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Performance of Ground Tire Rubber Modified Asphalt Mixture Overlays Over Jointed Concrete Pavements on US 60 in the Virginia Department of Transportation's Richmond District

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Final Report VTRC 23-R1

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Abstract:

Ground tire rubber (GTR) from scrap tires is used in asphalt mixtures (rubber modified asphalt [RMA]) for improving the performance of pavements. There are different ways to add GTR in asphalt mixtures, but the two primary methods are referred to as the "wet" and "dry" processes. The dry process incorporates GTR directly into the asphalt mixture during production (directly to the aggregates through the reclaimed asphalt pavement collar). The Virginia Department of Transportation (VDOT) has limited experience with RMA mixtures in Superpave dense-graded mixtures using the dry process, but the relative ease of mixture production makes the dry process an attractive option for RMA. In the fall of 2019, VDOT placed a dense-graded RMA mixture, SM 12.5 (GTR), on US 60 in VDOT's Richmond District (New Kent County). This was the first use of a SM 12.5 (GTR) mixture in Virginia using the dry process method. The purpose of this study was to establish a performance baseline for a GTR modified dense-graded asphalt mixture that was designed and produced using the dry process. The US 60 project also included the use of a thin hot mix asphalt concrete overlay (THMACO) as an interlayer. An assessment of the THMACO as an interlayer was a secondary objective of the study.

The study found that dry process SM 12.5 (GTR) mixture can be produced and placed with no significant field-related concerns and that the special provision developed for its use was effective. Density requirements were achieved, and the as-placed mat had excellent (very low) permeability characteristics. Laboratory performance testing showed the SM 12.5 (GTR) mixture to be more crack resistant than conventionally modified polymer (SM 12.5E) mixtures. Conventionally modified SM E mixtures had slightly better rutting performance. However, this conclusion was based on performance testing and thresholds that were developed for non-modified asphalt mixtures. Additional laboratory and field performance comparison is needed to develop mixture acceptance criteria for GTR mixtures. Further, THMACO mixtures had excellent laboratory reflective cracking resistance properties. They performed particularly well in the Texas overlay test. Grading of extracted (from the asphalt mixture) binder may not provide an accurate representation of the binder performance for the dry process GTR modified asphalt. Continued monitoring of performance will be needed to quantify any benefit of SM 12.5 (GFR) mixtures in comparison with regular SM E mixtures. The study recommends additional field trials with SM 12.5 (GTR) mixtures for performance evaluation. Further, the study recommends continued use of a THMACO as an interlayer to mitigate reflective cracking for composite pavements.

FINAL REPORT

PERFORMANCE OF GROUND TIRE RUBBER MODIFIED ASPHALT MIXTURE OVERLAYS OVER JOINTED CONCRETE PAVEMENTS ON US 60 IN THE VIRGINIA DEPARTMENT OF TRANSPORTATION'S RICHMOND DISTRICT

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Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

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DISCLAIMER

ABSTRACT

Ground tire rubber (GTR) from scrap tires is used in asphalt mixtures (rubber modified asphalt [RMA]) for improving the performance of pavements. There are different ways to add GTR in asphalt mixtures, but the two primary methods are referred to as the "wet" and "dry" processes. The dry process incorporates GTR directly into the asphalt mixture during production (directly to the aggregates through the reclaimed asphalt pavement collar). The Virginia Department of Transportation (VDOT) has limited experience with RMA mixtures in Superpave dense-graded mixtures using the dry process, but the relative ease of mixture production makes the dry process an attractive option for RMA. In the fall of 2019, VDOT placed a dense-graded RMA mixture, SM 12.5 (GTR), on US 60 in VDOT's Richmond District (New Kent County). This was the first use of a SM 12.5 (GTR) mixture in Virginia using the dry process method. The purpose of this study was to establish a performance baseline for a GTR modified dense-graded asphalt mixture that was designed and produced using the dry process. The US 60 project also included the use of a thin hot mix asphalt concrete overlay (THMACO) as an interlayer. An assessment of the THMACO as an interlayer was a secondary objective of the study.

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INTRODUCTION

Ground tire rubber (GTR) from scrap tires is used in asphalt mixtures (rubber modified asphalt [RMA]) for improving performance of pavements. A recent state of the knowledge report by Buttlar and Rath (2021) provided an up-to-date review of RMA, including its historical development and use, production methods, field performance, environmental impact, and sustainability benefits. Further, Baumgardner et al. (2020) provided further information regarding use of RMA in pavements. Based on their report, only 12 states had published specifications allowing GTR modified asphalt binders for use in construction of asphalt pavements. Way et al. (2011) indicated that blending GTR into asphalt binder improved its elasticity and physical properties and characteristics that promoted asphalt pavement performance. Further, studies have also shown that RMA can provide performance similar to that of pavements constructed with polymer modified binders (West et al., 2012; Willis, 2013).

There are different ways of adding GTR in asphalt mixtures (two primary processes referred to as the "wet" and "dry" processes). The wet process, which includes a traditional process (done on-site at the asphalt mixture plant) and a terminal-blend process (occurring at asphalt terminals), blends the GTR with the asphalt binder. The dry process incorporates GTR directly into the asphalt mixture during production (directly to the aggregates through the recycled asphalt pavement [RAP] collar). Each of these processes will produce RMA pavements with different properties and different performance (Federal Highway Administration, 2014).

The Virginia Department of Transportation (VDOT) specifies polymer modified asphalt binders for certain asphalt mixtures used on high-volume, high-priority routes including composite pavements (asphalt over existing concrete pavements). VDOT typically uses binders containing styrene-butadiene-styrene (SBS) modifiers. These binders must meet performance grade (PG) requirements for a PG 64E-22 (PG 76-22). RMA provides another alternative for modifying mixtures. VDOT has conducted a few studies with RMA (Diefenderfer and McGhee, 2015; Hughes, 1985; Maupin, 1995; Virginia General Assembly, 2013), with the most recent studies focused on using terminal blend (wet process) GTR in gap-graded mixtures (stone matrix asphalt). VDOT has limited experience with RMA mixtures in dense-graded mixtures using the dry process, but the relative ease of mixture production makes it an attractive option for RMA.

In the fall of 2019, VDOT placed a dense-graded RMA mixture, SM 12.5 (GTR), on US 60 in the Richmond District (New Kent County). This was the first use of SM 12.5 (GTR) mixture in Virginia using the dry process method. Figure 1 shows the location of the trial project, and Table 1 provides more project detail. Figure 2 shows examples of the existing pavement's distresses.

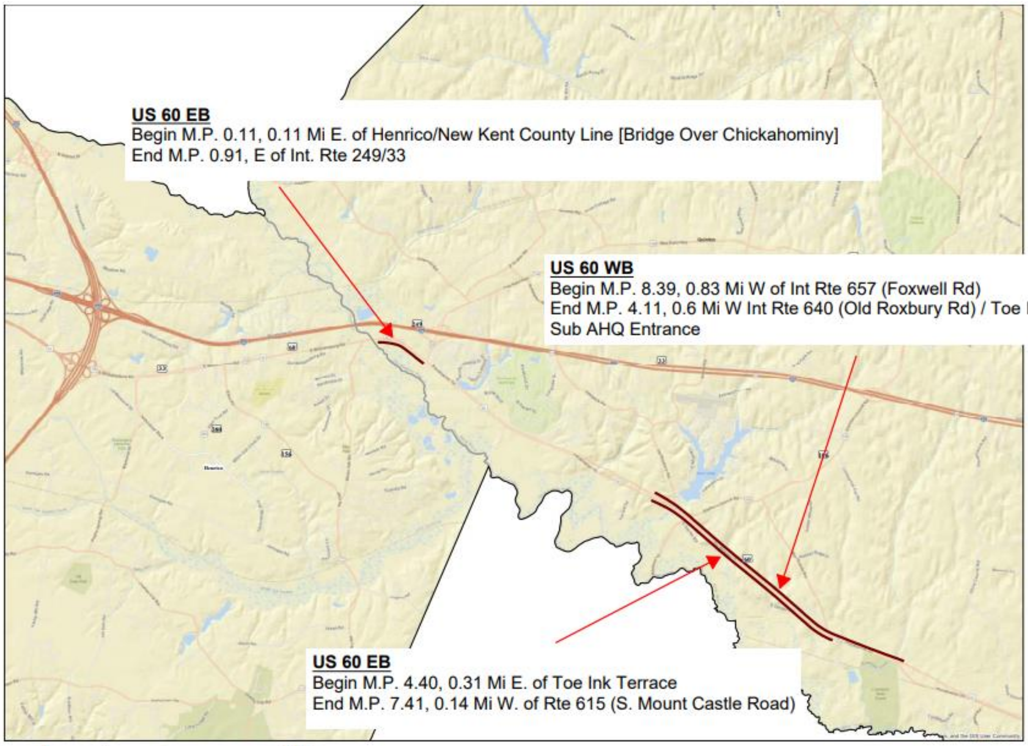

Figure 1. Project Location (US 60, New Kent County)

Table 1. US 60 Project Location Details

Route	Begin MP	End MP	Treatment
US 60 WB	4.11	8.39	BM-25.0D+0.4 patching, mastic repair, place back 0.75 in THMACO and 2.0 in SM-12.5 (GTR)
US 60 EB	4.4	7.41	BM-25.0D+0.4 patching, mastic repair, place back 0.75 in THMACO and 2.0 in SM-12.5 (GTR)
US 60 EB	0.11	0.19	Mill up to 2.5 in, place back 0.75 in THMACO and 2.0 in SM-12.5 (GTR)
US 60 EB	0.19	0.47	Place back 0.75 in THMACO and 2.0 in SM-12.5 (GTR)
US 60 EB	0.47	0.52	Mill up to 2.5 in, place back 0.75 in THMACO and 2.0 in SM-12.5 (GTR)
US 60 EB	0.52	0.91	Mill up to 2.0 in, place back 2.0 in SM-12.5 (GTR)

MP = milepost; WB = westbound; EB = eastbound; THMACO = thin hot mix asphalt concrete overlay; GTR = ground tire rubber.

Figure 2. Existing Pavement Distress on US 60 (New Kent County)

Pre-overlay activities in this section included patching using a base asphalt mixture (BM-25.0+0.4, an asphalt base mixture with 25 mm nominal maximum aggregate size and optimum plus 0.4% liquid asphalt binder). Longitudinal and transverse joints, cracks, and spalled areas were then sealed with Mastic One (a hot-applied, pourable, self-adhesive patching material used for filling wide cracks and joints). A 0.75-in thin hot-mix asphalt concrete overlay (THMACO) layer (gap-graded mixture with polymer modified binder) was placed over the patched and sealed concrete, followed by a 2-in SM 12.5 (GTR) mixture (GTR modified dense-graded surface mixture with 12.5 mm nominal maximum aggregate size).

As part of reflective cracking mitigation for composite pavements, VDOT has been trying various techniques including modified asphalt mixtures and interlayers. THMACOs have been used successfully as stress-absorbing interlayers and bond enhancement layers that have contributed to improved performance (e.g., I-66 in Northern Virginia and I-64/I-264 in Hampton Roads). It is expected that the use of a THMACO as an interlayer and RMA in a dense-graded mixture (using the dry process) as the top surface will provide a better performance against reflective cracking.

PURPOSE AND SCOPE

The purpose of this study was to establish a performance baseline for a GTR modified dense-graded asphalt mixture that was designed and produced using the dry process (i.e., GTR introduced to the aggregate during asphalt mixture production). The evaluation centered on the US 60 trial in Virginia from 2019, as described in Table 1, which also included the use of a THMACO as an interlayer. An assessment of the THMACO as an interlayer was a secondary objective of the study.

METHODS

Special Provision and Mix Design for SM 12.5 (GTR) Mixtures

As mentioned previously, this was the first use of an SM 12.5 (GTR) mixture in Virginia. As a first step, a special provision was developed for the mixture with input from the asphalt rubber industry. The industry provided recommendations for the GTR gradation requirement and GTR addition method. The researchers then worked with an asphalt producer, the GTR supplier, and the Richmond District Materials Office to develop an asphalt mix design for SM 12.5 (GTR) mixtures. The GTR supplier provided recommendations for asphalt binder content and percent GTR addition.

Laboratory Performance Testing of Asphalt Mixtures

Studies have shown that rubber binder interactions in typical RMA production processes remain primarily physical in nature and that GTR particles in a mixture inhibit crack propagation through mechanisms such as crack pinning and bridging (Ding et al., 2021; Rath et al., 2021). Dry process GTR is generally considered a mixture modifier, and therefore mixture performance testing is very important. Mixtures were characterized using a series of standard laboratory performance tests. Volumetric analyses were performed for all sampled mixtures. Laboratory performance testing was conducted on samples made by reheating the mixtures collected from the field.

Since this project provided no control section, the performance of mixtures from other projects in the Richmond District with more conventionally modified binder (i.e., SBS modification) were used for comparison (Table 2 gives mixture details). Data for this comparison came from an earlier study (Nair and Saha, 2021).

Table 2. Details of SM-E Mixtures Used for Comparison

Mix Type	Lab ID	District	% RAP	Design AC Content	Asphalt Binder Grade
SM 12.5E	18-1012	Richmond	15%	5.9%	PG 64E-22
SM 12.5E	18-1046	Richmond	15%	5.9%	PG 64E-22
SM 12.5E	18-1057	Richmond	15%	5.8%	PG 64E-22

RAP = reclaimed asphalt pavement; AC = asphalt concrete.

Dynamic Modulus

The primary material property input for AASHTOWare Pavement ME Design is the dynamic modulus (|E*|) of the asphalt concrete (AC) mixture. This property quantifies the modulus of the AC over a range of expected temperatures and traffic speeds as a function of loading frequency. Dynamic modulus tests were performed using the Asphalt Mixture Performance Tester 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. The specimen airvoid contents were 7 ± 0.5%. 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.

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 on specimens having 7.0 ± 0.5% air voids. 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 and having 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. All specimens had air voids within 7.0 ± 0.5%.

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, 2020). Tests were conducted at ambient laboratory temperature (approximately 21ºC). All specimens had air voids within 7.0 ± 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 had air voids within 7.0 ± 0.5%. The test was conducted in the displacement-control mode until failure occurred at a loading rate of 1 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.

Binder Recovery and Grading

Asphalt, binder, polymer modified binder, and extracted binder grading was performed in accordance with AASHTO M 320, Performance-Graded Asphalt Binder (AASHTO, 2020), through an outside testing laboratory. The multiple stress and creep recovery test was also performed in accordance with AASHTO T 350. Studies have shown that non-recoverable creep compliance (Jnr) based on this 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). 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. 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 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 and Mix Design for SM 12.5 (GTR) Mixtures

Special Provision Development for SM 12.5 (GTR) Mixtures

The special provision developed for SM 12.5 (GTR) mixtures is shown in Appendix A. In the dry process, GTR material must conform to the gradation requirements shown in Table 3.

The maximum percentage of RAP is 15%. Dry process GTR must be controlled with a feeder system using a proportioning device that is accurate to within ±3% of the amount required.

Table 3. Gradation Requirements for GTR

Sieve Size	Percent Passing
No. 20	100
No. 30 (600 µm)	99 ± 1
No. 40 (300 µm)	60 ± 10
No. 100 (150 µm)	10 ± 5

GTR = ground tire rubber.

Mix Design for SM 12.5 (GTR) and THMACO Mixtures

The mix designs used for SM 12.5 (GTR) and THMACO mixtures are shown in Table 4. SM 12.5 (GTR) used 15% RAP. Asphalt binder in this mixture was 6.5%, and binder content included the following: the RAP AC contribution was 0.72 (at 15% RAP); the virgin AC was 5.08; the GTR was 10% of the virgin AC, i.e., 0.508; additional binder added was 40% of added rubber, i.e., 0.2032 (0.508 x 40%). The mix design gradations used for these mixtures are given in Table 5. VDOT's special provision for THMACO provides the material design and placement requirements for the interlayer (VDOT, 2022).

As per the special provision, the GTR supplier tested the asphalt rubber binder (by laboratory mixing of base binder [PG 64S-22] and 10% GTR materials by weight of virgin binder) and confirmed that it met the requirements of ASTM M320 (the addition of 10% GTR resulted in a two-grade bump from base binder grade and met the PG 64E-22 binder grade specification) as shown in Appendix B.

Table 4. Mix Designs Used for SM 12.5 (GTR) and THMACO Mixtures

Material/Stone Size	SM 12.5 (GTR) Mix 19-1131	THMACO Mix 19-1129
No. 78	25%	-
No. 8	11%	75%
No. 57	-	-
Sand	20%	9%
No. 10 Screenings	29%	11%
Filler	-	5%
Additives	-	-
Recycled Asphalt Pavement, -½ in	15%	-
Asphalt Rubber (GTR)	10%	-
Asphalt Binder	6.5% (PG 64S-22)	5.3% (PG 64V-28)

GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay; - = not used.

Table 5. Mix Design Gradations for SM 12.5 (GTR) and THMACO Mixtures

Sieve Size, in (mm)	SM 1.2.5 (GTR) Mix 19-1131	THMACO Mix 19-1129
	% passing	
¾ in (19 mm)	100%	
½ in (12.5 mm)	98%	100%
3/8 in (9.5 mm)	89%	96%
No. 4 (4.75 mm)	60%	39%
No. 8 (2.36 mm)	48%	23%
No. 16 (1.18 mm)	-	18%
No. 30 (0.6 mm)	22%	13%
No. 50 (0.3 mm)	-	10%
No. 100 (0.15 mm)	-	7%
No. 200 (0.075 mm)	5.8%	5%

GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay; - = not used.

Production and Placement of Asphalt Mixtures

Paving work was started on November 4, 2019. Figure 3 shows GTR material as stored in bags and in its powder form. The GTR is fed into the RAP collar through a feeding machine, as shown in Figure 4.

Figure 3. GTR Material: left, GTR stored in bags; right, GTR material in powder form. GTR = ground tire rubber.

Figure 4. Adding GTR in the Asphalt Plant (Dry Process): left, GTR feeding machine; right, GTR added through the RAP collar. GTR = ground tire rubber; RAP = reclaimed asphalt pavement.

Figure 5 shows placement of the THMACO mixture (0.75-in thickness) in the field. The mixture was placed with a spray bar paver and with a higher tack content to achieve an enhanced bond and to prevent moisture ingress into lower layers. Paving operations for this job were conducted in the daytime. Figure 6 shows placement of the SM 12.5 (GTR) mixture (2-in thickness). Coring was conducted after placement of the SM 12.5 (GTR). Figure 7 shows the surface texture of both mixtures and a core reflecting the asphalt layers. Cores were tested (after the 0.75-in THMACO layer was removed) for air voids and permeability; the results are shown in Table 6 for SM 12.5 (GTR) mixtures. Air voids in the SM 12.5 (GTR) mixture ranged from 6.3% to 8.4%, and excellent permeability results were obtained for all cores (VDOT's permeability requirement is $<150 \times 10^{-5}$ cm/sec). The Richmond District quality assurance data for this project also showed passing density (using nuclear gauge and cores) results. No placement issues were observed with either mixture.

Figure 5. Placement of THMACO Layer. THMACO = thin hot mix asphalt concrete overlay.

Figure 6. Placement of SM 12.5 (GTR) Mixture. GTR = ground tire rubber.

Figure 7. Surface Texture of THMACO and SM 12.5 (GTR) Core: left, THMACO on left and SM 12.5 (GTR) on right; right, field core. THMACO = thin hot mix asphalt concrete overlay; GTR = ground tire rubber.

Table 6. Air Voids and Permeability Results for SM 12.5 (GTR) Mixtures

Specimen No.	VTM, %	Permeability x 10-5 cm/s
1	8.2	5
2	7.7	0
3	7.2	0
4	7.1	0
5	6.3	0
6	7.8	1
7	7.4	0
8	7.5	0
9	8.4	2
10	7.0	0

GTR = ground tire rubber; 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 both mixtures. Volumetric and gradation results, presented in Tables 7 and 8, indicated that all mixtures met the VDOT special provision requirements. However, a higher dust/asphalt ratio and % passing No.200 were obtained for SM 12.5 (GTR) mixtures, which may be due to the GTR particles, which act as fine particles in the mixture.

Table 7. Volumetric Properties of Asphalt Mixtures Studied

Property	SM 12.5 (GTR) Mix 19-1131	THMACO Mix 19-1129
%AC	6.67	5.67
%Air voids (V_a)	4.4	4
%VMA	19.3	16.5
%VFA	77.0	75.7
Dust/asphalt ratio	1.78	1.21
Effective % Binder (P_{be})	6.47	5.67
Effective film thickness (F_{be})	7.6	10.6

GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay; AC = asphalt content; VMA = voids in mineral aggregate; VFA = voids filled with asphalt.

Table 8. Gradation Analysis of All Mixtures

Sieve Size	SM 12.5 (GTR) Mix 19-131	THMACO Mix 9-1129
	% passing	
3/4 in (19.0 mm)	100.0	100.0
1/2 in (12.5 mm)	99.0	99.9
3/8 in (9.5 mm)	91.6	94.3
No. 4 (4.75 mm)	64.5	38.1
No. 8 (2.36 mm)	48.6	25.6
No. 16 (1.18 mm)	35.9	19.7
No. 30 (600 µm)	25.7	14.7
No. 50 (300 µm)	17.9	11.3
No. 100 (150 µm)	13.8	8.9
No. 200 (75 µm)	11.51	6.86

GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay.

Laboratory Performance

Dynamic Modulus

Figure 8 shows the dynamic modulus test results in semi-log scale for SM 12.5 (GTR) and THMACO mixtures in comparison with three traditional SM 12.5 E (SBS modified binder) mixtures (collected from the Richmond District during a previous project). SM 12.5 (GTR) mixtures showed a lower modulus compared with SM 12.5 E mixtures, especially at intermediate temperature. This may due to the higher binder content of SM 12.5 (GTR) mixtures compared to SM E mixtures. The THMACO mixture showed the lowest modulus among all mixtures due to the gap-graded nature of the mixture. In general, gap-graded mixtures had lower dynamic modulus values than dense-graded mixtures when tested under the unconfined compression condition (Nair and Saha, 2021). Detailed results are presented in Appendix C.

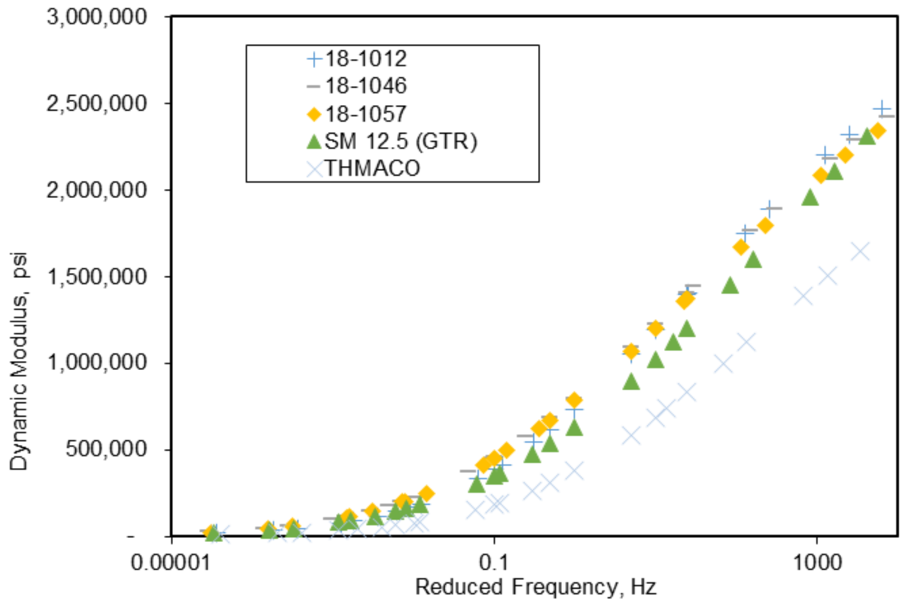

Figure 8. Dynamic Modulus Results (Semi-log Scale). Mixtures 18-1012, 18-1946, and 18-1057 are conventionally modified SM-12.5E mixtures from the previous season in the same district. GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay.

Rutting Susceptibility

Rutting measurements using the APA test indicate a mixture's ability to resist rutting. The APA test results for SM 12.5 (GTR) mixtures are shown in Figure 9. The rutting measurements were less than 5 mm, indicating good rut resistance. Regular SM-12.5E Mixtures 18-1012 and 18-1057 had an APA rut depth average of 2.1 mm and 4.1 mm, respectively. VDOT currently uses a criterion of an APA rut depth less than 8 mm as part of an ongoing balanced mix design effort regarding non-polymer modified mixtures (Diefenderfer and Bowers, 2019). VDOT does not specify a pass/fail criterion for the APA rut depth of mixtures subjected to heavy traffic. However, US 60 has an annual average daily traffic of 9,000 with 3% to 4% truck traffic, which is not considered heavy traffic.

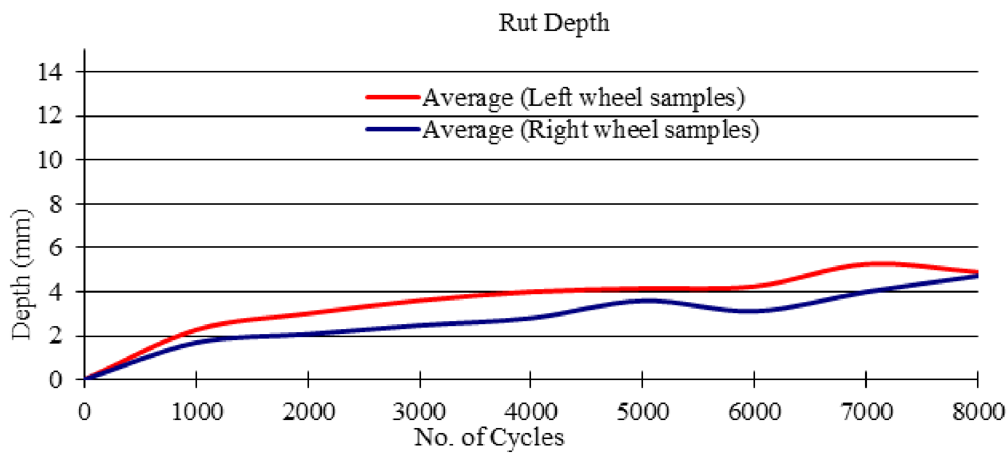

Figure 9. APA Test Results for SM 12.5 (GTR) Mixtures. APA = asphalt pavement analyzer.

Cracking

Table 9 shows the IDEAL-CT results. Higher cracking index (CT_{index}) values indicate a better ability of mixtures to resist cracking. VDOT currently uses a criterion of a CT_{index} greater than 70 as part of an ongoing balanced mix design effort for non-polymer modified mixtures (Diefenderfer and Bowers, 2019). It should be noted that for VDOT practices, there are currently no criteria developed for the CT index when polymer modified mixtures are evaluated. As shown in Table 9, SM 12.5 (GTR) mixtures had higher CT index numbers compared to traditional SM-E mixtures. In general, it is expected that mixtures with polymer modified binders would be more resistant to cracking. However IDEAL-CT numbers were not higher than for the traditional SM E mixtures. THMACO mixtures had an average CT index of 332, showing a much higher crack resistance than SM 12.5 (GTR) mixtures.

The cores collected were also tested with the IDEAL-CT; the results are shown in Table 10. The average value was 163, which was higher than production values. Air voids varied among the cores, and there was no correlation between air voids and IDEAL-CT results.

Table 9. IDEAL-CT Results

Mix ID	Mix Type	CT_{index}	
		Avg.	SD
19-1084	SM 12.5 (GTR)	85	14
19-1129	THMACO	332	38
SM-E mixtures from the Richmond District (previous project)			
18-1012	SM-E	44	20.7
18-1046	SM-E	55	19.4
18-1057	SM-E	78	27

SD = standard deviation; GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay.

Table 10. IDEAL-CT Results for SM 12.5 (GTR) Field Cores

Specimen No.	VTM, %	CT_{index}
1	8.2%	228
2	7.7%	197
3	7.2%	159
4	7.2%	144
5	6.3%	215
6	7.8%	131
7	7.4%	121
8	7.5%	110
9	8.4%	109
10	7.0%	225
Average	7.47%	163

GTR = ground tire rubber; VTM = voids in total mix.

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). FI results are shown in Table 11 for SM 12.5 (GTR) mixtures. Similar to IDEAL-CT results, SM 12.5 (GTR) mixtures had a higher FI when compared to SM-E mixtures (Mixtures 18-1046 and 18-1057 had average FIs of 1.36 and 2, respectively, and Mixture 18-1012 showed brittle failure).

In the Texas overlay test, the number of overlay test cycles to failure is expected to indicate a mixture's ability to resist reflective cracking. A higher number of OT cycles to failure indicates a better resistance to reflective cracking. 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). Overlay test results are presented in Table 12. SM 12.5 (GTR) mixtures showed higher reflective cracking resistance based on the results of the Texas overlay test (results also showed a high coefficient of variation). 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).

Table 11. SCB Test Results for SM 12.5 (GTR)

I-FIT									
Test Parameter	SM 12.5 (GTR)			Mix 18-1046			Mix 18-1057		
	Avg.	SD	COV	Avg.	SD	COV	Avg.	SD	COV
Flexibility Index	6.3	2.40	0.38	1.36	0.79	0.58	2	0.62	0.31
Strength	75.93	6.43	0.08	103	6.5	0.06	100	2.37	0.02
Fracture Energy	2586	160	0.06	2113	400	0.18	1882	164	0.08
Slope	-4.37	1.41	-0.32	-19.1	8.85	-0.46	-9.39	4.84	-0.51

SCB = Semi-circular bend test; I-FIT = Illinois flexibility index test; GTR = ground tire rubber; SD = standard deviation; COV = coefficient of variation.

Table 12. Texas Overlay Test Results

Criterion	SM 12.5 (GTR)			THMACO		
	Avg.	SD	COV (%)	Avg.	SD	COV (%)
93% Reduction in Initial Load (cycles)	1437	1229	85	2500	N/A	N/A
Max Load*Cycles	1383	1278	92	2495	7	0.3
Cracking Propagation Rate (CPR)	0.318	0.054	17	0.38	0.004	1.0
Crack Resistance Index (CRI)	90.9	7.18	7.9	82.7	0.50	0.6
Critical Fracture Energy (lb-in/in^2)	0.887	0.874	98.6	1.665	0.48	28.9

GTR = ground tire rubber; THMACO = thin hot mix asphalt concrete overlay; SD = standard deviation; COV = coefficient of variation; N/A = not applicable.

The THMACO mixture had higher load cycles with less variation compared to the SM 12.5 (GTR) mixture, higher fracture energy (>1), and a lower CPR value, indicating it should be more resistant to reflective cracking and therefore a good candidate for mitigating reflective cracking as an interlayer. Comparison Texas overlay test data were not available for the regular SM E mixtures used in this study. However, an earlier report from the Virginia Transportation Research Council (VTRC) showed Texas overlay cycles of 137 and 56 for SM 9.5 and SM 12.5 polymer modified mixtures, respectively (Habbouche et al., 2021).

Asphalt Binder Testing

Performance grading was conducted on the base binder and after the addition of 10% GTR material to the base binder in the laboratory. Table 13 summarizes the binder grading results. Results indicated that the blend of base binder and 10% GTR met the performance grade specified (combined grading was PG 64E-28, and specified was PG 64E-22). The base binder grading was PG 70-22 (a higher grade was obtained compared to the mix design binder grade of PG 64-22), and the combined grading showed a two-grade bump on high temperature side (PG 82) and the final grade showed PG 82-28. The final asphalt binder also had low Jnr values (<0.5 kPa^{-1}), indicating a better performance of these binders against rutting and in accommodating temperature variations and extreme loading conditions.

Extracted binder grading from the production mixture test was conducted for the SM 12.5 (GTR) mixture, as shown in Table 14. Binder graded to be only PG 64H-22 (PG 70-22), which did not meet the PG 64E-22 requirement. This may have been due to difficulty in fully extracting asphalt rubber binder from the mixture, which suggests that extracted binder may not be suitable for a quality assurance test for this mixture.

Table 13. Binder Test Results

Condition	Method	Property	Binder			
			Mix 19-1131		Mix 19-1131 and 10% GTR	
			Temperature, °C	Result	Temperature, °C	Result
Original	AASHTO T 316	Viscosity, Pa·s	135	0.886	135	2.88
	AASHTO T 315	G*, kPa	70	1.35	82	1.57
			76	0.750	88	0.904
		δ, degree	70	74.6	82	72.8
			76	76.7	88	76.3
		G*/sinδ, kPa	70	1.40	82	1.64
			76	0.771	88	0.930
RTFO Residue	AASHTO T 240	Mass change, %	163	-0.152	163	-0.143
	AASHTO T 315	G*, kPa	70	2.95	82	3.16
			76	1.62	88	1.88
		δ, degree	70	69.8	82	63.7
			76	71.9	88	68.1
		G*/sinδ, kPa	70	3.14	82	3.52
			76	1.70	88	2.03
	AASHTO T 350	$J_{nr1.0}$, kPa^{-1}	64	0.52	64	0.07
		$J_{nr3.2}$, kPa^{-1}	64	0.76	64	0.11
		J_{nrdiff}, %	64	45.6	64	50.3
		$R_{0.1}$, %	64	54.8	64	76.8
		$R_{3.2}$, %	64	37.6	64	66.4
PAV Residue	AASHTO T 315	G*, kPa	19	6940	16	6740
			16	10500	13	9710
		δ, degree	19	43.3	16	38.1
			16	40.6	13	35.9
		G*·sinδ, kPa	19	4760	16	4159
			16	6833	13	5694
	AASHTO T 313	Creep Stiffness, MPa	-18	225	-18	161
			-24	455	-24	319
		m-value	-18	0.310	-18	0.309
			-24	0.268	-24	0.263
Grade	AASHTO M 323		PG 70-22		PG 82-28	
	ASTM D7643		PG 73.4 (18.6) -27.9		PG 87.1 (14.2) -29.1	
	AASHTO M 332		PG 64V -22		PG 64E -28	

GTR = ground tire rubber; RTFO = rolling thin film oven; PAV = pressure aging vessel.

Table 14. Extracted Binder Grade Test Results

Method	Property	Mix 19-1131	
		Temperature, °C	Result
AASHTO T 164, Method A	Asphalt Content, %	N/A	6.23
AASHTO T 315	G^*, kPa	70	2.92
		76	1.39
	δ, degree	70	82.9
		76	84.9
	$G^*/\sin\delta$, kPa	70	2.94
		76	1.40
AASHTO T 350	$J_{nr1.0}$, kPa^{-1}	64	1.22
	$J_{nr3.2}$, kPa^{-1}	64	1.36
	J_{nrdiff}, %	64	11.98
	$R_{0.1}$, %	64	9.64
	$R_{3.2}$, %	64	3.57
AASHTO T 315	G^*, kPa	25	6310
		22	9090
	δ, degree	25	42.1
		22	39.8
	$G^*\cdot\sin\delta$, kPa	25	4230
		22	5819
AASHTO T 313	Creep Stiffness, MPa	-12	169
		-18	0.317
	m-value	-12	340
		-18	0.273
AASHTO M 323		PG 70-22	
ASTM D7643		PG 72.3 (23.4) -24.2	
AASHTO M 332		PG 64H -22	

In-Service Performance

In the past, typical rehabilitation activities on US 60 Eastbound (EB) and Westbound (WB) included concrete patching with a 2 in to 3.0 in asphalt overlay on jointed concrete pavement sections and a mill and fill operation on asphalt pavement sections. Appendix D provides some of the past performance data. Tables D1 and D2 in Appendix D show that the first and second overlays on US 60 were lasting 8 to 10 years on average. Various sections on the US 60 project also used different mixtures, such as SM 12.5 E, SMA, and THMACO, as shown in Table D3. However, additional future performance data are needed to calculate the service life of these mixtures.

The condition of the existing pavement (jointed reinforced concrete) before the overlay is an important contributor to an evaluation of a treatment's prospects for reflective cracking mitigation. To assess the pre-overlay condition state, data were extracted from VDOT's PMS and summarized for the trial sections in Tables 15 and 16 for the EB and WB directions. It can be seen that both sections had CCI values of 72 and 73 (based on 2019 distress data) and higher/poor roughness with IRI of 168 and 163 in/mi (typical range of poor IRI: 140-199 in/mi). The average joint faulting ranged from 0.16 in to 0.18 in.

Table 15. Past 10-Year Performance of US 60 EB JRCP Section Before Overlay (2009-2019)

Data Year	Mileposts	CCI	Transverse Cracking Severity 1 (linear ft)	No. of Transverse Joints	Transverse Joints Fully Sealed (No.)	Transverse Joints Spalled (No.)	Average Joint Fault in Left Wheel Path (in)	Average Joint Fault in Right Wheel Path (in)	Asphalt Patched Slabs (No.)	IRI Average (in/mi)
2009	4.76-7.41	63	48	487	454	16	0.19	0.20	27	151
2010	4.76-7.41	49	46	496	438	110	0.19	0.19	53	153
2011	4.76-7.41	59	59	494	350	31	0.20	0.19	40	155
2012	4.76-7.41	59	79	487	402	7	0.20	0.20	70	158
2013	4.76-7.41	59	80	484	411	19	0.21	0.25	80	162
2014	4.72-7.41	57	83	468	267	6	0.35	0.40	91	166
2015	4.72-7.41	61	78	508	394	19	0.14	0.18	101	166
2016	4.72-7.41	61	82	516	0	1	0.16	0.16	95	169
2017	4.72-7.41	58	52	504	0	49	0.15	0.17	60	164
2018	4.72-7.41	59	52	484	0	56	0.15	0.14	13	166
2019	4.43-7.41	72	49	558	0	69	0.17	0.18	18	168

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

Table 16. Performance of US 60 WB JRCP Section Before Overlay (2013-2019)

Data Year	Mileposts	CCI	Transverse Cracking Severity 1 (linear ft)	No. of Transverse Joints	Transverse Joint Fully Sealed (No.)	Transverse Joint Spalled (No.)	Average Joint Fault in Left Wheel Path (in)	Average Joint Fault in Right Wheel Path (in)	Asphalt Patched Slabs (No.)	IRI Average (in/mi)
2013	4.11-7.41	51	45	687	80	154	0.20	0.21	136	166
	7.41-9.58	64	42	464	2	54	0.19	0.21	43	163
2014	4.11-7.41	52	81	682	1	95	0.33	0.36	165	171
	7.41-9.58	62	63	464	0	67	0.32	0.37	62	168
2015	4.11-7.41	52	53	710	0	81	-	-	125	171
	7.41-9.58	62	44	487	0	32	-	-	44	165
2016	4.11-7.41	53	78	703	0	56	0.17	0.18	169	168
	7.41-9.58	63	55	456	0	34	0.17	0.18	107	164
2017	4.11-7.41	74	27	696	0	121	0.17	0.18	59	167
	7.41-9.58	63	23	473	0	67	0.17	0.18	47	162
2018	4.71-7.27	73	10	493	0	106	0.14	0.13	14	166
	7.27-9.58	77	25	466	0	82	0.14	0.15	6	167
2019	4.71-7.27	73	8	534	0	152	0.16	0.17	3	163

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

Table 17 summarizes the condition state of the SM 12.5 (GTR) / THMACO after 1 and 2 years in service. As expected, both the EB and WB sections were performing well (CCI above 90 indicates excellent condition with no distress). Both the EB and WB sections had very low IRI values (average value of 55 in/mi), indicating a very smooth pavement surface. More detailed distress data are shown in Table 18. Low rutting (average of 0.09 in) was observed for both sections, and some reflective cracking had appeared in both. Figure 10 shows examples of the reflective cracking observed in the experimental section. It was observed during paving that some of the joints were not repaired properly before overlay and because of the width of the joint, a shadow was seen in the THMACO layer, as shown in Figure 11. Proper repair and treatment of joints are needed to avoid early reflective cracking.

Figure 10. Reflective Cracking Observed on US 60 After 2 Years

Figure 11. THMACO Layer Showing Shadow of Concrete Pavement Joint. THMACO = thin hot mix asphalt concrete overlay.

Table 17. 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)
US 60 EB	New Kent	0.18	0.92	2020	BOJ	2	11.8	99	99	99	-
				2021				97	97	97	53
				2022				95	95	95	57
		4.43	7.41	2020			11.8	99	99	99	-
				2021				98	98	98	56
				2022				95	100	95	57
US 60 WB	New Kent	4.40	4.71	2020	BOJ	**2**	11.70	100	100	100	59
				2021				97	100	97	57
				2022				92	100	92	61
		4.71	7.27	2020				93	100	93	54
				2021				94	100	94	56
				2022				88	100	88	58
		7.27	8.39	2020				89	100	89	54
				2021				89	100	89	57
				2022				85	100	85	60

MP = milepost; CCI = Critical Condition Index; LDR = load related distress rating; NDR = non-load related distress rating; IRI = International Roughness Index; EB = eastbound; BOJ = bituminous over jointed concrete; - = not available; WB = westbound.

Table 18. 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)
US 60 EB (MP 0.18-0.92)	2020	0	0	0	0	0	0	0	0	0.10
	2021	0	0	0	0	0	0	0	0	0.13
	2022	0	0	0	0	0	0	0	7	0.14
US 60 EB (MP 4.43-7.41)	2020	0	0	0	0	0	0	0	0	0.10
	2021	0	0	0	0	2	0	0	129	0.07
	2022	0	0	0	0	3	0	0	904	0.07
US 60 WB (MP 4.4-4.71)	2020	0	0	0	0	0	0	0	0	0.10
	2021	0	0	0	0	0	0	0	80	0.13
	2022	0	0	0	0				134	0.08
US 60 WB (MP 4.71-7.27)	2020	0	0	0	0	20	0	0	0	0.10
	2021	0	0	0	0	55	0	0	301	0.08
	2022	0	0	0	0				1099	0.06
US 60 WB (MP 7.27-8.39)	2020	0	0	0	0	0	0	0	0	0.10
	2021	0	0	0	0	0	0	0	85	0.08
	2022	0	0	0	0				597	0.07

EB = eastbound; MP = milepost; WB = westbound.

CONCLUSIONS

- *A dry process SM 12.5(GTR) mixture can be produced and placed with no significant field-related concerns, and the special provision developed for it was found to be effective.* Density requirements were achieved, and the as-placed mat had excellent (very low) permeability characteristics.

- *Laboratory performance testing found the SM 12.5(GTR) mixture to be more crack resistant than conventionally modified SM E mixtures*. Conventionally modified SM E mixtures showed slightly better rutting performance. However, this conclusion was based on performance testing and thresholds that were developed for non-modified asphalt mixtures. Further laboratory and field performance comparisons are needed to develop mixture acceptance criteria for GTR mixtures.

- *THMACO mixtures had excellent laboratory reflective cracking resistance properties*. They performed particularly well in the Texas overlay test.

- *Grading of extracted (from the mixture) binder may not provide an accurate representation of the binder performance for this dry process GTR modified asphalt.* Despite promising performance properties of laboratory-blended base binder and GTR, performance grading of extracted binder indicated that the blend did not meet the minimum PG 64E-22 requirement. A laboratory-blended binder test may be needed to determine the proportion of GTR that is needed to meet a given binder performance specification (and included in the design submittal).

- *Continued monitoring of performance will be needed to quantify any benefit of SM 12.5 (GTR) mixtures in comparion with regular SM E mixtures.* Laboratory performance test results were promising, but these trials did not include control sections and the current condition state represents only the early days of in-service field performance.

RECOMMENDATIONS

1. *VDOT districts should consider additional field trials with SM 12.5 (GTR) mixtures for performance evaluation.* Control sections with regular SM 12.5 E mixtures should be included in these field trials for laboratory and field performance comparisons.

2. *VTRC should work with the VDOT districts to evaluate THMACO further as an interlayer to mitigate reflective cracking for composite pavements.*

3. *VTRC should continue to monitor the performance of the sections in this study to evaluate the cost-effectiveness of SM 12.5 (GTR) mixtures in comparison with that of conventionally (SBS) modified 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 is working with the Richmond District, and three field projects using SM 12.5 (GTR) mixtures are planned for the 2022 construction season on Rte. 76, Rte. 10, and Rte. 288. A control section with regular SM 12.5 mixtures will be included in these trials.

With regard to Recommendations 2 and 3, VTRC will continue to monitor the performance of these sections and will report it in future studies. VTRC will work with the districts to evaluate THMACO as an interlayer through additional field projects. A study is planned to start in fall 2022 that will address Recommendations 2 and 3.

Benefits

Every year, close to 300 million scrap tires are generated in the United States (Buttlar and Rath, 2021). Currently, there are about 10 million tires classified as waste each year in Virginia. In addition, there are approximately 1 million tires in 86 piles around Virginia (Department of Environmental Quality, personal communication). The use of GTR using a dry process helps reduce stockpiling of waste tires. The GTR industry gave a metric of one tire for every 2 tons of asphalt (when 10% of GTR material was used). Based on this metric, the US 60 project consumed close to 6,000 tires in the asphalt mixture.

Future performance monitoring (Recommendations 2 and 3) of the test sections in this study will help in assessing the benefit-cost of the use of these mixtures in pavements. Implementation of Recommendations 1 and 2 will help in developing a performance-related specification for SM 12.5 (GTR) mixtures.

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APPENDIX A

VIRGINIA DEPARTMENT OF TRANSPORTATION SPECIAL PROVISION FOR GROUND TIRE RUBBER (GTR) MODIFIED ASPHALT SURFACE COURSE

May 11, 2019

I. DESCRIPTION

This work shall consist of furnishing and placing a Ground Tire Rubber (GTR) Modified Asphalt Surface Course in accordance with Sections 211 and 315 of the Specifications and this Special Provision.

II. MATERIALS

Materials shall conform to Section 211 and of the Specifications and the following:

1. The mixture produced shall be Ground Tire Rubber (GTR) Modified Asphalt Surface Mixture (Dry Process), SM 12.5 (GTR) and shall conform to the following:

   A. The binder shall meet the requirements for AASHTO M320.

   B. The maximum percentage of Reclaimed Asphalt Pavement (RAP) shall be 15 percent.

   C. When the GTR is combined with the asphalt cement, the moisture content of the GTR shall not cause foaming of the blend.

   D. GTR shall have a specific gravity of 1.15± 0.05 when tested in accordance with ASTM D1517, Standard Test Method of Rubber Chemicals Density.

   E. The base asphalt binder used in a dry process GTR mixture modified shall be a PG 64S-22.

   F. The GTR shall be produce from processing automobile or truck tires by the ambient grinding method. Heavy equipment tires, uncured or de-vulcanized rubber will not be permitted. The GTR shall not exceed 1/16th-inch in length and shall contain no free metal particles. Detection of free metal particles shall be determined by thoroughly passing a magnet through a 2-ounce sample. Metal embedded in rubber particles will not be permitted.

   G. The dry process GTR shall be packaged and shipped in closed-top water-resistant bulk bags. The dry process GTR bags shall be stored in a dry location protected from the rain before use in the field. When the dry process GTR is combined with the asphalt binder and aggregate, the moisture content of the GTR shall not cause foaming of the blend.

H. Dry process GTR shall conform to the following gradation requirements:

SIEVE SIZE	PERCENT PASSING
No.20	100
No.30 (600 µm)	99± 1
No.40 (300µm)	60± 10
No. 100 (150 µm)	10± 5

2. The plant requirements for producing GTR mixture shall conform to the following: Dry Mixture Processing and Storage.

A. Dry process GTR shall be controlled with a feeder system using a proportioning device that is accurate to within ±3 percent of the amount required. This system shall always automatically adjust the feed rate to maintain the material within this tolerance and shall have a convenient and accurate means of calibration. The system shall provide in-process monitoring, consisting of either a digital display of output or printout of feed rate in pounds per minute to verify the feed rate. The supply system shall report the feed in 1-ounce increments using load cells that will enable the user to monitor the depletion of the GTR. Monitoring the system volumetrically will not be allowed. The feeder shall interlock with the aggregate weigh system and asphalt binder pump to maintain the correct proportions at all production rates.

B. Flow indicators or sensing devices for the system shall be interlocked with the plant controls to interrupt the mixture production if the GTR introduction output rate is not within the percent stated above. The interlock will immediately notify the operator if the targeted rate exceeds introduction tolerances. All plant production will cease if the introduction rate is not brought back within tolerance after 30 seconds. When the interlock system interrupts production and the plant has to be restarted, upon restarting operations, the modifier system shall run until a uniform feed can be observed on the output display. All mixture produced prior to obtaining a uniform feed shall be rejected.

III. EQUIPMENT AND PROCEDURES FOR PLACEMENT

Equipment and procedures for surface preparation, placement, and acceptance of placement of the Ground Tire Rubber (GTR) Modified Asphalt Surface Course shall be in accordance with Section 315 of the Specifications.

IV. MEASUREMENT AND PAYMENT

Ground Tire Rubber (GTR) Modified Asphalt Course will be measured in tons and paid for at the contract unit price per ton, which shall include surface preparation, all materials, additives, labor, testing and equipment as described herein.

Payment will be made under:

PAY ITEM	PAY UNIT
Ground Tire Rubber (GTR) Modified Asphalt Course	Ton

APPENDIX B

BINDER TEST RESULTS

Table B1. Lab Binder Test Results (Base Binder [PG 64-22] +10% GTR)

PROPERTY		AASHTO METHOD	TEST TEMP.	SPECIFICATION	RESULTS
ORIGINAL BINDER					
FLASH POINT		T48	-	≥230°C	317.8°C
ROTATIONAL VISCOSITY		T316	135°C	3.0 Pa·s	1.638 Pa·s
DYNAMIC SHEAR	δ	T315	76°C	N/A	79°
			82°C		81°
	G*/SIN(δ)		76°C	≥ 1.0 kPa	1.43 kPa
			82°C		.80 kPa
			$T_{crit.-HIGH}$ (Original)		79.7°C
RTFO BINDER (T240)					
MASS CHANGE		T240	-	≤ 1.00 % by wt.	-0.25%
DYNAMIC SHEAR	G*/SIN(δ)	T315	76°C	≥ 2.2 kPa	2.84 kPa
			82°C		1.57 kPa
			$T_{crit.-HIGH}$ (RTFO)		78.6°C
PAV BINDER (R28)					
DYNAMIC SHEAR	G*·SIN(δ)	T315	22°C	≤ 5000 kPa	3836 kPa
			19°C		5454 kPa
			$T_{crit.}$ (Int.)		19.7°C
BBR	STIFFNESS 60 sec.	T313	-12°C	≤ 300 MPa	119 MPa
			-18°C		243 MPa
			$T_{crit.-LOW}$ (Stiffness)		-29.8°C
	M-VALUE		-12°C	≥ 0.300	0.338
			-18°C		0.287
			$T_{crit.-LOW}$ (m-Value)		-26.5°C
1 PAV Delta Tc	$T_{C(Stiff)}$-$T_{C(m\text{-}value)}$	-	-	N/A	-3.3
Continuous Grade					PG 78.6-26.5
AASHTO M320 GRADE					**PG 76-22**

APPENDIX C

DYNAMIC MODULUS TEST RESULTS

Table C1. Dynamic Modulus Test Results for GTR SM 12.5 Mixtures

Temperature (°C)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
4	1121223	1452593	1602497	1958137	2111657	2312284
20	349726	536360	633290	895046	1022112	1201223
40	79224	143121	181401	301280	367906	470966
54	17778	35602	47459	89461	115661	159820

GTR = ground tire rubber.

Table C2. Dynamic Modulus Test Results for THMACO Mixtures

Temperature (°C)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
4	736922	1001121	119265	1390879	1503049	1644053
20	182,824	310,883	382,382	585,787	687,628	832,299
40	33,750	63,520	83,190	152,332	194,332	264,023
54	9,788	17,225	22,374	41,794	54,902	78,552

THMACO = thin hot mix asphalt concrete overlay.

APPENDIX D

PMS DATA FOR US 60

Table D1. Performance Data for US 60 (MP 11.63-15.5)

Milepost	11.63-12.62	12.62-14.91	14.91-15.55
Last Rehab Year	2000	1997	1990
Mix Type	SM 12.5D	SM 2-D	SM2-A
Year	Critical Condition Index (CCI)		
2007	66	49	28
2008	62	50	63
2009	59	23	42
2010	30	20	30
2011	34	19	26
Milepost		11.61-15.55	
Last Rehab Year	-	2011	-
Mix Type	-	SM 9.5A	-
Year	Critical Condition Index (CCI)		
2012		**96**	
2013		97	
2014		92	
2015		93	
Milepost	11.61-13.62	13.62-15.55	
Year	Critical Condition Index (CCI)		
2016	93	86	
2017	89	86	
2018	82	82	
2019	79	72	
2020	60	53	

Table D2. PMS Data for Various Sections on US 60

Milepost	6.96-9.60	0.84-10.40	7.41-8.25	11.61-13.62	3.89-9.70	18.40-19.02
Last Rehab	2007	2009	2010	2011	2012	2012
Year	Critical Condition Index (CCI)					
2010	80	100	-	-	-	-
2011	85	100	99	-	-	-
2012	89	96	99	100	-	-
2013	89	95	98	97	98	99
2014	72	82	96	92	96	97
2015	79	80	92	93	93	95
2016	51	79	92	93	84	81
2017	44	46	91	89	83	81
2018	-	33	89	82	69	96
2019	-	37	91	79		80
2020	-	-	79	60		70

PMS = VDOT's Pavement Management System.

Table D3. PMS Data for Various Mixtures Used on US 60

Mile Point	0.49-0.92	7.41-8.25	17.01-17.50	2.27-4.43	4.4-8.39
Last Rehab	2009	2010	2014	2018	2019
Mix Type	SM 12.5 E	SM 12.5 E	SMA-12.5(76-22)	SM 12.5	THMACO
Year	Critical Condition Index (CCI)				
2010	94.00				
2011	95.00				
2012	92.00				
2013	81.00				
2014	68.00	100			
2015	63.00	98			
2016	46.00	98			
2017	39.00	98	96.00		
2018	33.00	94	90.00		
2019	36.00	96	90.00	100	
2020		88	92.00	98	94

PMS = VDOT's Pavement Management System; THMACO = thin hot mix asphalt concrete overlay.