ARGG mixtures are durable structural pavement layers with good resistance to reflective cracking, rutting, and oxidation and have good frictional characteristics due to the gapped grading of the aggregate. ARGG are commonly used as overlays for rehabilitation or maintenance of asphalt and portland cement concrete pavements but can also be used as a surface or wearing course for new construction. ARGG mixtures can be used in many traffic levels: mainline interstates, ramps, and urban intersections with considerable stop-and-go traffic. They are not suggested for parking areas where the surface may scuff when exposed to continuous low-speed braking and turning movements common in these areas (Caltrans 2006).

ARGG mixtures generally have higher unit costs than conventionally modified mixtures due to mobilization, setup, and calibration costs of the asphalt rubber production equipment. As such, their use typically is limited to larger projects where the additional costs can be offset by increased service life, lower maintenance, and potentially reduced thicknesses. For small projects, mobilization costs can be disproportionately high, reducing feasibility. Caltrans recommends that ARGG mixtures not be used when project quantities are 1,000 tons or less, and there are no asphalt plants with full-time asphalt rubber blending plants on site or when the roadway elevation is above 3,000 feet (Caltrans 2022).

ARGG mixtures are typically placed at a thickness of 1.25 inches to 2.4 inches (30 mm to 60 mm). A mechanistic-empirical analysis conducted by Caltrans found that this range of thicknesses was structurally similar to dense-graded mixes. Its use in lower layers within a pavement structure provided no additional benefit. Caltrans recommends placing an intermediate dense-graded asphalt mixture before the ARGG mixture if greater structural capacity is needed. In addition, ARGG mixtures should not be placed directly on an aggregate base (Caltrans 2022). ARGG mixtures can be placed on milled surfaces. The suggested minimum lift thickness – not the maximum – is four times the NMAS for gap-graded mixtures (Asphalt Institute 2022).

Pavement Design Methods

The empirical method of the 1993 American Association of State Highway and Transportation Officials Pavement Design Guide[3] (AASHTO 1993) determines pavement thickness using structural layer coefficients based on material properties and mixture characterization. For years, most State DOTs have used a structural layer coefficient value of 0.44 for conventional asphalt layers. Laboratory research conducted by Caltrans indicated that ARGG mixtures could be considered equivalent to conventional asphalt mixtures up to a thickness of 2.4 inches on a structural basis. Caltrans found thicknesses greater than 2.4 inches to have reduced benefits when considering the costs and concern for potential rutting. When used as a method of preventing reflective cracking, Caltrans allows the substitution of ARGG mixtures for dense-graded mixtures at one-half this thickness (Caltrans 2006).

[3] AASHTO specifications referenced herein are optional and not Federal requirements.

In the case of the AASHTO mechanistic-empirical (ME) pavement design guide[4] (AASHTO 2020), material properties are critical inputs to determine the structural contribution of mixtures. Level 1 inputs rely on laboratory testing to determine the material properties used in the design.

The primary material property for ME pavement design is the dynamic modulus, |E*|, which quantifies the modulus of the asphalt mixture over a range of expected temperatures and traffic speeds as a function of loading frequency. Generally, the asphalt rubber binder is characterized by a lower dynamic modulus at warm and cold temperatures than those calculated according to the ME predictive equations (Pasquini et al. 2011). A lower stiffness at cold temperatures is desirable for better cracking resistance, while a low modulus at high temperatures may indicate poor resistance to permanent deformation or rutting. However, gap-graded mixtures, such as ARGG and stone matrix asphalt (SMA) mixtures, are highly rut-resistant due to the strong interlocking coarse aggregate structure.

In summary, mechanistic-empirical pavement design procedures use pavement modeling and predictive equations to predict performance to determine needed pavement thickness. Long-term field performance is needed to calibrate the transfer functions for these prediction equations properly. State DOTs are encouraged to conduct laboratory and field studies for their local materials.

Functional Designs

The primary consideration of functional overlays placed as part of maintenance or pavement preservation is the ability to adequately compact the overlay to achieve the proper density. Thinner pavement layers tend to cool quickly and allow less time for compaction. This cooling, coupled with the increased stiffness of the gap-graded aggregate, can create significant density challenges for the contractor. ARGG mixtures have higher mixing, placement, and compaction temperature requirements. The compaction window of ARGG mixtures is narrower compared to conventional dense-graded mixtures. Caltrans' experience suggests that lift thicknesses of 1.25 inches (30 mm) or greater are sufficient to obtain the desired density.

MATERIALS AND MIXTURES

Selecting and specifying the appropriate materials for ARGG mixtures can be complex. This section includes discussion of example specifications and material requirements that some State DOTs use.

Aggregates

Aggregate specifications for ARGG mixtures are typically the same as those for aggregates used in higher-volume, dense-graded mixtures. However, aggregates can be under greater stress due to stone-on-stone contact in a gap-graded mixture, similar to SMA mixtures. Some State DOTs use ASTM C131 and C131M, which place stricter requirements on the Los Angeles Abrasion loss to prevent degradation during production and placement.

[4] AASHTO specifications referenced herein are optional and not Federal requirements.

Ground Tire Rubber

GTR quality varies depending on the manufacturer. However, industry does have criteria it uses to determine product quality (Scrap Tire News 2015). These relate to specific gravity and the rubber's moisture, fiber, and metal content. Some State DOTs also have additional requirements regarding the chemical composition of acetone extract, ash, carbon black, rubber hydrocarbon, and natural rubber content to ensure that no substitution with unacceptable materials occurs.

Many State DOTs using rubber-modified asphalt binder have developed their own GTR specifications. For example, the Massachusetts Department of Transportation (MassDOT) specifies that GTR be vulcanized rubber from the ambient temperature processing of scrap and pneumatic tires. It should meet the gradation in Table 1 (MassDOT 2022).

Table 1. MassDOT Crumb rubber gradation.

Sieve Size	Percent by Weight Passing
No. 10	100
No. 16	90-100
No. 30	25-100
No. 80	0-20

MassDOT allows using multiple types of crumb rubber from many sources if the overall blend meets the gradation requirements in Table 1. The length of the individual rubber particles shall not exceed ⅛ inch, and the rubber should be certified by the crumb rubber manufacturer (MassDOT 2022).

The Caltrans 39-2.03A(4)(e)(ii)(C) Crumb Rubber Modifier GTR specification requires that the CRM be on the Authorized Materials List for Crumb Rubber Modifier. CRM should be a ground or granulated combination of scrap tire crumb rubber and high natural scrap tire crumb rubber; CRM should be 75.0 plus-minus 2.0 percent scrap tire crumb rubber and 25.0 plus-minus 2.0 percent high natural scrap tire crumb rubber by total weight of CRM. Scrap tire crumb rubber and high natural scrap tire crumb rubber should be derived from waste tires described in Pub Res Code § 42703 (Caltrans 2022).

Caltrans accepts scrap tire crumb rubber and high natural crumb rubber based on compliance with the requirements in Table 2.

Table 2. Caltrans crumb rubber modifier for asphalt rubber binder.

Quality Characteristic	Test Method	Requirement
Scrap tire crumb rubber gradation (% passing No. 8 sieve)	California Test 385	100
High natural crumb rubber gradation (% passing No. 10 sieve)	California Test 385	100
Wire in CRM (max, %)	California Test 385	0.01
Fabric in CRM (max, %)	California Test 385	0.05
CRM particle length (max, in)	-	3/16
CRM specific gravity	California Test 208	1.1-1.2
Natural rubber content in high natural crumb rubber (%)	ASTM D297	40.0-48.0

Scrap tire crumb rubber and high natural crumb rubber are sampled and tested separately.

Concerning the GTR gradation, ASTM D 5644 *Standard Test Methods for Rubber Compounding Materials-Determination of Particle Size Distribution of Recycled Vulcanizate Particulate Rubber*[5] is sometimes used by State DOTs to determine GTR gradation. A comparison of GTR gradation requirements for Massachusetts, California, Texas, and Arizona is shown in Table 3.

Table 3. Comparison of State DOT gradation requirements.

Sieve Size	MassDOT	Caltrans	TxDOT (Grade C)	ADOT (Type B)
No. 8	-	100	100	100
No. 10	100	-	100	100
No. 16	90-100	-	100	75-95
No. 30	25-100	-	90-100	30-60
No. 40	-	-	45-100	-
No. 50	-	-	-	5-30
No. 80	0-20	-	-	-
No. 200	-	-	-	0-5

Asphalt Rubber Binder

As discussed previously, asphalt rubber is a blend of asphalt binder, 15 to 22 percent GTR, and in some instances, other additives such as an extender oil, natural rubber, or a warm mix additive. The components are blended at elevated temperatures under high agitation, creating a physical interaction of the asphalt binder and some tire rubber components. This helps keep the tire rubber particles suspended in the blend. During the interaction with the asphalt binder, the rubber particles absorb a portion of the oils in the asphalt binder, causing the particles to swell, increasing the viscosity and stiffness of the asphalt rubber (Shatnawi 2011; Shen et al. 2012).

[5] ASTM standards referenced herein are optional and not Federal requirements.

The interaction between the asphalt binder and GTR depends on several factors, such as the rubber's size, gradation, texture, reaction time and temperature, amount of rubber, rubber type, and asphalt binder grade (Heitzman 1992; Hicks et al. 2010). For example, MassDOT specifies that a binder reaction design profile should be developed before producing asphalt rubber binders for a project (MassDOT 2022). The profile is developed in the laboratory by blending all the component materials for the asphalt rubber at the appropriate percentages and reaction temperatures and then determining certain characteristics of the asphalt rubber at various reaction times. This provides a profile of the asphalt rubber properties' behavior over time and indicates what to expect during field production (MassDOT 2022). An example of an asphalt rubber design profile is shown in Table 4.

Table 4. Asphalt rubber design profile example and minutes (min.) of reaction.

Test Performed	Test Method	45 Min.	90 Min.	240 Min.	360 Min.	1440 Min.	Limit
Viscosity, at 190°C, (centipoises)	ASTM D7741	2400	2800	2800	2800	2100	1500-4000
Resilience at 25°C, (% Rebound)	ASTM D5329	27	-	33	-	23	18 minimum
Softening Point, (°C)	ASTM D36	59.0	59.5	59.5	60.0	58.5	52-74
Cone Pen. at 25°C, (0.10 mm)	ASTM D217	39.0	-	45.0	-	50	25-70

One asphalt rubber binder limitation is that these binders cannot reliably be classified using the performance-graded binder grading system. The performance-graded system requires the gap opening to conduct dynamic shear rheometer (DSR) tests of 1 and 2 mm for high- and intermediate-temperature testing, respectively. Although DSR binder testing has been conducted on binders modified with GTR, the rubber particles have been limited to No. 30 mesh material or smaller sizes that the DSR parallel plate gap can handle. Since GTR particles in asphalt rubber may be bigger than No. 30 mesh, the test should not be conducted with parallel plater fixtures. Other fixtures for the DSR are available and have been proposed, such as the concentrical cylinder. In addition, the non-homogenous nature of the AR binder may affect the test results.

Many State DOTs specify that asphalt rubber meet the physical requirements of ASTM D6114 *Standard Specification for Asphalt-Rubber Binder*[6], shown in Table 5. They also generally specify the base asphalt binder, percent GTR, reaction times and temperatures, and end-result properties. Common test properties specified by State DOTs include rotational viscosity, resilience, softening point, and the cone/needle penetration test.

[6] MnDOT's RQI scale ranges from 0 to 5, with 0 indicating a very poor pavement.

Table 5. Asphalt-rubber binder physical requirements (ASTM D6114).

Binder Designation		Type I	Type II	Type III
Apparent Viscosity, 175°C (cP) – ASTM D7741	Min, Max	1500, 5000	1500, 5000	1500, 5000
Penetration, 25°C, 100g, 5s (0.1 mm) – ASTM D5	Min, Max	25, 75	25, 75	50, 100
Penetration, 4°C, 200g, 60s (0.1 mm) – ASTM D5	Min	10	15	25
Softening Point, (°C) – ASTM D36	Min	57	54	52
Resilience, 25°C, (%) ASTM D5329	Min	25	20	10
Flash Point, (°C) – ASTM D92	Min	232	232	232
Thin-Film Oven Residue Penetration Retention, 4°C – ASTM D5	Min	75	75	75

A summary of asphalt rubber requirements used by Arizona, California, Massachusetts, Virginia, and Texas is shown in Table 6.

Table 6. Examples of asphalt rubber GTR contents and State DOT blending requirements.

Requirement	ADOT	Caltrans	MassDOT	VDOT	TxDOT
GTR (%)	Min. 20	20±2	Min. 15	Min. 15	Min. 15
Base Binder[7]	PG 58-22	PG 64-16	PG 58-28 or PG 64-28	PG 64S-22	PG 64-22
Blending Temperature at the time, GTR is added (°F)	350-400	375-440	350-400	-	-
Blending Temperature during Blending (°F)	325-375	375-425	Above 325	-	-
Minimum Interaction Time (Minutes)	60	45	60	45	-

[7] Typical base binder, more than one binder can be used based on climatic location.

Asphalt rubber requirements can vary by State. For example, the MassDOT references ASTM D6114, specifies the allowable base asphalt binders, requires 15 percent GTR, and gives the reaction temperatures and times. MassDOT also requires that all AGG mixtures be modified with a warm mix additive (MassDOT 2022).

MassDOT Subsection M3.01.2 (B)

The modified binder shall be in accordance with ASTM D6114-09, Type II. Virgin PGAB for the crumb rubber modified asphalt shall be a PG 58-28 or PG 64-28 provided by an approved Supplier in accordance with the AASHTO R 26. The grade selected shall be based on laboratory testing by the asphalt rubber manufacturer.

The percent of crumb rubber shall be a minimum of 15 percent by weight of binder. The temperature of the asphalt shall be between 350 degrees Fahrenheit and 400 degrees Fahrenheit at the time of addition of the granulated crumb rubber. The asphalt and crumb rubber shall be combined and mixed together in a blender unit and reacted in the distributor for a period of time as required by design. The temperature of the asphalt-rubber mixture shall be above 325 degrees Fahrenheit during the reaction for a period of one hour.

Caltrans 39-2.03B(3)

The Caltrans 39-2.03B(3) Asphalt Rubber Binder specification requires an asphalt modifier, 18 to 22 percent GTR, and the GTR must contain approximately 25 percent high natural scrap tire rubber. A design profile must be established. Extender oils and high-natural tire rubber are also used. The production requirements section gives the required blending times and temperatures (Caltrans 2022).

39-2.03B(3)(a) General

Asphalt rubber binder must be a combination of the following:

1. *Asphalt binder*
2. *Asphalt modifier*
3. *CRM*

The combined asphalt binder and asphalt modifier must be 80.0 plus-minus 2.0 percent by weight of the asphalt rubber binder.

40-2.03B(3)(b) Asphalt Modifier

Asphalt modifier must be a resinous, high-flashpoint, aromatic hydrocarbon and must comply with the requirements (Table 7).

Table 7. Caltrans asphalt modifier requirements.

Quality Characteristic	Test Method	Requirement
Viscosity at 100 °C (m^2/s x 10-6)	ASTM D445	X ± 3[8]
Flashpoint (min, °C)	ASTM D92	207
Molecular analysis: Asphaltenes (max, % by mass) Aromatics (min, % by mass)	ASTM D2007, ASTM D2007	0.1, 55

[8] The symbol X is the proposed asphalt modifier viscosity. X must be between 19 and 36. A change in X requires a new asphalt rubber binder design.

Asphalt modifier must be from 2.0 to 6.0 percent by weight of the asphalt binder in the asphalt rubber binder.

39-2.03B(3)(d) Design and Profile

Design the asphalt rubber binder from testing performed for each quality characteristic and for the reaction temperatures expected during production. The profile must include the same component sources for the asphalt rubber binder used. The 24-hour (1,440-minute) interaction period determines the design profile. At a minimum, mix asphalt rubber binder components, take samples, and perform and record the tests (Table 8).

Table 8. Asphalt rubber binder reaction design profile and minutes (min.) of reaction.

Quality Characteristic	Test Method	45 Min.	60 Min.	90 Min.	120 Min.	240 Min.	360 Min.	1440 Min.	Limit
Cone Penetration at 25°C, (0.10 mm)	ASTM D7741	X	-	-	-	X	-	X	25-70
Resilience at 25°C, (min. % Rebound)	ASTM D5329	X	-	-	-	X	-	X	18
Field Softening Point, (°C)	ASTM D36	X	-	-	-	X	-	X	52-74
Viscosity, at 190°C, (centipoises)	ASTM D217	X	X	X	X	X	X	X	1500-4000

[a] Six hours (360 minutes) after CRM addition, reduce the oven temperature to 275 °F for 16 hours. After the 16-hour (960 minutes) cool down after CRM addition, reheat the binder to the reaction temperature expected during production for sampling and testing at 24 hours (1,440 minutes).

[b] X denotes required testing.

39-2.03B(3)(e) Asphalt Rubber Binder Production

39-2.03B(3)(e)(i) General

Deliver scrap tire crumb rubber and high natural crumb rubber in separate bags.

39-2.03B(3)(e)(ii) Mixing

Proportion and mix asphalt binder, asphalt modifier, and CRM simultaneously or premix the asphalt binder and asphalt modifier before adding CRM. If you premix the asphalt binder and asphalt modifier, mix them for at least 20 minutes. When you add CRM, the temperature of the asphalt binder and asphalt modifier must be from 375 to 440°F. After interacting for at least 45 minutes, the asphalt rubber binder must comply with the requirements in Table 9.

Table 9. Caltrans asphalt rubber binder requirements.

Quality Characteristic	Test Method	Requirement
Cone penetration at 25°C (0.10 mm)	ASTM D217	25-70
Resilience at 25°C (min, % rebound)	ASTM D5329	18
Softening point (°C)	ASTM D36/36M	52-74
Viscosity at 190°C (centipoises)[9]	ASTM D7741/ D7741M	1500–4000

[9] Prepare sample for viscosity test under California Test 388.

Do not use the asphalt rubber binder during the first 45 minutes of the reaction period. During this period, the asphalt rubber binder mixture must be between 375 degrees Fahrenheit and the lower of 425 or 25 degrees Fahrenheit below the asphalt binder's flash point shown in the Safety Data Sheet.

If any asphalt rubber binder is not used within 4 hours after the reaction period, discontinue heating. If the asphalt rubber binder drops below 375 degrees Fahrenheit, reheat before use. If you add more scrap tire crumb rubber to the reheated asphalt rubber binder, the binder must undergo a 45-minute reaction period. The added scrap tire crumb rubber must not exceed 10 percent of the total asphalt rubber binder weight. Reheated and reacted asphalt rubber binder must comply with the viscosity specifications. Do not reheat asphalt rubber binder more than twice (Caltrans 2022).

ARGG Mixture Design

ARGG mixtures are designed using various methods, but a widespread method in use today is a volumetric approach using the Superpave gyratory compactor. This is typically based on AASHTO M 323 Superpave *Volumetric Mix Design*[10], AASHTO R 35 *Superpave Volumetric Design for Asphalt Mixtures*, and the Asphalt Institute's MS-2 *Asphalt Mix Design Methods*, with some slight modifications.

Many State DOTs require a gradation of 12.5 mm NMAS. Specific mixture gradation requirements for Massachusetts, California, Arizona, and Virginia are shown in Table 5. In addition, MassDOT has developed a 9.5 mm version for thinner lift thicknesses.

Table 10. ARGG gradation requirement examples.

State DOT	MassDOT	Caltrans		ADOT	VDOT
Sieve/NMAS	12.5 mm	12.5 mm	19.0 mm	12.5 mm	12.5 mm
1"	-	-	100	-	-
3/4"	100	100	95-98	100	100
1/2"	90-100	90-98	83-87	80-100	90-100
3/8"	83-87	83-87	64-70	65-80	83-87
No. 4	28-42	28-42	28-42	28-42	28-42
No. 8	14-22	14-22	14-22	14-22	14-22
No. 200	0.0-6.0	0.0-6.0	0.0-6.0	0.0-2.5	0.0-6.0

Most State DOTs require 75 to 100 gyrations for basic volumetrics. The typical requirement for voids in mineral aggregate (VMA) ranges from 18 to 23 percent, while design air voids typically range from 3 to 5 percent. Some State DOTs check the stone-on-stone contact described in AASHTO R 46 *Designing Stone Matrix Asphalt*. A summary of some basic mixture design requirements typically used by State DOTs is shown in Table 11.

[10] AASHTO standards referenced herein are optional and not Federal requirements.

Table 11. Examples of State DOT mix design criteria.

Quality Characteristic	Caltrans	VDOT	MassDOT
VMA (Min, %)	18-23	18	18-23
No. Gyrations	50-150[12]	75	100
Air Voids, (%)	4.0	3-6	3-5
Binder Content (Min, %)	7.5	7.6	7.6
TSR (Min, %)	-	80	-
Moisture susceptibility, dry strength (min, psi)	100	-	-
Moisture susceptibility, wet strength (min, psi)	70[13]	-	-
Draindown (Max, %)	-	0.3	0.3
Hamburg wheel track (min number of passes at 0.5-inch rut depth) Base binder grade: PG 64 or lower; PG 70	15,000; 20,000	-	20,000 and no SIP before 15,000 passes
Voids in the Coarse Aggregate (VCA_{MIX})	-	<VCA_{DRC}	-
RAP Content (Max, %)	0	10	10

[12] Caltrans allows the Superpave gyratory compactor ram pressure to be increased to a maximum of 825 kPa, and specimens may be held at a constant height for a maximum of 90 minutes.

[13] Caltrans requires freeze-thaw.

One testing issue that can occur with mixtures that use asphalt rubber binder is that following compaction with the gyratory compactor, when the samples are extruded from their molds, the compacted specimens can expand due to the elastic nature of the binder. This expansion artificially increases the mixture's air voids content. Many States and contractors address this by holding the samples in the gyratory mold (under load) for an additional time.

Performance Testing

Running performance tests on ARGG mixtures during the design phase is common. Typical tests include draindown, moisture susceptibility, and rutting; other performance tests that may be used are permeability, raveling, durability, and cracking tests. Standard asphalt mixture performance tests are used for all these parameters with slight variations, such as air voids and gyration levels, to align with the mix design for the State DOT.

CONSTRUCTION

Asphalt Rubber Production

During the asphalt rubber blending operation, which is typically a portable unit, asphalt binder is pumped from a storage tank or truck into a heating tank, where the temperature is raised to approximately 350 to 425 degrees Fahrenheit. The hot asphalt binder is pumped into the mixing tank, and the other component materials, such as GTR and extender oil, are metered into the hot asphalt binder. The two material streams are blended in a mixing unit. The resulting blend is then pumped into a holding tank and slowly agitated to prevent separation while kept at an elevated temperature for a specified period, typically a minimum of 45 to 60 minutes (Caltrans 2006). A diagram of the blending process is shown in Figure 4, and an actual blending unit in Figure 5.

The GTR is typically supplied in one-ton super sacks fed into a weigh hopper for proportioning. The GTR metering system is typically controlled by load cells mounted on the GTR hopper. A variable-speed pump with a flow meter proportions the appropriate amount of asphalt binder. GTR and asphalt binder mixing occur in a tank equipped with a mechanical mixer, which breaks up GTR clumps and disperses the GTR particles into the asphalt binder to obtain a homogenous mixture. The blend is then transferred to a separate tank to complete the reaction process.

Holding the asphalt rubber at elevated temperatures for an extended period can degrade the binder. Caltrans requires that heating be discontinued if the asphalt rubber binder material is not used within 4 hours after the 45-minute reaction period. If the asphalt rubber binder drops below 375 degrees Fahrenheit, the binder should be heated before use. In addition, Caltrans requires that if more GTR is added to the asphalt rubber binder, the binder should undergo a 45-minute reaction period.

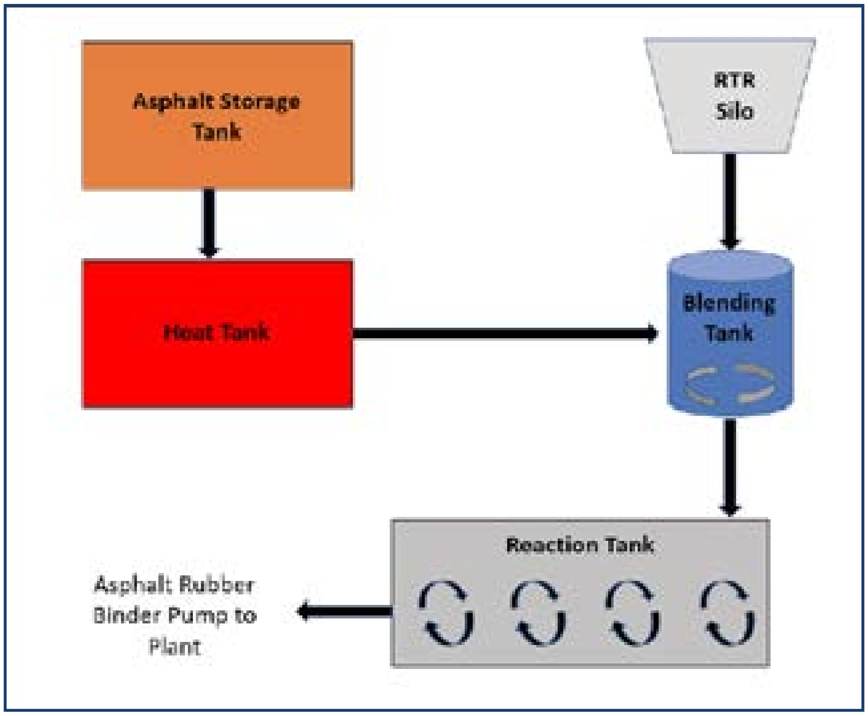

Figure 4. Asphalt rubber blending and reaction process. (Source: NCAT)

Mixture Production

ARGG mixture production involves additional asphalt rubber blending equipment, as described above. While some asphalt mixture producers have permanent blending equipment, the blending equipment commonly is a portable unit frequently operated by a specialty subcontractor. After the asphalt rubber is blended and allowed to react appropriately, it is pumped into a storage tank that is part of the blending equipment. The tank is then tied into the asphalt plant's existing binder line. The mass flow rate of the binder-rubber mixture is controlled from the mixing unit's control house to match the asphalt plant's production rate. It is not typically held in the plant's storage tanks, and the amount of time the binder is stored is generally minimized, typically under four hours.

Figure 5. Asphalt rubber blending unit. (Source: Granite Construction)

The temperature of the asphalt rubber binder, when pumped into the plant, is typically 375 to 425 degrees Fahrenheit, and typical mix production temperatures are generally less than 325 degrees Fahrenheit.

Storage and Transportation

Storing ARGG mixtures is generally limited to reduce the chances of draindown in the mixture and to minimize the impact storage has on the viscosity of the asphalt rubber binder. Transporting ARGG mixtures typically follows the same processes used for conventional polymer-modified mixes. Loads should be covered with tarps overlapping the sides and securely fastened to prevent significant decreases in temperature. It is also suggested that an approved asphalt release agent be sprayed over the interior of the truck bed to prevent the mix from sticking to the metal bed.

Surface Preparation

Surface preparation before ARGG mixture placement should follow the same guidelines as other mixtures. Milling may be performed to achieve a specified thickness or to eliminate surface distresses, especially minor rutting.

As with any asphalt mixture, an ARGG mixture should be placed on a clean, dry surface. A tack coat should be applied to bond the underlying surface properly. If an emulsion is used, it should be allowed to completely break and cure before starting paving operations.

Placement

Successful placement of ARGG mixtures largely depends on maintaining a continuous paving operation. It is essential that the asphalt rubber blending operation, plant production rate, number of trucks used, paver speed, and compaction operations all be properly balanced to avoid having trucks waiting for extended periods or rollers being left behind by the paver. Material transfer devices are frequently used to help establish this continuous paving process, with the added benefit of additional remixing to reduce physical and thermal segregation. Minimum ambient air temperature requirements are typically 50 to 55 degrees Fahrenheit, and the mixture's temperature behind the screed should be approximately 300 degrees Fahrenheit (Caltrans 2006).

Compaction

Coarse aggregate structure and the stiff asphalt rubber binder can make ARGG mixtures more difficult to achieve the specified density level. Compaction should be performed and completed promptly to achieve the target density while the mat is still about 175 to 180 degrees Fahrenheit, where no additional increase in density is possible.

In general, no special compaction equipment is required. However, some contractors use three vibratory rollers working in tandem as initial breakdown rollers to get maximum density early in the compaction process. Rubber tire rollers should not be used due to excessive pick-up by the tires. Breakdown rollers should be kept close to the paver, but adjusting rolling patterns to optimize density may still be necessary. Attention should be paid to the compaction operation so that rolling patterns are adequately maintained, and density is consistently achieved.

Acceptance

The same quality characteristics and test methods used for conventional mixtures may be used for the acceptance (and quality control) of ARGG mixtures. This can include binder content, gradation, volumetrics, roadway density, and smoothness. One thing to note concerning volumetrics is that it is not uncommon for the gyratory compacted specimens to “swell” after the ram has been lifted from the sample. This can artificially increase the air voids in the sample. One method of addressing this is to maintain the ram pressure on the sample until it cools adequately.

On many ARGG projects, State DOTs require contractors to place a test section before the start of production. The purpose of the trial section is for the contractor to demonstrate the ability to produce and place the ARGG mixture properly. Typically, the contractor can produce and place between 200 and 500 tons in the test section. Samples are then tested for the specified mixture properties (e.g., volumetrics, binder content, gradation, etc.) and density before full-scale production. Asphalt rubber samples can be taken at this time to ensure conformance with the State DOT binder requirements.

CONSTRUCTION AND MAINTENANCE PRACTICES

The following sections include known potential issues with ARGG mixtures and troubleshooting information.

Asphalt Rubber Blending

During production of asphalt rubber binder, a State DOT typically requires the producer to have a quality control plan describing testing and inspection activities. The following tests are frequently used for Quality Control purposes and occasionally for acceptance Table 12 (Hicks et al. 2010).

Table 12. Common quality control tests (Hicks et al. 2010).

Quality Control Tests	Temp °F/°C	Method	Specification
Apparent viscosity	350/175	ASTM D7741	1500-5000 cP
Softening point	-	ASTM D36	Min. 130°F (54°C)
Resilience	77/25	ASTM D5329	Min. 20%
Penetration	77/25	ASTM D5	25-75 dmm
DSR	82°C	ASTM D7175	-

Asphalt rubber binder samples should be obtained from an appropriate sample valve or the feed line into the asphalt plant, and the viscosity should be checked routinely. When sampling the asphalt rubber binder, a common practice is wasting at least one gallon of asphalt rubber binder to ensure that the sampling valve is clear and a good sample is obtained.

A field test for asphalt rubber binder is ASTM D7741 *Standard Test Method for Measurement of Apparent Viscosity of Asphalt-Rubber or Other Asphalt Binders by Using a Rotational Handheld Viscometer.* This is typically run on each batch of asphalt rubber produced, as maintaining a consistent viscosity is important when producing an ARGG mixture.

When the asphalt rubber binder is not used within four hours, Caltrans requires that heating be discontinued, as the rubber and asphalt will continue to react, and the rubber will break down (i.e., be digested) over time, which reduces viscosity. If the temperature of the binder drops below 375 degrees Fahrenheit, reheating is required by Caltrans. Caltrans allows two reheating cycles, but the specifications should still be met (Caltrans 2006).

Another common issue related to asphalt rubber blending is scheduling. Due to the limited storage time of the asphalt rubber binder, and most of the asphalt rubber binder blending is subcontracted, any delays in the construction schedule (weather, change orders, traffic control changes, etc.) will affect the blending operation. State DOT construction contract language typically specifies the contractor to have adequate asphalt rubber blending units to be available to avoid delays to the project.

Mixture Production

ARGG mixture production rates may be slightly lower than dense-graded asphalt mixture due to higher asphalt rubber binder content (increased mixing time) and the production rate.

One important area to monitor during mixture production is the consistency of the temperature of the asphalt rubber binder as it is pumped into the plant. Contractors have indicated that the material's viscosity changes accordingly as the binder's temperature fluctuates. These changes in viscosity can then impact the accuracy of the pumping/metering of the asphalt rubber binder, especially in continuous mixing plants, which then causes variations in the binder content of the mixture, which affect volumetrics and density. Specification requirements typically include daily time vs. temperature recordation charts be kept on file for inspection to limit temperature variations.

Mixture Storage

Storage of ARGG mixtures should be minimized, as it can potentially result in binder draindown if held for too long. Lengthy storage can also affect the binder's characteristics, resulting in compaction issues.

Placement and Compaction

The use of a material transfer device for the placement of ARGG mixtures allows for a more continuous paving operation, which helps ensure a smoother pavement and helps achieve density. Rubber tire rollers should not be used due to excessive pick-up by the tires. ARGG mixtures have a higher binder content, and the surface may be tacky until the new mat can cure. To prevent tracking and pickup of the newly placed mat when opened to traffic, a light dusting of clean sand may be spread on the surface of the pavement at a rate of about 2 to 4 pounds per square yard to act as a blotter.

Placement temperatures should be closely monitored and not drop below 290 degrees Fahrenheit unless a warm mix additive or technology is used.

SUMMARY

Asphalt rubber gap-graded mixtures are durable pavement layers with resistance to reflective cracking, rutting, and oxidation and have frictional characteristics due to the gapped grading of the aggregate.

- Asphalt rubber binder is a blend of asphalt binder, a minimum of 15 percent GTR, and in some instances, other additives such as an extender oil, natural rubber, or a warm mix additive.
- Asphalt rubber binders are typically required by State DOTs to meet the requirements outlined in ASTM D6114, *Standard Specification for Asphalt-Rubber Binder*[14]. A design blending profile generally is necessary to design the binder and meet the specification criteria.
- ARGG mixtures are gap-graded to facilitate stone-on-stone contact between the coarse aggregate particles. The gapped grading creates more void space between the aggregate particles, which is then filled with a blend of asphalt rubber binder, fine aggregate, undigested rubber particles, and mineral filler. Consequently, these mixtures contain a higher binder content (as compared to a conventional dense-graded mixture), which provides greater durability.
- The compacted thickness of an ARGG mixture ranges from 1.25 to 2.25 inches, depending on the mixture's NMAS. The most common NMAS in use is the 12.5 mm mixture (Heitzman 1992).
- ARGG mixtures are commonly used as overlays for rehabilitating or maintaining asphalt concrete and PCC pavements. Still, they can also be used as a surface or wearing course for new construction. ARGG mixtures are also a suitable substrate for open-graded mixtures.
- ARGG mixtures are typically designed using basic volumetric criteria, using the Superpave gyratory compactor. The number of gyrations generally is set from 75 to 100. A minimum VMA requirement is typically 18 percent, and the design air voids are set at 3 to 5 percent.
- Asphalt rubber binder typically is produced at 350 to 425 degrees Fahrenheit and requires specialized blending equipment. This equipment is typically portable and is frequently subcontracted out. Scheduling the blending operation can be challenging, mainly if the blending unit is portable and used at other plants or for other mix producers. The asphalt rubber binder is generally pumped directly from the storage tank on the blending unit into the mixing unit on the plant.
- Typical mix production temperatures are approximately 325 degrees Fahrenheit, and storage on the mixture is generally minimized.
- Maintaining a consistent binder temperature is critical to producing a mixture with a consistent binder content.
- The placement and compaction of ARGG mixtures are similar to high-volume conventional mixtures. The use of a material transfer device for the placement of ARGG mixtures is highly recommended. Contractors who use three vibratory rollers as breakdown rollers generally do not have difficulty achieving the target density levels.

[14] ASTM standards referenced herein are optional and not Federal requirements.

- The same quality characteristics and test methods used for conventional mixtures may be used for the acceptance (and quality control) of ARGG mixtures.
- Placement temperatures should be closely monitored and not drop below 290 degrees Fahrenheit unless a warm mix additive or technology is used.
- Some State DOTs like Caltrans permit using warm-mix technologies during ARGG production and placement.

REFERENCES

AASHTO. AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials, Washington, D.C. 1993. Non-binding.

AASHTO. Mechanistic-Empirical Pavement Design Guide: A Manual of Practice. 3rd Edition. 2020. Non-binding.

ASTM D8. Standard Terminology Relating to Materials for Roads and Pavements. 2022. Non-binding.

Baker, T. E., Allen, T.M., Jenkins, D.V., Mooney, T., Pierce, L.M., Christie, R.A., Weston, J.T. Evaluation of the Use of Scrap Tires in Transportation Related Applications in the State of Washington. Washington State Department of Transportation, Washington, D.C. 2003.

Baumgardner, G., Hand, A.J.T., Aschenbrener, T., Recycled Tire Rubber – Hybrid GTR Binders and Dry Added GTR – How to Use Them in Asphalt Pavement Mixtures, FHWA-HIF-22-011. Federal Highway Administration, Washington, D.C. 2021.

Baumgardner, G., Hand, A.J.T., Aschenbrener, T., Resource Responsible Use of Recycled Tire Rubber in Asphalt Pavements, FHWA-HIF-20-043. Federal Highway Administration, Washington, D.C. 2020.

California Department of Transportation, Highway Design Manual, Chapter 630 “Flexible Pavement.” 2022.

California Department of Transportation: “Standard Specifications.” 2022.

Caltrans. Asphalt Rubber Usage Guide. State of California Department of Transportation, Materials Engineering and Testing Services. 2006.

Clark, R., and R. Dongre. Laboratory and Field Performance of Dry-Process Rubber Mixes. Presentation 51st Petersen Asphalt Research Conference, Laramie WY. 2014.

Heitzman, M., State of the Practice. Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier, FHWA-SA-92-022. Federal Highway Administration, Washington, D.C. 1992.

Hicks, R. G., Cheng, D. and Duffy, T. Evaluation of Terminal Blend Rubberized Asphalt in Paving Applications, Report No. CP2C-2010-102TM, California Pavement Preservation Center. 2010.

Huang, B., M. Mohammad., P. Graves, C. Abadie. Louisiana Experience with Crumb Rubber-Modified Hot-Mix Asphalt Pavement. Transportation Research Record, No. 1789, pp. 1-13. 2002.

Lee, S.J., C. Akisetty and S. Amirkhanian. The Effect of Crumb Rubber Modifier (CRM) on the Performance Properties of Rubberized Binder in HMA Pavements. Construction and Building Materials 22, pp. 1368–1376. 2008.

Lewis, R.H. and Welborn, J.Y. The Effect of Various Rubbers on the Properties of Petroleum Asphalts. Public Roads, Vol. 28, No. 4, p. 64. 1954.

Massachusetts Department of Transportation: “Highway Division Standard Specifications for Highways and Bridges.” 2022.

National Academies of Sciences, Engineering, and Medicine. "A Manual for Design of Hot-Mix Asphalt with Commentary." 2011.

Pasquini, E., F. Canestrari, F. Cardone and F.A. Santagata. “Performance Evaluation of Gap Graded Asphalt

Rubber Mixtures.” Construction and Building Materials, Vol. 25. 2011.

Rodezno, C., D. Timm, M. Robbins, and N. Tran, “Material Selection Guidance for Asphalt Pavement Design-Research Synopsis 18-01,” National Center for Asphalt Technology. Auburn, AL. 2018.

Scrap Tire News Website. Crumb Rubber Overview, (https://scraptirenews.com/information-center/crumb-rubber/), Accessed June 2015.

Shatnawi, S. Comparisons of Rubberized Asphalt Binders, Asphalt-Rubber, and Terminal Blend. White Paper. 2011.

Shen, J., Z. Xie. Comprehensive Evaluation of the Long-Term Performance of Rubberized Pavements. Phase I Laboratory Study of Rubberized Asphalt Mix Performance, GDOT Research. 2012.

Venudharan, V., Biligiri, K., Sousa, J., & Way, G. Asphalt-Rubber Gap-Graded Mixture Design Practices: a State-of-the-Art Research Review and Future Perspective, Road Materials and Pavement Design. 2017.

TOPS

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