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Ground Tire Rubber Research at the NCAT Pavement Test Track

Buzz Powell, Carolina Rodezno

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By

Buzz Powell, PhD, PE
Associate Director and Research Professor

Carolina Rodezno, PhD
Associate Research Professor

National Center for Asphalt Technology
Auburn University, Auburn, Alabama

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1 INTRODUCTION

Over the years, there has been a growing interest in using ground tire rubber (GTR) as an opportunity to improve the performance of asphalt pavements while eliminating the growing amount of scrap tires being landfilled or impacting the environment.

Studies have documented that when properly designed and constructed, depending on the technology used, GTR can perform well and provide potential benefits that include improved resistance to rutting and several modes of cracking, reduced road maintenance, decreased temperature susceptibility of the asphalt binder, and reduced noise. Performance improvements with the use of GTR in asphalt pavements have been attributed to the interaction of GTR with base binders, which is influenced by different factors such as the amount of aromatic fraction in the binder, temperature, duration of the blending reaction, production method, particle size, specific surface area, and chemical composition of the GTR. Depending on the level of interaction between GTR and asphalt binder, each GTR technology can improve the mixture's properties differently.

Starting in 2009, NCAT has been actively involved in the field performance and laboratory evaluation of different GTR technologies to assess their impact on asphalt binder properties, their short and long-term durability, potential to prevent different modes of cracking, and noise reduction. Past research at the NCAT Pavement Test Track has included two traditional wet processes, terminal-blended binders, and asphalt rubber binders. In the current test track cycle, new dry GTR technologies are being evaluated. The following sections summarize key findings from past research, presented in chronological order, as well as current research expected to be completed as part of the current test track cycle in 2024.

2 NCAT PAVEMENT TEST TRACK RESEARCH WITH GTR

2.1 NCAT Pavement Test Track Phase IV (2009)

2.1.1 Comparing the Short-Term Performance of GTR-and SBS-Modified Dense Graded Mixes

In 2009, the Missouri DOT sponsored test sections S6 and S7 at the NCAT Pavement Test Track to determine if GTR would be an adequate substitute for SBS in asphalt mixtures (*1*). These two test sections were constructed on perpetual foundations to ensure that the distresses (rutting, roughness, raveling, and cracking) were indicative of the surface mixture’s performance. Both sections were resurfaced with 12.5-mm NMAS dense-graded Superpave mixtures designed at 100 gyrations using the same design aggregate gradation. The first mixture was designed and produced with a PG 76-22 polymer modified binder (with 2.5% SBS), while the second mixture was designed and produced with a GTR modified binder. The GTR-modified binder was produced by terminally blending a PG 67-22 asphalt binder with 11% #40 mesh ambient ground tire rubber and 4.5% transpolyoctenamer (TOR) by weight of the rubber to act as a co-linking agent between the rubber and the asphalt binder. After modification, the GTR modified binder was graded as a PG 76-22. Another difference between the two mixtures was their binder content, as the GTR-modified asphalt mixture was targeted to have an additional 0.4% asphalt to account for the presence of ground tire rubber in the mixture. Both mixtures were placed 1.75 inches thick at approximately 93% density.

After 10 million equivalent single axle loadings (ESALs) of truck traffic, neither mixture showed signs of cracking. Both mixtures showed good field rutting performance with final rut depths of 4.8 mm for the SBS mixture and 3.8 mm for the GTR section. In addition, both mixtures exhibited consistent mean texture depth (MTD) values of approximately 0.5 mm or less and IRI values of around 50 in/mi throughout the entire research cycle. The field performance results suggested that GTR mixtures could perform as well as SBS modified mixtures.

2.2 NCAT Pavement Test Track Phase V (2012)

2.2.1 Comparing the Long-Term Performance of GTR-and SBS-Modified Dense Graded Mixes

The SBS and GTR sections (S6 and S7) sustained a total of approximately 10 million ESALs during Phase IV. At the end of this cycle, neither section showed any signs of cracking, and the rutting for both was less than 5 mm. Although the SBS test section was removed due to funding constraints, Seneca Petroleum decided to sponsor the continuation of the trafficking study on the GTR section, given its excellent performance in assessing long-term outcomes (*2*). With an additional 10 million ESALs of traffic, the rutting remained approximately the same at 5 mm. The section showed no signs of cracking. At the end of the cycle, IRI had increased from 0.83 m/km to approximately 1.1 m/km, and texture had increased from 0.5 mm to 0.7mm. After 20 million ESALs, the GTR section proved its long-term durability and suitability as a substitute for SBS-modified mixtures. As a result of this finding, several states implemented a GTR-modified binder specification that could be used in lieu of SBS.

2.2.2 Constructing Quiet Pavement using GTR-Modified Porous Friction Course (PFC)

The Virginia DOT sponsored two sections, W10 and S1, to evaluate asphalt mixtures for quiet pavements in the 2012 Test Track research cycle (*4*). The sections were resurfaced with 12.5-mm NMAS PFC mixes using typical Virginia traprock and 10% reclaimed asphalt pavement (RAP). The PFC mixture in Section W10 used an SBS modified PG 76-22 binder, while Section S1 was modified with 12% GTR (terminally blended) by weight of the binder.

Two methods were used to assess the sound intensity using the On-Board Sound Intensity (OBSI) system and the Close Proximity (CPX) method. Based on OBSI and CPX testing, sound intensity was initially lower for the GTR section but increased over time to exceed that of the SBS section. Initially, noise absorption was higher for the GTR section, but it decreased at a greater rate than the SBS section over time. Rutting values less than 5 mm were reported for both sections at the end of the cycle. IRI values were better for the GTR section; however, the difference in smoothness was likely due to construction variability, as the values for both sections remained relatively constant over time *(2).*

2.2.3 Evaluating Durability of GTR-Modified Open Graded Friction Course (OGFC)

ALDOT evaluated three PFC mixes in the fifth research cycle with the goal of improving durability and preventing premature raveling. Section E9A was paved with a 9.5 mm NMAS PFC, while Sections E9B and E10 were paved with 12.5 mm NMAS mixes. The E9A mix contained 0.3%

cellulose fiber to prevent drain-down, and the E9B mix used 0.05% synthetic fiber to prevent raveling. The E10 mix incorporated 12% GTR (terminally blended) by weight of binder and was constructed without fibers to determine if GTR alone could prevent drain-down and resist raveling. The three mixes were verified during the mix design process to meet the maximum Cantabro loss of 15%, ensuring acceptable resistance to raveling as recommended by previous NCAT research. Based on Cantabro results of lab-produced mixes, increasing the asphalt content of PFC mixes can increase resistance to raveling without greatly reducing air voids or potential permeability. The 9.5 mm PFC with the cellulose fiber had lower Cantabro stone loss and higher tensile strength than either of the 12.5 mm mixes. The 12.5 mm PFC with GTR showed good performance in the laboratory for both Cantabro loss and tensile strength.

After two years of trafficking (10 million ESALs), none of the sections had any raveling or a significant amount of rutting. The mean texture depth of the 9.5 mm section (E9A) was approximately the same as the 12.5 mm sections (E9B and E10). The 9.5 mm section experienced an increase in roughness during the last summer of the test cycle, whereas roughness in the 12.5 mm sections remained steady throughout the cycle.

2.2.4 Evaluating the Use of GTR Modified Binders for Enhancing Structural Pavement Performance

Alabama DOT, the Alabama Department of Environmental Management (ADEM), North Carolina DOT, and South Carolina DOT sponsored a structural experiment in 2012 that utilized recycled materials to assess the structural and performance characterization of sustainable pavement materials under heavy traffic conditions (*4*). These sections featured the use of reclaimed asphalt shingles (RAS), GTR, and RAP. The goal of the experiment was to demonstrate how recycled materials could be used in pavement structures such that the overall performance of the pavements would exceed what can be achieved with current practices. Four test sections were included in the study, as presented in Figure 1.

Although the thicknesses of the test sections were not designed as perpetual pavements, the mixtures selected for each layer were designed with a perpetual design concept: a rut-resistant surface layer (e.g., SMA), a high-stiffness (i.e. high-modulus) intermediate layer to reduce deflections in the pavement, and a fatigue resistant lower layer to resist bottom-up cracking. Section N5 (standard RAP) served as the control section, representing current standard practices for mix designs, with 20% RAP in the surface layer and 35% RAP in the lower layers. In contrast, the other sections utilized a wider array of recycled materials and RAP contents. Section S5 (high RAP) utilized an SMA surface layer mix with cellulose fibers and 25% RAP, an intermediate Superpave layer mix containing 50% RAP, and a 35% RAP Superpave layer produced with highly polymer-modified binder (PG 94-28). Section S6 (RAP/RAS) incorporated 5% RAS into the SMA surface mix, the intermediate layer mix contained a combination of 25% RAP and 5% RAS, and the bottom lift contained 25% RAP and a PG 76-22 polymer-modified binder at reduced air voids. The GTR Section S13 included two GTR-modified binders. The SMA surface and dense-graded intermediate lifts contained 12% #30-mesh GTR added to a PG 67-22 binder, abbreviated as ARB12 (asphalt-rubber binder with 12% GTR). No fibers were added to the GTR-modified SMA since GTR had shown excellent resistance to drain down. The dense-graded intermediate layer mix also contained an ARB12 and 35% RAP. The bottom lift was designed using the Arizona method for a gap-graded asphalt-rubber mix with 20% #16 mesh GTR (ARB 20 AZ).

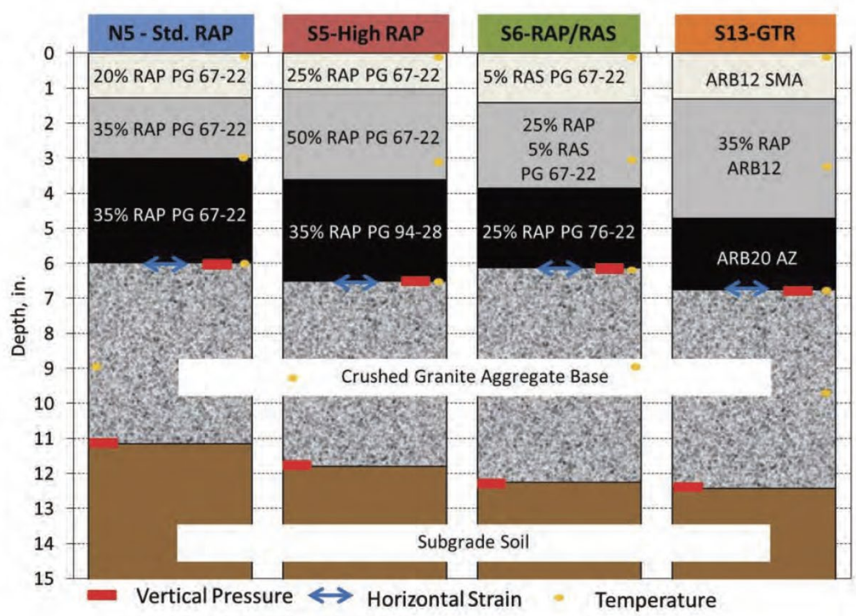

Figure 1 2012 Green Group Sections *(2)*

Surface mixes were also evaluated for rutting resistance using the APA (AASHTO T 340-10) and the FN test (AASHTO TP 79-13), and resistance to top-down cracking was evaluated using the Energy Ratio procedure. Intermediate layers were tested for dynamic modulus, and base layers were evaluated for fatigue resistance using the simplified viscoelastic continuum damage testing (SVECD). Each of the SMA surface mixes had excellent rutting resistance in the laboratory as indicated by the FN and APA test results. All the mixes satisfied the minimum energy ratio criterion for top-down resistance. In the field, all the sections had excellent rutting performance, and although there was no evidence of top-down cracking during the two-year research cycle, more traffic/time would have been needed to determine durability ranking in the field.

Results of the SVECD testing showed that the highly polymer-modified mix from S5 had very similar fatigue life as the conventional mix from N5 across all of the simulated strain levels. The results also indicated that the rich bottom mix from S6 was substantially better than the conventional mix, but the Arizona-style gap-graded asphalt-rubber mix outperformed all the base mixtures across all strain levels. The control section N5 reached the cracking threshold (25% of the total area) after approximately 4 million ESALs. The section was rehabilitated at approximately 7 million ESALs, but rut depths and IRI steadily increased after that. Section S5, designed with high RAP contents, failed after less than 2.5 million ESALs due to interface debonding between the intermediate and base layers. Section S6, featuring RAS in the surface layer and a combination of RAP/RAS in the stiff intermediate layer, reached the cracking threshold after approximately 5.7 million ESALs and was rehabilitated at about 7 million ESALs. Although the section was rehabilitated with a highly polymer-modified mix, and surface conditions were initially improved, pre-maintenance distress levels were rapidly exceeded.

Section S13 containing GTR-modified mixtures reached the cracking threshold at about 4.7 million ESALs. Compared to the control section N5, S13 endured 17% more ESALs before the cracking threshold was reached.

From this research, it was concluded that the GTR mix in section S13 with the most immediate implementation potential was the highly crack resistant base layer. Based on the results of this study, ALDOT recommended this mix be used in a surface layer in the 2015 track research cycle to prove the concept works as well at the surface of the pavement as at the bottom. Because the vast majority of roadway paving in Alabama is mill and inlay, good performance in a surface mix application will result in the most positive GTR economic impact.

2.3 NCAT Pavement Test Track Phase VI (2015)

2.3.1 Evaluating High Cracking Resistance Surface Mixes (Cracking Group), including Arizona Gap-Graded Mix

For the track's sixth cycle, NCAT and MnROAD developed an experimental plan to validate and assist state DOTs in implementing asphalt mixture cracking tests for future routine use in mix design and acceptance testing. The Cracking Group (CG) experiment, intended to validate top-down cracking, included seven surface mixtures designed with a range of recycled material contents, binder types, grades, and in-place densities to cover a range of field cracking performance where other variables, such as traffic, environment, and pavement structure, remained the same. Table 1 provides a description of the mixes, compositions, and anticipated cracking resistance based on the estimations of NCAT researchers. The mixtures were constructed as 38 mm surface lifts over highly polymer-modified intermediate and base layers of asphalt with a target thickness of 57 mm per layer. The asphalt pavement cross-section was intentionally relatively thin for the heavy load to be applied so that the surface layers would experience significant stress and strains but avoid bottom-up fatigue cracking with the use of the highly modified mix for intermediate and base layers (*3*).

Table 1 Summary of Surface Mixtures Used in the NCAT Top-Down Cracking Experiment *(3)*

NCAT Test Section	Mixture Description	NMAS (mm)	RAP Content	RAS Content	Expected Cracking Resistance
N1	Control (20% RAP)	9.5	20%	0%	Good
N2	Control, Higher Density	9.5	20%	0%	Better
N5	Control, Low Density, Low AC[a]	9.5	20%	0%	Worse
N8	Control+5% RAS	9.5	20%	5%	Worse
S5	35% RAP, PG 58-28	9.5	35%	0%	Good
S6	Control, HiMA[b] Binder	9.5	20%	0%	Better
S13	Gap-graded, Asphalt-rubber	12.5	15%	0%	Better

[a] asphalt content; [b] highly modified asphalt

Construction of these sections was completed in the summer of 2015. After two years of trafficking with ten million ESALs, N8 was the only section that had a substantial amount of top-down cracking in approximately 17% of the lane area. Three other sections, N1, N2, and N5, had very fine hairline cracks only visible to the trained eye. All of the sections demonstrated excellent rutting resistance. There were some differences in the changes in the international roughness index (IRI) among the test sections, but the differences are not considered meaningful.

Seven laboratory cracking tests were selected by the sponsors as the preferred candidates for evaluating top-down cracking: Energy Ratio, Texas Overlay (TX-OT) test, NCAT modified Overlay Test (NCAT-OT), semi-circular bend test (SCB) (Louisiana method), Illinois Flexibility Index test (I-FIT), the IDEAL Cracking Test (IDEAL-CT), and AMPT cyclic fatigue. The experimental plan included testing of reheated plant mixes and laboratory critically aged, as well as lab-prepared mixes short-term aged and critically aged. Critically aged mixes simulate approximately four years of field aging in Auburn, Alabama. The laboratory aging protocol was eight hours at 135°C in a loose mix state. NCAT refers to this protocol as "critically aged," representing 70,000 cumulative degree days (CDD) of in-situ aging, which occurs when top-down cracking typically happens in surface layers. Table 2 provides the range of coefficients of determination, R^2, for the correlations with top-down cracking performance of the different cracking tests (conducted at the different aging conditions). These results suggest that some tests have the potential to discriminate mixtures with good and bad performance, while others do not seem to be adequate candidates for further consideration.

Table 2 Correlation (R^2) of Cracking Test to Field Cracking at 20 Million ESALs *(4)*

Test	Parameter	Range of R^2
Energy Ratio	ER	0.03-0.28
SCB-LA	J_c	0.13-0.78
I-FIT	FI	0.76-0.89
OT-TX (β)	β	0.76-0.91
OT-NCAT (β)	β	0.79-0.97
IDEAL-CT	CT_{Index}	0.87-0.94
Cyclic Fatigue	S_{app}	0.89-0.90

2.4 NCAT Pavement Test Track Phase VII (2018)

2.4.1 Evaluating High Cracking Resistance Surface Mixes (Cracking Group), including Arizona Gap-Graded Mix-Traffic Continuation

At the end of the sixth test track cycle, sponsors of the cracking group agreed to support the continuation of traffic and monitoring of the experiment in the 2018 cycle of the Test Track. Table 3 summarizes preliminary field performance at 16 and 20 million ESALS. The results clearly show that the Arizona Rubber mix outperformed all of the other sections, proving to be a superior mix.

Table 3 NCAT Cracking Group Experiment-Field Performance *(4)*

Section	Description	As-Const. Density (%G_{mm})	% Lane Area Cracked	
			Feb. 2020 16 MSALs	**Feb. 2021 20 MESALs**
N1	20% RAP (Control)	93.6	11.2	44.5
N2	Control w/ High Density	96.1	7.7	12.5
N5	Low AC, Low Density	90.3	21.1	47.4*
N8	20% RAP 5% RAS	91.5	70.8	99.3*
S5	35% RAP PG 67-28	92.2	0.2	1.1
S6	Control with HiMA	91.8	0	0.9
S13	AZ Rubber Mix	92.7	0	0

Projected based on data after 16 million ESALs

2.4.2 Evaluating Reflective Cracking Interlayer Including GTR Modified Mix

The Georgia DOT sponsored two test sections (N12 and N13) to evaluate six potential methods for mitigating reflective cracking. The methods included PETROMAT fabric interlayer, GlasGrid interlayer, chip seal using virgin 7# stone, chip seal using reclaimed asphalt pavement, open graded interlayer (OGI), and GTR modified gap graded asphalt interlayer. In both sections, deep saw cuts 3.2 mm wide were made in the existing pavement for the full depth of the structural layer to simulate cracking in the pavement structure. Therefore, the factor affecting the reflective cracking performance was only the crack relief treatment method.

Section N12 was divided into three subsections for different treatment methods, which included N12-A (GlasGrid CG100), N12-B (PETROMAT fabric), and N12-C (chip seal with 7# granite stone). A PG 64-22 asphalt binder was used as tack coat for N12-A and N12-B subsections with an application rate of 0.27 and 0.30 gallon/sq. yard, respectively. CRS-2h emulsion tack was applied onto the existing pavement of N12-C subsection with an application rate of 0.30 gallon/sq. yard immediately prior to the chip application. A 70 mm thick 9.5 mm NMAS Superpave mix was placed as the surface layer for N12-A and N12-B, while 50 mm was placed on N12-C to account for the thickness of the chip seal interlayer.

Section N13 was also divided into three subsections for different treatment methods, which included N13-A (chip seal using reclaimed asphalt pavement), N13-B (GTR modified asphalt interlayer), and N13-C (OGI). CRS-2h emulsion tack was applied onto the existing pavement of N13-A subsection with an application rate of 0.30 gallon/sq. yard immediately prior to the chip application. UltraTack trackless tack emulsion was used for subsection N13-B with an application rate of 0.10 gallon/sq. yard (residual of 0.05 gallon/sq. yard). UltraFuse trackless tack was used for subsection N13-C with an application rate of 0.15 gallon/sq. yard. The thickness of the interlayer mix in both N13B and N13-C was approximately 35 mm. The same Superpave mix was used as the surface layer with a thickness of 50 mm for N13-A (to account for the thickness of the chip seal interlayer), and 40 mm for N13-B and N13-C, respectively (to account for the thickness of the mix interlayers).

At the completion of the research cycle, no significant reflective cracking was observed in any of the sections. Traffic continuation was recommended on these sections, and their field performance is being monitored in the current research cycle.

2.5 Phase VIII Track (Ongoing work-2021)

2.5.1 Recycled Tire Rubber in Additive Group (AG) Study

As part of the 2021 Test Track research cycle, NCAT developed an Additive Group (AG) study to evaluate a wide range of asphalt additive technologies, including GTR (wet and dry), recycled plastics (wet and dry), reactive polymers, and high strength aramid fibers to provide sustainable and resilient technologies with the potential of outperforming current materials. Additionally, it is anticipated that this research will lead to the development of a framework for evaluating the performance impact of future asphalt additives. To guide the selection of the additives, a series of Phase 1 evaluations were conducted that included a laboratory characterization and theoretical structural analysis for each technology. Alabama, Florida, Mississippi, New York, Tennessee, Texas, and FHWA pooled their resources to fund the 2021 AG study. The Phase 1 evaluation results were presented to sponsors for the selection of the five technologies that would be used for the construction of structural test sections at the NCAT Pavement Test Track. The additives selected by the sponsors included two GTR technologies (one wet and one dry), two plastic technologies (one wet and one dry), and one high-strength aramid fiber additive. Sections containing these additives are currently under evaluation.

2.5.2 New Dry GTR Technologies

As presented in previous sections, experience at the NCAT Pavement Test Track with GTR has been limited to wet GTR technologies; however, GTR technologies have evolved over the years, and new dry GTR technologies claim to address past problems with the production and placement of GTR modified mixtures while providing enhanced pavement performance. For Phase VIII of the NCAT Pavement Test Track, two dry GTR technologies are being evaluated. SmartMix was utilized for the construction of a structural section as part of the AG study, and Elastiko™ Engineered Crumb Rubber (ECR) was utilized for a mill/inlay test section sponsored by the Oklahoma Department of Transportation (ODOT). The objective of the ODOT research is to assess the performance of a rubber-modified mix and its potential to prevent reflection cracking from the underlying layer.

SmartMix

This technology combines asphalt binder, GTR, and other additives. The GTR is allowed to react and swell at a prescribed temperature. Once the required rubber-binder interaction is achieved, the material is transferred into a cooling system where it is mixed with other mineral fillers to produce a free-flowing rubber-modified binder in dry form that can be transported and stored at ambient temperature. During production, the pretreated rubber is added through the RAP collar, where it is blended with the heated aggregate and asphalt to produce a rubber-modified asphalt mix. Since the rubber is pre-reacted and pre-swelled, it does not absorb any additional binder.

Elastiko^R Engineered Crumb Rubber (ECR)

This technology utilizes finely ground, chemically modified tire rubber. It is added like a fine aggregate during asphalt mix production. Being a dry process technology, it requires minimal modification to existing plant equipment, and the chemical modification is designed to prevent any material hold-up or workability issues.

2.5.3 Recycled Tire Rubber in Balanced Mix Design

As mentioned previously, as part of the AG Phase 1 study, several dry and wet GTR technologies were evaluated. One of the limitations of dry GTR technologies for further implementation by state DOTs has been that the performance grade of the binder (required for Superpave mix design) cannot be verified since the modification of the binder provided by the GTR is intended to occur during production. Asphalt mixtures have been primarily designed using the Superpave mix design methodology, where proportioning of mixture components relies on volumetric requirements. The increased use of recycled materials in asphalt mixtures, along with the adoption of nontraditional asphalt binder modifiers, has prompted a shift among agencies toward a balanced mix design (BMD) methodology. BMD is defined as a mix design procedure that utilizes performance tests to address multiple modes of distress, taking into consideration mix aging, traffic, climate, and location within the pavement structure. A BMD mixture is designed to achieve an optimal balance between rutting resistance and cracking resistance rather than relying on volumetric requirements. Since BMD relies on mixture performance tests rather than volumetrics, it incentivizes innovation for the inclusion of new technologies, such as dry GTR products, in the design of quality asphalt mixtures. Results from the 2021 AG study may further promote the implementation and utilization of BMD and non-traditional materials.

3 SUMMARY AND CONCLUSIONS

- Research conducted at the NCAT Pavement Test Track showed that dense-graded mixes produced with GTR-modified binder (S7 in 2009) had comparable performance to mixes containing SBS-modified binder, and therefore represent suitable alternatives for SBS-modified mixes.
- PFC mixes with GTR-modified binder (S1 in 2012) showed higher noise absorption initially, but it decreased at a greater rate than the SBS section over time.
- PFC mixes with GTR modified binder (E10 in 2012) showed comparable performance to mixes containing cellulose fiber, and synthetic fibers to prevent drain-down potential and provide overall improved durability.
- Gap-graded GTR mixes have been successfully placed on the NCAT Pavement Test Track on the top (S13 in 2015), middle (N13B in 2018), and bottom (S13 in 2012) of pavement structures to prevent new and/or reflective cracking. This type of mix is a premium specialty mix designed to provide a uniquely high level of cracking resistance for placement in high-strain environments (e.g., jointed concrete overlays). Additionally, there is currently no conventional alternative to gap-graded recycled tire rubber mixes that has been proven to provide a comparable level of cracking performance.

- Asphalt pavements that contain recycled tire rubber should provide a life cycle value that is at least as good as a conventional mix. If it costs more to produce, it should pay for itself through a longer life.
- Newly developed and emerging technologies that eliminate the need for an asphalt producer to store suspended GTR particles in their asphalt storage tank may reduce industry opposition and accelerate adoption. BMD may incentivize the use of nontraditional materials and additives, such as GTR, recycled plastic, and high-strength aramid fibers.
- The 2021 AG study is expected to quantify the impact of additives on pavement performance and validate a laboratory framework for future evaluations.

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