Summary of Findings for Section N7 at the NCAT Pavement Test Track:

Surface Paving with 35% RAP Content and Delta S

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Field Evaluation of High RAP Mixture with Delta S Rejuvenator

It is a common practice among producers to use recycled asphalt pavement (RAP) as a component in new asphalt mixtures. Most state highway agencies allow up to 25% RAP to be used in their asphalt mixtures with the nationally average RAP content being 20.1% in 2017 (*2*). The amount of RAP allowed in asphalt mixtures has not increased over the years likely due to concerns that using higher proportions of RAP could result in asphalt mixtures that are prone to cracking and/or other durability issues.

Several methods have been investigated to reduce the potential effect of RAP binder on the field performance of asphalt mixtures. One method is to use rejuvenators to restore some rheological properties of oxidized asphalt binders in RAP mixtures. These rejuvenators can be petroleum-based or bio-based materials that have been formulated to restore the balance of maltenes that were lost or transformed to asphaltenes in the oxidized RAP binder.

Delta S is a bio-based, commercially available rejuvenator developed by Collaborative Aggregates for use in recycled asphalt mixtures. This rejuvenator was used in an asphalt mixture with recycled materials placed in the surface layer of Section N7 for field performance evaluation on the NCAT Pavement Test Track.

Construction of Section N7

The surface layer of Section N7 at the NCAT Pavement Test Track was originally built in July 2015 using a 9.5-mm nominal maximum aggregate size (NMAS) mixture with 20% RAP and 5% recycled asphalt shingles (RAS). The Delta S rejuvenator was added to the virgin PG 67-22 binder at a dosage of 10% by weight of the recycled binders available in the RAP and RAS materials.

After approximately four months of truck trafficking (1.8 million ESALs), the original surface showed slippage cracks. The cores extracted from this layer suggested that the cracks were caused by delamination between the surface and intermediate asphalt layers. An evaluation of the original surface mixture conducted later found that the delamination was not caused by a weak bond strength (a common cause of delamination), but in fact due to reduced stiffness and splitting tensile strength of the original surface mixture. This evaluation included field cores and specimens prepared using (1) laboratory-prepared mixtures that were unaged, 2-hour aged at 135°C, and 4-hour aged at 135°C and (2) reheated plant mix.

The original surface mixture was laid and compacted without any silo storage as it was produced and hauled to the Test Track (approximately 10 minutes away) for immediate paving. Because of the short haul, the interaction between Delta S (blended with the virgin binder) and the recycled binder, especially in the RAS, may not have been completed, leaving a higher proportion of Delta S in the virgin binder than originally intended. This caused a decrease in stiffness and splitting tensile strength, leading to slippage cracking problems in the original surface mixture.

After discussions with the sponsor, it was decided that the interaction between Delta S and the aged binder in the RAS should be further studied and that the wearing course of Section N7 would be replaced with a mixture containing only RAP materials. This mix would have 35% RAP with a recycled binder ratio similar to that of the original surface mixture in Section N7. Because this mix design did not include RAS (even though it had a similar recycled binder ratio), the Delta S

dosage was reduced to 5% by weight of the aged RAP binder, which was 5% lower than the dosage used in the original N7 surface mixture with 20% RAP and 5% RAS. The N7 surface mixture was redesigned to compare directly with the N1 surface mix with 20% RAP, which is the control mix for the Cracking Group experiment. Finally, it was determined that the mixture would be kept in a silo for two hours before paving so that the rejuvenator could interact with the RAP binder.

The corrective actions taken for the new surface mixture in Section N7 helped address the problems identified in the original surface mixture. To the end of the 2015 research cycle, the re-designed surface mixture in Section N7 endured around 7.5 million ESALs (compared to 1.8 million ESALs for the original surface mixture), and no slippage failures have been observed thus far.

Experimental Plan

The re-designed surface mixture with 35% RAP and 5% Delta S (by weight of the RAP binder) in Section N7 was compared to the surface mixture in Section N1 with 20% RAP. The cross-sections of the pavements included in this field evaluation are shown in Figure 1.

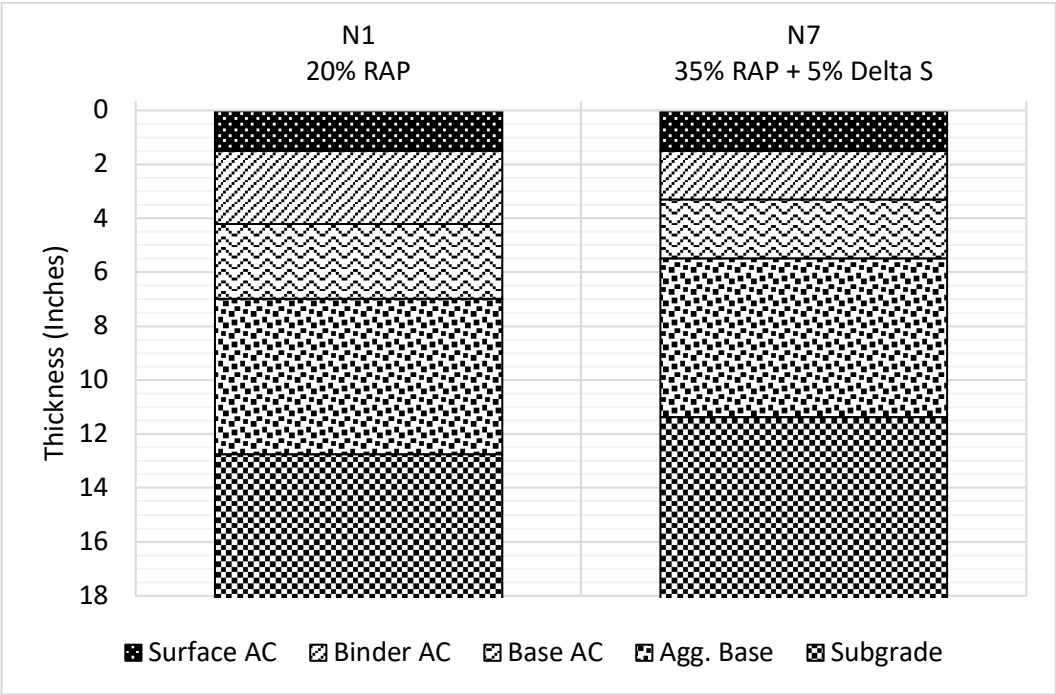

Figure 1. Pavement Structures of Sections N1 and N7 (AC = Asphalt Concrete).

A summary of properties for the two surface mixtures is shown in Table 1. The two mixtures were designed to meet the volumetric requirements specified in AASHTO M323 with a design compaction effort (N_{des}) of 80 gyrations. The base and binder asphalt layers in the two sections consisted of the same highly polymer-modified (HiMA) asphalt mixture, which was designed to be resistant to fatigue cracking so that all cracking would occur in the surface layer. The aggregate base layer consisted of a crushed granite base. The subgrade at the Test Track is classified as an A-4 material according to the AASHTO soil classification system. A brief description of each surface mixture follows.

- The surface layer of Section N1 was built using a 9.5 mm NMAS mixture with 20% RAP and a PG 67-22 virgin binder. It represents a typical asphalt mixture being used in the United States, where according to NAPA, an average of approximately 20% RAP is used in asphalt mixtures (2). This mixture was selected as the control mixture for the Cracking Group experiment, which was carried out at the NCAT Pavement Test Track as part of the 2015 research cycle.
- The surface layer of Section N7 was built with a 35% RAP surface mixture. The construction of this section was part of a study sponsored by Collaborative Aggregates to evaluate the effectiveness of Delta S on the field performance. To produce the N7 surface mixture, Delta S was in-line injected into the PG 67-22 binder supply at a target rate of 5% by weight of RAP binder. To give the Delta S time to interact with the aged binder in the RAP and to avoid issues related to slippage and de-bonding caused by mix softness, the mixture was stored in a silo for two hours before being transported to the Test Track for paving in Section N7.

Table 1. Surface Mixture Quality Control (QC) Properties

Mixture	Virgin Binder PG	As-built Thickness (in)	In Place $\%G_{mm}$	QC P_{be} (%)	QC V_a (%)	QC VMA (%)	Recycled Binder Ratio
N1 20% RAP	67-22	1.6	93.6	4.7	7.0	14.7	0.177
N7 35% RAP + Delta S	67-22	1.5	92.1	5.2	7.0	16.0	0.282

In addition to the field performance evaluation at the NCAT Pavement Test Track, samples of plant mix were taken during construction of the two sections and tested in the laboratory to determine the stiffness, rutting, and cracking resistance of these mixtures. These results were used to assist the field performance evaluation using the ride quality, rutting, and cracking measurements taken weekly at the NCAT Pavement Test Track.

Laboratory and Field Performance

The final measurements were taken after 10 million ESALs had been applied on Sections N1 and 7.5 million ESALs had been applied on Section N7 since the resurfacing of Section N7 with the re-designed surface mixture.

Table 2 shows the ride quality and rut depth results measured at the NCAT Pavement Test Track. The two sections had relatively low IRI readings (less than 1.1 m/km or 70 in/mile), indicating good ride quality at the end of the 2015 research cycle. The two sections had rutting measurements less than 5 mm, which was also considered in a good condition.

Table 2. Ride Quality and Field Rut Depth Measurements

Section	IRI (m/km)	Rut Depth (mm)
N1 20% RAP	1.1	1.8
N7 35% RAP + Delta S	0.9	3.3

Based on the field cracking measurements shown in Figure 2, the first appearance of hairline cracks was noticed in Section N1 shortly after 6 million ESALs and in Section N7 after 3.5 million ESALs (from the resurfacing with the re-designed surface mixture). The hairline cracks were less than 1 mm wide as shown in Figure 3. These cracks were manually surveyed as they were not detectable by an automated survey system. This information was reported for research purposes but should not be used to rank the performance of these test sections as these sections would show no cracks if they were surveyed using an automated cracking survey system. A shown in Figure 2, Sections N1 had a low percentage of hairline cracks up to 9 million ESALs, and Section N7 showed a low percentage of hairline cracks up to 6.5 million ESALs (from the resurfacing with the re-designed surface mixture). After that, hairline cracks grew quickly in these sections because of colder weather at the NCAT Pavement Test Track. At the end of the 2015 research cycle, the hairline cracks were observed in approximately 20 percent of the lane area in each section, and these cracks were still very tight (less than 1 mm wide) and undetectable by an automated cracking survey system.

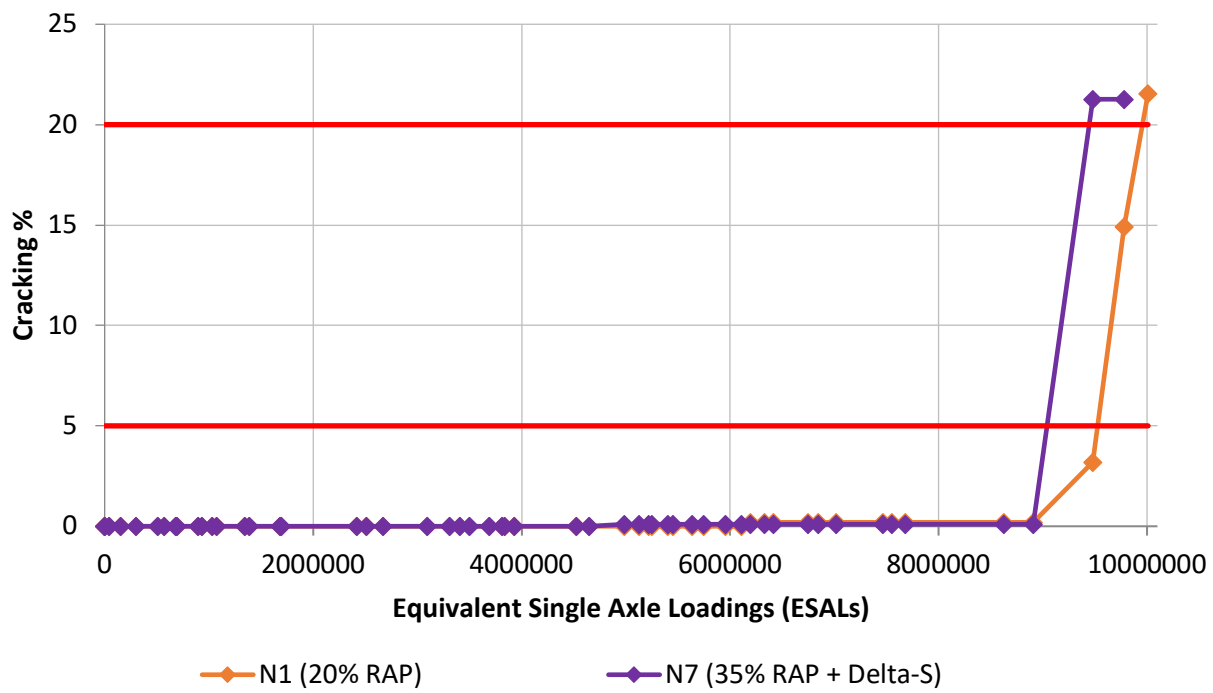

Figure 2. Field Cracking Measurements

Figure 3. Close-up of Hairline Cracks in Sections N7 and N1

Table 3 summarizes the laboratory test results performed on the plant mixtures and their extracted binders for comparing with the field cracking measurements. The overlay test (OT) was conducted in accordance with the Tex-248F procedure while the Illinois Flexibility Index Test (I-FIT) was done following the AASHTO TP 124-16 procedure. Both tests have been used to evaluate the cracking resistance of asphalt mixtures (*2-5*). While the average test results shown in Table 3 were different, they were statistically similar (same letter) when considering the variability of the test results. They also appeared to agree with the field cracking measurements, which were almost the same for the two sections.

Table 3. Laboratory and Field Cracking Performance

Mixture	Overlay (Nf)	I-FIT (FI)	Field Cracking Measurement (width < 1mm) (%)
N1 20% RAP	25 (A)	3.58 (A)	21.5
N7 35% RAP + Delta S	10 (A)	3.43 (A)	21.3

*Letters next to Texas OT and I-FIT results represent groupings from statistical analysis.

Summary

The re-designed surface mixture with 35% RAP and 5% Delta S in Section N7 showed good ride quality and rutting performance. The cracking performance of the re-designed surface mixture in Section N7 was comparable to that of the surface mixture with 20% RAP in Section N1, which is the control section for the Cracking Group Experiment in the 2015 research cycle of the NCAT Pavement Test Track. Both sections (N1 and N7) will be kept in place for continuing traffic for another research cycle to allow for a thorough field performance evaluation.

References

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