Performance-Based Evaluation of Asphalt Binder Additives and Modifiers

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National Center for Asphalt Technology NCAT AT AUBURN UNIVERSITY

RECYCLING BY THE NUMBERS – 2023

89%

of the asphalt mixture reclaimed from old pavements was put back to use in new pavements.

96.1 million tons

of RAP recycled

4.8 million tons

of asphalt binder recycled

91.3 million tons

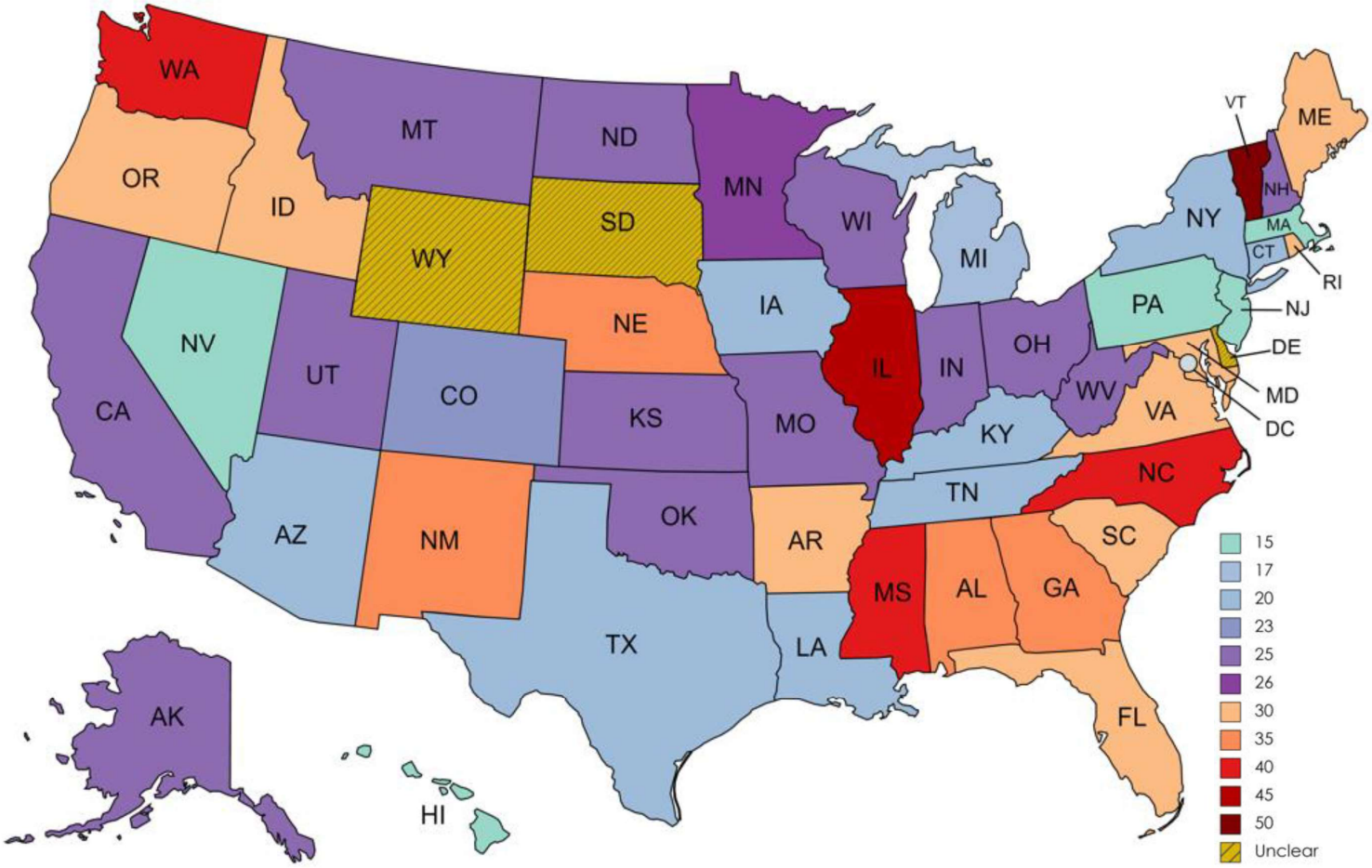
of aggregate recycled

$4.5 billion

total estimated value of recycled materials

Source: NAPA Annual Asphalt Pavement Industry Survey, 2023

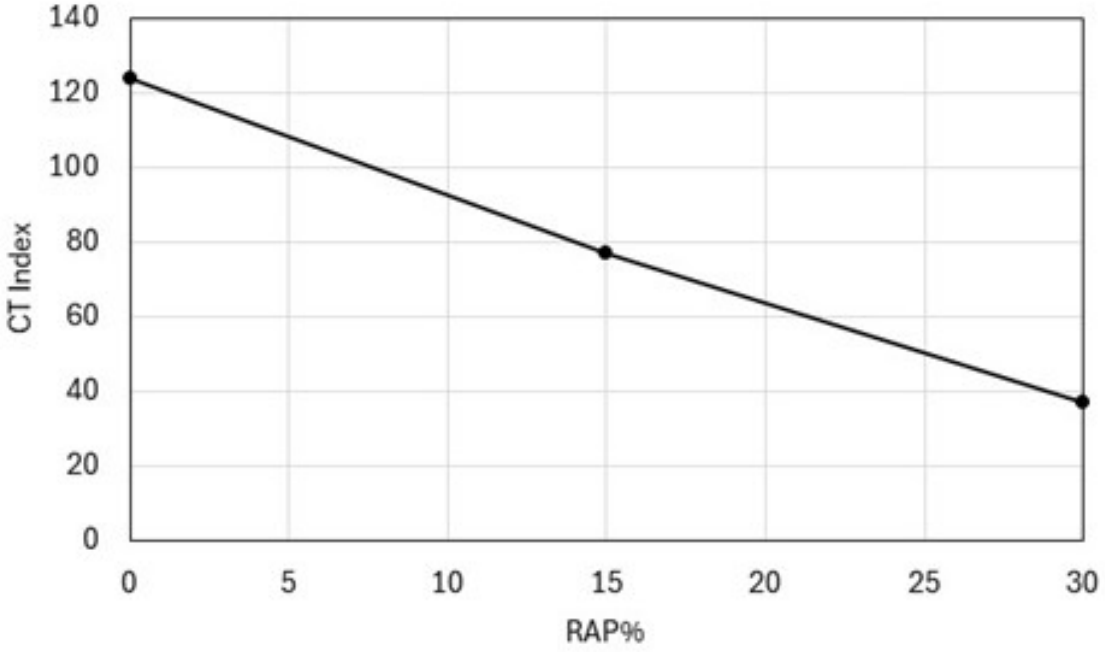
Maximum RAP Content Allowed in Surface Mixtures



Source: *Recycling* 2023, *8*(6), 100

RAP + Rejuvenators/Softeners

RAP binder = Brittle and stiff



Modifiers can improve aged binder

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Rejuvenators vs. Softeners 101

- Asphalt binder needs BOTH stiffness (S) & flexibility (m)
- Crack resistance is tied to the low temperature (LT) performance grade, specifically flexibility
  - i.e. BBR
- Oxidative aging increases stiffness and reduces flexibility
  - i.e. More crack susceptible
- Improving LT performance depends more on restoring flexibility versus reducing stiffness

Rejuvenators vs. Softeners 101

Softeners

Significantly decreases stiffness

No/little change in flexibility

Improves workability but not long-term cracking performance

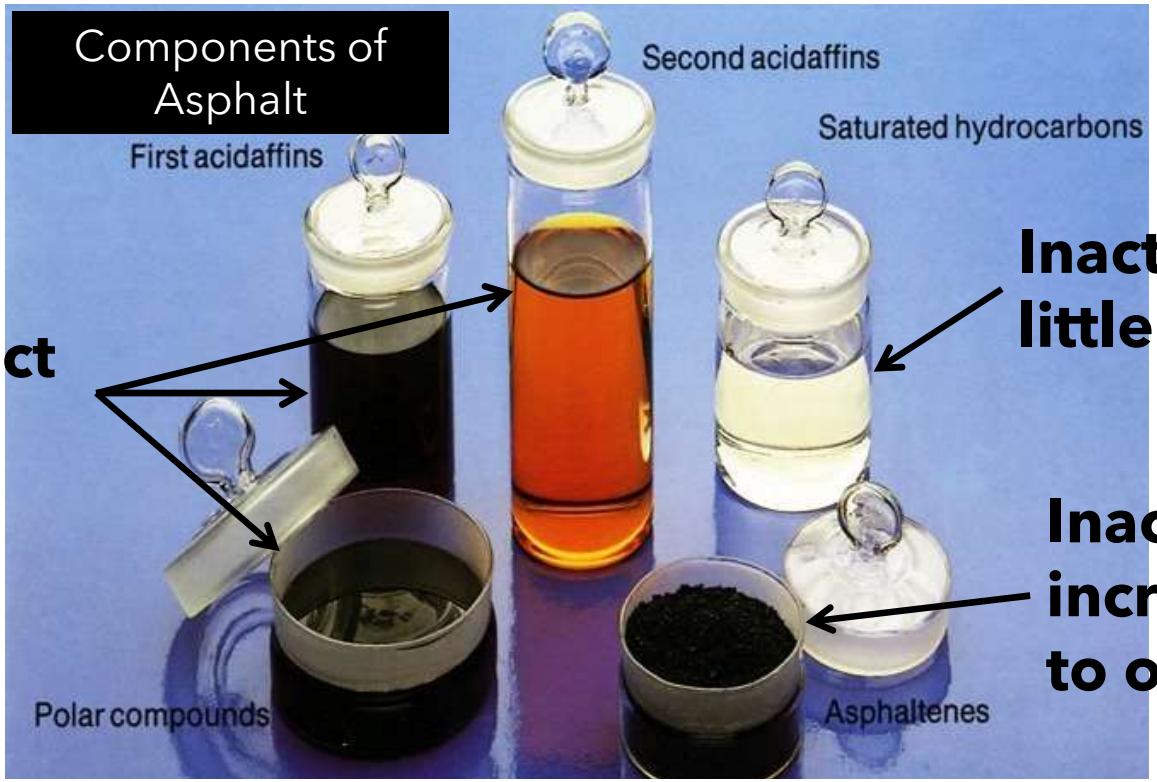
Rejuvenators

Significantly decreases stiffness

Improves flexibility

Often improves long-term cracking performance, but not all are equal

Components of Asphalt Binder



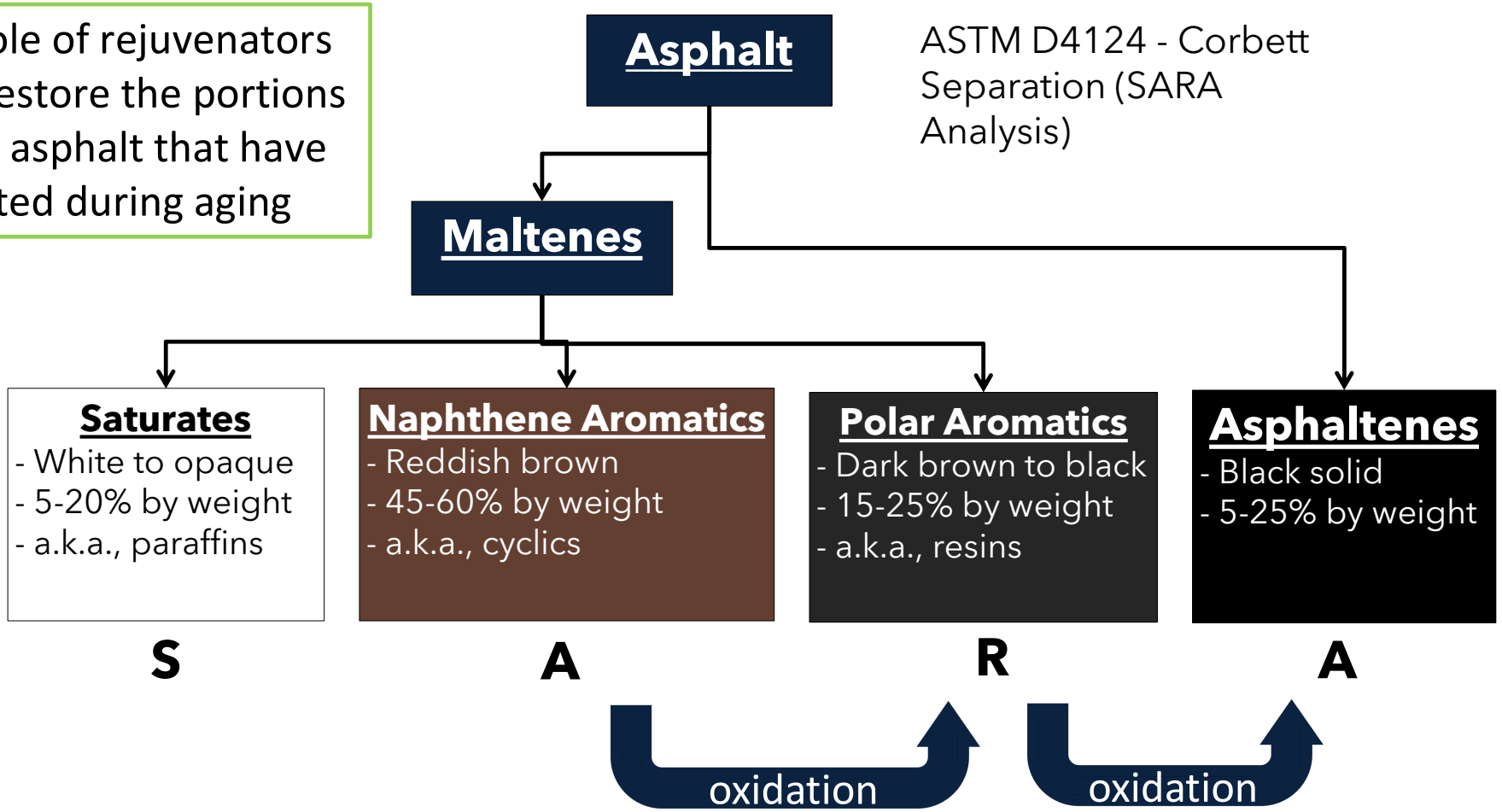
Active, subject to oxidation

Inactive, little change

Inactive, increase due to oxidation

Changes in Components and Role of Rejuvenator

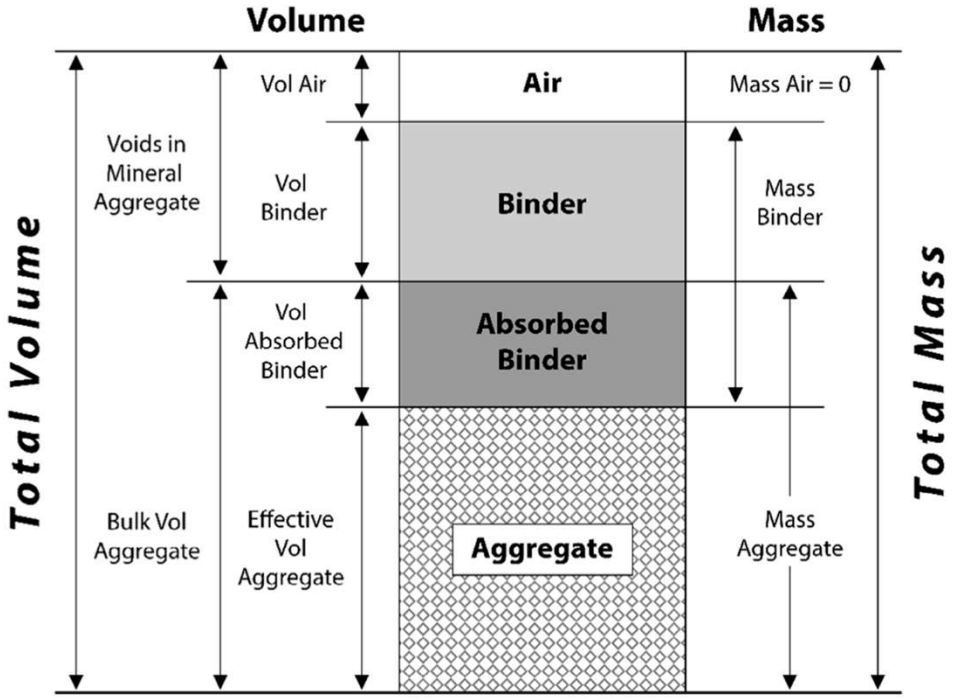
The role of rejuvenators is to restore the portions of the asphalt that have depleted during aging



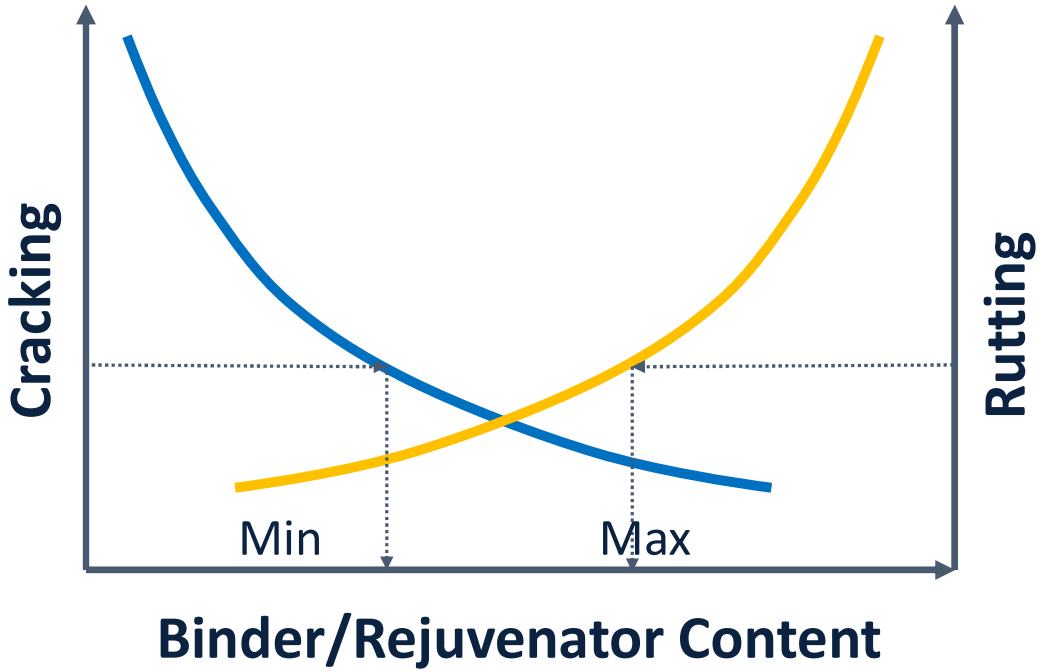
Categories of Rejuvenators

Paraffinic Oils	Aromatic Extracts	Napthenic Oil	Triglycerides and Fatty Acids	Amines
• Refined used lubricating oils • Environment concerns with waste engine oil and waste engine oil bottoms	• Refined crude oil products with polar aromatic oil components • Health concerns	• Engineered hydrocarbons for asphalt modification	• Derived from vegetable oils • Odor problems	• Paper industry byproducts • Same chemical family as liquid antistrip agents and emulsifiers

Mix Design with Rejuvenator



VMD: The dosage may **NOT** be optimized for mix performance.



BMD: The dosage is **OPTIMIZED** for mix performance.

Rejuvenators & BMD

- Rejuvenators allow for optimized/engineered mixes but they aren't all the same

Rejuvenator Dosage	CT_{index}
No rejuvenator	21.1
Low	38.1
Medium	44.1
High	42.2

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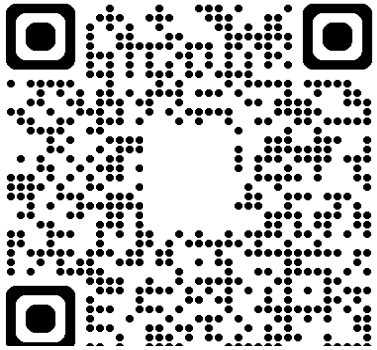
Examples of Rejuvenators on Test Track

- First instance was 2015 – Collaborative Aggregates
- Dozens of uses since 2015:
  - High RAP, BMD, with WMA, with other alternative materials, etc.
- Webinar Topic:



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BMD with Rejuvenator at NCAT Test Track

- To design, produce, and pave on Test Track
  - 45% RAP mixture with bio-based recycling agent
  - 30% RAP mixture with compaction aid

- Both mixtures are designed to balance rutting and cracking resistance.

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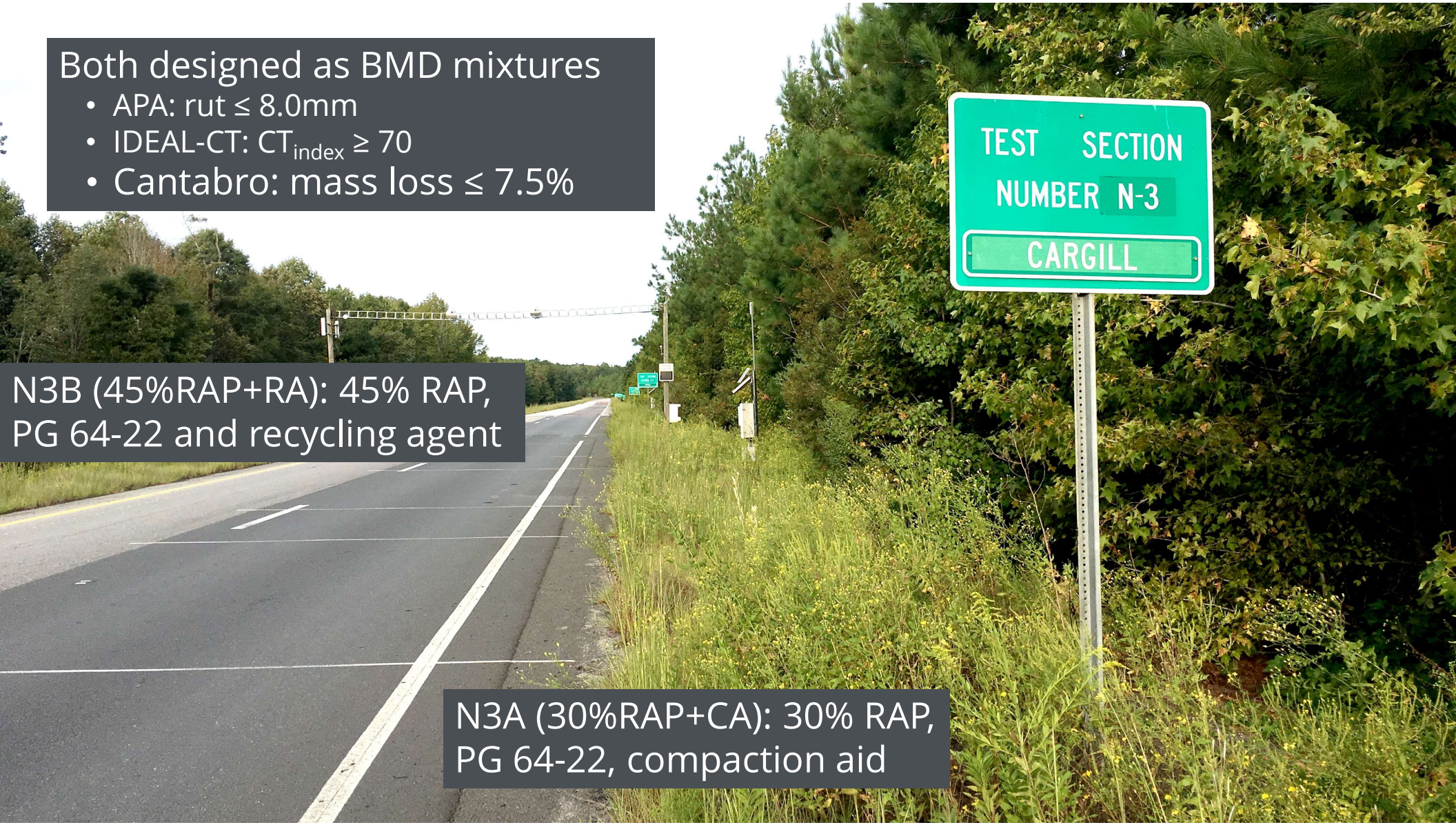
TEST SECTION
NUMBER N-3
CARGILL

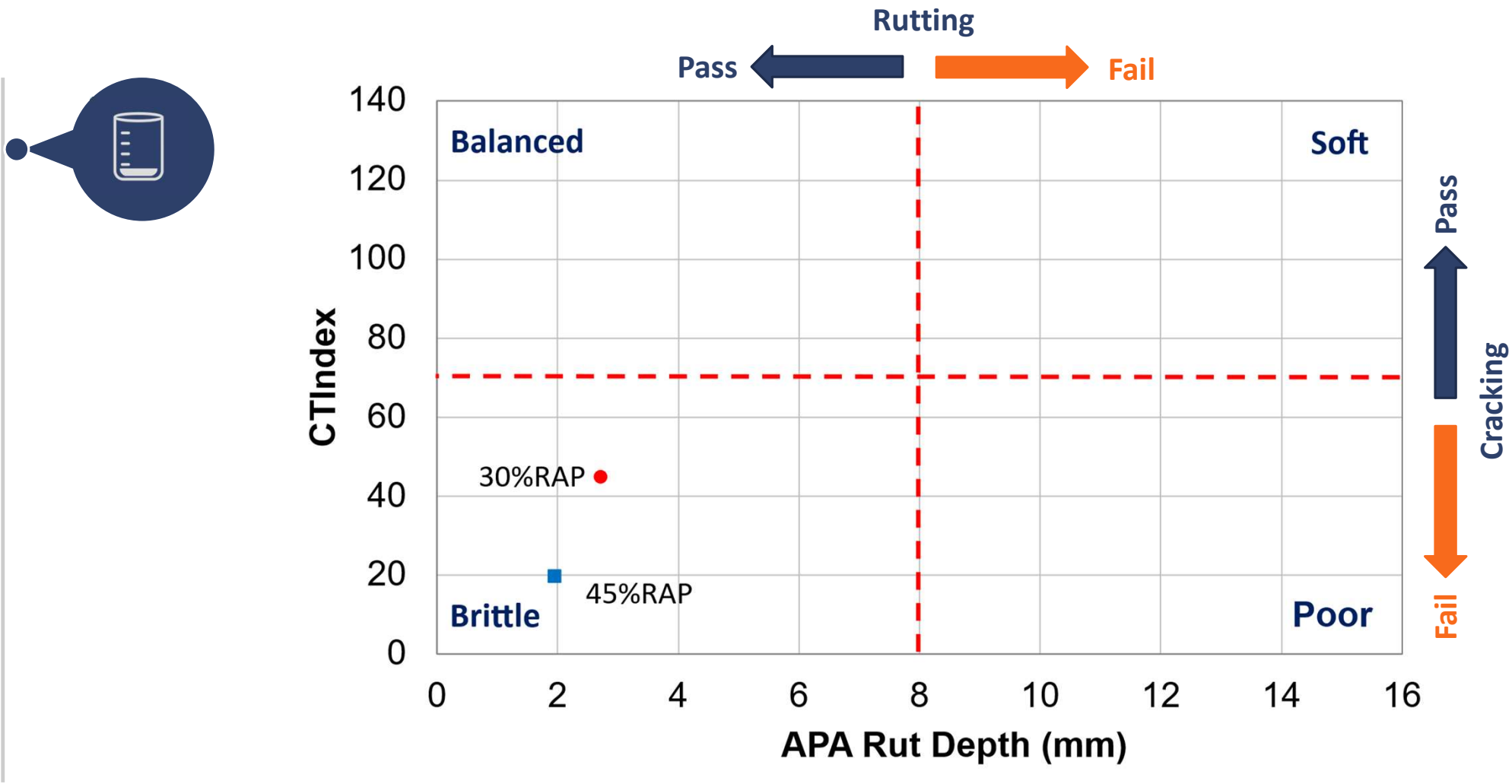


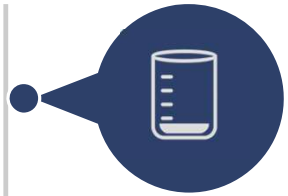
Both designed as BMD mixtures

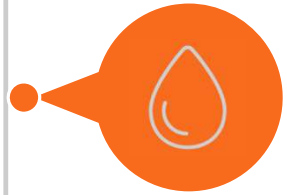
- APA: rut ≤ 8.0mm
- IDEAL-CT: CT_{index} ≥ 70
- Cantabro: mass loss ≤ 7.5%

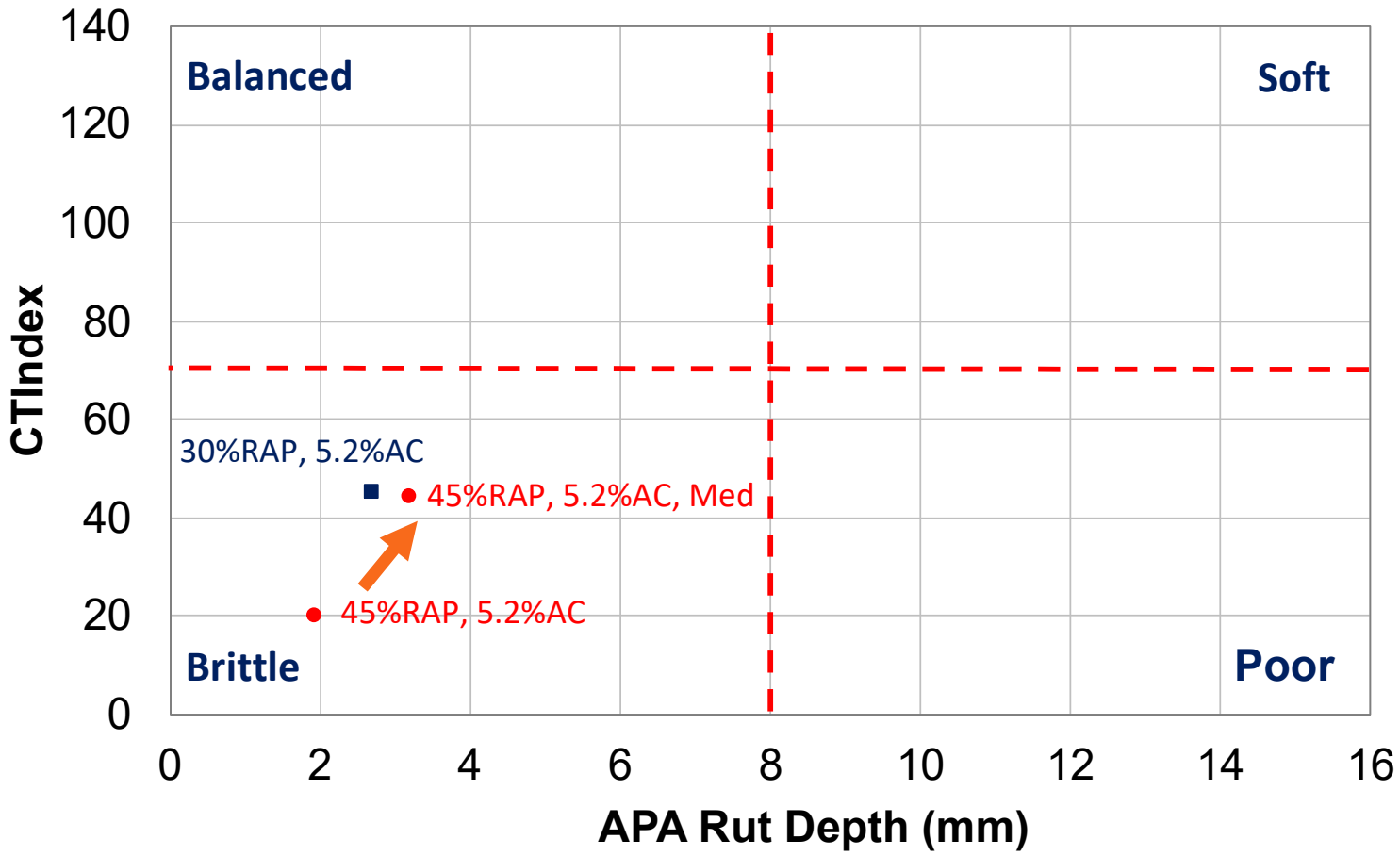
N3B (45%RAP+RA): 45% RAP, PG 64-22 and recycling agent

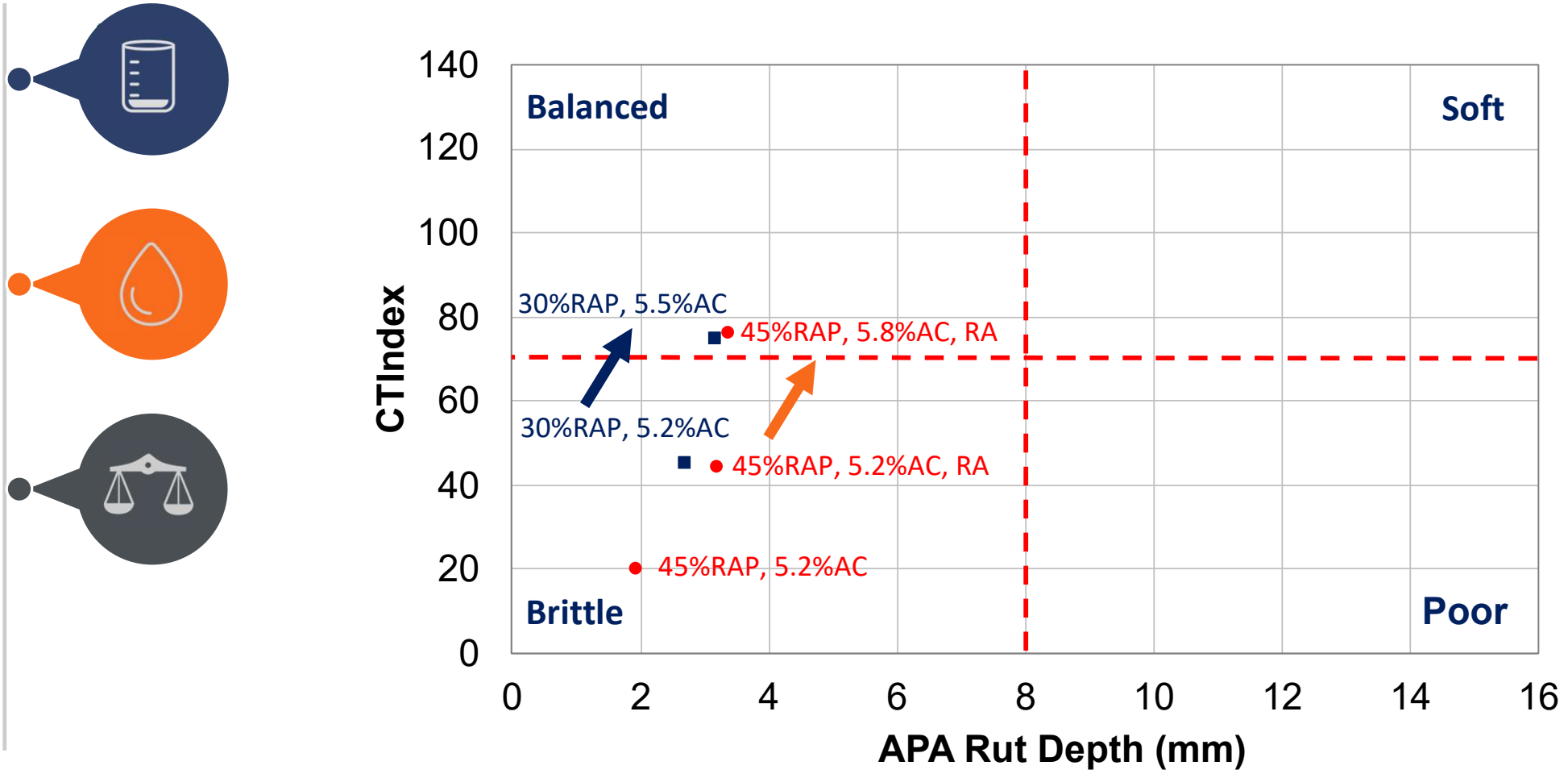
N3A (30%RAP+CA): 30% RAP, PG 64-22, compaction aid

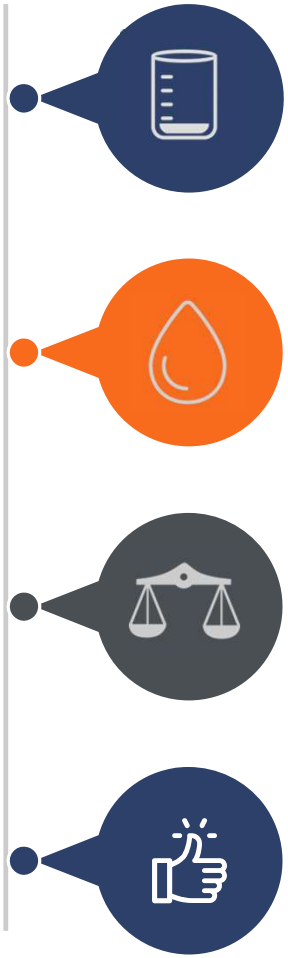

Rutting
Pass
Fail
Balanced
Soft
Brittle
Poor
30%RAP
45%RAP
CTIndex
APA Rut Depth (mm)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
Pass
Fail
Cracking



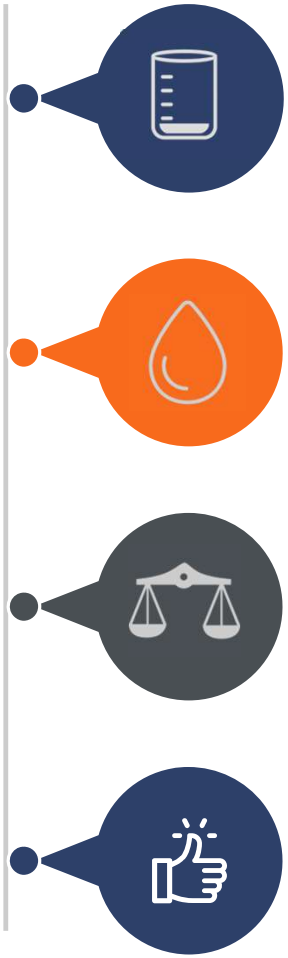



140
120
100
80
60
40
20
0
CTIndex
Balanced
Soft
30%RAP, 5.2%AC
45%RAP, 5.2%AC, Med
45%RAP, 5.2%AC
Brittle
Poor
0
2
4
6
8
10
12
14
16
APA Rut Depth (mm)


Balanced
Soft
Brittle
Poor
30%RAP, 5.5%AC
45%RAP, 5.8%AC, RA
30%RAP, 5.2%AC
45%RAP, 5.2%AC, RA
45%RAP, 5.2%AC
CTIndex
APA Rut Depth (mm)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16



Design Method:	BMD		
Ndes:	50 gyrations		
Binder PG:	64-22		
Mix Properties	30% RAP, CA	45% RAP, RA	Criteria
% Total AC (Pb):	5.5	5.8	
% Virgin Binder:	4.17	3.59	
% AC from RAP:	1.33	2.21	
RAP Binder Ratio:	24.2	38.1	
APA Rut (mm)	3.2	3.4	Max. 8.0
CTIndex	74.6	75.6	Min. 70
Mass Loss (%)	4.7	2.9	Max. 7.5
Rice Gravity (Gmm):	2.715	2.691	
Design Air Voids (Va):	2.9	2.4	3.0 – 4.5
VMA*:	15.8	16.2	Min. 16.0
VFA:	82	86	70 - 85
Dust/Binder:	1.0	1.1	0.7 - 1.3
Pbe:	5.21	5.51	
Pba	0.31	0.31	



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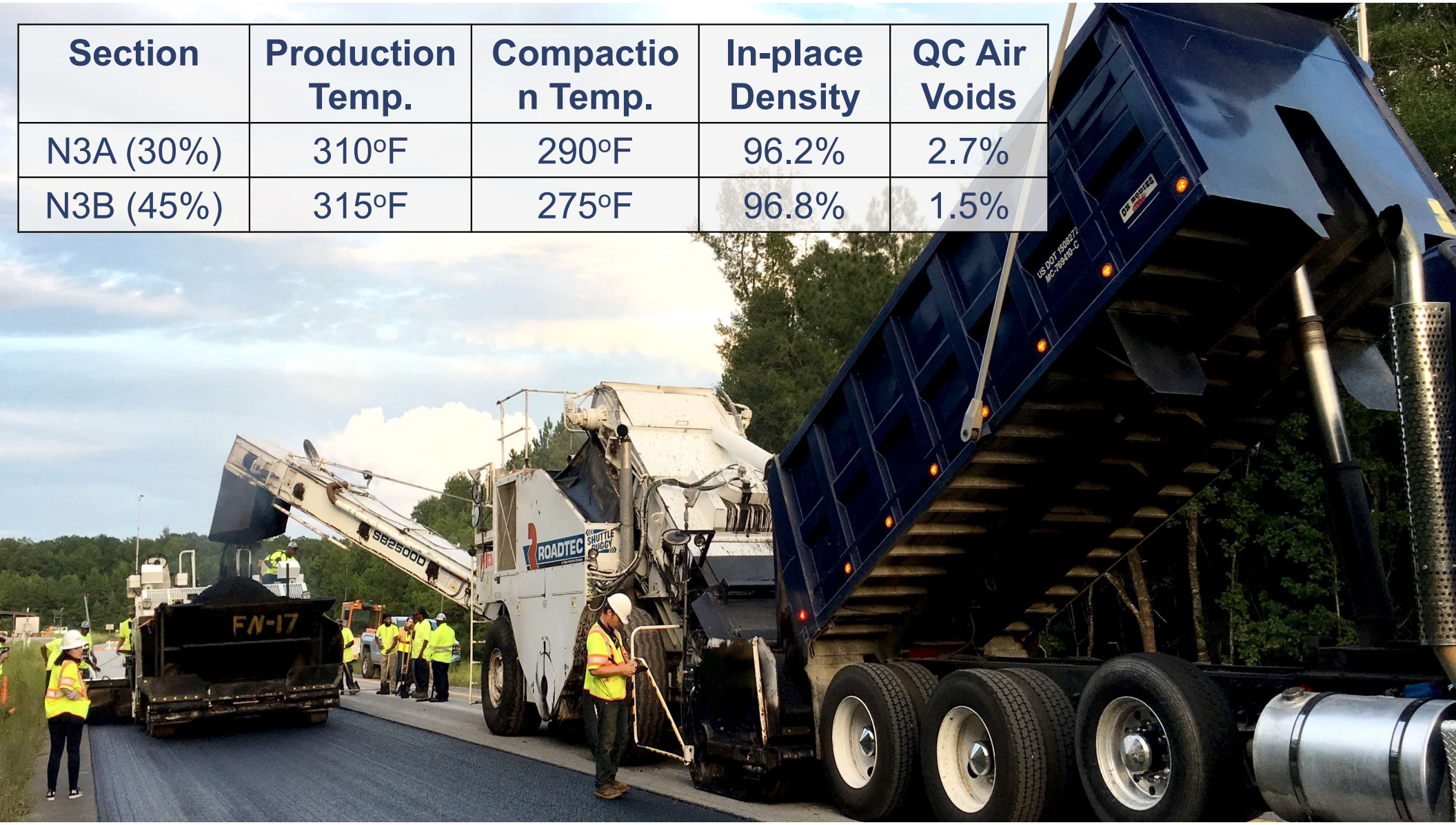
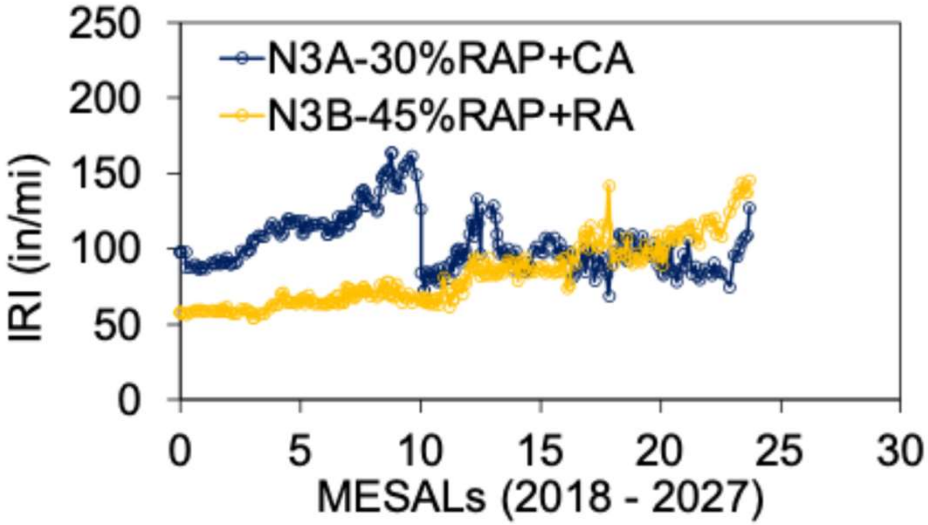
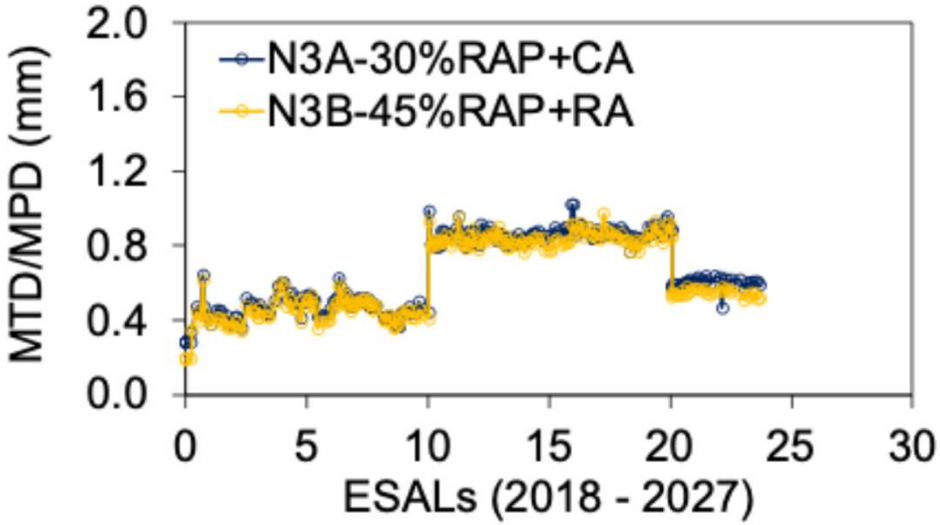
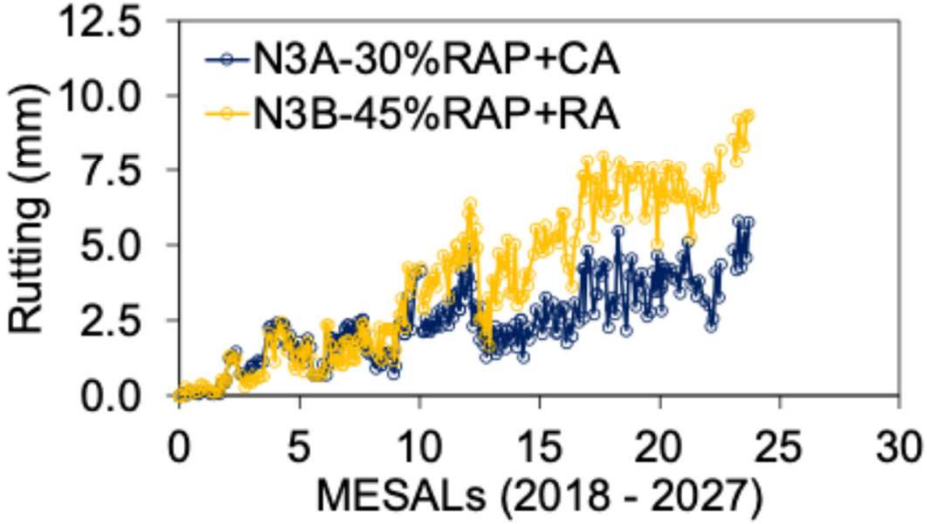
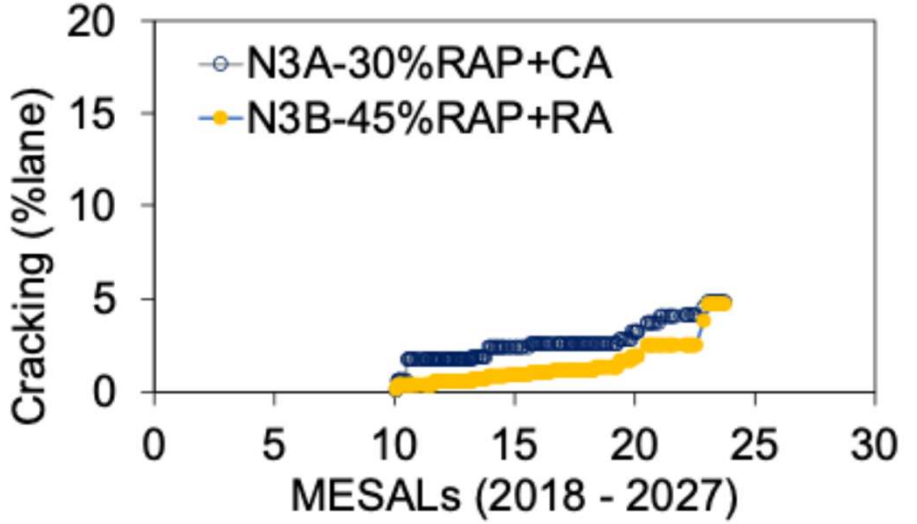
Section	Production Temp.	Compaction Temp.	In-place Density	QC Air Voids
N3A (30%)	310°F	290°F	96.2%	2.7%
N3B (45%)	315°F	275°F	96.8%	1.5%




IRI (in/mi)
250
200
150
100
50
0
N3A-30%RAP+CA
N3B-45%RAP+RA
0
5
10
15
20
25
30
MESALs (2018 - 2027)


MTD/MPD (mm)
2.0
1.6
1.2
0.8
0.4
0.0
N3A-30%RAP+CA
N3B-45%RAP+RA
0
5
10
15
20
25
30
ESALs (2018 - 2027)


Rutting (mm)
12.5
10.0
7.5
5.0
2.5
0.0
N3A-30%RAP+CA
N3B-45%RAP+RA
0
5
10
15
20
25
30
MESALs (2018 - 2027)


Cracking (%lane)
20
15
10
5
0
N3A-30%RAP+CA
N3B-45%RAP+RA
0
5
10
15
20
25
30
MESALs (2018 - 2027)

Hairline Cracks in Both Sections

N3A (30%RAP+CA)
30% RAP, PG 64-22, Compaction Aid

N3B (45%RAP+RA)
45% RAP, PG 64-22 and Recycling Agent

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Key Findings

- Both mixtures were designed based on BMD approach.
  - VMD mixtures did not meet BMD requirements (cracking)
  - BMD mixtures did not meet VMD requirements (air voids & VFA).
- BMD mixtures were compacted to achieve high density (> 96%).
  - No severe rutting with low QC air voids
- Both sections show good performance, with some rutting and hairline cracks.

THANK YOU!

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