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Promotion of the Cost-Effective Use of Recycled Tire Rubber in Pavement Construction, Maintenance, and Preservation on the 2015 NCAT Pavement Test Track

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1 INTRODUCTION

The NCAT Pavement Test Track was originally constructed as a result of the interest and support from state Departments of Transportation (DOTs) who shared a concern for building and maintaining safe and cost-effective pavement infrastructure. Track research operations began in the summer of 2000, and 46 200-ft test sections were subjected to 10 million equivalent single axle loadings (ESALs) of heavy truck traffic through December 2002. Positive experiences with implementable findings that reduce the life cycle cost of flexible pavements and facilitate rapid deployment of sustainable technologies have made Test Track research an outstanding investment for numerous state DOTs, who pool their resources to share the cost of construction, operations, and research in a cooperative manner. Test sections were rebuilt in 2003, 2006, 2009, and 2012, with 10 million ESALs applied within each three-year research cycle.

The summer 2015 rebuild was the starting point for the sixth research cycle, with many high-reward studies available for potential sponsors. Two of these multi-state research cooperatives were ideal investments for the Alabama Department of Environmental Management (ADEM) to promote the cost-effective use of recycled tire rubber (RTR) in pavement construction, maintenance, and preservation to the Alabama Department of Transportation (ALDOT), eighteen other partner state DOTs, and the Federal Highway Administration (FHWA). ADEM's proposed participation in the sixth research cycle consisted of RTR sections in the Cracking Group (CG), and Preservation Group (PG15) experiments. The purpose of the Cracking Group was to validate asphalt mixture cracking tests using surface mixtures designed with a range of recycled materials that include RTR, binder grades and types and in-place densities. The Preservation Group study's objective is to quantify the life-extending and condition-improving benefits of different pavement preservation treatments (effort currently ongoing).

For the Cracking Group section, all three asphalt pavement layer mixes were produced using RTR. The most innovative technology used in this section was the highly crack resistant "Arizona rubber" gap graded asphalt mix produced with 20% coarsely ground RTR. ALDOT's interest in specifying this mix inspired its use as the surface mix in structural section S13 (i.e., south tangent section number 13) as a key treatment in the Cracking Group study. In addition to demonstrating the cracking performance potential of "Arizona rubber" surface mix (ARSM), being able to identify laboratory tests that predict cracking performance was important to successful implementation. Similarly, the objective of the proposed Preservation Group research in section E6 (i.e., east curve section number 6) was to promote the use of RTR in pavement preservation. In this section, liquid asphalt modified with 20% coarsely ground RTR was used as tack material to bind 100% coarse fractionated reclaimed asphalt pavement (RAP) to the surface of an existing aged pavement versus a conventional #7 granite chip seal stone pre-coated with liquid asphalt. This process is referred to as an asphalt rubber chip seal (ARCS).

1.1 Project Objective

ADEM sponsored two research experiments in the NCAT Test Track's sixth cycle, the Cracking Group, and the Pavement Preservation Group, to promote RTR for Alabama DOT's implementation in pavement construction as well as pavement maintenance and preservation in the state. NCAT would facilitate an Implementation Roadmap to:

1. Document positive construction and short-term performance of both ARCS and ARSM as a function of time and traffic on the NCAT Pavement Test Track with Phase I funding;
2. With Phase II funding, document positive long-term performance and work with ALDOT to develop special provisions for both ARCS and ARSM;
3. Host an open house at the track for county engineers and ALDOT maintenance personnel, including distribution of special provisions;
4. Assist ALDOT maintenance personnel and county engineers in project selection, with a goal for an increasing number of projects each year (as funds allow);
5. Provide technical support for ALDOT maintenance personnel and county engineers from project development to construction; and
6. Promote successes by making presentations at select meetings.

2 BACKGROUND ON RTR RESEARCH AT THE NCAT TEST TRACK

Starting in 2009, NCAT has been actively involved in the field performance and laboratory evaluation of different RTR 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. Researchers have evaluated two traditional wet processes on the track to incorporate RTR: terminal blended binders and asphalt rubber binders. The following sections summarize key findings of this research in chronological order.

2.1 NCAT Test Track Phase IV

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

In 2009, the Missouri DOT sponsored test sections S6 and S7 at the NCAT Test Track to determine if RTR 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 (cracking or rutting) 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 RTR modified binder. The RTR 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 RTR modified binder was graded as a PG 76-22. Another difference between the two mixtures was their binder content, as the RTR modified asphalt mixture had an additional 0.6% 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 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 RTR section. In addition, both mixtures showed consistent MTD values near or below 0.5 mm and IRI values of approximately 50 in/mi for the entire research cycle. The field performance results suggested that RTR mixtures could perform as well as SBS modified mixtures.

2.2 NCAT Test Track Phase V

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

The SBS and RTR sections (S6 and S7) sustained a total of approximately 10 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, Seneca Petroleum decided to sponsor the trafficking continuation on the RTR section due to its excellent performance to assess its long-term performance (*2*). With an additional 10 million ESALs of traffic, the rutting remained approximately the same at 5 mm. The section did not show any 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 RTR section proved its long term durability and suitability as substitute for SBS modified mixtures.

Constructing Quiet Pavement using RTR-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% RAP. The PFC mixture in Section W10 used a SBS modified PG 76-22 binder while Section S1 was modified with 12% RTR 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 RTR section but became greater than the SBS section over time. Initially, noise absorption was higher for the RTR 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 RTR section, but the difference in smoothness was likely due to construction variability, as the values for both sections were relatively constant over time *(2).*

Evaluating Durability of RTR-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% RTR by weight of binder and was constructed without fibers to determine if RTR alone could prevent drain-down and resist raveling. The three mixes were verified during the mix design process to pass the maximum Cantabro loss of 15% in order to have 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 RTR 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.

Evaluating the Use of RTR Modified Binders for Enhancing Structural Pavement Performance

Alabama DOT, ADEM, North Carolina DOT, South Carolina DOT, and Tennessee 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), recycled tire rubber (RTR), and reclaimed asphalt pavement (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 high tensile strains. Section N5 (standard RAP) was the control section representing the current standard practices for mix designs, 20% RAP in the surface layer and 35% RAP in lower layers, while the other sections used 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, the bottom used 35% RAP, and 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. The RTR Section S13 included two RTR modified binders. The SMA surface and dense-graded intermediate lifts contained 12% #30-mesh RTR added to a PG 67-22 binder, abbreviated as ARB12 (asphalt-rubber binder with 12% RTR). No fibers were added to the RTR modified SMA since RTR 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 RTR (ARB 20 AZ).

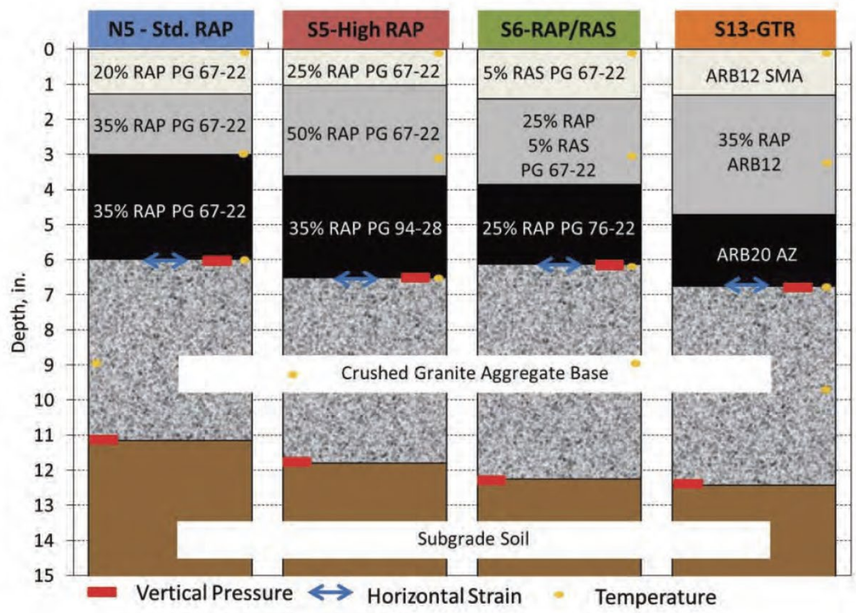


Figure 1 2012 Green Group Sections *(2)*

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 being needed to determine durability ranking in the field.

Results of the SVECD testing showed that the high 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 was outperformed any of the mixtures at different strain levels. The control section N5 reached the cracking threshold (25% of 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 design 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 rehabilitation with a highly polymer modified mix, and surface conditions were initially improved, pre-maintenance distress levels were rapidly exceeded. Section S13 containing RTR 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 RTR 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 RTR economic impact.

2.3 NCAT Test Track Phase VI

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 materials contents, binder types and grades, and in-place densities with the goal of covering 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 inches per layer. The asphalt pavement cross-section was purposely 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" and it represents 70,000 cumulative degree days (CDD) of in-situ aging, which is 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 considerations.

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 Test Track Phase VII

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 w HiMA	91.8	0	0.9
S13	AZ Rubber Mix	92.7	0	0

Projected base on data after 16 million ESALs

Evaluating Reflective Cracking Interlayer Including RTR 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, OGI, and RTR modified 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), N12-B (PETROMAT fabric), and N12-C (chip seal with 7# stone). A PG 64-22 asphalt binder was used as tack coat for N12-A and N12-B subsections with an application rate of 0.30 and 0.27 gallon/sq. yard, respectively. CRS-2h emulsion tack was applied onto the existing pavement of N12-C subsection with a residue rate of 0.23 gallon/sq. yard. A 50 mm thick 9.5 mm NMAS Superpave mix was placed as the surface layer for these three subsections. Section N13 was also divided into three subsections for different treatment methods, which included N13-A (chip seal using reclaimed asphalt pavement), N13-B RTR modified asphalt interlayer), and N13-C (OGI). CRS-2h emulsion tack was applied onto the existing pavement of N13-A subsection with a residue rate of 0.23 gallon/sq. yard. UltraFuse trackless tack was used for subsections N13-B and N13-C with an application rate of 0.25 gallon/sq. yard. The same Superpave mix was used as the surface layer with a thickness of 50mm for N13-A, and 38 mm for N13-B and N13-C, respectively.

At the completion of the research cycle, no reflective cracking was observed in any of the sections. Traffic continuation was performed on these sections and their field performance was monitored in the following research cycle.

3 PHASE VI RESEARCH APPROACH

Since ADEM participation in this study focused on research conducted during Phase VI of the NCAT Test Track, the research approach is presented in this section. Following completion of construction in the summer of 2012, truck traffic was initiated in the fall and was completed in

2014. A final report documenting Phase VI research findings is available on the NCAT website *(3).* The specific research funded by ADEM in this project included the following seven tasks:

Task 1 – Practical ways to use RTR in pavement construction

NCAT consulted with ALDOT and the Alabama Asphalt Pavement Association (AAPA) to determine how to optimize the use of RTR in pavement construction. Consideration of alternatives began with a literature review to develop a comprehensive list of possible methods. This list was shortened by working with AAPA and ALDOT to establish practical limits on implementation. For example, some exotic methods may increase the use of recycled tire rubber; however, they could not be considered good candidate technologies if they would not be approved by ALDOT or embraced by the industry.

Task 2 – Design mixes in the laboratory using select candidate technologies

A short list of formulations were blended in the laboratory, with performance specimens prepared for optimized mixes. Specimens were subjected to laboratory performance testing suitable for their location in the pavement structure. Specimens representing all layers were tested in the Asphalt Mixture Performance Tester (AMPT) in order to define unique stiffness master curves. Surface mixes were tested in the Asphalt Pavement Analyzer (APA), and beam fatigue testing was performed on all base layers.

Task 3 – Model performance using laboratory performance data

Data from Task 2 was used to model performance on the NCAT Test Track using mechanistic-empirical methodologies. Multiple combinations of selected mixtures were utilized to determine the ideal combination of methods and materials for placement on the track.

Task 4 – Mix designs and construction of experimental pavements

The ARSM placed in section S13 was an Arizona-style Marshall mix design with a 12.5-mm nominal maximum aggregate size (NMAS) gap-graded aggregate gradation and an asphalt-rubber binder with 20% #16-mesh GTR (ARB20). This mix was designed based on the methodology discussed in an FHWA report published in 2012 *(5).* Relevant pages from this reference are provided in Appendix A. The ARCS was placed in section E6 following industry standard rates for both chips (targeting 25 to 30 pounds per square yard) and GTR-modified binder (targeting 0.65 gallons per square yard). Trial mixes for the ARSM and ARCS were produced and placed on August 13, 2015. The final mixes were produced and placed on August 14, 2015. Over 30 showcase ALDOT guests observed the placement of ARSM and ARCS. Figure 2 through Figure 4 show the placement, compaction, and completed ARSM surface for Section S13. Figure 5 includes a construction report for the ARSM. The as-constructed total binder content of S13 was 7.4%, and the ARSM contained 15% coarse fractionated RAP.

Figure 2 ALDOT Showcase Attendees Observe Placement of ARSM in Section S13

Figure 3 Compaction of ARSM in Section S13 during ALDOT Showcase

Figure 4 Completed ARSM Test Section S13

Quadrant: S
Section: 13
Sublot: 1

Laboratory Diary

General Description of Mix and Materials

Design Method:	AZ
Compactive Effort:	75 blows
Binder Performance Grade:	ARB20
Modifier Type:	GTR
Aggregate Type:	Granite/Sand/C-RAP
Design Gradation Type:	GAP

Avg. Lab Properties of Plant Produced Mix

Sieve Size	Target	QC
25 mm (1"):	100	100
19 mm (3/4"):	100	100
12.5 mm (1/2"):	96	96
9.5 mm (3/8"):	79	85
4.75 mm (#4):	40	35
2.36 mm (#8):	24	22
1.18 mm (#16):	19	19
0.60 mm (#30):	12	14
0.30 mm (#50):	7	8
0.15 mm (#100):	5	5
0.075 mm (#200):	3.4	3.6
Binder Content (Pb):	7.4	7.4
Eff. Binder Content (Pbe):	6.7	6.7
Dust-to-Eff. Binder Ratio:	0.6	0.5
RAP Binder Replacement (%):	7.5	7.5
RAS Binder Replacement (%):	0.0	0.0
Total Binder Replacement (%):	7.5	7.5
Rice Gravity (Gmm):	2.418	2.402
Bulk Gravity (Gmb):	2.273	2.319
Air Voids (Va):	6.0	3.4
Agg. Bulk Gravity (Gsb):	2.649	2.63
VMA:	19.9	18
VFA:	71	81

Construction Diary

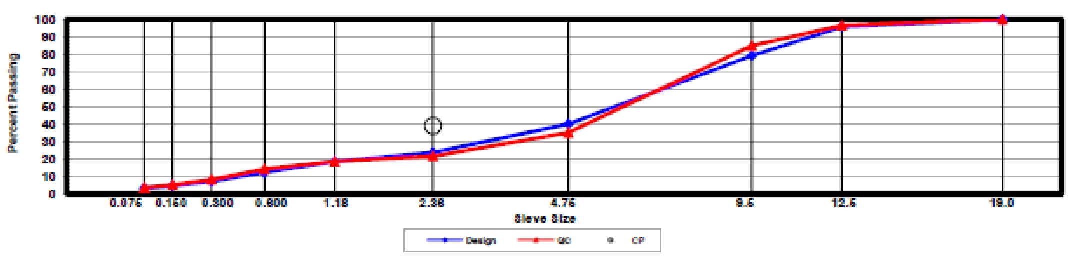
Relevant Conditions for Construction

Completion Date:	August 14, 2015
24 Hour High Temperature (F):	91
24 Hour Low Temperature (F):	73
24 Hour Rainfall (in):	0.00
Planned Subot Lift Thickness (in):	1.5
Paving Machine:	Roadtec

Plant Configuration and Placement Details

Component	% Setting
Binder Content (Plant Setting)	7.4
78 Granite	55.0
89 Granite	19.0
Coarse Sand	11.0
EAP Coarse RAP	15.0
Evotherm P15	0.5

As-Built Sublot Lift Thickness (in):	1.6
Total Thickness of All New Sublots (in):	6.7
Approx. Underlying HMA Thickness (in):	5.0
Type of Tack Coat Utilized:	NTSS-1HM
Undilluted Target Tack Rate (gal/sy):	0.10
Approx. Avg. Temperature at Plant (F):	305
Avg. Measured Mat Compaction:	92.7%



General Notes:
- References are by quadrant (E=East, N=North, W=West, S=South, L=Lee Rd 159, U=US-280), section #, and sublot (top=1).
- DGA, SMA, & OGFC refer to dense graded asphalt, stone matrix asphalt, & open-graded friction course, respectively.
- Production Gsb estimated using the actual production Gse and the difference between Gse and Gsb in the mix design.

Section and/or Sublot Specific Notes:
Binder for this surface mix contained 20% (by total binder mass) -#16 mesh ground tire rubber to build on the success of the base layer in S13 on the 2012 Track, this time in a surface mix application at the request of ALDOT in order to support implementation of the new mix technology.

Figure 5 ARSM Construction Quality Data

The ARCS was placed in the afternoon of August 14, 2015, as the second part of the ALDOT showcase. The measured rate of the asphalt rubber binder was 0.43 gallons per square yard. The measured chip rate was 28 pounds per square yard. The temperature of the distributor was 232°C. Figure 6 and Figure 7 show the chip rate calibration and tack application. Two chip types were applied, including coarse fractionated RAP (Figure 8) and coated #7 granite chips (Figure 9), before compaction (Figure 10). Figure 11 shows the completed ARCS surface for Section E6.

Figure 6 **Chip Rate Calibration for ARCS**

Figure 7 **Hot Liquid Tack Application for ARCS**

Figure 8 **Coarse Fractionated RAP (C-RAP) Application for ARCS**

Figure 9 **Coated #7 Granite Application for ARCS**

Figure 10 **Rubber Tire Rolling to Seat Chips for ARCS**

Figure 11 Completed ARCS in Section E6 (Coated #7 Granite Chips on Left, C-RAP on Right)

Field Performance of ARCS Surface in Section E6

After approximately 1.4 million ESALs, the ARCS surface in Section E6 started experiencing flushing (Figure 12), and bleeding and delamination occurred after 2.6 million ESALs (Figure 13). Due to a reduction in the budget originally allocated to conduct this research (as discussed previously in Section 1.3), it was not possible to conduct any forensic investigation to determine causes for the early failure in this section.

Figure 12 Flushing of ARCS in Winter 2016 After 1.4 Million ESALs in 170 Days (Coated #7 Granite Chips on Left, C-RAP on Right)

Figure 13 Bleeding and Delamination of ARCS in Summer 2016 After 2.6M ESALs in 270 Days

Task 5 – Apply a design lifetime of pavement damage

Following construction completion, NCAT's fleet of heavy triple trailer trucks was used to apply a design lifetime of pavement damage (10 million ESALs) in approximately two years. Fleet operations were documented to facilitate the construction of a comprehensive strain history, and surface performance measurements were made on a weekly basis so that change in pavement condition resulting from the previous week of truck traffic was precisely known.

Task 6 – Compare section performance to experimental control

The timing of fleet operations was carefully planned to provide short, mid, and long term pavement performance data. Early fleet operations provided an excellent opportunity to challenge experimental pavements immediately after construction when the weather was hot and properties of the mat would still be changing significantly. In the second summer, after mixes had aged for approximately one year, a significant amount of age hardening had occurred. In the third summer, after two years of age hardening, the majority of expected stiffness change had occurred, and response was representative of long term expectations. Weekly performance measurements in the ground tire rubber test section were compared to the control section on a weekly basis in every phase of the aging process.

Task 7 – Promote findings via peer reviewed paper(s) and technical presentations

Results from the previously mentioned tasks were packaged into peer reviewed technical paper(s) that documented NCAT's experience with mix design, laboratory characterization, performance modeling, construction quality, and field performance measurements. Results were shared with the sponsor oversight group, with special focus on communication of findings directly to ALDOT. Specification changes were recommended, which are intended to result in a significant increase in the use of recycled tire rubber for pavement construction.

4 BUDGET RECAPITULATION

A breakdown of the direct and nonprofit overhead (indirect) costs for Phases I and II are shown below. The focus of Phase I was planning, construction, short-term traffic, and initial performance. The focus of Phase II was long-term traffic, final performance, and implementation. Direct costs included the cost of labor for operations and research, NCAT Service Center costs (for laboratory testing essential for implementation), Track Service Center costs (for fleet operations), and other direct costs (e.g., necessary pavement instrumentation, travel to present findings that promote implementation, etc.) as follows:

Phase I – Planning, Construction, Short-Term Traffic, and Initial Performance

$92,350	for Research Labor and Benefits
$51,796	for Laboratory Testing
$155,684	for Track Fleet Operations
$4,223	in Other Direct Costs (Travel, Supplies, etc.)
$145,946	in Indirect Cost Recovery
$450,000	in Phase I Cost

Phase II – Long-Term Traffic, Final Performance, and Implementation

$277,297	for Track Fleet Operations
$20,000	in Other Direct Costs (Travel, Supplies, etc.)
$142,703	in Indirect Cost Recovery
$100,000	Pavement Condition Data Collection Equipment
$540,000	in Phase II Cost
$990,000	in Total Cost for Phase I and Phase II

ADEM unilaterally elected to provide $450,000 to partially fund promotion of the cost-effective use of RTR in pavement construction, maintenance, and preservation on the 2015 NCAT Pavement Test Track. With less than half of the nonprofit cost to execute the proposed study, it was necessary to significantly reduce the scope of work and scale back expenditures. For example, no forensic studies were conducted to determine why surface treatment failed and how it could be corrected. Although significant adjustments to the proposed budget were required, no project funds were spent without explicit ADEM approval. The total nonprofit cost of the PG15 study was $5.8 million, and the total nonprofit cost of the CG study was $6.3 million (for a total cost of the two experiments of $12.1 million). The NCAT Pavement Test Track is a nonprofit research endeavor, and the cost to execute each research cycle is minimized in a very deliberate way. Through cooperative funding, the cost of the research was significantly shared between ADEM, approximately 20 state DOTs, and two private sector entities.

Only labor necessary for the proper execution of ADEM research was charged to this project. This included principal investigators (PIs), graduate student(s), and associated benefits charges, calculated at the federally audited rate for all projects. Indirect cost recovery is a mechanism in the federal accounting guidelines to fund expenses that are essential to the execution of nonprofit research but are not specific research expenses. Auburn University's rate for indirect cost recovery is fixed from the time a project is initiated in accordance with federal accounting guidelines and NCAT receives no budget allocation to cover these costs. No direct project expenses (e.g., costs for laboratory testing, test section construction, fleet operations, etc.) can be funded from indirect cost recovery, which is limited by law to non-research, nonprofit overhead costs. Federal accounting guidelines must be followed on all nonprofit Auburn University projects; consequently, this is something that cannot be changed.

The cost of laboratory testing was recovered through the NCAT Service Center. "Fleet operations" is an all-inclusive cost to apply a design lifetime of pavement damage to experimental pavements in an accelerated manner. This includes trucks, trailers, drivers, fuel, tires, maintenance, etc. Incidental costs for fleet operations were recovered through the Track Service Center's (Track SC) budget line items. Essential instrumentation for the ground tire rubber focused CG section and travel to present findings in the promotion of implementation were categorized as "Other Direct Costs" simply because they did not fit into other budget categories.

5 PROJECT ACCOMPLISHMENTS AND RESULTS

This project accomplished the successful planning, construction, and traffic monitoring of test sections with RTR at the NCAT Test Track. Laboratory testing to aid in the planning process began in fall 2014, preparations to rebuild the track began in March 2015, and construction of experimental pavements began in the spring to early summer of 2015. Truck traffic began in fall 2015 and was completed by fall 2017. Phase I research consisted of test section construction and proof of short-term performance potential. Although the Phase II research of this project to produce proof of long-term performance and support implementation was unfunded, the successful experience gained with the use of RTR supported follow up activities at the NCAT Test Track, Phase VI cycle.

- *Traffic continuation of S13:* The need to continue monitoring the CG sections to assess the different cracking performance tests and the excellent performance of the ARSM promoted traffic continuation of S13 for another test cycle.
- *Inclusion of S13 surface in GDOT interlayer study:* The successful performance of S13 promoted the inclusion of ARSM in the GDOT interlayer study currently under evaluation.

6 ONGOING WORK

6.1 Phase VIII Track

6.1.1 Promotion of 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 RTR (wet and dry), plastics (wet and dry), reactive polymers, and fibers to provide sustainable and resilient technologies with the potential of outperforming current materials. 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 Track. The additives selected by the sponsors included two RTR technologies (one wet and one dry), two plastic technologies (one wet and one dry), and one high strength aramid fiber additive.

6.1.2 New Dry RTR Technologies

As presented in previous sections, experience at the NCAT Test Track with RTR has been limited to wet RTR technologies; however, RTR technologies have evolved over the years, and new dry RTR technologies claim to address past problems with the production and placement of RTR modified mixtures while providing enhanced pavement performance. For Phase VIII of the NCAT Test Track, two dry RTR 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, RTR, and other additives. The RTR 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 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 consists of a finely ground recycled tire rubber that has been chemically modified to significantly improve rutting and cracking resistance in asphalt pavements. 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.

6.2 Recycled Tire Rubber in Balanced Mix Design

As mentioned previously, as part of the AG Phase 1 study, several dry and wet RTR technologies were evaluated. One of the limitations of dry RTR 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 RTR 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, as well as the use of nontraditional asphalt binder modifiers, has encouraged a shift by agencies toward a balanced mix design (BMD) methodology. BMD is defined as a mix design procedure that uses performance tests to address multiple modes of distress while 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 RTR products to design quality asphalt mixtures. Results from the 2021 AG study may further promote BMD implementation and utilization of nontraditional materials.

7 SUMMARY AND CONCLUSIONS

- ALDOT has an existing recycled tire rubber modified binder specification, but it has not been able to compete with conventional polymer modified asphalt binder in dense graded mixes.
- Asphalt pavements that contain recycled tire rubber must provide life cycle value that is at least as good as conventional mix. If it costs more to produce, it must pay for itself through longer life.

- Gap-graded recycled tire rubber mixes are premium specialty mixes designed to provide a uniquely high level of cracking resistance for placement in high strain environments (e.g., jointed concrete overlays).
- Rubber particle sizes required for gap-graded recycled tire rubber mixes (#16 to #20 sieve) are larger than those typically used for dense-graded mixes (#30 to #40 sieve).
- Gap-graded recycled tire rubber 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.
- Arizona mix design practices and construction specifications for gap-graded recycled tire rubber mixes have been used successfully with Alabama material at the NCAT Pavement Test Track and are available for adoption by ALDOT.
- There is not currently a conventional alternative to gap-graded recycled tire rubber mixes that has been proven to provide a comparable level of cracking performance.
- Coarse fractionated RAP can be used to replace a significant amount of the virgin rock needed to produce gap-graded recycled tire rubber mix and increase sustainability.
- Each time gap-graded recycled tire rubber mixes have been placed on the NCAT Pavement Test Track, warm mix additive technology has been used to reduce production temperature and prevent an increase in odor.
- Newly developed and emerging technologies that eliminate the need for an asphalt producer to store suspended recycled tire rubber particles in their asphalt storage tank may reduce industry opposition and accelerate adoption.
- Gap-graded recycled tire rubber mixes represent the best implementation option for recycling ground tires in asphalt pavements in a manner that provides greater life cycle value than conventional mixes.
- BMD may incentivize the use of nontraditional materials and additives, such as RTR, 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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APPENDIX A
– Excerpts from Pages 21-25 of FHWA-HRT-11-045 Publication in 2012

ARIZONA WET PROCESS CRUMB RUBBER MODIFIED ASPHALT

A firm in Phoenix, AZ, developed the blending and modification of the CR-AZ asphalt binder. An unmodified base binder meeting PG58-22 was used along with recycled crumb rubber particles shown in table 4. The blend consisted of 17 percent crumb rubber and 83 percent asphalt binder. Table 5 provides the physical properties of the crumb rubber asphalt binder blend held at 399 °F (204 °C) at various time intervals up to 24 h to evaluate the storage stability of the binder.

Table 4. Recycled crumb rubber particle size in CR-AZ binder.

Sieve Size (mm)	Sieve Number	Percent Passing	Arizona Test Method 714 Gradation Limits[23]
2.36	8	100	100
2.00	10	100	100
1.18	16	98.3	65–100
0.600	30	51.3	20–100
0.300	50	11.9	0–45
0.075	200	0.6	0–5

1 mm = 0.039 inches

Table 5. Physical properties of CR-AZ binder during blending.

Test	Minutes of Reaction 60	90	240	360	1,440	ASTM D6114 Type-I Limits[24]
Viscosity, Haake at 177 °C, cP	2,500	2,900	3,100	3,100	2,900	1,500–4,000
Resilience at 25 °C, percent rebound (ASTM D5329)[25]	36	—	36	—	41	25 minimum
Ring and ball softening point, °F (ASTM D36)[26]	147.0	150.0	150.0	149.0	149.0	130 minimum
Needle penetration at 4 °C, 200 g, 60 s, 1/10 cm (ASTM D5)[27]	29	—	30	—	31	15 minimum

°F = 1.8(°C) + 32
1 g = 0.035 oz
1 cm = 0.39 inches
— Indicates test data were not measured at every point in time.

The size of the crumb rubber particles in the modified asphalt limited the ability to age and test the binder in standard instruments for the PG grading system. The unaged crumb rubber asphalt binder was successfully tested in the DSR, and the temperature at which it met the specification criteria $|G^*|/\sin\delta$ value of 0.145 psi (1 kPa) at 10 radians/s was 202 °F (94.4 °C). The binder could not be successfully aged in the rolling thin film oven (RTFO) and pressure-aging vessel (PAV) or tested in the DSR for the high-temperature rutting specification criteria $|G^*|/\sin\delta$ value of 0.32 psi (2.2 kPa) and intermediate-temperature fatigue cracking specification criteria of $|G^*| \times \sin\delta$ value of 725 psi (5,000 kPa).

The CR-AZ binder was characterized a second time in a more comprehensive manner. The original unaged binder was tested in the DSR using 0.975-inch (25-mm)-diameter plates but with a 0.078-inch (2-mm) gap rather than the standard 0.039-inch (1-mm) gap. The binder did not run out from between the plates and could be trimmed satisfactorily. The original high-temperature PG was 195.98 °F (91.1 °C), which was similar to the 194.18 °F (90.1 °C) PG determined in the earlier characterization. The binder was then aged in an RTFO oven that was tilted backwards to the limit of the specification to prevent the binder from coming out of the bottles. The binder did not completely coat the bottles. The RTFO-aged binder was then characterized in the DSR using 0.975-inch (25-mm)-diameter plates with a 0.078-inch (2-mm) gap. The RTFO high-temperature PG was 187.52 °F (86.4 °C), which was lower than the estimated value discussed above. The binder was then aged in a PAV, degassed, and characterized in a DSR with a 0.312-inch (8-mm)-diameter plate and a 0.078-inch (2-mm) gap as well as a BBR. The intermediate PG was 53.42 °F (11.9 °C), which was lower than the estimated value discussed above. The low temperature PGs from the BBR S-value and m-value were -35.14 and -30.64 °F (-37.3 and -34.8 °C), respectively.

Table 6. Laboratory mix design evaluation of volumetrics.

Asphalt Binder Type	PG70-22	CR-AZ	Air Blown	SBS-LG	CR-TB	Terpolymer	Fiber	SBS 64-40
Lane	1 (bottom), 2 and 8	1 (top)	3 and 10	4 and 11	5	6 and 12	7	9
Total binder content, percent by mass	5.3	7.1	5.3	5.3	5.3	5.3	5.3	5.3
Effective binder content, percent by mass	5	6.6	5	4.9	5	5	5	4.9
Asphalt binder absorption, percent by mass	0.3	0.5	0.3	0.4	0.3	0.3	0.3	0.4
Effective binder content, percent by total volume	12.5	16	12.6	12.7	12.6	12.5	11.9	12.7
Dust, percent passing the 75-μm sieve	6.3	3	6.3	6.3	6.3	6.3	6.3	6.3
Dust to effective binder content	1.26	0.45	1.26	1.29	1.26	1.26	1.26	1.29
Specific gravity of binder	1.03	1.028	1.026	1.023	1.019	1.024	1.03	1.005
Design air voids, percent	5	5.5	4.1	4.2	4.6	4.9	4.8	3.6
VMA at design air voids, percent	17.5	21.5	16.7	16.9	17.3	17.5	18.1	16.3
VFA at design air voids, percent	71.2	74.5	75.4	75.2	73.3	72.1	65.9	78.2
Maximum specific gravity	2.704	2.627	2.703	2.700	2.700	2.701	2.705	2.699
Effective specific gravity of aggregate	2.975	2.981	2.975	2.971	2.974	2.973	2.976	2.981
Bulk dry specific gravity of aggregate	2.947	2.948	2.947	2.947	2.947	2.947	2.934	2.947

1 μm = 0.039 mil

Gap-Graded Crumb Rubber Mix Design

The CR-AZ mixture was designed according to the Arizona Department of Transportation's asphalt-rubber asphaltic concrete design specifications.[30] Five materials were used: No. 68 diabase, No. 78 diabase, No. 8P diabase, No. 10 diabase, and hydrated lime. The aggregate blending percentages were 32.7 percent No. 68 stockpile, 46.5 percent No. 78 stockpile, 8.9 percent No. 8P stockpile, and 10.9 percent No. 10 screenings. In addition, 1 percent hydrated lime was used. The 75 blow-per-side Marshall Method was used for the mixture design. The compaction temperature was 325 °F (163 °C). The volumetric requirements were that the air voids had to be between 4.5 and 6.5 percent and the VMA had to be a minimum 19.0 percent. Four asphalt binder contents were tried: 6.0, 7.0, 8.0, and 9.0 percent. The optimum asphalt binder content was found to be 7.1 percent and may appear lower than typical contents near 8 percent for this type of mixture. However, the effective volumetric binder content was 16 percent, and the high specific gravity of the diabase aggregate (2.98) can make gravimetric binder contents appear lower. If the aggregate specific gravity was lower (i.e., around 2.7), then the gravimetric binder content would have been around 7.8 percent.