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Performance of Asphalt Rubber Gap-Graded Mixture Overlays Over Jointed Concrete Pavements

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Final Report VTRC 23-R2

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Performance of Asphalt Rubber Gap-Graded Mixture Overlays Over Jointed Concrete Pavements

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Abstract:

The Virginia Department of Transportation (VDOT) maintains 3,343 lane-miles of composite pavements (asphalt over jointed concrete or continuously reinforced concrete pavements). Propagation of cracks from existing pavements into new asphalt concrete overlays (reflective cracking) is a major problem with composite pavements. Treatments that are used to reduce or mitigate reflective cracking include the use of asphalt mixtures with highly modified binders. One way of modifying asphalt mixtures is by using ground tire rubber (GTR), also referred to as rubber modified asphalt. There are three ways of adding GTR to asphalt mixtures: (1) traditional wet process, (2) terminal-blend wet process, and (3) dry process. The traditional wet process blends GTR with asphalt binder or bitumen on-site at the asphalt mixture plant prior to mixing the GTR modified asphalt binder with aggregate. The traditional wet process, along with a gap-graded stone structure, is typically used for incorporating higher GTR concentrations (>15%). VDOT has limited experience with rubber modified asphalt mixtures in general and even less experience with GTR content that exceeds 10%.

The purpose of this study was to establish a performance baseline for an asphalt rubber gap-graded mixture (AR-GGM 12.5) using the wet process on I-85 in the Richmond District (I-85 Southbound, Dinwiddie County). Another objective was to compare its performance with VDOT's stone matrix asphalt (SMA) mixture, which is also a gap-graded mixture.

This study found that AR-GGM mixtures can be placed with no special field accommodations (compared with SMA mixtures), and the special provision developed for AR-GGM mixtures is effective. Further, based on laboratory performance testing, both the AR-GGM and SMA control mixtures tested in this demonstration project were crack and rutting resistant, with the AR-GGM mixture exhibiting more flexibility (i.e., lower stiffness). Both sections are performing as expected after 3 years of traffic and exhibiting minor to no distresses, with a Critical Condition Index greater than 90. However, at this early stage of field service, it is too soon to quantify a performance advantage of AR-GGM mixtures in comparison with conventional SMA mixtures. This study recommends continued use of AR-GGM mixtures for suitable projects as a reflective cracking mitigation tool. Further, the study recommends continued performance monitoring of the study sections to evaluate the cost-effectiveness of AR-GGM mixtures in comparison with SMA mixtures.

FINAL REPORT

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ABSTRACT

The Virginia Department of Transportation (VDOT) maintains 3,343 lane-miles of composite pavements (asphalt over jointed concrete or continuously reinforced concrete pavements). Propagation of cracks from existing pavements into new asphalt concrete overlays (reflective cracking) is a major problem with composite pavements. Treatments that are used to reduce or mitigate reflective cracking include the use of asphalt mixtures with highly modified binders. One way of modifying asphalt mixtures is by using ground tire rubber (GTR), also referred to as rubber modified asphalt. There are three ways of adding GTR to asphalt mixtures: (1) traditional wet process, (2) terminal-blend wet process, and (3) dry process. The traditional wet process blends GTR with asphalt binder or bitumen on-site at the asphalt mixture plant prior to mixing the GTR modified asphalt binder with aggregate. The traditional wet process, along with a gap-graded stone structure, is typically used for incorporating higher GTR concentrations (>15%). VDOT has limited experience with rubber modified asphalt mixtures in general and even less experience with GTR content that exceeds 10%.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) maintains 27,058 lane-miles of interstate and primary network with a sufficiency rate of 85.2% (based on 2021 data); 3,343 lane-miles are composite pavements (asphalt over jointed concrete or continuously reinforced concrete pavements). Propagation of cracks from existing pavements into new asphalt concrete (AC) overlays (reflective cracking) is a major problem with composite pavements. As reflective cracking in pavements compromises ride quality and reduces the service life of the pavement, VDOT has been trying various available treatment methods to delay or mitigate reflective cracking in rehabilitated pavements. Such treatments include the use of asphalt mixtures with highly modified polymer binder, use of fabric interlayers, or use of stone matrix asphalt (SMA) mixtures.

Another way of modifying asphalt mixtures is by using ground tire rubber (GTR), also referred to as rubber modified asphalt. Modification of asphalt binders with GTR is well established and can provide high performance pavements that aid in reducing the number of waste tires disposed in landfills and elsewhere (Baumgardner et al., 2020). The incorporation of rubber into asphalt mixtures produces stiffer and more elastic pavements with enhanced rutting and cracking resistance (Buttlar and Rath, 2021).

There are three ways of adding GTR in asphalt mixtures: (1) traditional wet process, (2) terminal-blend wet process, and (3) dry process. The traditional wet process blends GTR with asphalt binder or bitumen on-site at the asphalt mixture plant prior to mixing the GTR modified asphalt binder with aggregate. Terminal blends are rubber-modified bitumen produced and stored at asphalt terminals (through the wet process) and transported to asphalt plants in specialized tankers. The dry process incorporates GTR directly into the asphalt mixture (prior to introducing the asphalt binder) during production. The exact introduction of GTR varies by plant design.

VDOT uses SMA mixtures on concrete pavement surfaces (on interstates) as one of the reflective cracking mitigation techniques. These mixtures are composed of a gap-graded aggregate that is intended to maximize rutting resistance and durability with a stable stone-on-stone skeleton held together by a rich mixture of asphalt binder, mineral filler, and cellulose fibers. SMA mixtures have been used since 1995 and more extensively by VDOT since 2003.

The field performance of SMA in Virginia has been generally excellent, with reported service lives of 15 to 18 years (McGhee et al., 2010). SMA mixtures are often used with polymer modified asphalt binder (styrene-butadiene-styrene [SBS]). GTR, which predominantly contains styrene-butadiene rubber, is comparable with SBS polymer modification in terms of performance due to the perceived similarity in polymeric building blocks (Baumgardner et al., 2020; Buttlar and Rath et al., 2021). There has been extensive growth in the use of wet process technologies using GTR in states such as Arizona, California, Florida, and Texas due to positive field results (Cheng et al., 2014; Zhou et al., 2014). Use of a higher GTR concentration (>10%) in dense-graded asphalt mixtures is uncommon since this involves selecting an aggregate gradation that will make room for swollen GTR particles. Gap-graded asphalt mixtures are typically used for incorporating higher GTR concentrations (>15%). A portion of the fine aggregates is removed to allow room for the rubber particles within the gradation.

VDOT's experience with asphalt rubber gap-graded mixtures (AR-GGM mixtures) is limited to several terminally blended modified SMA mixtures from a decade ago, but those mixtures involved minimal (<10%) rubber content (Virginia General Assembly, 2013). Those earlier trials also failed to provide a good comparison of performance with conventional SMA mixtures over the challenging platform of jointed concrete pavement.

PURPOSE AND SCOPE

The purpose of this study was to establish a performance baseline for the AR-GGM 12.5 mixture using a wet process on I-85 in the Richmond District (I-85 Southbound, Dinwiddie County). Another objective was to compare its performance with VDOT's SMA mixtures. This performance baseline study and comparison with SMA mixtures (control section) will help VDOT to address future use of these mixtures. Figure 1 shows the location of the trial project on I-85.

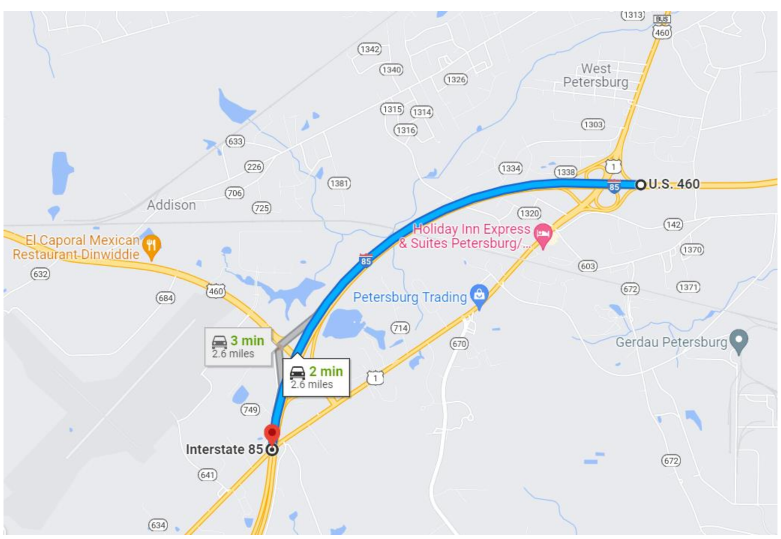

Figure 1. Location of Trial Project

The I-85 project is a two-lane section (>40,000 annual average daily traffic with >15% trucks) where most distresses were in the right lane. As shown in Figure 2, the entire test section (from mile marker 64.14 to 61.56) was divided into two halves with one-half of the section (red line) paved with an AR-GGM mixture and the other (green line) paved with a conventional SMA mixture.

Pre-overlay activities in this section included full-depth patching using a base asphalt mixture (instead of a conventional Type I and II patch with portland cement concrete). Repair steps included first saw cutting faulted joints and mid-slab distresses and then patching with two 4.5-in lifts of BM-25.0+0.4 (asphalt base mixture with 25 mm nominal maximum aggregate size [NMAS] and optimum plus 0.4% liquid asphalt binder). Cracks and joints were sealed with Mastic One (hot-applied, pourable, self-adhesive patching material used for filling wide cracks and joints). The total overlay thickness used was 4 in on the entire test section. The control section included a 2-in SMA 19.0 mixture (SMA mixture with 19 mm NMAS) with another 2-in SMA 12.5 mixture (SMA mixture with 12.5 mm NMAS) as the wearing course. The test section included 4 in of AR-GGM mixture (two lifts of AR-GGM at 2-in thickness each with 12.5 mm NMAS).

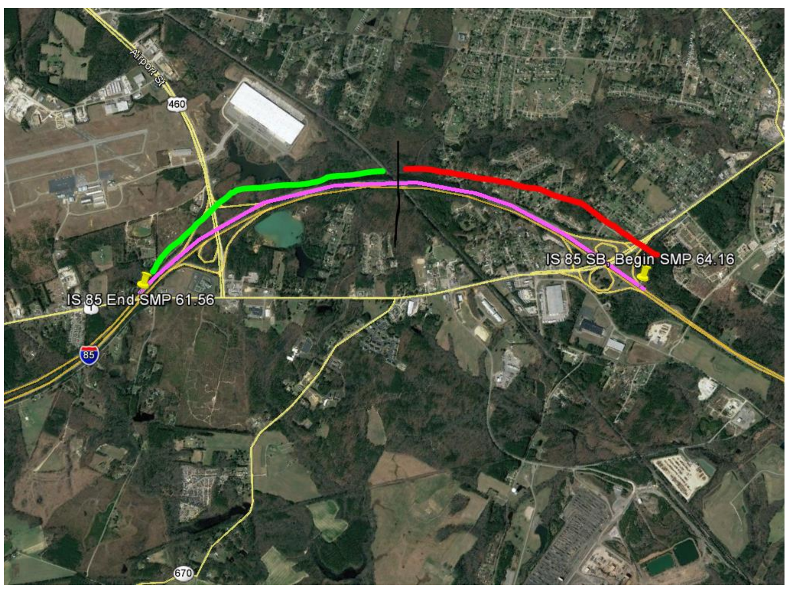

Figure 2. Test Section. Red line = AR-GGM; green line = SMA.

METHODS

Special Provision for AR-GGM Mixtures

As mentioned previously, this was the first application of the wet process AR-GGM mixture in Virginia. As a first step, a special provision was developed for AR-GGM mixtures with input from the asphalt rubber industry, VDOT's Materials Division, the Virginia Asphalt Association, and the National Center for Asphalt Technology.

Mix Design and Short Test Section With AR-GGM Mixtures

The researchers worked with the asphalt producer, GTR supplier, and Richmond District Materials Office to come up with an asphalt mix design for the AR-GGM mixture. A short test section was constructed to identify any field placement issues beforehand. This section (Figure 3) was also located on I-85 and was adjacent to the planned formal demonstration project (Mileposts 64.21 to 64.47 Northbound, approximately 0.264 mi long, left lane only, involving 2-in milling and placement of 2-in AR-GGM mixture).

Figure 3. Test Placement Section (Marked in Red) for AR-GGM Mixture

Field Trial for SMA and AR-GGM Mixtures

The field trials with SMA and AR-GGM mixtures were completed on the existing jointed concrete section on I-85 during the July-August 2019 construction season. The process of AR-GGM mixture production was documented. Samples of the asphalt mixtures and binders were collected from the projects for further testing. Cores were also taken to measure in-place air voids and permeability and to conduct other performance testing in the laboratory.

Laboratory Performance Testing of Asphalt Mixtures

The AR-GGM and SMA mixtures were characterized using a series of standard laboratory performance tests. Volumetric analyses were performed for all sampled mixtures. Data collected and compiled for each mixture included asphalt content and gradation, voids in total mix (VTM), voids in mineral aggregate (VMA), voids filled with asphalt (VFA), dust/asphalt ratio, percent binder absorbed (P_{ba}), and effective binder content (P_{be}). The sampled mixtures were also prepared into specimens or processed in such a way as to enable various laboratory performance testing. There were two objectives for performance testing.

1. Determine specific mixture properties (dynamic modulus and rutting coefficients) and binder properties for the AASHTOWare Pavement ME Design catalogue.

2. Compare the laboratory cracking and rutting performance of the AR-GGM and SMA mixtures using commonly used tests. Cracking tests including the indirect tensile asphalt cracking test (IDEAL-CT), semi-circular bend test (SCB), and Texas overlay tests are used to evaluate a mixture's ability to resist cracking. As Virginia works toward laboratory performance parameters that match field performance, having these test results for these mixtures will be helpful for future studies. Laboratory performance tests were conducted at 6 ± 0.5% air voids, selected because of the higher in-place density requirement (94% minimum) for these mixtures.

Dynamic Modulus

The primary material property input for AC mixtures in AASHTOWare Pavement ME Design is the dynamic modulus (|E*|). This property quantifies the modulus of the AC over a range of expected temperatures and traffic speeds as a function of loading frequency. To support this research, the dynamic modulus tests were performed using the Asphalt Mixture Performance Tester (AMPT) with a 25 to 100 kN loading capacity in accordance with AASHTO TP 79, Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT). Tests on laboratory-produced specimens were performed on 100-mm-diameter by 150-mm-high specimens. All dynamic modulus tests were conducted in the uniaxial mode without confinement. Stress versus strain values were captured continuously and used to calculate dynamic modulus.

Repeated Load Permanent Deformation Test

The rutting performance of asphalt mixtures are characterized in Pavement ME Design using two coefficients, intercept and slope, that are used to define repeated load permanent deformation (RLPD) curves in log-log space. The intercept defines the permanent deformation on the first load cycles, and the slope describes how the permanent deformation increases with increasing number of loading cycles. The permanent deformation intercept and slope are measured using the RLPD test with the AMPT. RLPD tests were conducted at temperatures of 20, 35, and 54ºC. The test temperature of 54°C was based on LTPPBind software and represents the 50% reliability maximum high pavement temperature at sites in central Virginia. A repeated haversine axial compressive load pulse of 0.1 s every 1.0 s was applied to the specimens. The tests were performed in the confined mode using a deviator stress of 482.6 kPa. Air was used to supply the confining pressure, and it was constant throughout the test at 68.9 kPa. The tests were continued for 10,000 cycles or a permanent strain of 10%, whichever came first. Three specimens were tested at 54ºC, and two specimens each were tested at 20ºC and 35ºC. The accumulated permanent deformation is recorded from the actuator displacement at the end of each loading cycle. The RLPD test included a specimen load conditioning sequence before the data were collected for the permanent strain curve (100 load cycles using a confining pressure of 68.9 kPa, repeated deviator stress of 48.3 kPa, and contact deviator stress of 2.4 kPa).

Asphalt Pavement Analyzer (APA) Test

The APA test was conducted in accordance with Virginia Test Method 110 (VDOT, 2014). APA tests were conducted on gyratory-compacted specimens at a test temperature of

64ºC. The APA test used an applied load of 100 lb and a hose pressure of 100 psi. The rut depth after 8,000 cycles of load applications was reported. It included the average rut depth of the four replicates for each mixture type.

Ideal Cracking Test (IDEAL-CT)

The IDEAL-CT for cracking resistance was proposed by researchers at the Texas Transportation Institute (Zhou et al., 2017). According to Zhou et al., this test shows promise in relating a laboratory-measured index to field performance, reasonable repeatability, and simplicity by requiring no cutting, drilling, gluing, or notching of the specimen. The IDEAL-CT is typically run at 25ºC with 150-mm-diameter and 62-mm-high cylindrical specimens and a loading rate of 50 mm/min. This test uses a gyratory compactor to prepare specimens that are placed in a Marshall load frame (or similar load frame) and loaded to failure in the indirect tensile mode. The load-displacement curve is used to determine the CT index, a crack susceptibility indicator.

Semi-Circular Bend (SCB) Test

An additional cracking test, the SCB Illinois Flexibility Index Test (I-FIT), was conducted in accordance with AASHTO TP 124-16, Standard Method of Test for Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature (AASHTO, 2022). Tests were conducted at ambient laboratory temperature (approximately 21ºC). All specimens had air voids within 6.0 ± 0.5%.

Texas Overlay Test

The Texas overlay test was performed in accordance with TX-248-F-2019 (Texas Department of Transportation [DOT], 2019) to assess the susceptibility of mixtures to reflective cracking. All specimens were within 6.0 ± 0.5% air voids. The test was conducted in the displacement-control mode until failure occurred at a loading rate of one cycle per 10 seconds with a maximum displacement of 0.63 mm at 25 ± 0.5°C. The number of cycles to failure is defined as the number of cycles to reach a 93% drop in initial load.

Cantabro Mass Loss Test

The Cantabro mass loss test was conducted in accordance with AASHTO TP 108-14, Standard Method of Test for Abrasion Loss of Asphalt Mixture Specimens (AASHTO, 2022). The test was performed by placing one compacted specimen in a Los Angeles abrasion test drum and subjecting it to 300 drum revolutions in the absence of the abrasion charges. Mass loss is calculated at the end of the experiment. Relative loss is considered a durability indicator.

Binder Recovery and Grading

Asphalt rubber binder, polymer modified binder. and extracted binder grading was performed in accordance with AASHTO M 320, Performance-Graded Asphalt Binder

(AASHTO, 2022), through an outside testing laboratory. The multiple stress and creep recovery (MSCR) test was also performed in accordance with AASHTO T 350. Studies have shown that non-recoverable creep compliance (Jnr) based on the MSCR test is better correlated to pavement rutting (FHWA, 2011).

Field Performance Baseline Assessment

An early-life performance baseline was established through VDOT's Pavement Management System (PMS) after the mixtures were placed. The surface distresses that were collected for VDOT's PMS included transverse cracking, longitudinal cracking, reflective transverse cracking, reflective longitudinal cracking, alligator cracking, longitudinal joint cracking, patching, potholes, delamination, bleeding, and rutting. Within VDOT's PMS, three condition indices are used to rate pavement sections based on the observed distresses. The first is the load related distress rating (LDR), which measures pavement distresses caused by traffic loading. The second is the non-load related distress rating (NDR), which measures pavement distresses that are not load related, such as those caused by environmental or climatic conditions. These two condition indices range from 0 to 100, where 100 signifies a pavement having no distresses. The third is the Critical Condition Index (CCI), which is the lesser of the LDR and the NDR. In addition to storing the individual distress data, VDOT's PMS calculates and stores the LDR, the NDR, the CCI, and the International Roughness Index (IRI) for all sections. It should be noted that the LDR and NDR are used only for asphalt-surfaced pavements. The Slab Distress Rating is used for jointed concrete pavements, and the Concrete Punchout Rating and the Concrete Distress Rating are used for continuously reinforced concrete pavements. However, the same concept of CCI (indices range from 0 to 100) applies to the jointed and continuously reinforced concrete pavement types. More details about concrete pavement condition indices are documented in other VDOT reports (McGhee, 2002; McGhee et al., 2002).

RESULTS AND DISCUSSION

Special Provision for AR-GGM Mixtures

The special provision developed for AR-GGM mixtures is given in Appendix A. VDOT's *Road and Bridge Specifications* provide the details of SMA mix design and placement requirements (VDOT, 2022). The two major differences among these mixtures are the gradation requirement (mainly No. 200 sieve passing) and the minimum AC content, as shown in Tables 1 and 2. The minimum AC for AR-GGM mixtures reflects GTR, so the 7.6% value is based on a minimum binder content of 6.3% (as in SMA mixtures) and accounting asphalt content for 20% rubber in the mixture (by weight of total asphalt rubber binder). Because the rubber particles will act as fine aggregates in the mixture, a lower percentage passing No. 200 sieve is specified for the AR-GGM mixture. As per the special provision, the minimum percentage of granulated rubber required by weight of total asphalt rubber binder is 15%. Another requirement is that the asphalt rubber binder must conform to the requirements of the ASTMD 6114 Type II specifications. The base asphalt must have a PG grading of PG 64S-22. The supplier may substitute PG 58S-28 where needed to meet the requirements of ASTM D 6114 (Type II). The maximum percentage of RAP allowed for AR-GGM mixtures is 10%, whereas SMA mixtures using polymer modified binder are allowed up to 15%.

Table 1. Gradation Requirements for AR-GGM and SMA 12.5 Mixtures

Mix Type	% Passing Sieve						
	3/4 in	1/2 in	3/8 in	No. 4	No. 8	No. 30	No. 200
AR-GGM 12.5	100	90-100	83-87	28-42	14-22	-	0-6
SMA 12.5	100	83-93	80 max.	22-28	16-24	15-20	9-11

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; - = not applicable.

Table 2. Volumetric Requirements for AR-GGM and SMA 12.5 Mixtures

Mix Type	Design Binder, %	Drain-down, %	VCA Design and Production	Design Gyrations	VTM, %	Min. VMA, %	TSR, %
AR-GGM 12.5	Min. 7.6 (asphalt rubber binder)	0.3 max.	$<VCA_{DRC}$	75	3-6	18.0	80 min.
SMA 12.5	Min. 6.3	0.3 max.	$<VCA_{DRC}$	75	2.0-4.0	18.0	80 min.

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; VCA = voids in coarse aggregate; VTM = voids in total mix; VMA = voids in mineral aggregate; TSR = tensile strength ratio; VCA_{DRC} = voids in coarse aggregate in dry rodded condition (DRC).

Mix Design for AR-GGM and SMA Mixtures

Mix designs used for the AR-GGM and SMA mixtures are shown in Table 3. The AR-GGM mixture used 10% RAP, and the SMA 12.5 and 19 mixtures used 13% and 15% RAP, respectively. Asphalt binder contents were also varied among mixtures. Mix design gradations used for these mixtures are given in Table 4.

As per the special provision for AR-GGM mixtures, asphalt rubber binder was tested by the GTR supplier, who confirmed that it met the ASTM D6114, Type II, specification, as shown in Table 5. It should be noted that some of the tests shown in Table 5 were not performed by VDOT as part of regular binder acceptance.

Table 3. Mix Designs for AR-GGM and SMA Mixtures

Material	AR-GGM Mix 19-1084	SMA 12.5 Mix 19-1095	SMA 19.0 Mix 19-1093
No. 78	50% (granite)	54% (granite)	-
No. 8	30% (granite)	-	-
No. 57	-	-	20% (granite)
No. 68	-	21% (granite)	55% (granite)
No. 10 Screenings	10% (granite)		
Filler	-	12%	10%
Additives	0.07% (Zycotherm)	0.3% (cellulose fiber)	0.3% (cellulose fiber)
Reclaimed asphalt pavement, -½ in	10%	13%	15%
Asphalt rubber (GTR)	17.5%	-	-
Asphalt binder	8.1% (PG 64S-22 base binder)	6.9% (PG 64E-22)	5.9% (PG 64E-22)

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; - = not used; GTR = ground tire rubber.

Table 4. Mix Design Gradations for AR-GGM and SMA Mixtures

Sieve Size	AR-GGM Mix 19-1084	SMA 12.5 Mix 19-1095	SMA 19.0 Mix 19-1093
	% passing		
¾ in (19 mm)	100	100	100
½ in (12.5 mm)	93	84	95
3/8 in (9.5 mm)	83	65	60
No. 4 (4.75 mm)	42	25	40
No. 8 (2.36 mm)	20	19	18
No. 30 (0.6 mm)	-	16	14
No. 200 (0.075 mm)	4.5	9	8

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; - = not used.

Table 5. Asphalt Rubber Binder Test Results

Test	Temp, °F/°C	Method	Test Result		Specification
Apparent viscosity	347/175	ASTM D2196	2513	cP	1500-5000 cP
Softening point	-	ASTM D36	138	°F	Min. 130°F (54°C)
Resilience	77/25	ASTM D5329	33	%	Min. 20%
Penetration	77/25	ASTM D5	37	dmm	25-75 dmm
DSR	82°C	ASTM D7175	2.364	kPa	$G^*/\sin \Delta > 1.00$ kPa

DSR = dynamic shear rheometer.

Short Test Section With AR-GGM Mixture

As per the special provision, a short test section was constructed with approximately 200 tons of AR-GGM mixture and was successful, with no placement issues noted. Passing density and volumetric results were obtained. APA rutting tests were conducted (at 64°C), and the results were less than 4 mm (tests were conducted at two air voids, 4% and 7%, and average rut depths were 1.9 mm and 3.4 mm, respectively), indicating good rutting resistance. The APA rut test was not part of the special provision but was conducted since this mixture was being placed for the first time. This mixture was considered to be rut resistant based on previous research by Prowell et al. (2002) where a criterion of 4.0 mm was proposed for Virginia's SMA when tested at a temperature of 49°C.

Documentation of Production and Mixture Placement

Paving work was started on July 1, 2019. Figure 4 shows GTR material stored in bags and a GTR sample. Figure 5 shows the mixing plant used for the wet process to blend the asphalt binder with the dry rubber additive and the storage tank. The liquid asphalt binder is introduced to the mixing tank (Figure 6) at 350°F and stirred into a "whirlpool." The GTR is then fed into the center of the vortex and stirred constantly to blend and then transferred to a custom storage tank to cure (Figure 7). After mixing, the rubber binder mixture must cure for at least 45 minutes; the rubber will "swell" during this curing phase, and therefore this curing must take place prior to the asphalt mixture production. The storage tank has two internal tanks so that material can be cured in one compartment while previously cured material is pumped to the asphalt plant for production. 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.

Figure 4. GTR Material: a) on-site storage at plant; b) ground rubber particles. GTR = ground tire rubber.

Figure 5. GTR Feed Bins to the Left (Green Bins) and Mixing Tank to the Right (Silver Vertical Tank). GTR = ground tire rubber.

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Figure 6. GTR and Asphalt Binder Mixing Tank to the Left and System Control House to the Right. GTR = ground tire rubber.

Figure 7. Asphalt Rubber Binder Holding Tank

Figure 8 shows the placement of the AR-GGM mixture in the field. The paving operation for this job was conducted at nighttime. No placement issues were observed for AR-GGM mixtures in comparison with SMA mixtures, and roller patterns for compaction were similar.

Figure 8. Placement of AR-GGM Mixture

Coring was conducted after placement of two lifts of AR-GGM mixture (2 in each). Ten cores each were collected from the control (SMA 19 and SMA 12.5) and AR-GGM sections. Cores were tested for air voids and permeability, and the results are shown in Table 6 for the AR-GGM mixtures. Each core was separated into 2-in layers for testing; cores were taken after the two lifts (4 in) of placement were completed. Air voids in the top 2 in of the AR-GGM mixture ranged from 4.2% to 9.7%, and the bottom layer voids ranged from 4.2% to 8.1%. Overall, excellent permeability results were obtained (VDOT's permeability requirement is less than 150 x 10^{-5} cm/sec) except for three top cores where the air voids were higher than 9%. One of the bottom layer cores (A4B) had a higher value than the VDOT permeability limit.

Table 7 shows air voids and permeability values for the SMA 12.5 and SMA 19 mixtures. Air voids for the SMA 12.5 mixtures ranged from 1.9% to 6.1% and for SMA 19 mixtures ranged from 0.9% to 5.3%. These lower air voids (thus, higher in-place density) resulted in very low permeability values except for two samples.

Table 6. Air Voids and Permeability Results for AR-GGM Mixtures

AR-GGM Top 2-in Layer			AR-GGM Bottom 2-in Layer		
Specimen No.	**VTM, %**	**Perm. x 10-5 cm/s**	**Specimen No.**	**VTM, %**	**Perm. x 10-5 cm/s**
A1T	7.9	95	A1B	6.2	100
A2T	9.0	558	A2B	7.1	52
A3T	7.4	74	A3B	6.6	18
A4T	9.7	522	A4B	8.1	186
A5T	9.2	533	A5B	6.6	83
A6T	7.3	103	A6B	5.8	87
A7T	5.7	26	A7B	5.9	55
A8T	5.8	3	A8B	4.9	0
A9T	4.2	0	A9B	6.7	0
A10T	5.7	0	A10B	4.8	0

AR-GGM = asphalt rubber gap-graded mix; VTM = voids in total mix.

Table 7. Air Voids and Permeability Results for SMA 19 and SMA 12.5 Mixtures

SMA 19.0 Mix			SMA 12.5 Mix		
Specimen No.	**VTM, %**	**Perm. x 10-5 cm/s**	**Specimen No.**	**VTM, %**	**Perm. x 10-5 cm/s**
B1	5.3	281	T1	4.8	0
B2	2.8	3	T2	3.4	20
B3	2.9	101	T3	5.2	0
B4	1.4	0	T4	6.1	206
B5	1.3	4	T5	4.5	13
B6	2.2	30	T6	4.0	19
B7	1.3	0	T7	1.9	0
B8	2.0	0	T8	5.0	44
B9	1.3	0	T9	3.3	3
B10	0.9	0	T10	5.2	90

SMA = stone matrix asphalt; VTM = voids in total mix.

Laboratory Evaluation of Asphalt Mixtures

Volumetric and Gradation Analysis

Asphalt mixtures were collected and volumetric and gradation analyses were performed for all sampled mixtures. Volumetric and gradation results, presented in Tables 8 and 9, indicate that all mixtures met VDOT specification requirements. The sample collected for SMA 12.5 mixtures had a lower binder content (6.3%) than the mix design value (6.9%). Design % passing No. 200 sieve was 9%, and the results in Table 9 indicate production % passing was near 11%; this may be the reason for the lower AC content during production. A comparison of the VCA_{DRC} values with the VCA_{Mix} values showed that all mixtures met the criterion of $VCA_{Mix} < VCA_{DRC}$, indicating good stone-on-stone contact.

Table 8. Volumetric Properties of the Asphalt Mixtures Studied

Property	AR-GGM-12.5 Mix 19-1084	SMA 12.5 Mix 19-1095	SMA 19.0 Mix 19-1093
%AC	7.92	6.3	6.32
%Air voids (V_a)	4.4	3.2	2.0
%VMA	20.9	17.2	16.5
%VFA	78.9	81.3	87.7
VCA_{Mix}	36.2	39.2	38.1
Dust/asphalt ratio	0.60	1.87	1.33
Effective % binder (P_{be})	7.55	6.05	6.29
Effective film thickness (F_{be})	20.1	7.7	10.1
VCA_{Dry}	41.1	42.1	42

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; AC = asphalt content; VMA = voids in mineral aggregate; VFA = voids filled with asphalt, VCA = voids in coarse aggregate.

Table 9. Gradation Analysis of All Mixtures

Sieve Size	AR-GGM-12.5 Mix 19-1084	SMA 12.5 Mix 19-1095	SMA 19.0 Mix 19-1093
	% passing		
3/4 in (19.0 mm)	100.0	100.0	100.0
1/2 in (12.5 mm)	93.3	84.2	69.1
3/8 in (9.5 mm)	82.8	60.1	45.5
No. 4 (4.75 mm)	36.3	27.3	25.5
No. 8 (2.36 mm)	17.9	21.8	20.2
No. 16 (1.18 mm)	13.4	19.9	18.2
No. 30 (600 µm)	10.5	18.6	16.2
No. 50 (300 µm)	8.2	17.2	14.4
No. 100 (150 µm)	6.3	15.2	11.9
No. 200 (75 µm)	4.55	11.33	8.38

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt.

Laboratory Performance

Dynamic Modulus

Figure 9 shows dynamic modulus test results in semi-log scale for all three mixtures. Modulus values were different, and SMA 12.5 and SMA 19 mixtures showed higher stiffness compared to AR-GGM mixtures. Modulus differences among mixtures are due to changes in binder content (the AR-GGM mixture had a higher binder content and hence a lower modulus) and binder stiffness. Detailed results are provided in Appendix B.

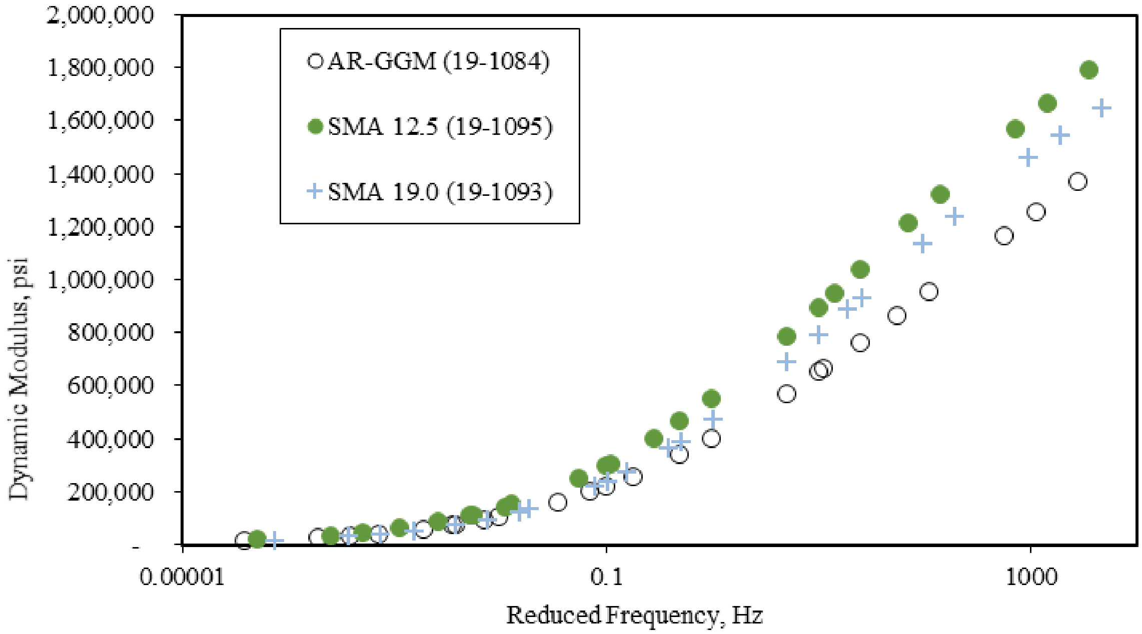


Figure 9. Dynamic Modulus Results (Semi-log Scale)

RLPD Test

The rutting model used in the MEPDG is shown In Equation 1. RLPD tests were conducted to develop rutting coefficients **(**k_1, k_2, k_3) for AR-GGM and SMA 12.5 mixtures.

$$Asphalt\ rutting = \beta_r k_z 10^{k_1} T^{k_2 \beta_2} n^{k_3 \beta_3} \quad \text{[Eq. 1]}$$

where

n = number of axle load repetitions
T = temperature in the asphalt sublayer, ºF
kz = depth correction factor
k_1, k_2, k_3 = laboratory-determined permanent deformation coefficients
β_1, β_2, β_3, = local calibration coefficients.

More details about this test and analysis procedure are given by Nair and Saha (2021). Permanent deformation coefficients developed for the AR-GGM and SMA mixtures from their study are shown in Table 10.

Table 10. Laboratory Rutting Coefficients for SMA Mixtures

Mix	Rutting Coefficient		
	k_1	k_2	k_3
AR-GGM (19-1084)	-10.02	4.04	0.17
SMA 12.5 (19-1095)	-12.39	5.07	0.17

SMA = stone matrix asphalt; AR-GGM = asphalt rubber gap-graded mix.

Mixtures with k_3 slope values greater than 0.30 are more susceptible to rutting, and mixtures with values less than 0.20 are more resistant to rutting (Von Quintus et al., 2020). It can be seen that for both AR-GGM and SMA 12.5 mixtures, the slope values were less than 0.20, indicating higher rut resistance even though dynamic modulus values were different. This shows that dynamic modulus alone, as measured in the laboratory, is not enough to explain the differences between the mixtures in terms of rutting.

Cracking

Table 11 shows the IDEAL-CT results from tests performed on specimens prepared from reheated loose mixture. Higher CT index values indicate a better ability of mixtures to resist cracking. VDOT regular mixtures (SM 9.5 and 12.5, non-polymer modified mixtures) had an average CT index value of 80 in a previous study (Diefenderfer and Bowers, 2019). VDOT currently uses a criterion of CT_{index} greater than 70 as part of an ongoing balanced mix design effort for non-polymer modified mixtures. It should be noted that for VDOT practices, there are currently no criteria developed for the CT index when polymer modified Superpave mixtures and SMA are used. DEAL-CT values were higher for AR-GGM mixtures than for SMA mixtures, indicating higher crack resistance.

The cores collected were also tested with the IDEAL-CT. The results for the AR-GGM mixtures are shown in Table 12, and those for SMA mixtures are shown in Table 13. Trends were similar to laboratory made specimens, where AR-GGM mixture cores had a higher CT index value. In general, higher densities (lower air voids) should result in better cracking performance. However, CT index values were higher with an increase in air-void level regardless of mixture type. No correlation of air voids and CT index values was observed from core test results.

Examples of the IDEAL-CT data are shown in Figure 10. It can be seen that the SMA mixture with the polymer modified binder had higher indirect tensile strength and low deformation in comparison with the AR-GGM mixture. AR-GGM mixtures had lower strength and higher deformation (more flexibility), which resulted in higher CT index values.

Table 11. IDEAL-CT Results

Mix ID	Mix Type	CT_{index}	
		Avg.	SD
19-1084	AR-GGM	507	155
19-1095	SMA 12.5	230	133
19-1093	SMA 19.0	226	62

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; SD = standard deviation.

Table 12. IDEAL-CT Results for AR-GGM Field Cores

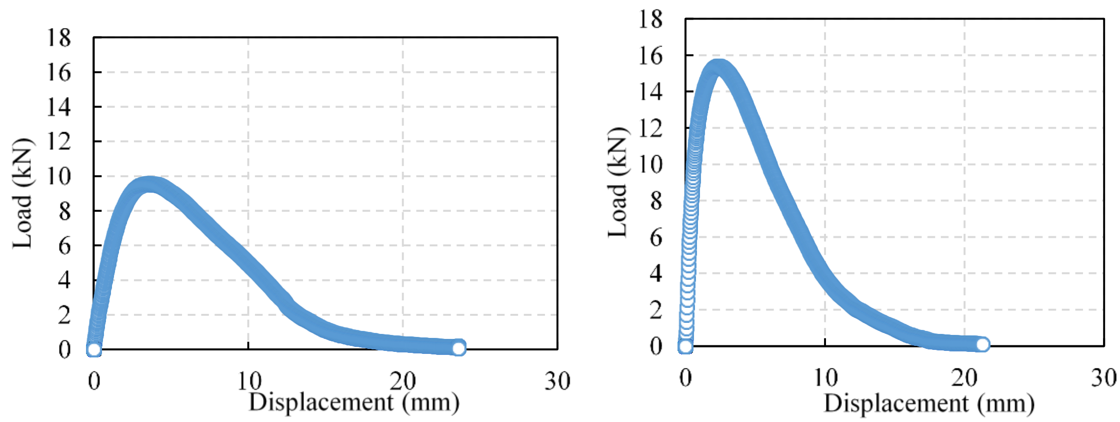
AR-GGM Top 2-in Layer			AR-GGM Bottom 2-in Layer		
Specimen No.	**VTM, %**	**IDEAL-CT**	**Specimen No.**	**VTM, %**	**IDEAL-CT**
A1T	7.9	557	A1B	6.2	397
A2T	9.0	760	A2B	7.1	520
A3T	7.4	587	A3B	6.6	361
A4T	9.7	532	A4B	8.1	622
A5T	9.2	630	A5B	6.6	410
A6T	7.3	614	A6B	5.8	427
A7T	5.7	385	A7B	5.9	337
A8T	5.8	507	A8B	4.9	557
A9T	4.2	366	A9B	6.7	370
A10T	5.7	853	A10B	4.8	376
Average	7.2	579	Average	6.0	437

AR-GGM = asphalt rubber gap-graded mix; VTM = voids in total mix.

Table 13. IDEAL-CT Results for SMA Field Cores

SMA 19.0 Mix			SMA 12.5 Mix		
Specimen No.	**VTM, %**	**IDEAL-CT**	**Specimen No.**	**VTM, %**	**IDEAL-CT**
B1	5.3	212	T1	4.8	237
B2	2.8	200	T2	3.4	177
B3	2.9	71	T3	5.2	222
B4	1.4	141	T4	6.1	163
B5	1.3	122	T5	4.5	226
B6	2.2	109	T6	4.0	182
B7	1.3	107	T7	1.9	212
B8	2.0	91	T8	5.0	132
B9	1.3	168	T9	3.3	148
B10	0.9	106	T10	5.2	126
Average	2.1	132	Average	4.3	182

SMA = stone mix asphalt; VTM = voids in total mix.



(a) AR-GGM (IDT strength = 737 kPa) **(b) SMA 12.5 (IDT strength = 1278 kPa)**

Figure 10. IDEAL-CT Load Displacement Graph. IDT = indirect tensile strength.

The Flexibility Index (FI) is determined through an SCB test. A higher FI is indicative of a mixture exhibiting a more ductile failure, and a lower FI indicates a more brittle failure. Al-Qadi et al. (2015) found that FI values varied from 15 to 1 for the best and poorest performing laboratory-produced mixtures, respectively. FI results from reheated loose mixture are shown in Table 14. Similar to the IDEAL-CT results, AR-GGM mixtures had higher FI values (average

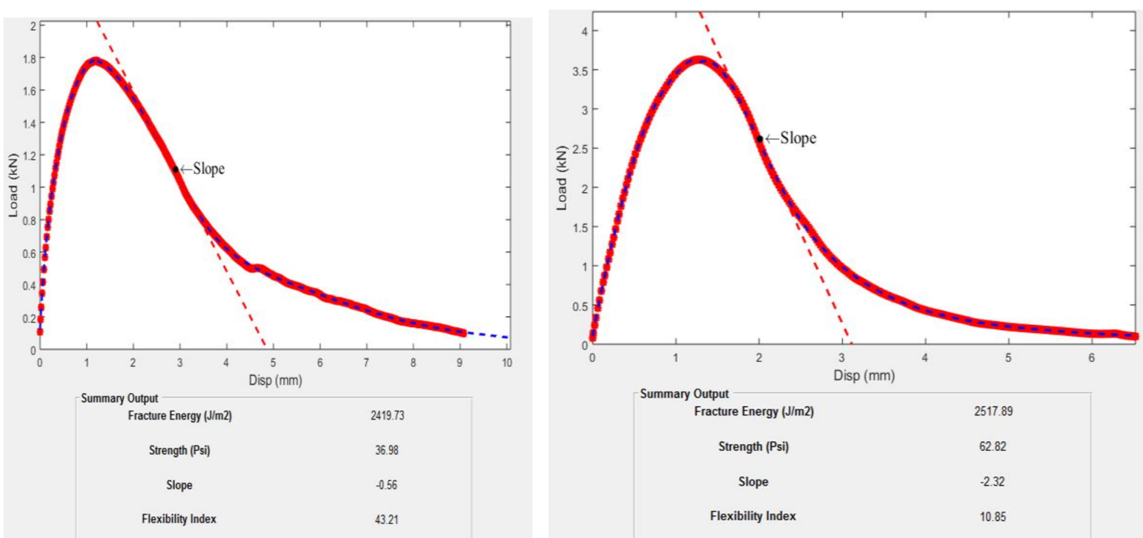
FI value of 45) compared to SMA 12.5 (average FI value of 9) and SMA 19 mixtures (average FI value of 11).

The factors affecting FI values are fracture energy and slope of the post-peak load displacement curve. The fracture energy is a function of both the strength and ductility of the material. If the material displays a high peak load, this high strength may compensate for lack of ductility (Al-Qadi et al., 2015). From Figure 11 it can be seen that although SMA mixtures had higher fracture energy and a high peak load, their FI is lower than that of the AR-GGM mixtures due to higher slope in the post-peak region.

Table 14. Flexibility Index Results

Test	AR-GGM			SMA 12.5			SMA 19.0		
	Mix 19-1084			Mix 19-1095			Mix 19-1093		
	Mean	SD	COV	Mean	SD	COV	Mean	SD	COV
Flexibility Index	45	18	0.41	9	3.82	0.43	11	3.23	0.28
Strength	38	1.70	0.04	75	11	0.15	67	8.37	0.12
Fracture Energy	2611	374	0.14	2807	585	0.21	2780	682	0.25
Slope	-0.66	0.29	-0.44	-3.62	1.65	-0.46	-2.42	0.43	-0.18

AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt; SD = standard deviation; COV = coefficient of variation.



(a) AR-GGM **(b) SMA 12.5**

Figure 11. Example Load Displacement Plot From SCB Test. SCB = semi-circular bend test

Conceptually, the Texas overlay test speaks most directly to reflective cracking, as the number of overlay test cycles to failure is expected to indicate a mixture's ability to resist reflective cracking. The New Jersey DOT currently recommends more than 150 cycles to failure in the overlay test for surface mixtures with a PG 64-22 binder (New Jersey DOT, 2007), whereas the Texas DOT's 2014 specification requires a minimum of 300 cycles to failure for their thin overlay (0.5 in to 1.25 in thickness) mixtures (Texas DOT, 2016). Both AR-GGM and SMA mixtures had higher reflective cracking resistance (>300 cycles, based on Texas DOT criteria) based on Texas overlay test results as shown in Table 15. The SMA 12.5 mixture had better performance compared to other mixtures. However, coefficient of variation of test results were higher.

A higher number of overlay test cycles to failure indicates a better resistance to reflective cracking. The overlay test data were further analyzed to quantify the resistance of the evaluated mixtures to cracking initiation and cracking propagation in accordance with the approach of Garcia et al. (2016). The crack initiation is represented and evaluated using the critical fracture energy (Gc), and the resistance to cracking during the propagation of the crack is evaluated using the crack propagation rate (CPR). A greater Gc value indicates that the evaluated AC mixture is tough and requires high initial energy to initiate a crack. On the other hand, a greater CPR value indicates that the evaluated AC mixture is more susceptible to cracking (a fast CPR indicates a shorter reflective cracking life) (Habbouche et al., 2021). All mixtures had a CPR value lower than 0.5, indicating good cracking resistance. However only the SMA 12.5 mixture had a Gc greater than 1, indicating good resistance to crack initiation. Overall, the Crack Resistance Index was comparable for all mixtures.

GTR particles predominantly contain styrene-butadiene rubber and behave as inclusions in asphalt binder/mixtures, whereas SBS polymers create a cross-linked elastomer network once mixed with asphalt binder (Baumgardner et al., 2020). Although both provide performance benefits to the asphalt binder and mixture, the mode of failures for GTR and SBS modified binders in different temperature regimes can be fundamentally different (Baumgardner et al., 2020). SBS resists crack propagation through stretching of the cross-linked network under stress, and GTR introduces crack-impeding mechanisms such as crack pinning or crack bridging (Rath et al., 2021).

Table 15. Texas Overlay Test Results

	AR-GGM Mix 19-1084			**SMA 12.5 Mix 19-1095**			**SMA 19.0 Mix 19-1093**		
Criterion	**Avg.**	**SD**	**COV (%)**	**Avg.**	**SD**	**COV (%)**	**Avg.**	**SD**	**COV (%)**
93% Reduction in Initial Load (cycles)	1053	1013	96	1888	863	45	1165	985	84
Max., Load Cycles	1047	1011	96	1855	900	48	1060	1065	100
Crack Propagation Rate	0.33	0.19	59	0.32	0.05	18	0.34	0.025	7.40
Crack Resistance Index	89	26	29	90	7.73	8	87.21	3.41	3.91
Critical Fracture Energy (lb-in/in^2)	0.69	0.64	93	1.13	0.36	32	0.95	0.27	28.47

AR-GGM = asphalt rubber gap-graded mix**;** SMA = stone matrix asphalt; SD = standard deviation; COV = coefficient of variation.

Durability

Cantabro average mass loss was less than 2.9% for the AR-GGM mixture and 5.65% and 5.85% for the SMA 12.5 and SMA 19 mixtures, respectively. VDOT's provisional limit on mass loss for balanced mix design trials is less than 7.5%, so durability issues are not expected for these mixtures.

Rutting Susceptibility

Rutting measurements using the APA test indicate a mixture's ability to resist rutting. Field rutting data results will also help to validate these tests. The APA test results are shown in Table 16. Table 16 also shows that the APA results were less than 4 mm for all mixtures. When GTR is mixed with asphalt, the rubber particles tend to absorb lighter components within the binder, and this leads to softening and swelling of the rubber particles and an increase in the binder viscosity (Daly et al., 2019). As a result, the binder becomes stiffer and thus resistant to rutting in the pavement.

Table 16. APA Rut Depth

Mix ID	Mix Type	Average Depth (mm)
19-1084	AR-GGM	3.3
19-1095	SMA 12.5	1.6
19-1093	SMA 19.0	3.4

APA = asphalt pavement analyzer; AR-GGM = asphalt rubber gap-graded mix; SMA = stone matrix asphalt.

Asphalt Binder Testing

Performance grading was conducted on the asphalt rubber binder samples collected during production. Table 17 summarizes the results, which indicate that the binder met the performance grade specified (PG 64E-22). It should be noted that dynamic shear rheometer testing of original and rolling thin film oven residue of asphalt rubber binder (Mix 19-1084) was performed using a 2-mm gap to accommodate large rubber particles. Asphalt rubber binder also had low Jnr values (<0.5 kPa^{-1}), indicating that these binders will perform well against rutting and will accommodate temperature variations and extreme loading conditions. Earlier research show that non-recoverable creep compliance (Jnr) based on the MSCR test is better correlated to pavement rutting (FHWA, 2011).

The extracted binder grading test was conducted for the AR-GGM and SMA mixtures, as indicated in Table 18. As expected, polymer modified binder met the PG 64E-22 specification and had a lower Jnr value, indicating higher rutting resistance. However, when the extracted binder test was conducted on asphalt rubber binder, the binder graded to be only PG 64H-22 and did not meet the PG 64E-22 requirement. This may have been due to difficulty in fully extracting asphalt rubber binder from the AR-GGM mixtures. Figure 12 shows the asphalt binder during the extraction process.

Table 17. Binder Test Result for Asphalt Rubber Binder (Mix 19-1084)

Condition	Method	Property	Temp., °C	Result
Original	AASHTO T 316	Viscosity, Pa·s	135	8.88
	AASHTO T 315	G*, kPa	94	0.984
			100	0.639
		δ, degree	94	77.8
			100	79.8
		G*/sinδ, kPa	94	1.01
			100	0.649
RTFO Residue	AASHTO T 240	Mass change, %	163	-0.220
	AASHTO T 315	G*, kPa	88	2.27
			94	1.49
		δ, degree	88	69.6
			94	71.4
		G*/sinδ, kPa	88	2.42
			94	1.57
	AASHTO T 350	$J_{nr1.0}$, kPa^{-1}	64	0.09
		$J_{nr3.2}$, kPa^{-1}	64	0.13
		J_{nrdiff}, %	64	52.7
		$R_{0.1}$, %	64	70.6
		$R_{3.2}$, %	64	56.5
PAV Residue	AASHTO T 315	G*, kPa	13	7790
			10	11200
		δ, degree	13	36.7
			10	35.0
		G*·sinδ, kPa	13	4655
			10	6424
	AASHTO T 313	Creep Stiffness, MPa	-18	155
			-24	300
		m-value	-18	0.311
			-24	0.268
Grade	AASHTO M 323		PG 88-28	
	ASTM D7643		PG 89.3(12.3)-29.5	
	AASHTO M 332		PG 64E-28	

RTFO = rolling thin film oven; PAV = pressure aging vessel.

Table 18. Extracted Binder Grade Test Results

Condition	Method	Property	Mix			
			19-1095 (PG 64E-22)		19-1084 (Asphalt Rubber)	
			Temperature, °C	Result	Temperature, °C	Result
As Recovered	AASHTO T 164, Method A	Asphalt Content, %	NA	5.99	NA	6.89
	AASHTO T 315	G*, kPa	76	3.33	70	2.41
			82	1.82	76	1.24
		δ, degree	76	71.8	70	79.9
			82	73.9	76	82.1
		G*/sinδ, kPa	76	3.51	70	2.45
			82	1.89	76	1.25
	AASHTO T 350	$J_{nr1.0}$, kPa^{-1}	64	0.22	64	1.32
		$J_{nr3.2}$, kPa^{-1}	64	0.27	64	1.58
		J_{nrdiff}, %	64	24.77	64	19.81
		$R_{0.1}$, %	64	55.9	64	16.4
		$R_{3.2}$, %	64	45.8	64	6.6
PAV Residue	AASHTO T 315	G*, kPa	28	5500	19	7290
			25	8140	16	10300
		δ, degree	28	43.6	19	42.4
			25	41.1	16	40.2
		G*·sinδ, kPa	28	3793	19	4916
			25	5351	16	6648
	AASHTO T 313	Creep Stiffness, MPa	-12	216	-12	111
			-18	433	-18	245
		m-value	-12	0.302	-12	0.356
			-18	0.249	-18	0.294
Grade	AASHTO M 323		PG 76-22		PG 70-22	
	ASTM D7643		PG 80.5(25.6)-22.2		PG 71.0(18.8)-27.4	
	AASHTO M 332		PG 64E-22		PG 64H-22	

RTFO = rolling thin film oven, PAV = pressure aging vessel.

(a) Centrifuge Extractor **(b) Asphalt Rubber** **(c) Aggregate**

Figure 12. Asphalt Rubber Extraction

In-Service Performance

In the past, typical rehabilitation activities on I-85 included concrete patching with 3.5 in to 4.0 in overlay on northbound direction and concrete patching with 5.5 in overlay on southbound direction. For the current trial project, the condition of the existing pavement (jointed reinforced concrete pavement) before the overlay is an important contributor to an evaluation of a reflective cracking mitigation and other distress evaluation. To assess the pre-overlay construction condition, data were extracted from VDOT's PMS and summarized for the trial sections in Table 19 for the past 10 years (2009-2019). It can be seen that the test section had a very low CCI value (66) and a higher/poor IRI value (157 in/mi), indicating the need for rehabilitation (the typical range for a poor IRI is 140 to 199 in/mi). The average joint faulting in the left and right wheel path was 0.19 in and 0.18 in, respectively.

Table 20 gives 3-year performance data for both overlays (SMA and AR-GGM). As expected, both sections are performing well (a CCI above 90 indicates excellent condition with no distress). The initial IRI value for the AR-GGM section indicated a slightly higher value than for the SMA section (85 vs. 78 in/mi). Condition indices such as the CCI alone do not capture the increase in reflective cracks over time and do not isolate other deterioration such as rutting and fatigue cracking. A detailed example of distress data collection for future performance analysis is shown in Table 21. Low rutting values were observed for both sections. Detailed distress data (including severity) along with the traffic and past performance of the section will be used to assess the effectiveness of these mixtures in mitigating reflective cracking.

Summary of Findings

- The major differences between the AR-GGM and SMA mixtures were the gradation (mainly percent passing the No. 200 sieve and minimum AC requirements. Because the rubber particles will act as fines in the mixture, a lower percentage passing the No. 200 sieve is required for AR-GGM mixtures.

- Some of the tests required (softening point, resilience, penetration, and apparent viscosity) per ASTM D6114 are not performed by VDOT as part of regular binder acceptance.

- The maximum percentage of RAP allowed for AR-GGM mixtures was 10%, whereas that for SMA mixtures was up to 15% (when polymer modified binder was used).

- No placement issues were observed with AR-GGM mixtures.

- AR-GGM mixtures were placed in two lifts, each 2-in thick. Air voids in the top 2 in of the AR-GGM mixture ranged from 4.2% to 9.7%, whereas those for the bottom layer ranged from 4.2% to 8.1%. Overall, excellent permeability results were obtained (VDOT's permeability requirement is $<150 \times 10^{-5}$ cm/s) except for three cores where the air voids were higher than 9%.

Table 19. 10-Year Performance of I-85 Southbound JRCP Section Before Overlay (2009-2019)

Data Year	Mileposts	CCI	Transverse Cracking Severity 1 (linear ft)	No. of Transverse Joints	Transverse Joints Fully Sealed	Transverse Joints Spalled	Average Joint Fault in Left Wheel Path	Average Joint Fault in Right Wheel Path	Asphalt Patched Slabs	IRI Average
2009	61.67-64.18	81	10	515	51	29	0.19	0.18	17	134
2010	61.67-64.18	76	6	512	498	21	0.18	0.18	39	135
2011	61.67-64.18	71	17	513	496	9	0.19	0.19	35	138
2012	61.67-64.18	68	32	509	503	10	0.18	0.18	51	138
2013	61.67-64.18	66	31	486	5	12	0.21	0.19	58	141
2014	61.63-64.23	68	29	513	77	19	0.36	0.28	50	146
2015	61.63-64.12	62	26	477	65	27	0.19	0.17	60	152
2016	61.48-64.07	72	15	497	0	32	0.15	0.14	32	151
2017	61.48-64.07	70	0	494	0	29	0.17	0.17	63	156
2018	61.48-64.07	62	31	446	0	50	0.17	0.17	68	155
2019	61.67-64.07	66	15	460	0	54	0.19	0.19	59	157

JRCP = jointed reinforced concrete pavement; CCI = Critical Condition Index; IRI = International Roughness Index.

Table 20. Three-Year Performance of Pavements (Sections Placed in 2019)

Project	County	Beginning MP	Ending MP	Data Year	Pavement Type	No. Travel Lanes	Lane Width (ft)	CCI	LDR	NDR	IRI Avg. (in/mi)
I-85 SB (SMA mix)	Dinwiddie	61.56	62.94	2020	BOJ	2	12	98	98	99	78
				2021				92	98	92	78
				2022				92	98	92	81
I-85 SB (AR-GGM mix)	Dinwiddie	62.94	64.14	2020	BOJ	2	12	100	100	100	85
				2021				91	98	91	90
				2022				91	96	91	96

MP = milepost; CCI = Critical Condition Index; LDR = load related distress rating; NDR = non-load related distress rating; IRI = International Roughness Index; BOJ = bituminous over jointed concrete; SB = southbound.

Table 21. Detailed Distress Data (Sections Placed in 2019)

Route Name	Data Year	Transverse Cracking Severity 1 (linear ft)	Transverse Cracking Severity 2 (linear ft)	Long. Cracking Severity 1 (linear ft)	Long. Cracking Severity 2 (linear ft)	Alligator Cracking Severity 1 (ft^2)	Alligator Cracking Severity 2 (ft^2)	Alligator Cracking Severity 3 (ft^2)	Reflective Transverse Cracking Severity 1 (linear ft)	Rut Depth (in)
I-85 SB (SMA mix)	2020	0	0	0	0	0	0	0	44	0.12
	2021	0	0	0	0	12	0	0	71	0.12
	2022	0	0	0	0	0	0	0	112	0.13
I-85 SB (AR-GGM mix)	2020	0	0	0	0	3	0	0	0	0.10
	2021	0	0	0	0	8	0	0	68	0.12
	2022	0	0	0	0	0	0	0	117	0.15

Long. = longitudinal; SB = southbound; SMA = stone matrix asphalt; AR-GGM = asphalt rubber gap-graded mix.

- Air voids for SMA 12.5 mixtures ranged from 1.9% to 6.1% and for SMA 19 mixtures ranged from 0.9% to 5.3%. The lower air voids (thus higher in-place density) resulted in very low permeability values.

- Volumetric and gradation results indicated that AR-GGM and SMA mixtures met VDOT special provision and specification requirements.

- All mixtures met the criterion of $VCA_{Mix} < VCA_{DRC}$, indicating good stone-on-stone contact.

- Dynamic modulus values were different for the mixtures, and SMA 12.5 and SMA 19 mixtures had higher stiffness compared to AR-GGM mixtures. This may be due to the higher binder content in AR-GGM mixtures.

- RLPD tests were conducted to develop rutting coefficients (k_1, k_2, k_3) for AR-GGM and SMA 12.5 mixtures. For both mixtures, the slope value was less than 0.20, indicating higher rut resistance even though dynamic modulus values were different among mixtures.

- Higher CT index values were obtained for AR-GGM mixtures (507) than for SMA mixtures (230), indicating higher crack resistance. A similar trend was observed when the field cores were tested. No correlation of air voids and CT index values was found in core test results.

- IDEAL-CT results showed that SMA mixtures with the polymer modified binder had higher indirect tensile strength and low deformation. AR-GGM mixtures had lower strength and higher deformation (more flexibility), which resulted in higher CT index values.

- AR-GGM mixtures had higher FI values (average FI value of 45) compared to SMA 12.5 (average FI value of 9) and SMA 19 (average FI value of 11) mixtures.

- Both AR-GGM and SMA mixtures had higher (>300 cycles) reflective cracking resistance based on Texas overlay test results. All mixtures had a crack propagation value lower than 0.5, indicating good cracking resistance. The SMA 12.5 mixture had higher critical fracture energy, indicating good resistance to crack initiation compared to AR-GGM and SMA 19 mixtures.

- Based on the Cantabro average mass loss, durability issues are not expected for AR-GGM and SMA mixtures

- APA test results were less than 4 mm for all mixtures, indicating good rut resistance.

- Asphalt rubber binder met the performance grade specified (PG 64E-22). However, dynamic shear rheometer testing of original and rolling thin film oven residue for asphalt rubber binder was performed using a 2-mm gap to accommodate large rubber particles.

- Asphalt rubber binder had low Jnr values ($<0.5\ kPa^{-1}$), indicating good rut resistance of the binder used.

- Extracted binder grading testing was conducted for the polymer modified binder used in the SMA mixtures, and the binder met the PG 64E-22 specification. However, when the extracted binder test was conducted on asphalt rubber binder, the binder graded to be only a PG 64H-22 binder and did not meet the PG 64E-22 requirement. This may be due to difficulty in fully extracting asphalt rubber binder from AR-GGM mixtures.

- Before overlay, the existing jointed concrete had severe distress, a very low CCI value (66), and a higher/poor IRI (157 in/mi). Average joint faulting in the left and right wheel path was 0.19 in and 0.18 in, respectively.

- Three-year performance data for both overlays (SMA and AR-GGM) indicated that both sections are performing well, as expected (a CCI above 90 indicates excellent condition with no distress).

- The initial IRI for the AR-GGM section indicated a slightly higher value compared to that for the SMA section (85 vs. 78 in/mi). The average IRI value before the asphalt overlay was 157 in/mi.

CONCLUSIONS

- *An AR-GGM mixture can be placed with no special field accommodations when compared with SMA mixtures.*

- *The special provision developed for AR-GGM mixtures was found to be effective.*

- *Based on laboratory performance testing, both the AR-GGM and SMA control mixtures tested in this demonstration project were crack and rutting resistant. AR-GGM mixtures were more flexible than SMA mixtures.*

- *Both sections are performing as expected after 3 years of traffic and are exhibiting minor to no distresses with a CCI greater than 90. However, at this early stage of field service, it is too soon to quantify a performance advantage of AR-GGM mixtures over conventional SMA mixtures.*

RECOMMENDATIONS

1. *VDOT districts should consider AR-GGM mixtures as an alternate tool (to SMA) for mitigating reflective cracking in composite pavements.* The special provision shown in Appendix A can be used for continued field trials for suitable projects.

2. *VDOT districts should continue using SMA mixtures for mitigating reflective cracking in composite pavements.*

3. *VTRC should continue to monitor the performance of the sections in this study to evaluate the cost-effectiveness of AR-GGM mixtures in comparison with SMA mixtures.*

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, VTRC will work with the VDOT districts to identify suitable projects for future trials. This would be undertaken when an existing concrete pavement is scheduled to be overlaid with asphalt mixtures. Project selection (and scaling) is very important to lower the cost of AR-GGM mixtures. In the current field trial, the cost of AR-GGM mixtures was 40% higher than for SMA mixtures. This may be due to several reasons including (1) accommodation for the various risks because of the first trial project; (2) cost of mobilization of additional mixing and storage equipment; and (3) use of lower tonnage of AR-GGM mixtures (approximately 5,000 tons in this project). The prospects for additional trials will be revisited every spring as the current season's resurfacing schedules are released (March to April).

With regard to Recommendation 2, no implementations steps are needed. VDOT predominantly uses SMA mixtures for composite pavements and as overlays for concrete pavements, especially on interstate pavements.

With regard to Recommendation 3, VTRC will continue to monitor the performance of these sections. VTRC will coordinate and collect performance data for the sections used in this study annually from VDOT's regular PMS data collection effort and share the data with the Richmond District. It is also planned to produce an annual technical brief for the performance data from year 2023.

Benefits

AR-GGM mixtures provide an additional tool for mitigating reflective cracking in composite pavements. The use of GTR binder provides an additional modification technique as VDOT predominantly uses SBS for polymer modified mixtures. The use of AR-GGM mixtures also helps reduce stockpiling of waste tires. The GTR industry gave a metric of one tire for every 2 tons of asphalt when 10% GTR content is used. However, AR-GGM mixtures have close to 20% GTR content and a higher binder content, so if one tire for every ton of asphalt is assumed, this project consumed nearly 5,000 tires.

Future performance monitoring (Recommendation 3) of the test sections from this study will help local calibration efforts to verify and validate the MEPDG transfer functions for composite pavement, and long-term performance data are needed to assess the benefit-cost of the use of these mixtures in pavements.

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APPENDIX A

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
ASPHALT RUBBER GAP GRADED SURFACE MIXTURE (AR-GGM)

October 15, 2018

I. DESCRIPTION

This work shall consist of furnishing and placing an Asphalt Rubber Gap Graded Mixture (AR-GGM) bituminous mixture in accordance with Sections 211 and 315 of the Specifications and this Special Provision.

II. MATERIALS

(a) Coarse Aggregate: Coarse aggregate shall conform to the following requirements:

PROPERTY	TEST	REQUIREMENT
Los Angeles Abrasion	AASHTO T96	40% max.
Flat and Elongated Particles	ASTM D4791	
Measured on No. 4 retained, max. to min.	VTM-121	
3:1		25% max.
5:1		10% max.
Magnesium Sulfate Soundness Loss 5 cycles	AASHTO T104	15% max.
Particles retained on the No. 4 sieve shall have at least	ASTM D5821	
one fractured face		100% min.
two fractured faces		90% min.
Absorption	AASHTO T85	2% max.

The aggregate properties specified are for each stockpile of coarse aggregate material designated on the job mix form (TL-127). The material contained in each stockpile shall meet the minimum or maximum criteria specified, except that Flat and Elongated testing will be performed on GGM Plant Sample and acceptance shall be in accordance with Section IV herein.

Use of slag will not be permitted.

(b) **Fine Aggregate:** shall conform to the requirements of Section 202 of the Specifications, except for grading, which shall be tested according to AASHTO T 304 (Method A) with a value of not less than 40 percent and a sand equivalent value of not less than 45 (AASHTO T 176).

(c) Asphalt Binder: The base asphalt shall have a PG Grading of PG64S-22. The supplier may substitute PG58S-28 where needed to meet the requirements of ASTM D 6114 (type II) as approved by the Engineer.

(d) **Asphalt-Rubber Binder (ARB):** The physical requirements for the asphalt-rubber binder shall conform to ASTM D 6114 type II specifications. The minimum percentage of granulated rubber by weight of total asphalt-rubber binder is 15%.

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

The specific gravity of reclaimed vulcanized ground rubber shall be not less than 1.10 or greater than 1.20.

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

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

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

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

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

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

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

(f) **Mineral Filler:** shall conform to the requirements of Section 201 of the Specifications except the minimum amount passing the No. 200 sieve shall be 55 percent. At the time of use, the mineral filler shall be sufficiently dry to flow freely and be essentially free from agglomerations.

(g) **RAP:** Use of RAP will be permitted. The maximum percentage of RAP shall be 10%.

(i) **Tack Coat:** Unless otherwise directed in the contract or by the Engineer, tacking will follow the *supplemental specification of section 310.*

(j) **WMA**: The AR-GGM shall be modified using a Warm-Mix Asphalt (WMA) additive capable of lowering compaction temperatures to below 280° F. Warm Mix Asphalt Technology will reduce compactive effort and permit lower production temperatures than conventional hot mix asphalt.

No warm-mix technologies which involve the mechanical injection of water directly into the asphalt will be considered for this contract. The WMA Manufacturer shall have an on-site representative at the beginning of paving operations. The Manufacturer's representative shall be available for additional consultation during the remaining AR-GGM production.

III. MIX FORMULA

The Contractor shall submit for the Engineer's approval, a job mix formula within the following design ranges of percent passing each sieve size as noted in Table A. In addition, the AR-GGM mixture shall conform to all the requirements in Table B. One percent hydrated lime will be required as an anti-stripping additive. An alternative anti-stripping additive can only be used if permitted by the Engineer.

TABLE A – AR-GGM DESIGN RANGE

Percentage by Weight Passing Square Mesh Sieves (in)

Mix Type	**¾**	**1/2**	**3/8**	**No. 4**	**No. 8**	**No. 200**
AR-GGM 12.5	100	90-100	83-87	28-42	14-22	0-6

TABLE B – AR-GGM Mixture Requirements

Mix Type	Design ARB %	Drain-down %	VCA Design and Production	Design Gyrations	VTM %[1]	Min. VMA %	TSR %
AR-GGM 12.5	Min. 7.6	0.3 max	<VCA_{DRC}	75	3-6	18.0	80 min

1 Asphalt Rubber Binder content shall be selected at the mid-point of the VTM range and shall not be less than the minimum design ARB percentage.

Draindown testing shall be in accordance with VTM-100 Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures.

The Voids in Coarse Aggregates (VCA) of the Dry Rodded Condition (DRC) and mix shall be determined in accordance with VTM-99.

Calculations for volumetrics shall be performed in accordance with VTM-57 and VTM-58, 6-inch specimens.

The tensile strength ratio shall be determined using a modified AASHTO T283 procedure. Specimen shall be compacted to the design number of gyrations using AASHTO T312. The specimen shall be saturated by applying 26 inches of mercury vacuum for 10 minutes. The specimen shall be conditioned using one freeze-thaw cycle.

In addition to the job mix submittal, the Contractor shall submit ignition furnace calibration data in accordance with VTM-102 and aggregate property test results for the aggregate components or blend prepared by an approved testing laboratory.

IV. MIXTURE ACCEPTANCE

A lot will be considered acceptable for gradation and asphalt content if the mean of the test results obtained is within the tolerance allowed from the job-mix formula as shown in Section 211.08 and Section 211 of the Road and Bridge Specifications. The Contractor shall check and report the percentage of F&E particles in the coarse aggregates of the mix during production. When the AR-GGM material is sampled for acceptance (gradation and asphalt content), two of the first eight sublots must be selected for F&E particle verification. The F&E particle testing will be performed on the coarse aggregate material retained on the No. 4 sieve in accordance with VTM-121 after the gradation analysis is performed. At initial start-up of production, the F&E particles shall be determined for each of the first two lots of material produced and compared to the maximum limits specified in section II (a). If passing results are obtained on each sample in the first two lots, then F&E particle testing shall be performed on a frequency of every second lot of material produced (e.g., lots 4, 6, 8, etc.). If the results for the mix exceed the specified limits, the Contractor shall stop production and notify the Engineer. Production shall not resume until the Contractor has taken corrective action and the Engineer has approved the corrective action. Once production has resumed, the Contractor shall determine the F&E particles of the mix for two consecutive lots. If passing results are obtained for these two lots, the F&E particle testing frequency shall return to every second lot of material produced. In the event the Department determines that the mixture being produced still does not conform to the approved job-mix formula and volumetric properties in Table A and B based on the Department's or the Contractor's test results, the Contractor shall immediately make corrections to bring the mixture into conformance with the approved job-mix formula or cease paving with that mixture. Subsequent paving operations using either a revised or another job-mix formula that has not been verified for acceptance as described herein will be limited by the Department to a test run of 300 tons maximum. No further paving using that specific mixture shall occur until the acceptability of the mixture being produced has been verified using the 300-ton constraint. Delays due to the failure on the part of the Contractor to produce an acceptable mix design shall not relieve the Contractor of his obligation to meet the requirements of the Contract and complete the work within the time limit established for the Contract.

V. AR-GGM MIXING PLANT

Plants used for the preparation of the AR-GGM mixture shall conform to the following:

(a) **Mixing and Reaction Equipment:** The method and equipment for combining the ground rubber and PG asphalt binder shall be so designed and accessible that the Engineer can readily determine the percentage of each material being incorporated into the mixture.

Equipment utilized in the production and proportioning of Asphalt-Rubber binder shall include the following as a minimum:

> A mechanical blender shall be utilized for proper proportioning and thorough mixing of the PG asphalt binder and ground rubber. This unit shall have a coriolis type mass flow meter capable of measuring and recording the flow rate and total quantity of asphalt binder in both gallons and weight. The quantity of ground rubber shall be determined by weight utilizing either a hopper equipped with load cells or a feeder equipped with a belt scale. The percentage of ground rubber based on total asphalt rubber binder shall be recorded.
>
> An asphalt rubber storage tank equipped with a heating system to maintain the proper temperature of the binder and an internal mixing unit capable of maintaining a homogeneous mixture of asphalt and ground rubber.

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

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

When continuous mixing type asphalt concrete plants are used to produce the rubberized asphalt concrete, the asphalt-rubber binder shall be proportioned by an asphalt meter of the mass flow, coriolis effect type.

(c) **Hot Mixture Storage:** When the hot mixture is not hauled immediately to the project and placed, suitable bins for storage shall be provided. Such bins shall be either surge bins to balance production capacity with hauling and placing capacity or storage bins, which are heated and insulated and which have a controlled atmosphere around the mixture. The holding times shall be within limitations imposed by the Engineer, based on laboratory tests of the stored mixture.

(d) **Mixing Temperatures:** The temperature of the asphalt-rubber mixture immediately after mixing shall be no greater than 325°F.

VI. WEATHER RESTRICTIONS

Weather Restrictions: The asphalt-rubber GGM shall not be applied when weather conditions are unfavorable to obtaining a uniform spread. Construction shall proceed only when the atmospheric temperature is at least 10°C, (50°F), and rising. No water shall be present on the road surface. AR-GGM shall not be applied after September 30 as a final surface unless approved by the Engineer.

VII. PLACING AND FINISHING

Placing and Finishing: The application rates of the AR-GGM will be specified in the contract or as directed by the Engineer.

The asphalt rubber GGM shall be delivered to the paver hopper at a temperature conforming to the asphalt liquid supplier's recommendation and shall be measured in the paver hopper.

The Contractor shall plan his operation such that a continuous paving operation that provides for constant steady movement of the paver is maintained. In the event that excessive stop and go of the paver is occurring, the Engineer may direct the Contractor to stop production and laydown of the mixture may be stopped until the Contractor has made satisfactory changes in the production, hauling, and placement operations resulting in a constant steady movement of the paver.

The Contractor shall employ a Material Transfer Vehicle (MTV) during the placement of AR-GGM. The Contractor's paving operation shall have remixing capability in either the MTV or a paver-mounted hopper to produce a uniform, non-segregated mix with uniform temperature. The MTV and paver combination shall have a minimum storage capacity of 15 tons. In the event of an equipment break down of the paving train, paving shall be discontinued and no more material shall be shipped from the hot-mix plant.

Should visual examination by the Engineer reveal that the material in any load, or portion of the paved roadway is contaminated, segregated, or flushed with asphalt cement, that load, or portion of the paved roadway may be rejected at the sole discretion of the Engineer without additional sampling of the material.

VIII. ROLLING

Rolling: Immediately after the mixture has been spread and struck off, it shall be thoroughly and uniformly rolled. Breakdown rolling shall be accomplished with steel wheel roller(s) with a minimum weight of 10 tons. A minimum of two rollers shall be available at all times for rolling.

To minimize coarse aggregate fracture/breakage in the aggregate skeleton of AR-GGM mixes, the use of vibratory rollers is cautioned and should not exceed 3 vibratory passes.

Rollers should move at a uniform speed not to exceed 3 mph with the drive wheel nearest the paver.

To prevent adhesion of the mixture to the rollers, it shall be necessary to keep the wheels properly moistened with water possibly mixed with very small quantities of detergent or other approved material.

IX. FIELD ACCEPTANCE

For the purposes of evaluating and determining acceptance, each day’s production shall be considered a lot unless the paving length is less than 3,000 linear feet or greater than 7,500 linear feet. When paving is less than 3,000 feet, it shall be combined with the previous day’s production or added to the next day’s production to create a lot as described below.

The standard size of a lot shall be 5,000 linear feet, with 1,000 foot sublots, of any pass 6 feet or greater made by the paving train for the thickness of the course. With the Engineer’s approval the lot size may be increased to 7,500 linear foot lots with 1,500 foot sublots when the normal daily production is in excess of 7,000 feet. Pavers traveling in echelon will be considered as two passes. When a partial lot occurs at the end of a day’s production or upon completion of the project, the lot size shall be redefined as follows:

- If the partial lot contains one or two sublots, the sublots will be added to the previous lot.
- If the partial lot contains three or four sublots, the partial lot will be redefined to be an entire lot.

The Contractor shall perform acceptance testing for density for each sublot by obtaining one sawed 4 inch by 4 inch specimen, or one 4-inch-diameter cores, at a single random test site specified by the Engineer. Test sites shall not be located within 12 inches of the edge of any application width for surface and intermediate mixes.

- The sub-lot site shall be marked as described in VTM-76.
- The bulk specific gravity of the cores shall be determined in accordance with VTM-6.
- The density of the cores shall be determined in accordance with the requirements of VTM-22.

Cores or plugs shall be bulked in the presence of the Department. The Department reserves the right to have the cores or plugs bulked on the project site. Sublot test sites shall be numbered sequentially per lot, marked on the pavement, filled with the paving mixture, and compacted prior to completion of each day's production. The payment for lot density will be in accordance with the following schedule:

Payment Schedule

% Density Achieved	% of Payment
More than 98.0	97
94.0 to 98.0	100
92.0 to 93.9	90
90.0 to 91.9	80
Less than 90.0	Remove and replace

X. PREPAVING CONFERENCE

Prior to the start of production, a prepaving conference shall be conducted between the Department and the Contractor. This meeting will discuss the production and paving operations.

XI. AR-GGM TRIAL PRODUCTION

Prior to the start of production, the Contractor shall demonstrate ability to produce and place material by constructing a 200 ton minimum trial section with the AR-GGM. This trial section shall be constructed at least 7 days and no more than 30 days prior to roadway paving. The trial section shall be at a location selected by the Contractor and approved by the Engineer. The Contractor shall demonstrate the production of the material. Three random samples shall be obtained for volumetric, asphalt rubber binder content and aggregate gradation verification. Volumetric results shall meet Table B; ARB content and gradations shall meet the approved job-mix formula and be within the tolerances established in Section 211.08 and Section 211 of the Road and Bridge Specifications. A passing trial section is required prior to roadway paving.

During the trial section(s), the Engineer will randomly select 3 plugs or core locations to determine the in-place density in accordance with VTM-22. Payment for density will be in accordance with the Payment Schedule listed in Section X. The Contractor shall remove and replace failing trial sections based on the following criteria. The Engineer will deem a trial section to have failed if the VTM is less than 1.0 percent or exceeds 5.0 percent; if the VCA of the mix exceeds the VCA of the dry rodded condition; if the field density is less than 90.0 percent of the maximum theoretical density; or if excessive flushing/bleeding occurs in the wheel paths. Payment for, and limitations on, the trial section shall be as stipulated in Section XIII. The Contractor shall be responsible for the cost for removing any failed trial section.

XII. MEASUREMENT AND PAYMENT

Asphalt Rubber Gap Graded Mixture will be measured in tons and paid for at the contract unit price per ton, which shall include furnishing and application of tack coat, surface preparation, all materials, additives, labor, testing and equipment as described herein.

The initial trial section will be paid for at the contract unit price for the mix type specified. Up to one additional trial section of the mix type specified will be paid for at the contract unit price. If additional trial sections are needed, the Department and the Contractor shall negotiate the price based upon a reduced percentage of the contract unit price. The Department will pay for no more than four trial sections. The contractor shall be fully responsible for any additional test sections required to produce and install an acceptable mixture at the Contractor's expense.

Payment will be made under:

Pay Item	**Pay Unit**
Asphalt Rubber Gap Graded Mixture, AR-GGM 12.5	Tons

APPENDIX B

DYNAMIC MODULUS TEST RESULTS

Table B1. Dynamic Modulus Test Results for AR-GGM Mixture

Temperature (°C)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10	1379299	1553249	1629563	1810708	1890545	1997802
4	744977	917265	991064	1161435	1234711	1331923
20	219661	339723	400870	558689	631025	728488
40	34912	63092	80758	139434	173830	228810
54	12871	23739	30835	55961	71821	98969

Table B2. Dynamic Modulus Test Results for SMA 12.5 Mixture

Temperature (°C)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10	2082521	2336383	2445334	2697285	2805174	2946944
4	1125809	1389375	1502266	1761739	1872421	2017978
20	335535	518188	611125	851159	961382	1110155
40	55389	99951	127834	220060	273843	359418
54	21219	38943	50523	91460	117218	161131

Table B3. Dynamic Modulus Test Results for SMA 19.0 Mixture

Temperature (°C)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10	1651999	1851464	1935245	2126873	2208654	2316426
4	900777	1139107	1238964	1460925	1552251	1669561
20	260218	414997	496710	713765	814871	951145
40	45992	82131	104988	182007	227902	302295
54	18447	32625	41903	74913	95887	132041