Implementation of Balanced Mix Design (BMD) in Texas: Progress & Challenges

Materials & Asphalt Technology Research Summit (MASTERS)

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CTR

Texas Department of Transportation

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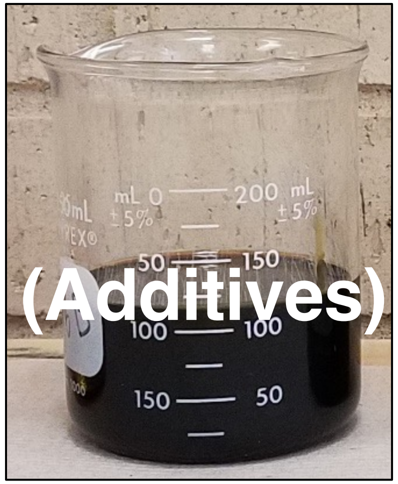
Asphalt Concrete Mix Design



What is a “Balanced Mix Design”?

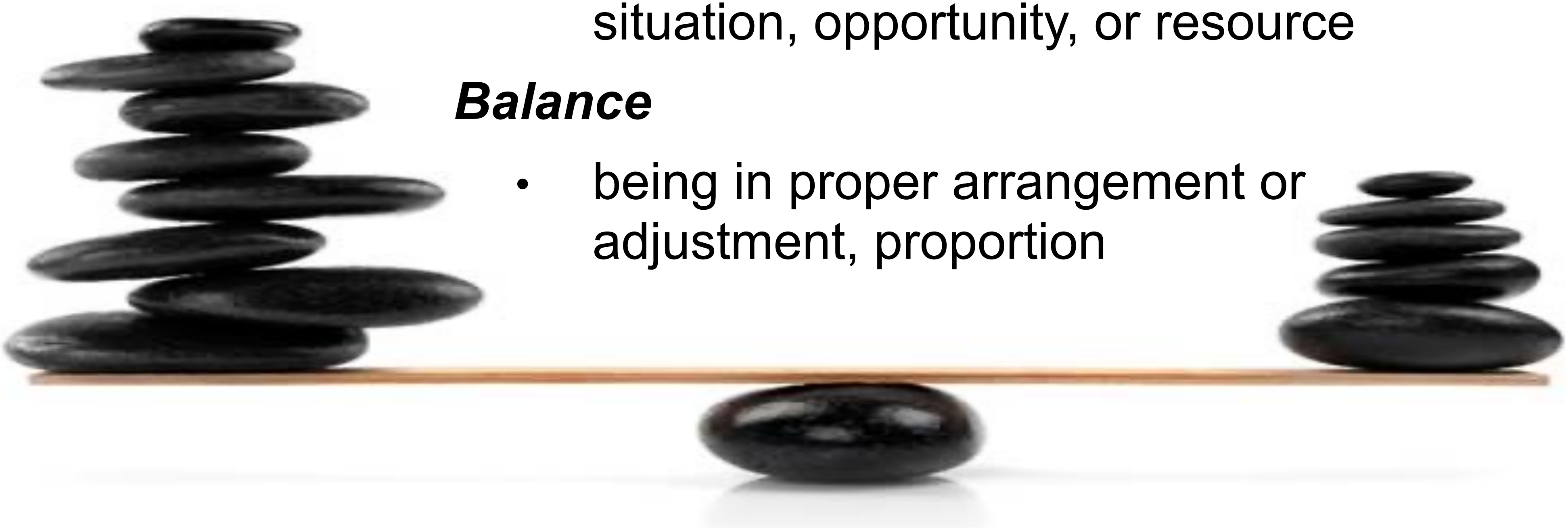
- **optimize mixture proportions to provide balance among properties to provide long life pavement performance**

Optimize

- make best or most effective use of situation, opportunity, or resource

Balance

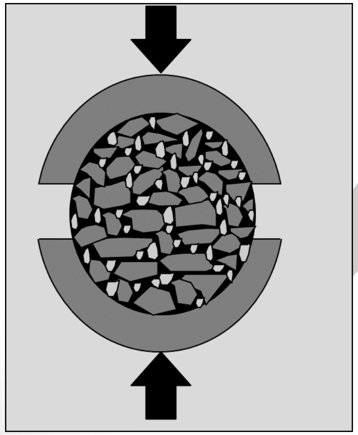
- being in proper arrangement or adjustment, proportion



- **asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate, and location within the pavement structure (AASHTO PP 105)**

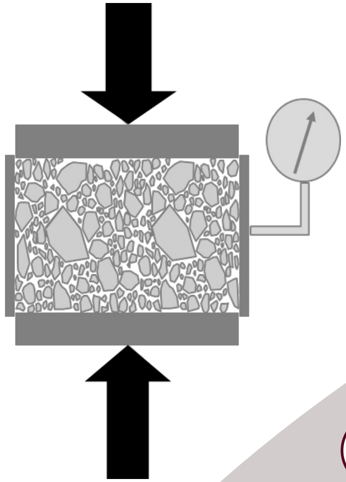
Asphalt Concrete Mix Design

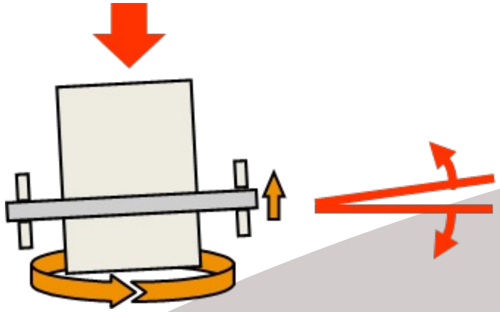
Surface 94% of 2.8M paved miles



1930-40s
Marshall

- Stability
- Flow
- Volumetrics





1930-40s

Hveem

- Stability
- (Cohesion)
- AV

1990s

Superpave

- Volumetrics
- Compaction
- + Durability Check

2010s

Balanced Mix Design (BMD)

- Rutting
- Cracking
- Volumetrics?

High RAM Asphalt Mixtures

NAPA 2022

98.1M tons RAP

0.7M tons RAS

\$4.7B materials

68M yd^3 landfill

2.7M m tons CO_{2e}

✓ **Economical Advantages**
- Materials Costs
- Transportation Costs

✓ **Environmental Benefits**
- Natural Resources
- Landfill Space
- Greenhouse Gas Emissions

✓ **Engineering Performance**
- Rutting Resistance
- Durability/Cracking Resistance

High RAM Mitigation Strategies for Balanced Performance

- Components
    - Additive(s) such as Recycling Agent, WMA Product
    - Substitute Binder = ***Binder Quality***
        - Virgin Binder Source
        - Virgin Binder Grade (Softer)
        - PMA
- Proportions
    - Increased Effective AC = ***Binder Quantity***
        - Reduced Recycled Binder Availability (RBA)
        - Adjusted Aggregate Gradation to Increase VMA
        - Regressed AV
        - Reduced N
        - Minimum Total or Virgin AC
    - Reduced RAM Content or RBR, RAS/RAP Balance
    - Increased Additive Dose
- Hybrid Combo for Very High RAP PGH

TxDOT BMD Implementation Effort (2019-)

produce implementable BMD&A specification that balances engineering performance (rutting, cracking) & provides economic and environmental benefits

- Partners
  - TxDOT MTD + Districts
  - University Transportation Centers
  - TxDOT-Industry & National Working Groups
  - Contractors & Materials Suppliers

2019-2022

9 Test Projects

33 Sections @ ½-1 day

2022-2025

4-6 Pilot/Shadow Projects

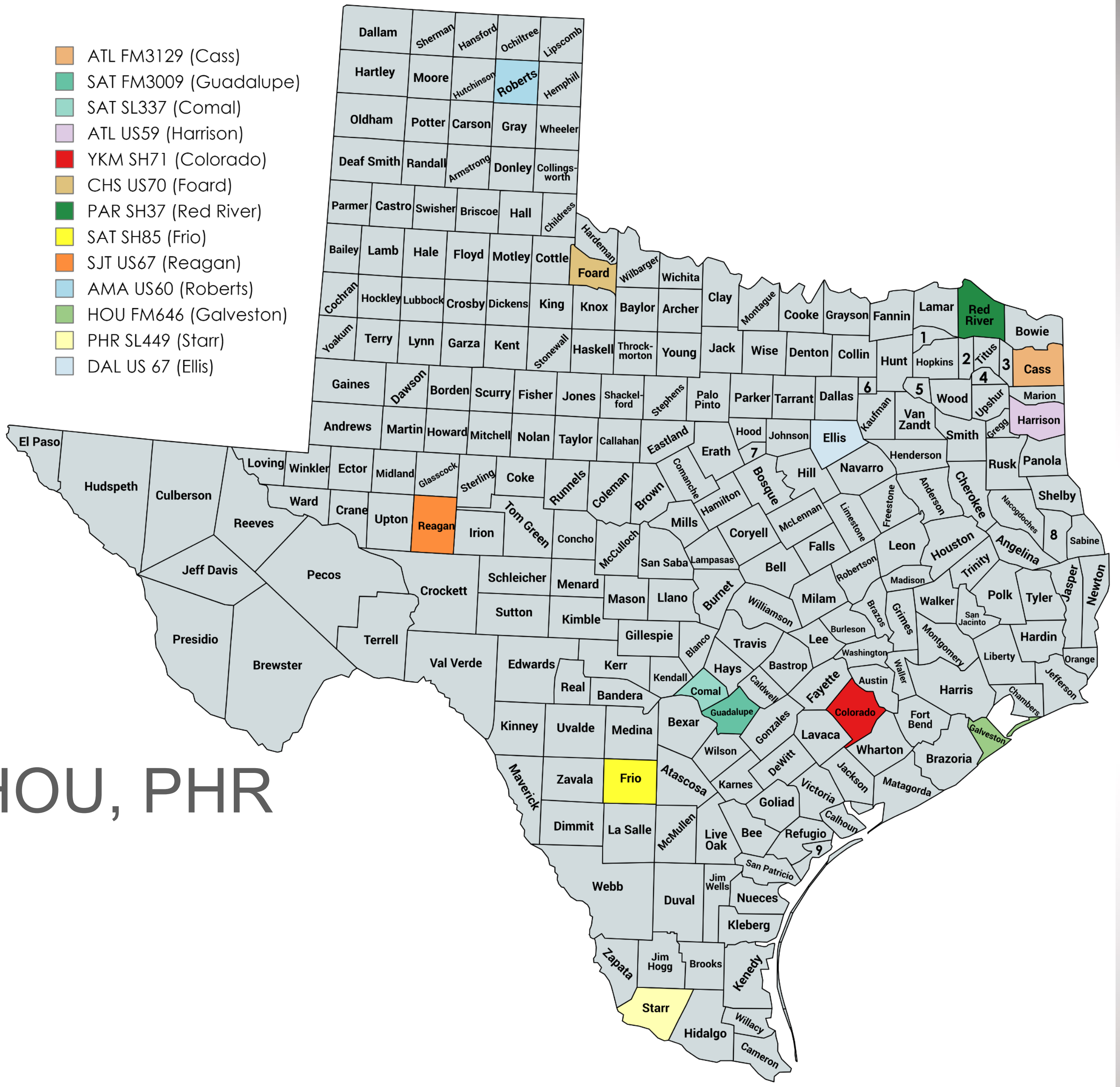
8-12 Sections @ 3-5 days

Lead District Projects

Statewide Projects

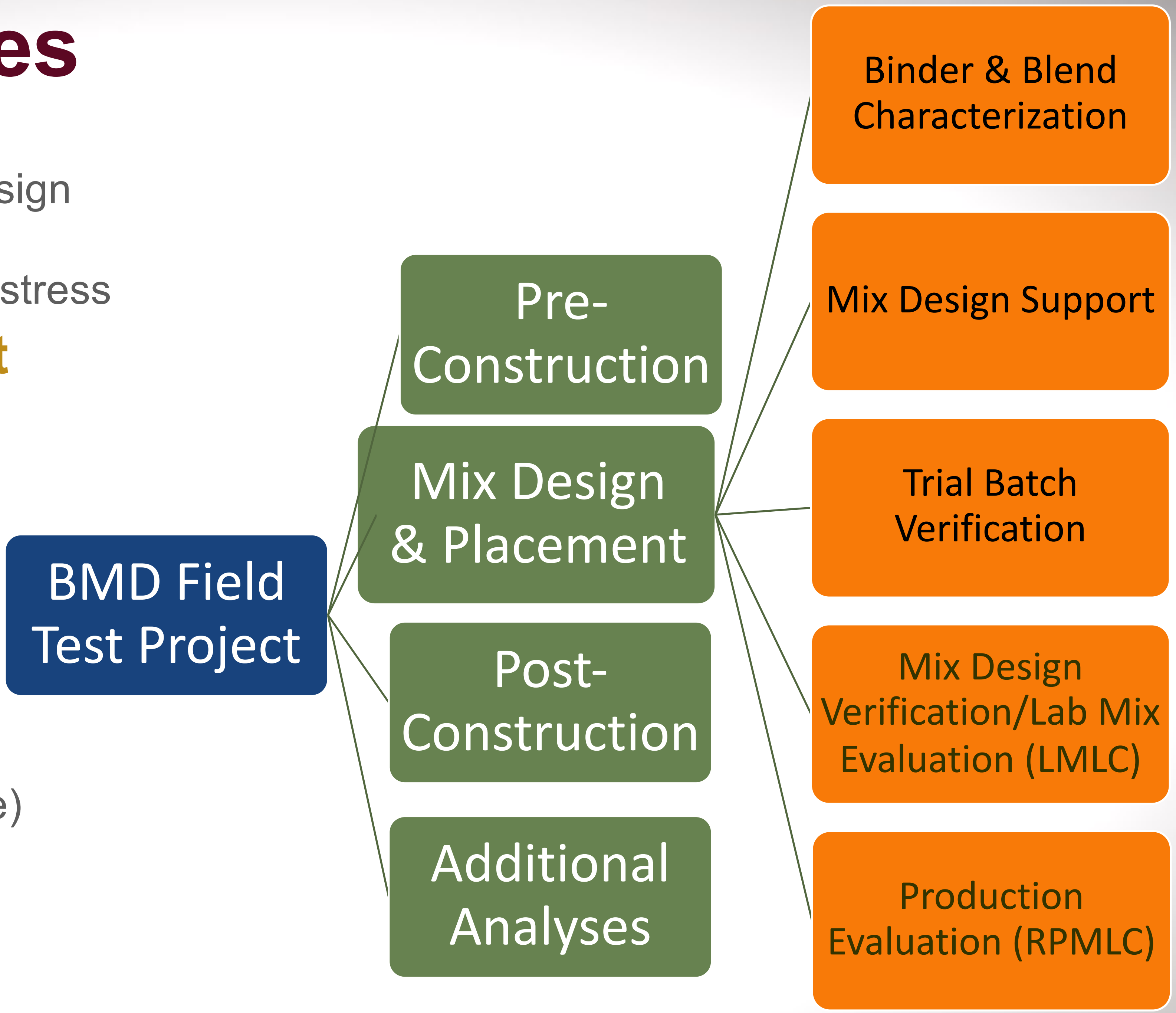
Field Projects

- 2019: ATL
- 2020: SAT x2, YKM, ATL, PAR
- 2021: CHS
- 2022: SJT, SAT
- 2024: DAL, AMA, SJT, BWD, HOU, PHR



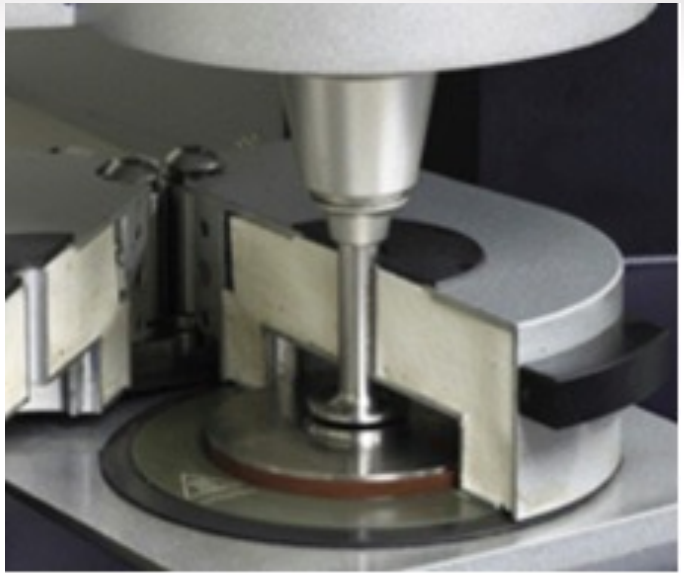
Evaluation Phases

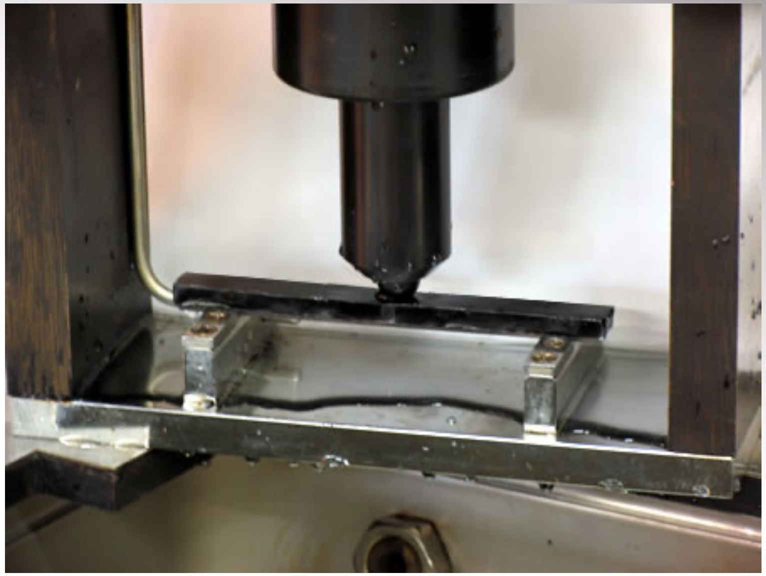
- Pre-Construction
  - Plans, Specs, Pavement Design
  - FWD, GPR
  - Evaluation Subsections & Distress
- **Mix Design & Placement**
- **Post-Construction**
  - Cores
  - Distress
  - (Texture & Friction)
- Additional Analyses
  - Variability
  - Multi-Phase (Specimen Type)
  - Aging
  - Correlations

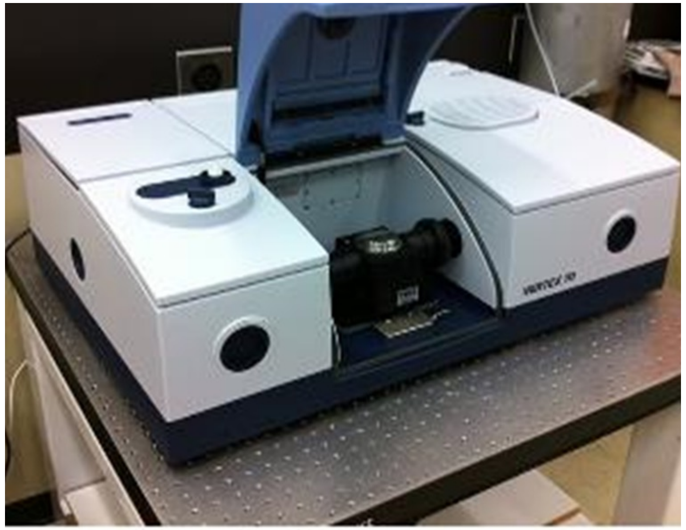


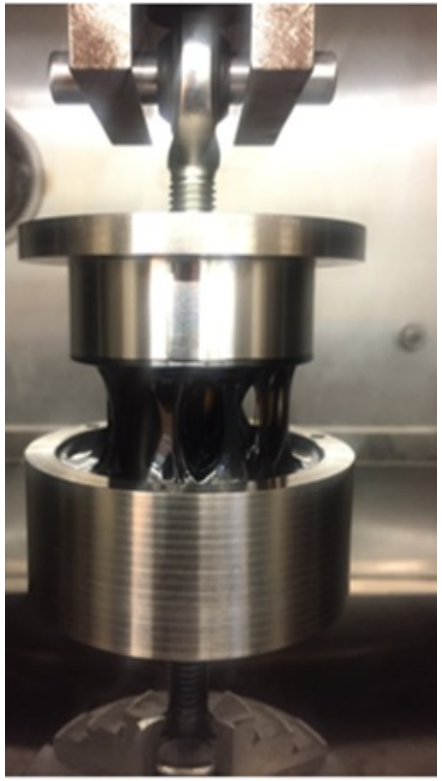
Binder Testing

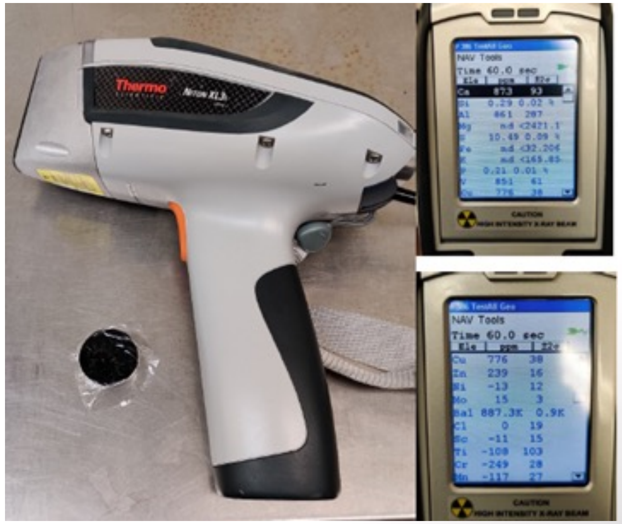
- DSR
  - PGH
  - Jnr, %R
  - G-R with aging
- Ductility (Poker Chip)
- BBR
  - PGL
  - DTc
- FTIR
- XRF
- SARA











Rutting Evaluation

- HWTT (Tex 242-F)
  - $N_{12.5} \geq$ 10k for PG64
  - $N_{12.5} \geq$ 15k for PG70
  - $N_{12.5} \geq$ 20k for PG76

- IDEAL-RT (Draft Tex XXX-F)

Table 11C
IDEAL Rutting Test (RT) Requirements

High-Temperature Binder Grade[1]	Test Method	Minimum Rutting Tolerance Index (RT-Index) @ 50°C
PG 64 or lower	Tex-XXX-F	60
PG 70		65
PG 76 or higher		75

1. Calculated by LTPP Bind 20 mm below the pavement surface and adjusted for traffic and climate conditions but not for inclusion of recycled materials.

- Aging [LMLC: STOA 2hr@T_{comp}, RPMLC: Reheat to T_{comp}]

Cracking Evaluation

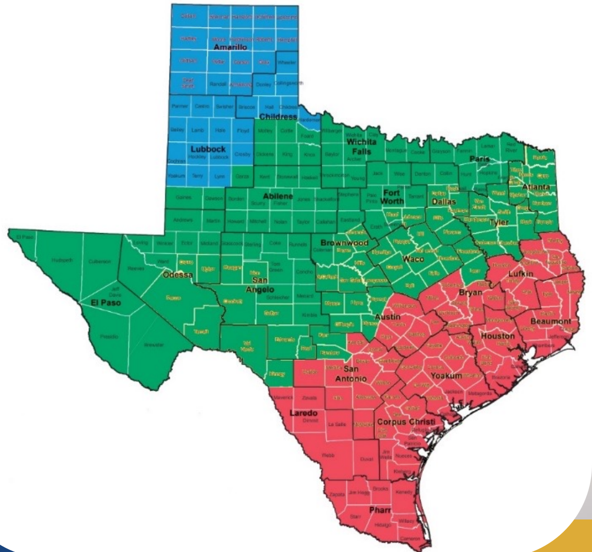
- OT (Tex 248-F)
  - CPR $\leq$ 0.45
  - CFE $\geq$ 1.0
- IDEAL-CT (Tex 250-F)

Table 11D
IDEAL Cracking Test (CT) Requirements

Low-Temperature Binder Grade[1]	Test Method	Min Cracking Tolerance Index (CT-Index) @ 25°C
PG -22 or higher	Tex-250-F	80
PG -28 or lower		95

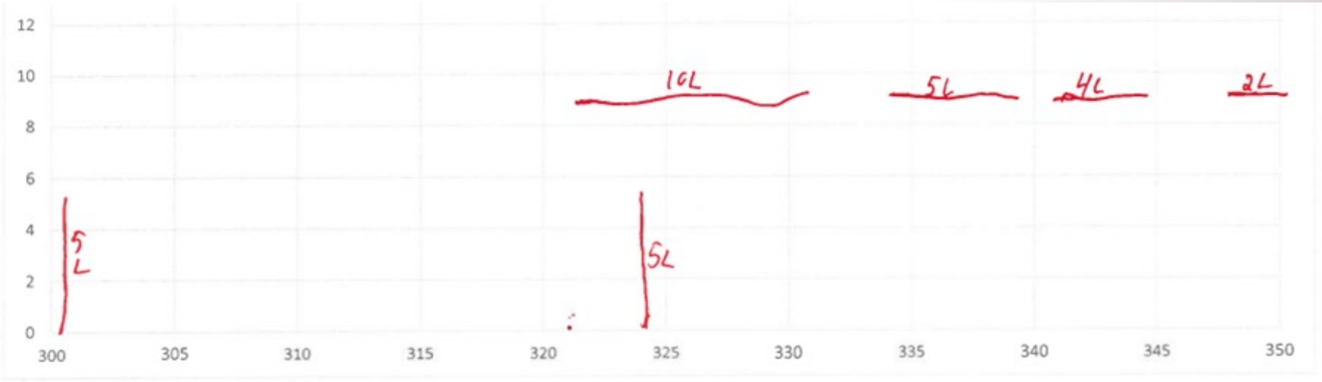
1. Calculated by LTPP Bind at the pavement surface and adjusted for traffic and climate conditions but not for inclusion of recycled materials.

- Aging
  - LMLC: STOA 2hr@T_{comp} [+ MTOA 20hr@95C for mix design?]
  - RPMLC: Reheat to T_{comp}



Annual Field Performance Evaluation

- %Cracking by Crack Mapping
- Rut Depth by Wedge & PathWeb
- Cumulative Degree Days (CDD) > 32F to capture field aging



$$Cracking\ (\%lane) = \frac{(Cracking_{long} + Cracking_{trans}) * 1ft}{Lane\ width * Evaluation\ Area\ Length} * 100$$

$$CDD = \sum (T_{dmax} - 32)$$

where:

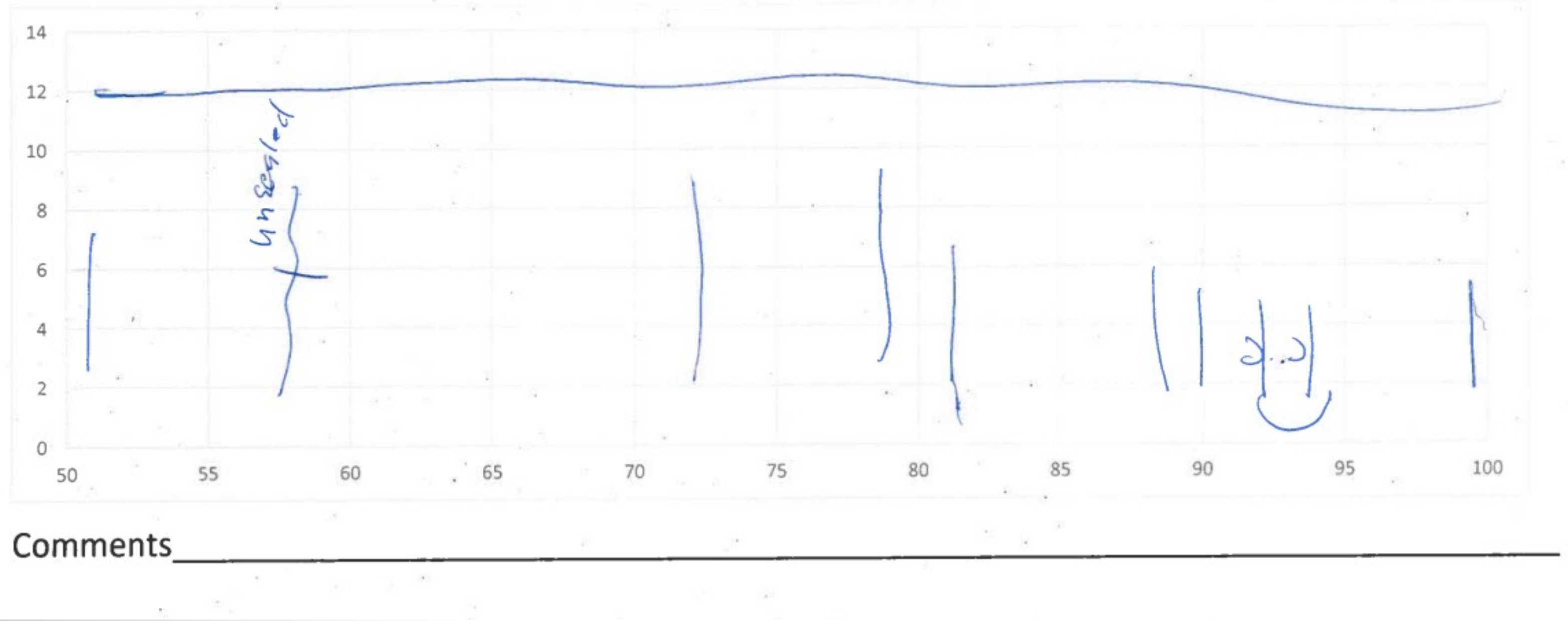
$Cracking_{long}$ = Longitudinal Cracking (ft)

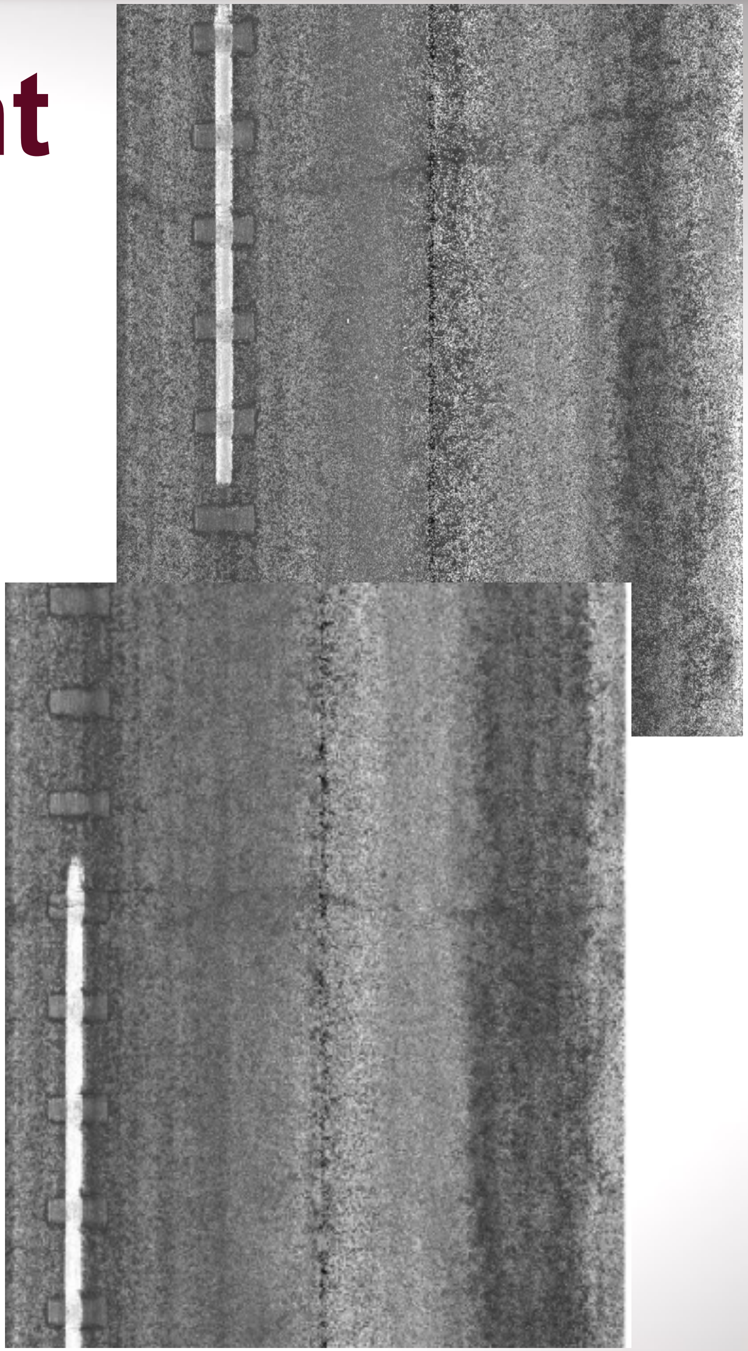
$Cracking_{trans}$ = Transverse Cracking (ft)

T_{dmax} = daily maximum temperature, °F.

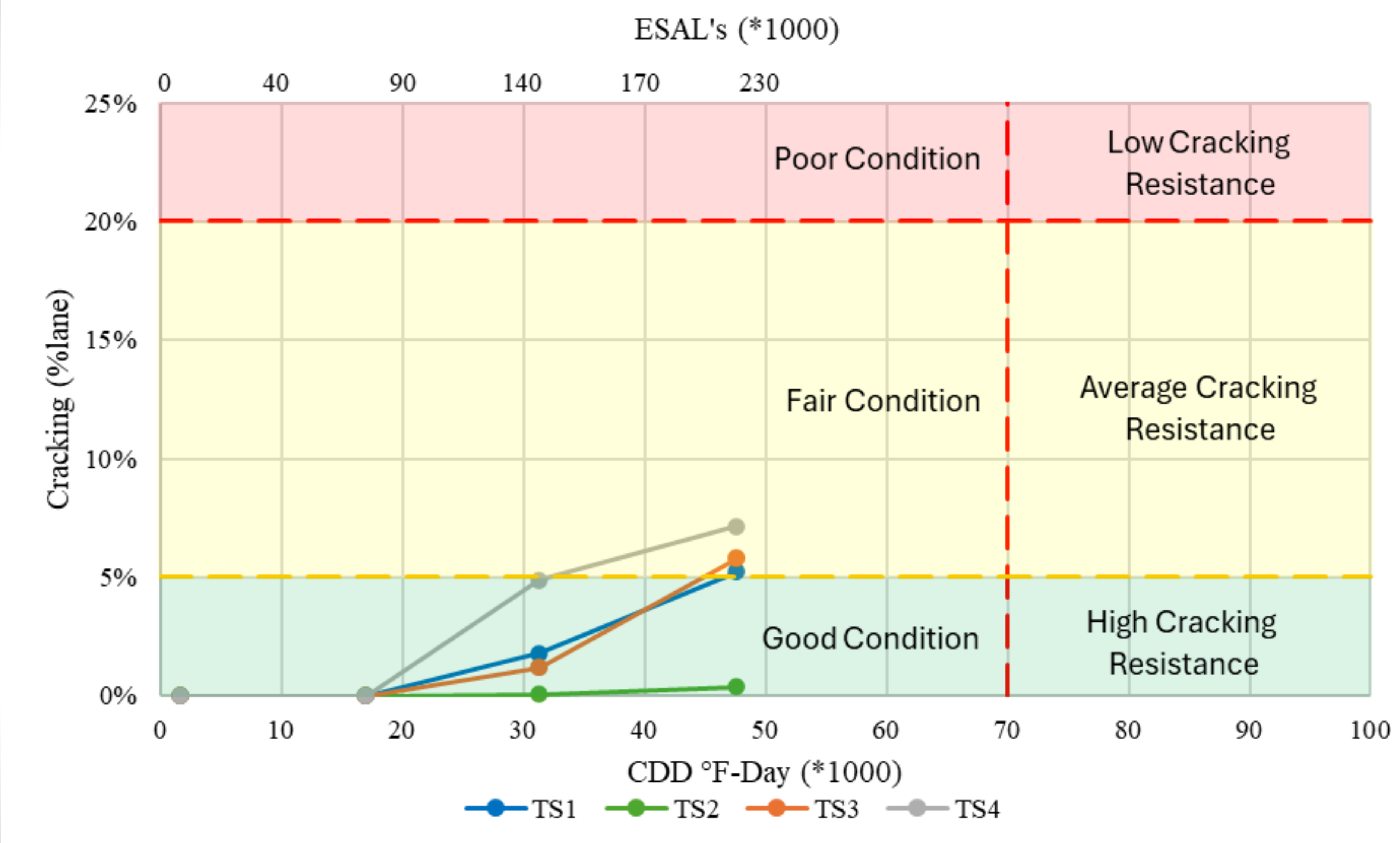
Pre-Construction Assessment

- Preconstruction Crack Maps
- Video and Photos after milling when possible
- PathWeb information to capture preconstruction condition





Example Cracking Analysis



Jul 2024 TxDOT BMD Overview w/ FHWA 8 Tasks (FHWA-HIF-22-048)

Task	Description + Notes	Status	Completion
1 Providing Motivation	Benefits – Sustainability	Complete	2019
2 Overall Planning	TxDOT Industry WG, Mega States, IWG	Ongoing	Semi-Annually
	Goals, Tasks, Timeline – IACs	Complete	2019, 2022
3 Selecting Performance Tests	Distress – Cracking, Rutting	Complete	2019
HWT, OT, CT, RT	Validation – Lab vs Field	Ongoing	Annually
4 Acquiring Equipment	Evaluation – Contractor Package	In Progress	2023
	Inter-Lab Studies – CTIS, NCAT	In Progress	2022, 2024 construction
5 Establishing Baseline Data	TX Benchmarking + WesTrack	In Progress	2023 + 2024
	Specimen type, fabrication, aging	In Progress	2024
	Shadow Projects	In Progress	2024 construction
	Variability	In Progress	2022, 2025
	Strategies – AASHTO draft practice	In Progress	2024
6 Developing & Piloting Spec	Revised SS 3074	Ongoing	2023, 2024, 2025 +
	Lead District Projects	Not Started	2026 +
	Acceptance	Ongoing	2025 +
7 Training & Certification	Training & Accreditation	Not Started	2026 +
8 Initial Implementation		Not Started	2026 +

TxDOT BMD Overview w/FHWA 8 Tasks

1. Providing Motivation

2. Overall Planning

3. Selecting Performance Tests
   - Validation

4. Acquiring Equipment
   - Evaluation
   - Inter-Lab Studies

5. Establishing Baseline Data
   - Benchmarking
   - WesTrack
   - Multi-Day Shadow Projects
   - Variability
   - Strategies

6. Developing & Piloting Specification
   - Lead District Projects
   - Acceptance
   - Revisions

7. Training & Certification

8. **Initial Implementation**

FHWA Critical Challenges for BMD

Management Challenges

- Change Management
- Cost-Benefit Analysis
- Specifications & Risk Management
- Resource Allocation
- Implementation Planning
- Stakeholders Engagement

Technical Challenges

- BMD Tests Validation
- Testing Procedures & Protocols
- Variabilities
- Database Setup, Collection, Analysis, & Management
- Pathway for Use in Field QA
- Volumetrics Historical Usage

- Integration with Existing Practices
- Education, Training, & Skill Development
- Information Sharing & Collaboration Among Peers

* Adapted from Nener-Plante; SEAUPG, Nov 2023

Proposed Specification Changes

Special Specification 3074

Superpave Mixtures – Balanced Mix Design

Texas Department of Transportation

1. DESCRIPTION

Construct a hot-mix asphalt (HMA) surface pavement layer composed of a compacted, Superpave (SP) mixture of aggregate and asphalt binder mixed hot in a mixing plant utilizing a Balanced Mix Design (BMD) approach. Payment adjustments will apply to HMA ~~placed under~~in accordance with this Sspecification unless the HMA is deemed exempt in accordance with Section 344.4.9.4., "Exempt Production."

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- Increasing RAP/RBR
- Adding IDEAL-RT
- Utilizing IDEAL-CT, Limiting OT
- Changing IDEAL-CT Thresholds
- Simplifying Requirements
  - Removing IDT Strength
  - Removing Min RD by HWTT
  - Standardizing N_{design}=50
- Considering Reduced Recycled Binder Availability (RBA) with Adjusted Lab %Density
- Adjusting Production Testing and Frequency
- Adding Operational Tolerances

Increasing RAP Content & RBR up to 35%

Table 4
Maximum Allowable Amounts of RAP[1]

Maximum Allowable Fractionated RAP[2] (%)
Surface
35.0

1. Must also meet the recycled binder to total binder ratio shown in Table 5.
2. Up to 35% RAS may be used separately or as a replacement for fractionated RAP.

Table 5
Allowable Substitute PG Binders and Maximum Recycled Binder Ratios

Originally Specified PG Binder	Allowable Substitute PG Binder for Surface Mixes	Maximum Ratio of Recycled Binder[1] to Total Binder (%)[1]
		Surface
76-22[3]	70-22	350.0
70-22[2]	N/A	350.0
64-22[2]	N/A	350.0
76-28[3]	70-28	350.0
70-28[2]	N/A64-28	350.0
64-28[2]	N/A	350.0

1. Combined recycled binder from RAP and RAS.
2. ~~Binder substitution is not allowed for surface mixtures, unless otherwise approved by the Engineer.~~
3.2. ~~Use no more than 30.0% recycled binder in surface mixtures when using this originally specified PG binder.~~

- Utilize reduced RBA (for RAP > 20%, PGH > 100C; for RAS > 0%) to ensure higher effective/available & virgin binder content OR other High RAM Strategies for Balanced Performance
- Effect of substitute unmodified binders *needs* to be explored further

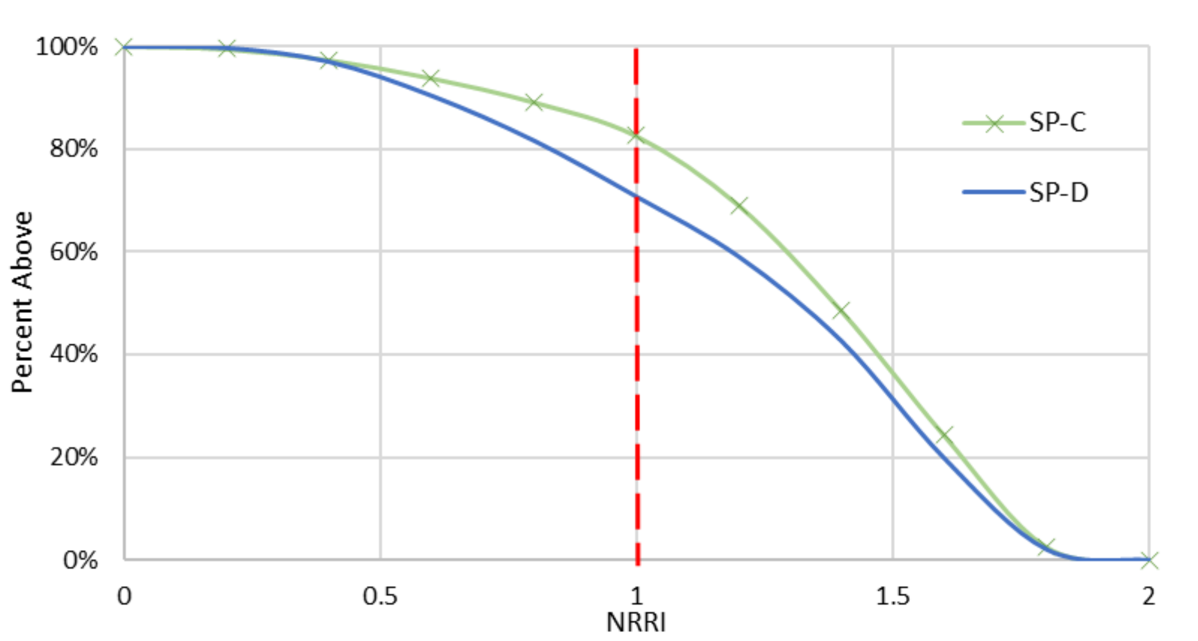
IDEAL Equipment Evaluation

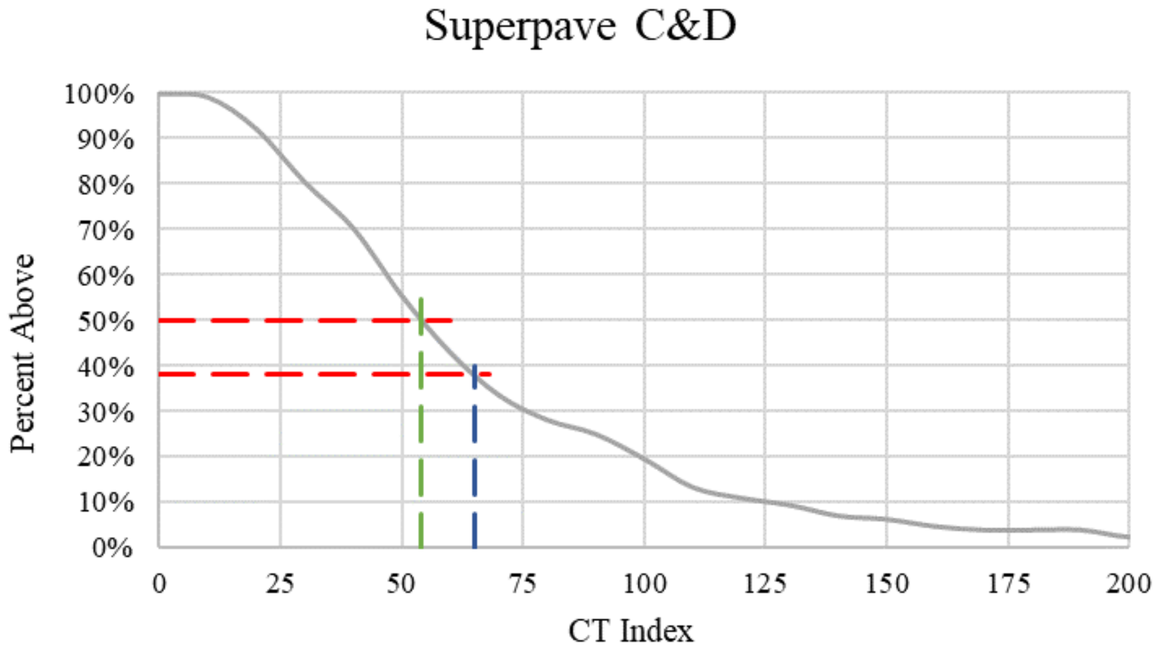
- Common Equipment
  - Gyratory Compactor + Accessories ~ $50k
  - Scale ~ $3.8k
  - Bench Oven ~ $2.6K
  - Specific Gravity equipment ~ $5K
- Additional Equipment
  - Smart Loader + CT/RT frames ~ $11.5k
  - Conditioning Baths ~ $1.3k each
- Total Investment ~ $74k
- Expected Investment Required ~ $14k
- Improved testing efficiency with water baths with results in 2 hrs from molding
- Facilitates mixture performance testing during production

NEW IDEAL-RT
Rutting Jig for SmartLoader

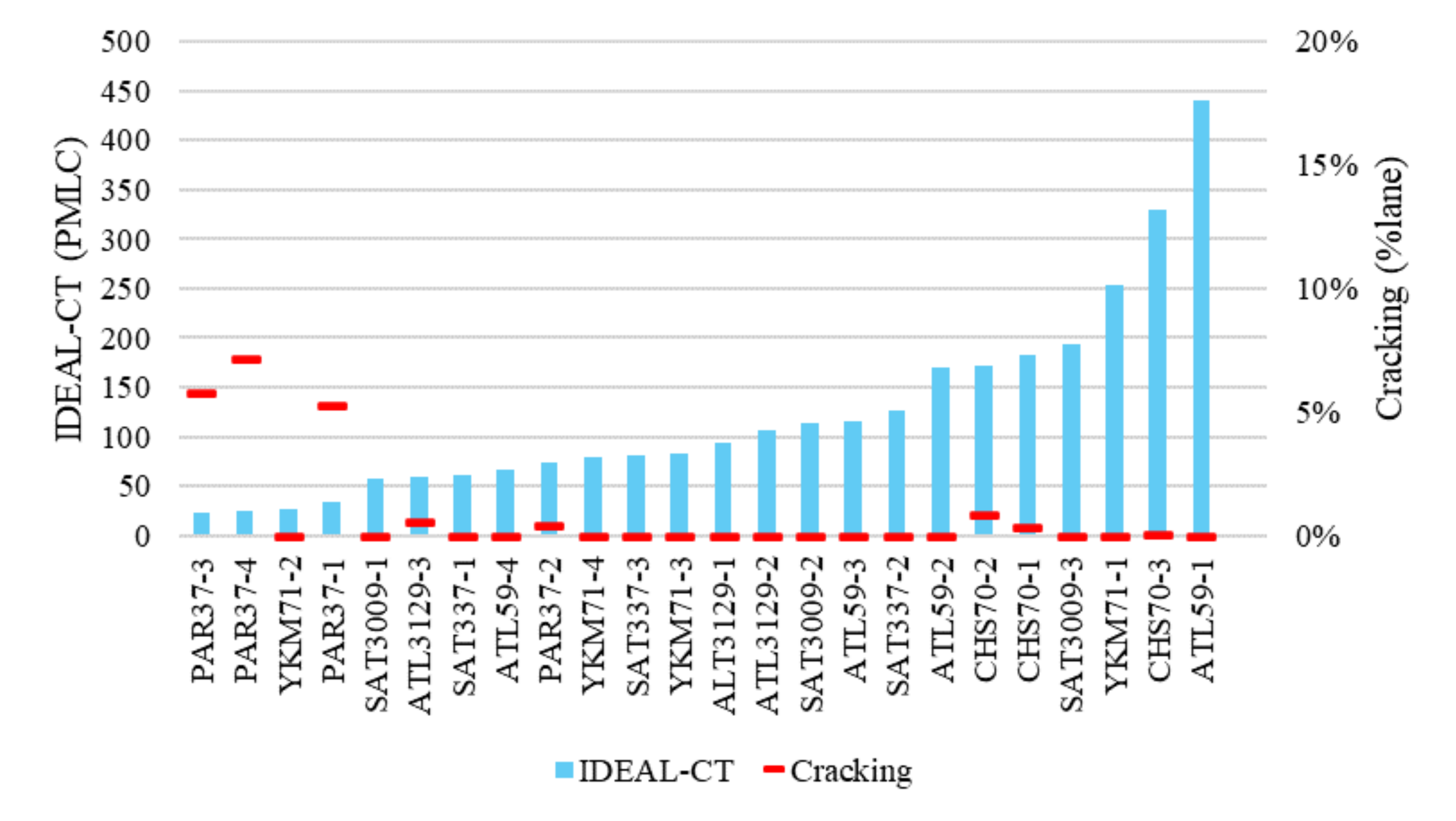
Benchmarking

- HWTT: ~1,800 SP-C/D mixtures (~20yrs) with 83% SP-C, 71% SP-D passing
- OT: 23 SP-C/D mixtures with 100% passing
- CT: 127 SP-C/D mixtures (~5yrs) with ~30% > 80
- CT: 33 2019-2022 BMD mixtures with 55% > 80

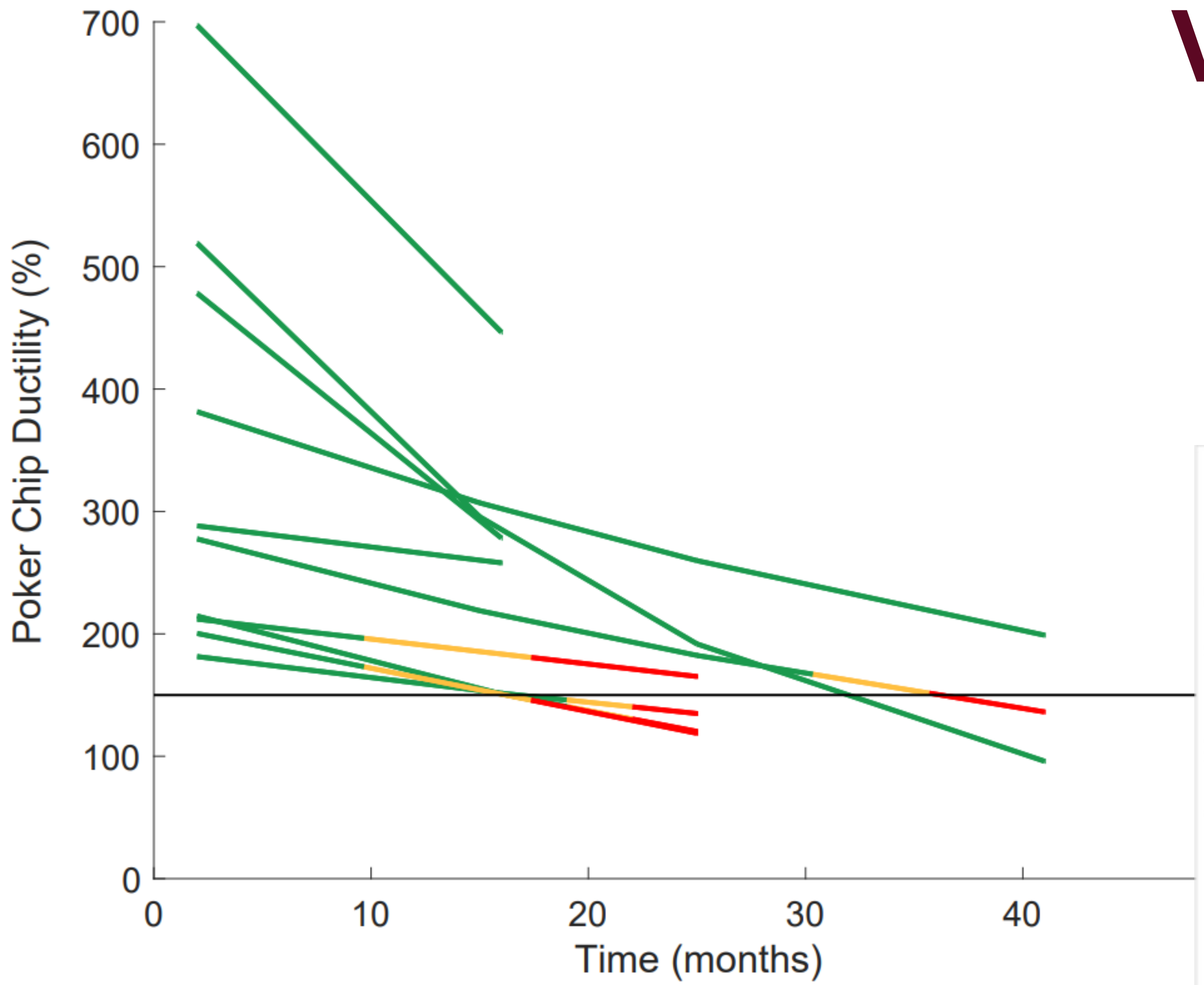




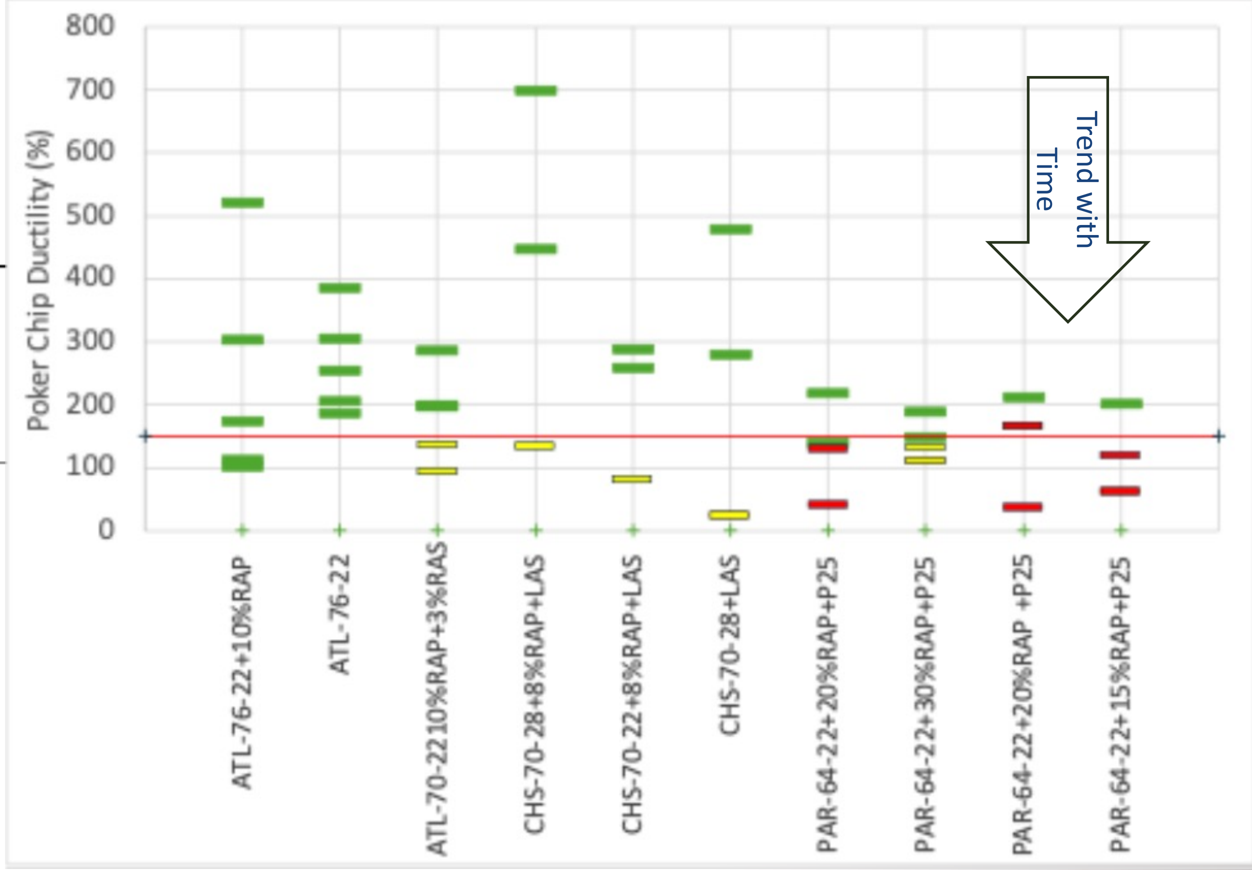
Validation – Mixture Test



Validation – Binder Test

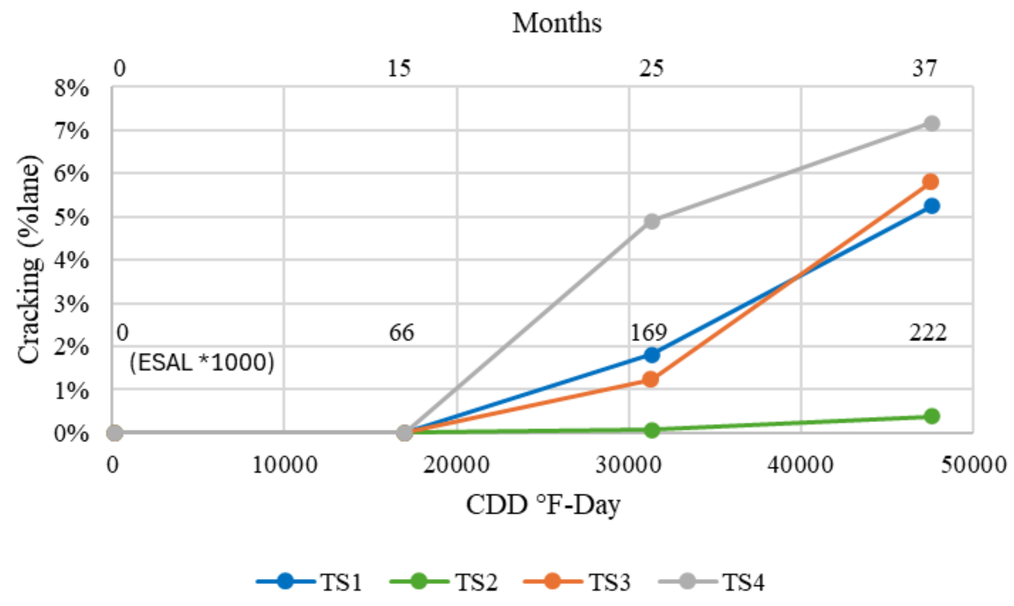


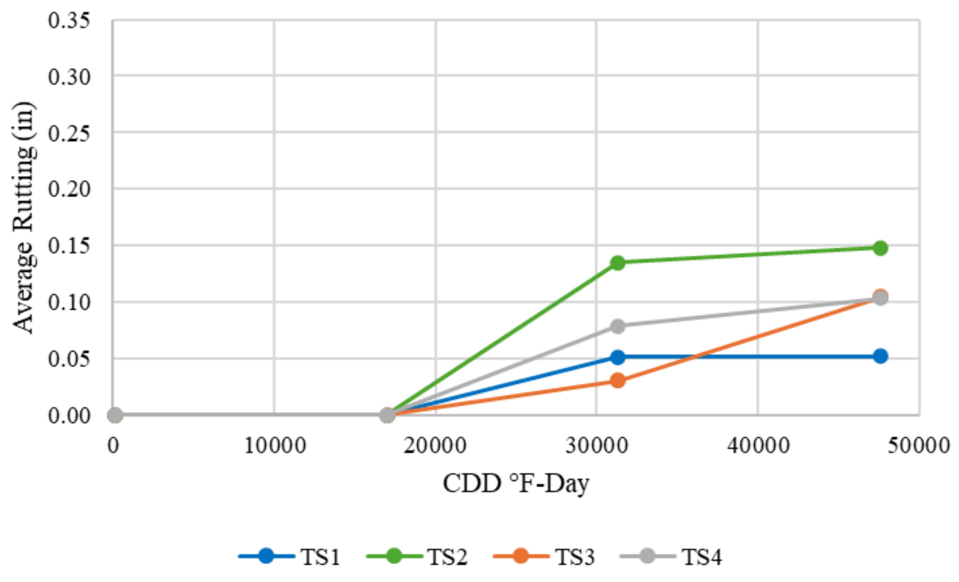
- Green = No Cracking
- Yellow = 0-5%Cracking
- Red = > 5%Cracking

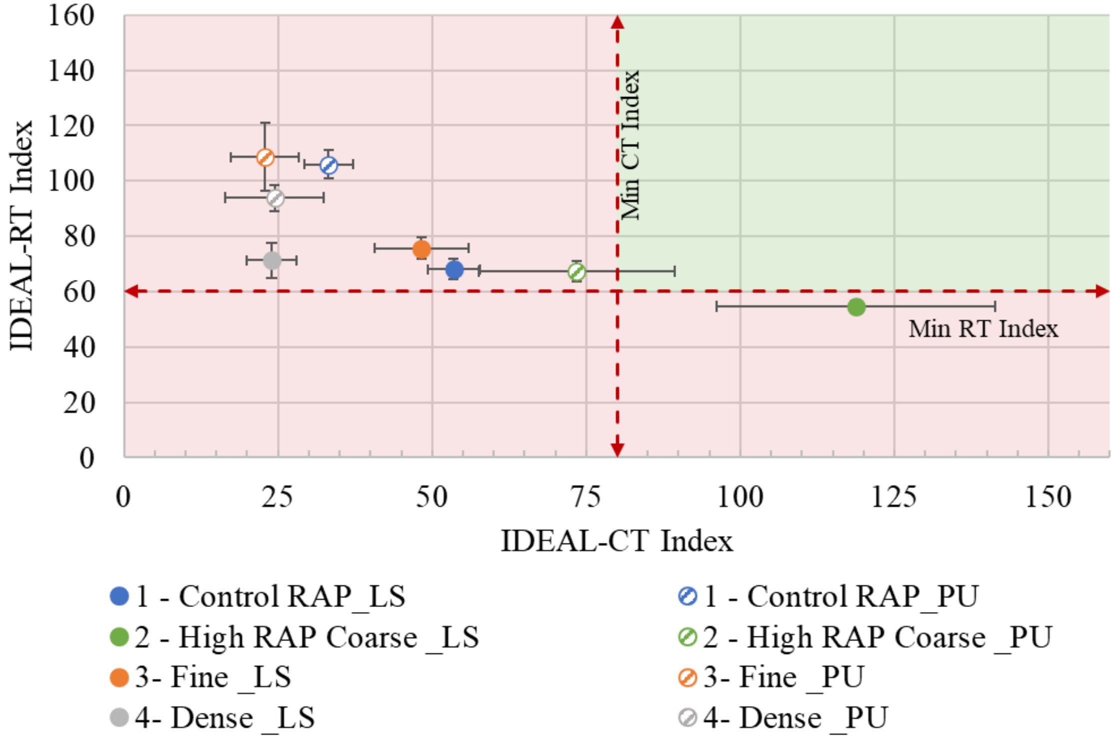


PAR SH 37

Mixture	Spec	Binder	RAP	Additive	VMA	OAC	Virgin AC
Section 1 Control RAP	3077	64-22	20%	0.4% WMA	16.0	5.3%	4.4%
Section 2 High RAP Coarse	3074	64-22	30%	0.4% WMA	17.3	5.9%	4.6%
Section 3 Fine	3074	64-22	20%	0.4% WMA	16.3	5.4%	4.5%
Section 4 Dense	3076	64-22	15%	0.4% WMA	14.0	4.7%	3.9%

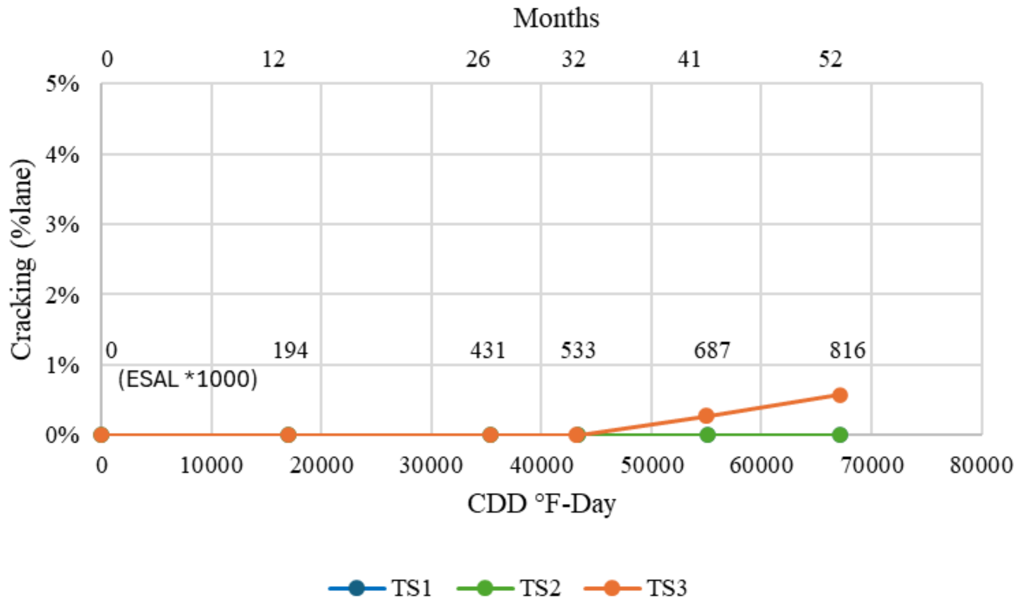


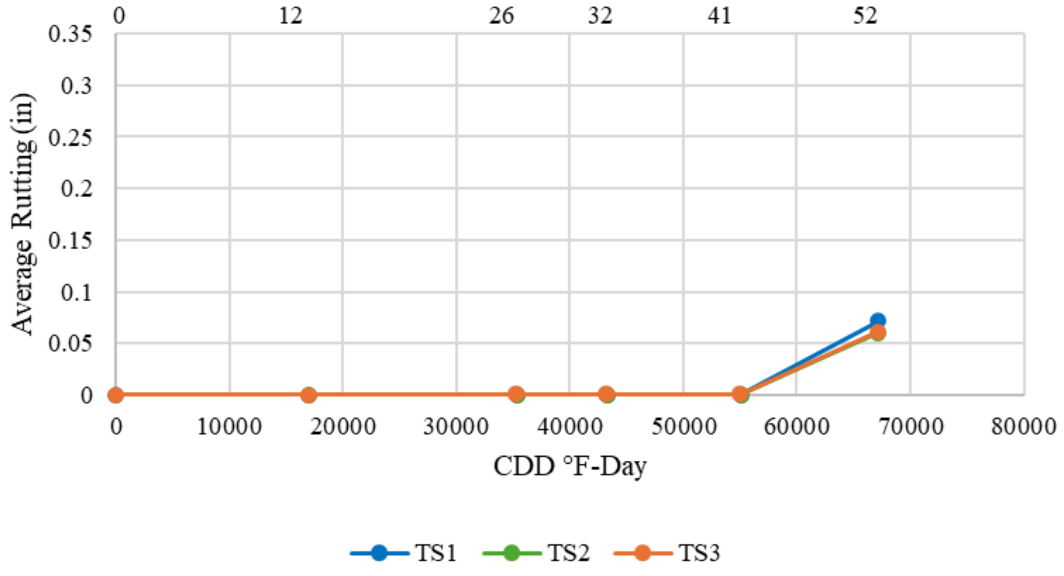


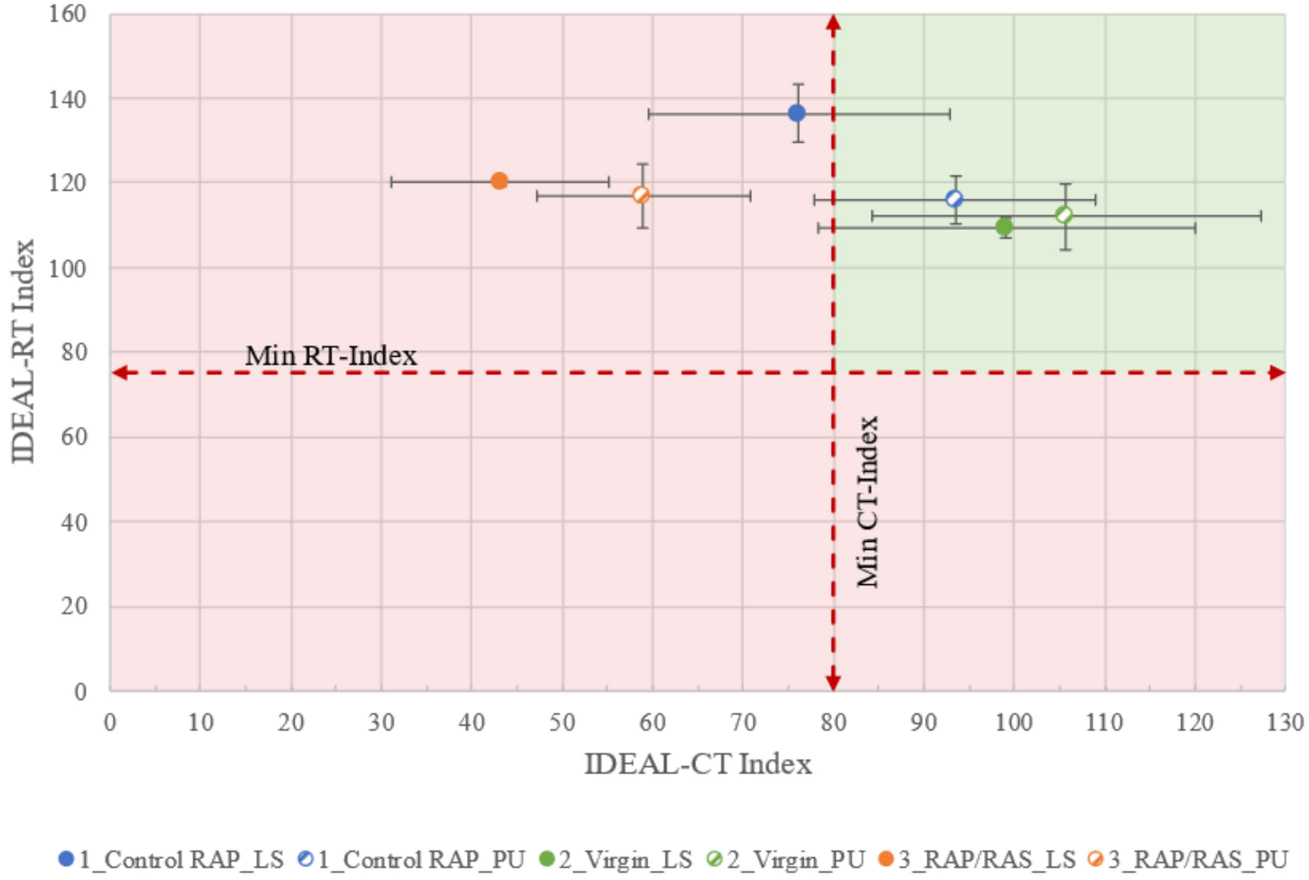


ATL FM 3129

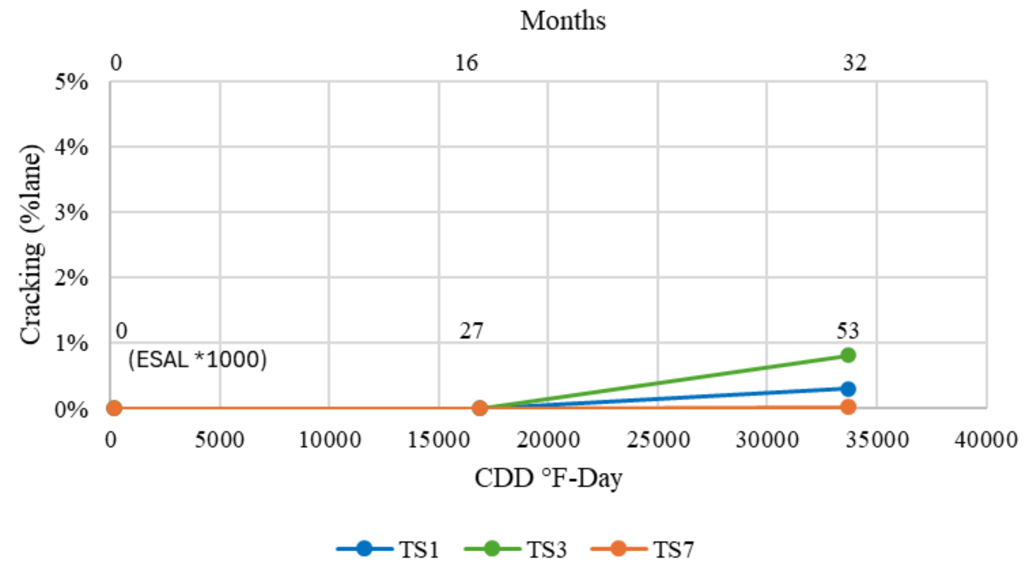
Mixture	Spec	Binder	RAP/ RAS	Additive	OAC	Virgin AC
Section 1 Control RAP	344	76-22	10%	1% Lime	5.5%	5.1%
Section 2 Virgin	344	76-22	0%	1% Lime	5.6%	5.6%
Section 3 RAP/RAS	344	70-22	11%/ 3%	1% Lime	5.5%	4.5%

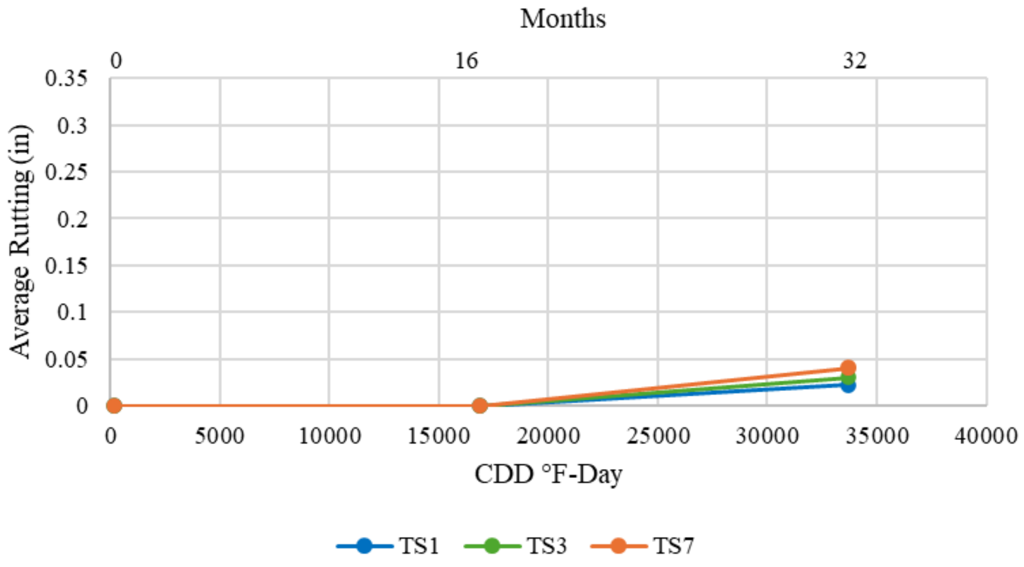




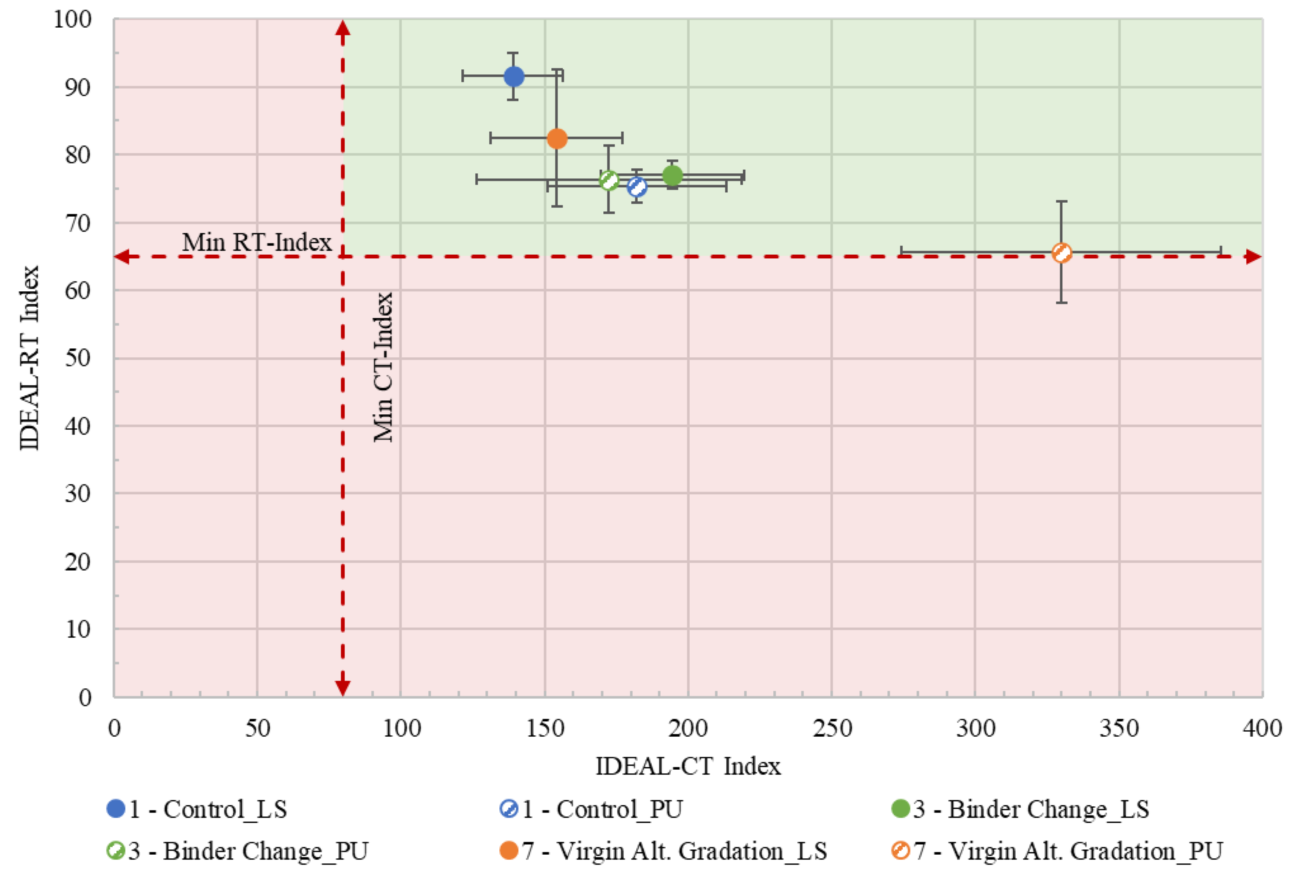


CHS US 70





Mixture	Spec	Binder	RAP	Additive	OAC	Virgin AC
Section 1 Control	3076	70-28	8.5%	0.3% LAS	5.6%	5.1%
Section 3 Binder Change	3074	70-22	8.5%	0.3% LAS	5.6%	5.1%
Section 7 Virgin	3074	70-28	0%	0.3% LAS	5.6%	5.6%



Simplifying & Relaxing Volumetrics with Reduced RBA

Table 10
Laboratory Mixture Design Properties

Mixture Property	Test Method	Requirement
Target laboratory-molded density, %	Tex-207-F	96.0[1]
Design gyrations (Ndesign)	Tex-241-F	50~~[1]~~
~~Indirect tensile strength (dry), psi~~		~~85–200[2]~~
Dust and /asphalt binder ratio[213]	–	0.6–1.6
Boil test[324]	Tex-530-C	–

~~1. Adjust within a range of 35–100 gyrations when shown on the plans or specification or mutually agreed between the Engineer and Contractor.~~
~~The Engineer may allow the IDT strength to exceed 200 psi if the corresponding Hamburg Wheel rut depth is greater than 3.0 mm and less than 12.5 mm.~~

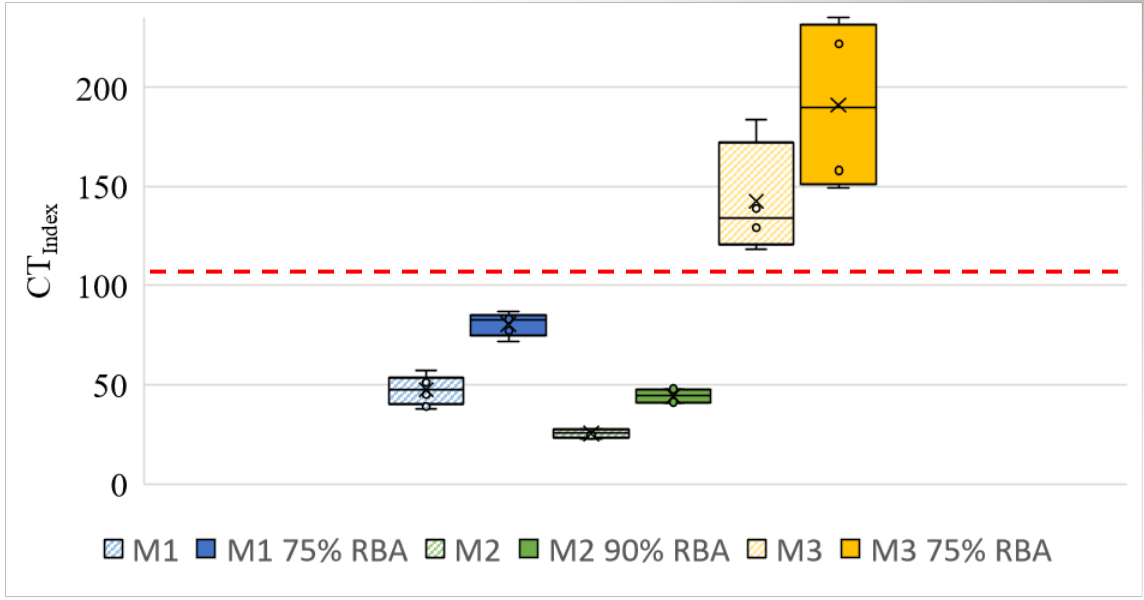
1. When using a reduced recycled binder availability factor, the target laboratory-molded density can be adjusted ± 1.0% at the discretion of the engineer.
2. Defined as % passing #200 sieve divided by asphalt binder content.
3. Used to establish baseline for comparison to production results. May be waived when approved.

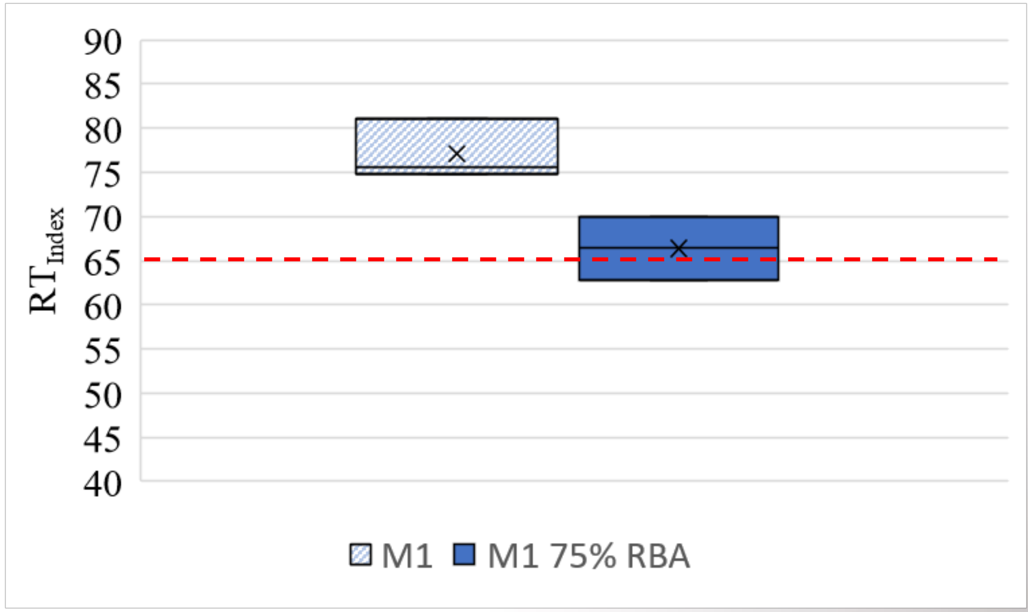
Reasonable Recycled Binder Availability Factors

- RAP: 60-85%
- RAS: 60-75%

Considering Reduced RBA

- Even 90% RBA significantly improved CT_{Index}
- Consider for RAP > 20% and/or PGH > 100C
- For 75% RBA, CT_{Index} increased, RT_{Index} decreased (balance needed)





GDOT (GA) Corrected OAC (COAC) Approach for Reduced RBA

- OAC determined using volumetrics
- Corrected OAC (COAC) determined using decreased RBA
- Performance verified at COAC
- Volumetrics are <u>not</u> verified
- Initially Implemented in 2012 with 75% RBA, reduced to 60% in 2019 with industry collaboration

Corrected Optimum Asphalt Content (COAC)

(60% RAP Binder Contribution)

RAP and Virgin Binder Calculation

- Total optimum AC in mix design = 4.25%
- Percentage of RAP in mix design = 30%
- AC in RAP = 5.09% • RAP AC contribution = (5.09 x .30) = 1.53%
- Using GDOT 0.60 RAP binder credit ratio
- 1.53% x 0.60 = 0.92% • 1.53% – 0.92% = 0.61%
- JMF COAC = 4.25 + 0.61 = **4.86%**
- Virgin AC % = 4.86 – 1.53% = 3.33%

For this example, 0.61% increase in virgin binder content. All mix design performance testing will be conducted at 4.86% binder content.

Volumetric Changes with Reduced RBA

- Expect volumetric changes when reducing recycled binder availability (RBA) factor

- Preliminary data indicates < 1% change in density when reducing RBA to 60% for mixtures with 20-30% RAP

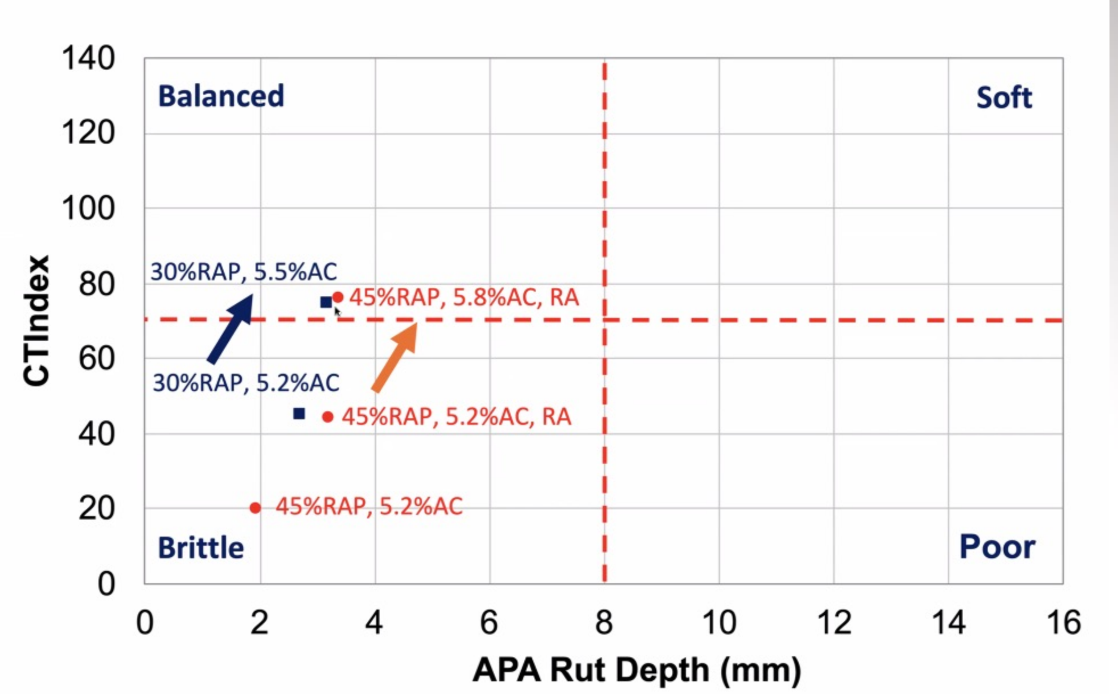
Density
VMA
Virgin Binder
↑

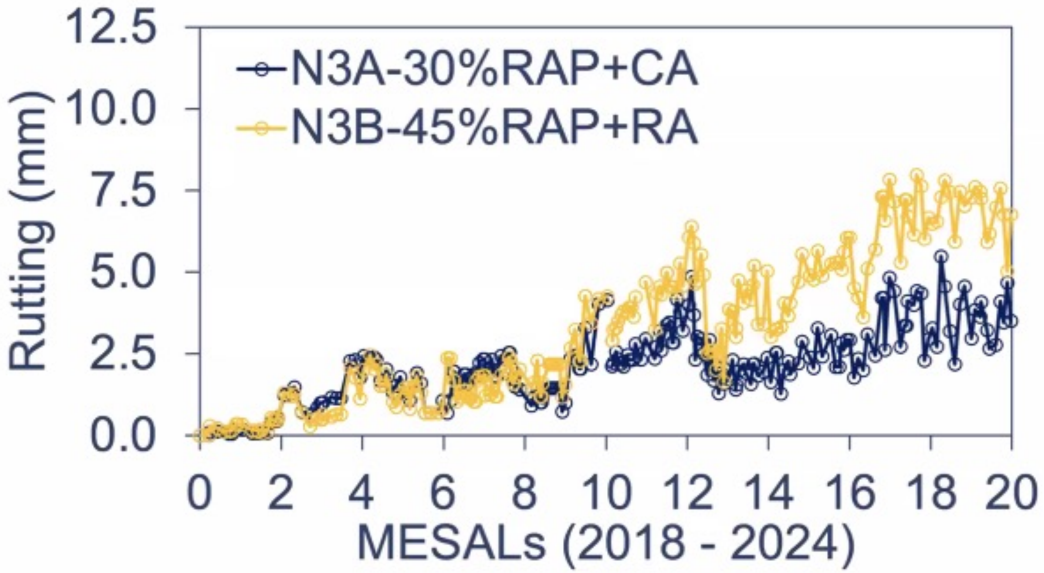
Recycled Binder Availability (RBA)	Δ Density	Δ VMA
75% RBA	+0.5%-0.8%	+0.1-0.3
60% RBA	+0.5-1.0%	+1.0-1.5

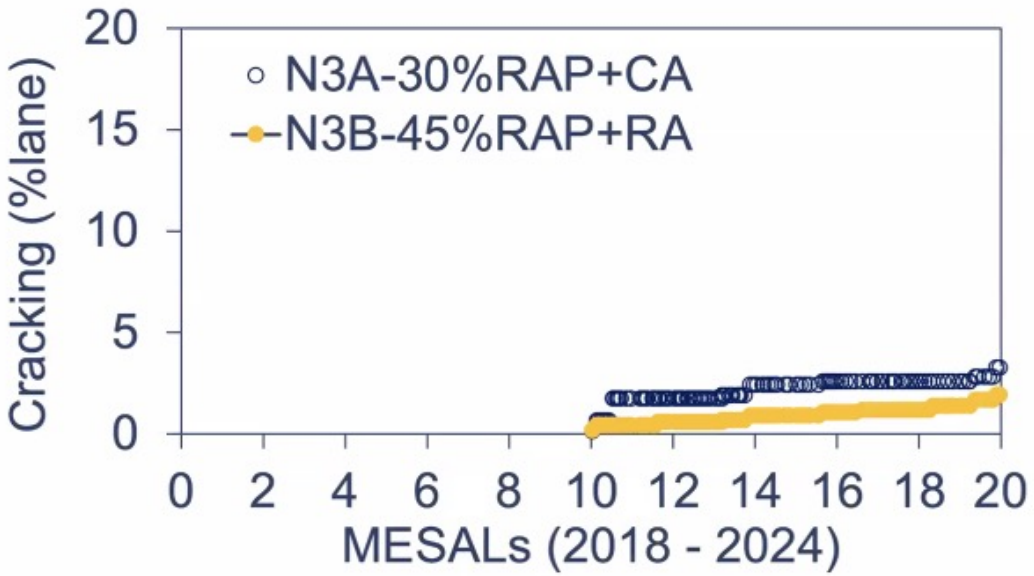
Good Performance with Reduced RBA

- High Lab %Density
- Good cracking and rutting performance after 20 Million ESALS @ NCAT Test Track

Section	%RAP	Strategies	Lab %Density	Field %Density	T_{prod}	T_{comp}
N3A	30	ACeff	97.3	96.2	310	290
N3B	45	RA, ACeff	98.5	96.8	315	275



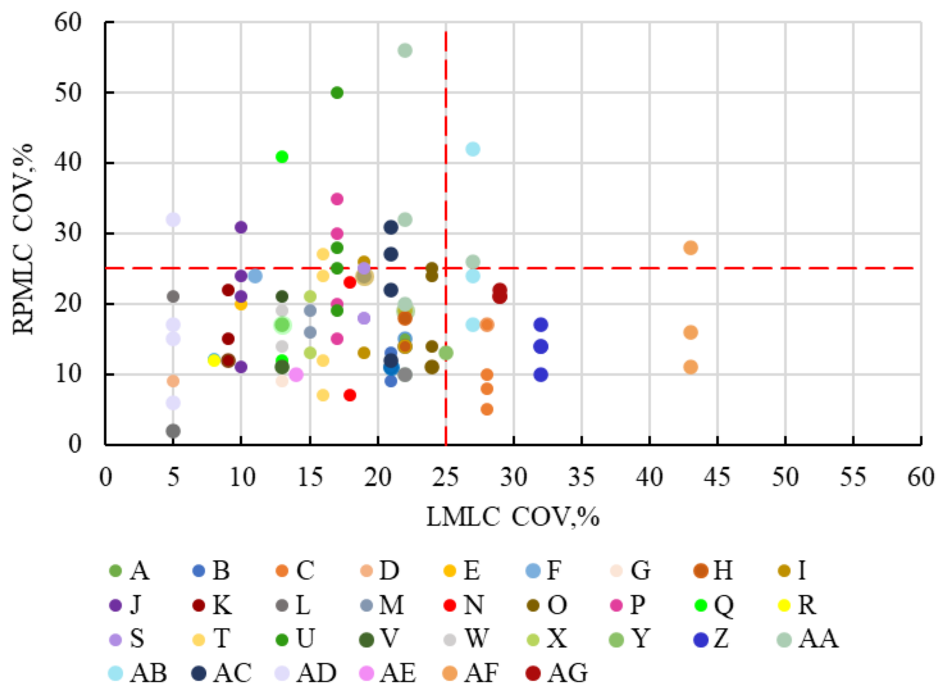




Variability

IDEAL-CT	Specimen Type	Within Lab COV (%)	Between Lab COV (%)
TTI (BMD)	LMLC	18	
VTRC	LMLC	18	21
Rutgers	LMLC	15	23
TTI (BMD)	RPMLC	19	
NCAT RR 2020	RPMLC	21	30

OT CPR	Specimen Type	Within Lab COV (%)	Between Lab COV (%)
TTI (BMD)	LMLC	14	
TTI (BMD)	RPMLC	15	



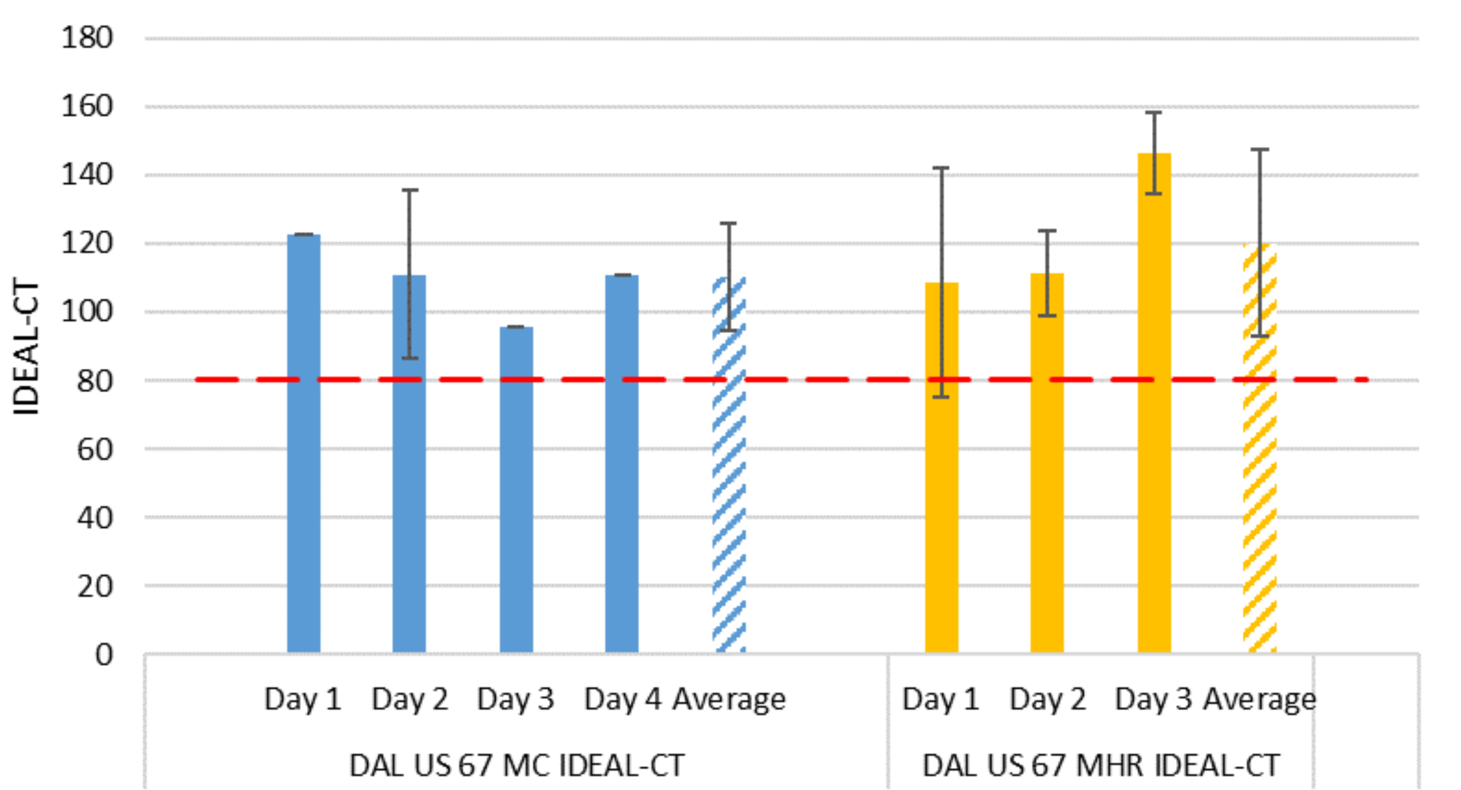
IDEAL-RT	Specimen Type	Within Lab COV (%)	Between Lab COV (%)
TTI (BMD)	LMLC	5	
TTI (BMD)	RPMLC	5	
NCAT RR 2022	RPMLC	8	24

HWTT @ 10k	Specimen Type	Within Lab COV (%)	Between Lab COV (%)
NCAT RR 2022	RPMLC	10	30

Variability (RPMLC)

IDEAL-CT Coefficient of Variation		
	MC	MHR
Mix Average	14%	21%
Day 1	*	35%
Day 2	22%	11%
Day 3	*	8%
Day 4	*	-

* Only 1 sublot tested



Possible Variables to control:

- Average Daily Value
- Day to Day COV

Production Testing Frequency

- Analyzed all possible sampling scenarios for 12 mixtures (47 sublots, 4 replicates each)
- Sampling
  2 sublots per lot (4 replicates each)
  provides balance between accuracy and practicality
- Marginal/Satisfactory mixture will FAIL 4% of the time
- Unsatisfactory mixture (near threshold) will PASS 4% of the time

Table 17
Production and Placement Testing Frequency

Description	Test Method	Min~~imum~~ Contractor Testing Frequency	Min~~imum~~ Engineer Testing Frequency
Individual % retained for #8 sieve and larger	Tex-200-F or Tex-236-F	1 per sublot	1 per 12 sublots[1]
Individual % retained for sieves smaller than #8 and larger than #200			
% passing the #200 sieve			
Laboratory-molded density	Tex-207-F	~~N/A~~	1 per sublot[1]
Laboratory-molded bulk specific gravity			
In-place air voids			
VMA	Tex-204-F		
Segregation (density profile)	Tex-207-F, Part V	1 per sublot[2]	1 per project
Longitudinal joint density	Tex-207-F, Part VII		
Moisture content	Tex-212-F, Part II	When directed	
Theoretical ~~m~~Max~~imum~~ specific (Rice) gravity	Tex-227-F	~~N/A~~	1 per sublot[1]
Asphalt binder content	Tex-236-F	1 per sublot	1 per lot[1]
Hamburg Wheel test[3]	Tex-242-F	~~N/A~~	1 per project
Overlay test[3]	Tex-248-F	~~N/A~~	
IDEAL RT test	Tex-XXX-F	Information only	1 per lot[1,4]
IDEAL CT test	Tex-250-F	Information only	2 per ~~sublot~~[1,4]
Recycled Asphalt Shingles (RAS)[3]	Tex-217-F, Part III	~~N/A~~	1 per project
Thermal profile	Tex-244-F	1 per sublot[2]	
Asphalt binder sampling and testing	Tex-500-C, Part II	1 per lot (sample only)[~~5~~4]	
Tack coat sampling and testing	Tex-500-C, Part III	~~N/A~~	
Boil test[~~6~~5]	Tex-530-C	1 per lot	
Shear Bond Strength Test[~~7~~6]	Tex-249-F	1 per project (sample only)	
~~IDEAL CT test[3]~~	~~Tex-250-F~~	~~N/A~~	~~1 per sublot[1]~~

1. For production defined in Section 3074.4.9.4., "Exempt Production," the Engineer will test one per day if 100 tons or more are produced. For Exempt Production, no testing is required when less than 100 tons are produced.
2. To be performed in the presence of the Engineer, unless otherwise approved. Not required when a thermal imaging system is used.
3. Testing performed by the Materials and Tests Division or designated laboratory.
4. Testing performed on a randomly assigned sublot(s).

~~4.~~5. Obtain samples witnessed by the Engineer. The Engineer will retain these samples for one year.
~~5.~~6. The Engineer may reduce or waive the sampling and testing requirements based on a satisfactory test history.
~~6.~~7. Testing performed by the Materials and Tests Division or District for informational purposes only.

Operational Tolerances

Table 12
Operational Tolerances

Description	Test Method	Allowable Difference Between Trial Batch and JMF1 Target	Allowable Difference from Current JMF Target	Allowable Difference between Contractor and Engineer[1]
Individual % retained for #8 sieve and larger	Tex-200-F or Tex-236-F	Must be wWithin mMaster gGrading lLimits in Table 8	±5.0[2,3]	±5.0
Individual % retained for sieves smaller than #8 and larger than #200			±3.0[2,3]	±3.0
% passing the #200 sieve			±2.0[2,3]	±1.6
Asphalt binder content, %	Tex-236-F	±0.5	±0.3[3]	±0.3
Dust/asphalt binder ratio[4]	–	Note 5	Note 5	N/A
Laboratory-molded density, %	Tex-207-F	±1.0	±1.0	±0.5
In-place air voids, %		N/A	N/A	±1.0
Laboratory-molded bulk specific gravity		N/A	N/A	±0.020
VMA, % min	Tex-204-F	Note 6	Note 6	N/A
Theoretical Mmaximum specific (Rice) gravity	Tex-227-F	N/A	N/A	±0.020
IDEAL RT test	Tex-XXX-F	7	7	7
IDEAL CT test	Tex-250-F	10	10	15

1. Contractor may request referee testing only when values exceed these tolerances. Engineer may waive if meeting performance requirement.
2. When within these tolerances, mixture production gradations may fall outside the master grading limits; however, the % passing the #200 will be considered out of tolerance when outside the master grading limits.
3. Only applies to mixture produced for Lot 1 and higher.
4. Defined as % passing #200 sieve divided by asphalt binder content.
5. Verify that Table 10 requirement is met.
6. Verify that Table 8 requirements are met.

Proposed Specification Changes

Special Specification 3074

Superpave Mixtures – Balanced Mix Design

1. DESCRIPTION

Construct a hot-mix asphalt (HMA) surface pavement layer composed of a compacted, Superpave (SP) mixture of aggregate and asphalt binder mixed hot in a mixing plant utilizing a Balanced Mix Design (BMD) approach. Payment adjustments will apply to HMA ~~placed under~~in accordance with this ~~S~~specification unless the HMA is deemed exempt in accordance with Section 344.4.9.4., "Exempt Production."

Texas Department of Transportation

Texas A&M Transportation Institute

- Increasing RAP/RBR
- Adding IDEAL-RT
- Utilizing IDEAL-CT, Limiting OT
- Changing IDEAL-CT Thresholds
- Simplifying Requirements
  - Removing IDT Strength
  - Removing Min RD by HWTT
  - Standardizing N_{design}=50
- Considering Reduced Recycled Binder Availability (RBA) with Adjusted Lab %Density
- Adjusting Production Testing and Frequency
- Adding Operational Tolerances

THANK YOU!

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Implementation Partners

TxDOT, TxAPA

Contractors, Materials Suppliers