Reclaimed Asphalt Pavement (RAP) Characterization in Massachusetts

MassDEP's Fall-2023 C&D Materials Market

Development Webinar Series

Ed Naras
Pavement Management Engineer
MassDOT - Highway Division

Walaa S. Mogawer, P.E.
Professor and Director
Highway Sustainability Research Center
University of Massachusetts Dartmouth

Outline

- Background
- Problem Statement
- Objectives
- Methodology
- Data and Analysis
- Conclusions
- Recommendations

Background

- RAP use in a mixture is typically specified by State agencies following the guidance of the AASHTO M323.

Method #1:Percent by Dry Weight of the Mixture

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	<15
Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used)	15 to 25
Follow recommendations from Appendix X1	>25

Method #2: RAP Binder Ratio (RAPBR)

Recommended Virgin Asphalt Binder Grade	RAPBR
No change in binder selection	<0.25
Follow recommendations from Appendix X2	>0.25

- AASHTO M323 also provides blending equations for higher RAP percentages

Problem Statement

- For surface mixtures, MassDOT specification currently allows up to 15% RAP by dry weight of the mixture with no change to the typical specified binder (PG64-28).

- The specification implies that:

  1. The required binder properties of the mixture will be met regardless of the properties of the aged RAP binder or the RAP binder content.

  2. Mixture performance will be independent of the source of the virgin PG64-28 asphalt binder.

Objectives

1. Determine if MassDOT specification which allows up to 15% RAP in surface mixtures is valid regardless of RAP source and virgin binder source.

2. Determine if the MassDOT specification should be based on RAPBR instead of by dry weight.

3. Use a Balanced Mix Design (BMD) procedure to determine the effects of using 15%, 25%, and 35% percent RAP without using a softer binder or a rejuvenator, and which mixtures would remain balanced.

4. Determine what changes are needed, if any, to the current MassDOT specification for RAP use in surface mixtures.

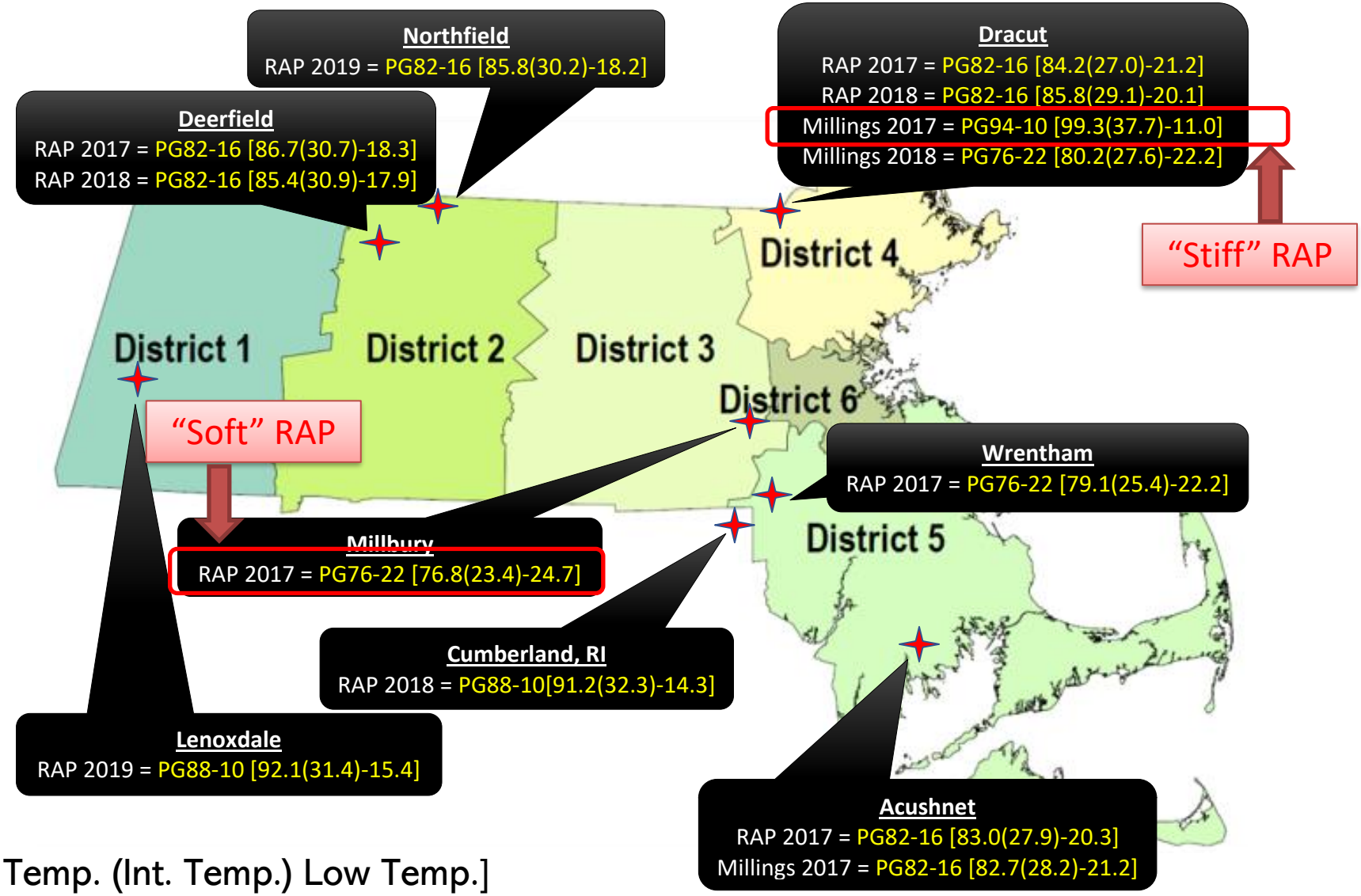
Methodology

Four Steps:

- Determination of RAP Properties Throughout Massachusetts
- Determination of Virgin Binders Properties Throughout Massachusetts
- Analysis of Methods to Specify RAP in a Mixture
- Mixture Design with RAP Using a BMD Approach

Step 1:
Determination of RAP Properties Throughout the State

Average RAP Binder Grading



[High Temp. (Int. Temp.) Low Temp.]

Step 2:
Determination of Virgin Binders Properties Throughout the State

Property	PG64-28 Virgin Binder Source			
	Deerfield [A]	Providence [B]	Newington [C]	Canada [D]
Performance Grade	PG64-28	PG64-28	PG64-28	PG64-28
Average Continuous Grade	65.8(15.8)-30.9	66.2(20.4)-28.6	65.0(16.3)-30.6	65.5(16.8)-30.9
Average Delta T_c (ΔT_c)	+0.8°C	-1.2°C	-1.2°C	-0.1°C

Close to thresholds for a PG 64-28
22°C Intermediate temperature
-28.0°C Low temperature

Step 3:
Analysis of Methods to Specify RAP in a Mixture

Methods of RAP Specification

1. Percent Dry Weight of Mixture Method
2. RAP Binder Ratio (RAPBR) Method
3. AASHTO M323 Blending Charts/Equations

Percent Dry Weight of Mixture Method

$$\% \, RAP = \frac{T_{Blend} - T_{Virgin}}{T_{RAP} - T_{Virgin}}$$

Where:

T_{Virgin} = Critical temperature of the virgin asphalt binder (high, intermediate, or low)

T_{Blend} = Critical temperature of the blended asphalt binder (high, intermediate, or low)

T_{RAP} = Critical temperature of the recovered RAP binder (high, intermediate, or low)

Percent Dry Weight of Mixture Method

Predicted Allowable Percent RAP

Location	PG64-28 Virgin Binder Source			
	Deerfield [A]	Providence [B]	Newington [C]	Canada [D]
District 1				
Lenoxdale RAP 2019	18.7	**4.5F**	17.1	18.7
District 2				
Deerfield RAP 2017	23.0	**5.8F**	21.1	23.0
Deerfield RAP 2018	22.3	**5.6F**	20.5	22.3
Northfield RAP 2019	22.8	**5.8F**	21.0	22.8
District 3				
Millbury RAP 2017	46.8	**15.4**	44.1	46.8
Cumberland RAP 2018	17.5	**4.2F**	16.0	17.5
District 4				
Dracut RAP 2017	29.9	**8.1F**	27.7	29.9
Dracut RAP 2018	26.9	**7.1F**	24.8	26.9
Dracut Millings 2017	**14.6F**	**3.4F**	**13.3F**	**14.6F**
Dracut Millings 2018	33.3	**9.4F**	31.0	33.3
District 5				
Wrentham RAP 2017	33.3	**9.4F**	31.0	33.3
Acushnet RAP 2017	27.4	**7.2F**	25.2	27.4
Acushnet Millings 2017	29.9	**8.1F**	27.7	29.9

F = Failed to have a percentage of RAP greater than or equal to 15%.

RAPBR Method

$$RAPBR_{max} = \frac{T_{Need} - T_{Virgin}}{T_{RAP} - T_{Virgin}}$$

Where:

$RAPBR_{max}$ = Maximum RAP binder ratio

T_{Virgin} = Critical temperature of the virgin asphalt binder (high, intermediate, or low)

T_{Need} = Critical temperature needed for the climate or pavement layer (high, intermediate, or low)

T_{RAP} = Critical temperature of the recovered RAP binder (high, intermediate, or low)

Estimate of % RAP from $RAPBR_{max}$

The maximum percentage of RAP corresponding to the calculated $RAPBR_{max}$ can be determined:

$$\%\ RAP = \frac{100(RAPBR_{max})(Pb_{Total})}{(Pb_{RAP})}$$

Where:

$RAPBR_{max}$ = Maximum RAP binder ratio

Pb_{RAP} = Binder content of RAP

% RAP = P_{RAP} = Percent RAP by dry weight of mixture

Pb_{Total} = Total binder content of the mixture (5.5% for this study which corresponds to mixture testing)

$RAPBR_{max}$ To Maintain PG64-28

	PG64-28 Virgin Binder Source							
	Deerfield [A]		Providence [B]		Newington [C]		Canada [D]	
District 1	$RAPBR_{max}$	% RAP	$RAPBR_{max}$	% RAP	$RAPBR_{max}$	% RAP	$RAPBR_{max}$	% RAP
Lenoxdale RAP 2019	**0.19F**	17.2	**0.05F**	4.2	**0.17F**	15.7	**0.19F**	17.2
District 2								
Deerfield RAP 2017	**0.23F**	19.2	**0.06F**	4.9	**0.21F**	17.6	**0.23F**	19.2
Deerfield RAP 2018	**0.22F**	19.5	**0.06F**	4.9	**0.20F**	17.9	**0.22F**	19.5
Northfield RAP 2019	**0.23F**	20.9	**0.06F**	5.3	**0.21F**	19.2	**0.23F**	20.9
District 3								
Millbury RAP 2017	0.47	44.4	**0.15F**	14.6	0.44	41.8	0.47	44.4
Cumberland RAP 2018	**0.17F**	16.6	**0.04F**	4.0	**0.16F**	15.1	**0.17F**	16.6
District 4								
Dracut RAP 2017	0.30	31.6	**0.08F**	8.6	0.28	29.3	0.30	31.6
Dracut RAP 2018	0.27	27.3	**0.07F**	7.2	0.25	25.2	0.27	27.3
Dracut Millings 2017	**0.15F**	13.4	**0.03F**	3.1	**0.13F**	12.2	**0.15F**	13.4
Dracut Millings 2018	0.33	29.6	**0.09F**	8.3	0.31	27.5	0.33	29.6
District 5								
Wrentham RAP 2017	0.33	35.9	**0.09F**	10.1	0.31	33.4	0.33	35.9
Acushnet RAP 2017	0.27	32.7	**0.07F**	8.6	0.25	30.2	0.27	32.7
Acushnet Millings 2017	0.30	27.9	**0.08F**	7.6	0.28	25.8	0.30	27.9

F = Failed to have a $RAPBR_{max}$ of at least 0.23.

Blending Charts/Equations

- Used at larger RAP contents (>15%) and larger RAPBR (>0.25). Analysis conducted at 15%, 25% & 35% RAP.
- Method shows what continuous PG would be provided if a certain percentage of RAP were to be used.
- Goal is to maintain a PG64-28.
- $$T_{Virgin} = \frac{T_{Blend} - (\%RAP \; x \; T_{RAP})}{(1 - \%RAP)}$$

Where:

T_{Virgin} = Critical temperature of the virgin asphalt binder (high, intermediate, or low)
T_{Blend} = Critical temperature of the blended asphalt binder (high, intermediate, or low)
T_{RAP} = Critical temperature of the recovered RAP binder (high, intermediate, or low)
% RAP = Percentage of RAP expressed as a decimal

Blending Charts – Results 15% RAP

	Source A	Source B	Source C	Source D
District 1				
Lenoxdale RAP 2019	PG 64-28	**PG 70-22 F**	PG 64-28	PG 64-28
District 2				
Deerfield RAP 2017	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Deerfield RAP 2018	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Northfield RAP 2019	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
District 3				
Millbury RAP 2017				PG 64-28
Cumberland RAP 2018				PG 64-28
District 4				
Dracut RAP 2017	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Dracut RAP 2018	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Dracut Millings 2017	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**
Dracut Millings 2018	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
District 5				
Wrentham RAP 2017	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Acushnet RAP 2017	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Acushnet Millings 2017	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28

15% RAP

29% of Combinations Failed

Blending Charts – Results 25% RAP

	Source A	Source B	Source C	Source D
District 1				
Lenoxdale RAP 2019	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**
District 2				
Deerfield RAP 2017	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**
Deerfield RAP 2018	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**
Northfield RAP 2019	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**
District 3				
Millbury RAP 2017				PG 64-28
Cumberland RAP 2018				**PG 70-22 F**
District 4				
Dracut RAP 2017	PG 70-28	**PG 70-22 F**	PG 64-28	PG 70-28
Dracut RAP 2018	PG 70-28	**PG 70-22 F**	PG 70-28	PG 70-28
Dracut Millings 2017	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**	**PG 70-22 F**
Dracut Millings 2018	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
District 5				
Wrentham RAP 2017	PG 64-28	**PG 64-22 F**	PG 64-28	PG 64-28
Acushnet RAP 2017	PG 70-28	**PG 70-22 F**	PG 64-28	PG 64-28
Acushnet Millings 2017	PG 70-28	**PG 70-22 F**	PG 64-28	PG 64-28

25% RAP

60% of Combinations Failed

Blending Charts – Results 35% RAP

	Source A	Source B	Source C	Source D
District 1				
Lenoxdale RAP 2019	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
District 2				
Deerfield RAP 2017	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
Deerfield RAP 2018	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
Northfield RAP 2019	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
District 3				
Millbury RAP 2017				PG 64-28
Cumberland RAP 2018				PG 70-22 F
District 4				
Dracut RAP 2017	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
Dracut RAP 2018	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
Dracut Millings 2017	PG 70-22 F	PG 76-22 F	PG 76-22 F	PG 70-22 F
Dracut Millings 2018	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
District 5				
Wrentham RAP 2017	PG 70-22 F	PG 70-22 F	PG 64-22 F	PG 70-22 F
Acushnet RAP 2017	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F
Acushnet Millings 2017	PG 70-22 F	PG 70-22 F	PG 70-22 F	PG 70-22 F

35% RAP

94% of Combinations Failed

Methods of RAP Specification - Discussion

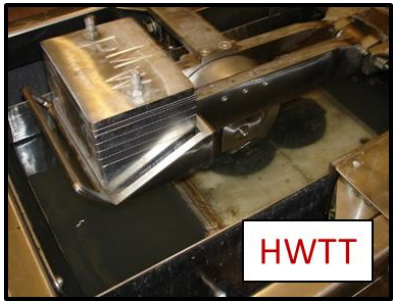
- Percent dry weight of mixture method: Analysis showed 15% RAP could be not used in 15 of 52 combinations (29%).
- RAPBR method: 31 of 52 combinations (60%) failed to have a $RAPBR_{max}$ of at least 0.25.
- None of the methods showed agreement to each other.
- The accuracies of the above methods need to be determined by looking at the performances of actual mixtures incorporating different RAP sources and virgin binder sources.

Step 4:
Mixture Design with RAP Using a Balanced Mix Design (BMD) Approach

Balanced Mixture Design (BMD)

- Utilized volumetric properties followed by performance evaluation.
- RAP sources selected were the Dracut Millings 2017 (Stiff RAP) and Millbury RAP 2017 (Soft RAP).
- Source A (Deerfield) & B (Providence) binders were selected as they represented the two extremes in terms of the intermediate and low temperature continuous grade.

BMD Performance Evaluation Measures

DISTRESS	TEST	AGING	CRITERIA
Rutting	Hamburg Wheel Tracking Test (AASHTO T324) 	Short-Term 4 hrs. at 135°C	45°C Test Temperature < 12.5 mm & No SIP before 15,000 passes
Intermediate Temperature Cracking	Flexibility Index Test (AASHTO TP124) 	Short-Term 4 hrs. at 135°C	25°C Test Temperature FI > 8.0

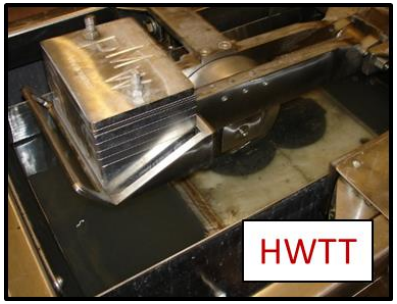
Balanced Mixture Design

RAP Source = Stiff RAP PG94-10 (99.3-11.0)				
	15% RAP	25% RAP	35% RAP	Criteria
Volumetric Properties				
Air Voids, %	4.2	4.8	5.2	4%
Voids in Mineral Aggregate (VMA), %	15.5	15.9	15.9	15% min.*
Voids Filled with Asphalt (VFA), %	73.1	69.9	67.2	65-78%
Dust to Binder Ratio	0.95	0.96	1.00	0.6-1.2
Performance - Rutting				
HWTT rutting at 20,000 passes, mm	3.3	3.0	2.4	< 12.5 mm**
HWTT Stripping Inflection Point	NONE	NONE	NONE	-
Performance - Cracking				
Average FIT Flexibility Index (FI) @ 25°C	14.5	11.8	9.4	≥8.0**
RAP Source = Soft RAP PG76-22 (76.8-24.7)				
	15% RAP	25% RAP	35% RAP	Criteria
Volumetric Properties				
Air Voids, %	3.9	3.9	3.9	4%
Voids in Mineral Aggregate (VMA), %	15.3	15.0	14.5	15% min.*
Voids Filled with Asphalt (VFA), %	74.6	74.0	73.2	65-78%
Dust to Binder Ratio	0.94	0.98	1.02	0.6-1.2
Performance - Rutting				
HWTT rutting at 20,000 passes, mm	1.8	2.0	2.2	< 12.5 mm**
HWTT Stripping Inflection Point	NONE	NONE	NONE	-
Performance - Cracking				
Average FIT Flexibility Index (FI) @ 25°C	8.8	10.6	10.7	≥8.0**

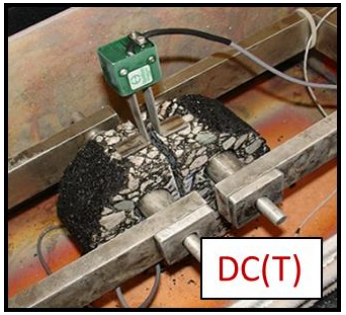
* MassDOT specifications require a 1% increase in VMA as presented here.

** Specimens were short-term aged.

Mixture Performance Evaluation with Respect to RAP Source and Virgin Binder Source

DISTRESS	TEST	AGING	CRITERIA
Rutting	Hamburg Wheel Tracking Test (AASHTO T324) 	Short-Term 4 hrs. at 135°C	45°C Test Temperature < 12.5 mm & No SIP before 15,000 passes
Intermediate Temperature Cracking	Flexibility Index Test (AASHTO TP124) 	Long-Term 5 Days Loose at 95°C	25°C Test Temperature FI > ???

Mixture Performance Evaluation with Respect to RAP Source and Virgin Binder Source

DISTRESS	TEST	AGING	CRITERIA
Intermediate Temperature Cracking	IDEAL-CT (ASTM D8225) 	Long-Term 5 Days Loose at 95°C	15°C Test Temperature CT_{Index} > ???
Low Temperature (Thermal) Cracking	Disc Shaped Compact Tension DC(T) (ASTM D7313) 	Long-Term 11 Days Loose at 95°C	-18°C Test Temperature FE > ????

HWTT Results @ 45°C

RAP Source	PG64-28 Virgin Binder Source	% RAP Specified by Weight	RAPBR	Stripping Inflection Point (SIP)	Maximum Rut Depth at 20,000 Passes (mm)
Stiff RAP PG94-10 (99.3-11.0)	CG (65.8-30.9)	15%	0.16	None	3.3
	CG (66.2-28.6)	15%	0.16	None	2.4
	CG (65.8-30.9)	25%	0.27	None	3.0
	CG (66.2-28.6)	25%	0.27	None	2.5
			38	None	2.4
			0.38	None	2.0
So PG (76.8-24.7)			0.16	None	1.8
			0.16	None	1.4
			0.26	None	2.0
			0.26	None	1.3
	CG (65.8-30.9)	35%	0.37	None	2.2
	CG (66.2-28.6)	35%	0.37	None	1.3

< 12.5 mm & No SIP before 15,000 Passes

FIT Results @ 25°C

RAP Source	PG64-28 Virgin Binder Source	% RAP Specified by Weight	RAPBR	Blended Intermediate CG	FI	FE (J/m²)
Stiff RAP PG94-10 (99.3-11.0)	CG (65.8-30.9)	15%	0.16	23.0	3.3	1,907
	CG (66.2-28.6)	15%	0.16	23.0	1.9	1,782
	CG (65.8-30.9)	25%	0.27	21.3	3.3	1,830
	CG (66.2-28.6)	25%	0.27	24.7	2.0	1,773
	CG (65.8-30.9)	35%	0.38	23.5	2.7	1,933
	CG (66.2-28.6)	35%	0.38	26.5	1.0	1,332
Soft RAP PG76-22 (76.8-24.7)	CG (65.8-30.9)	15%	0.16	16.9	3.4	1,816
	CG (66.2-28.6)	15%	0.16	20.9	3.7	1,801
	CG (65.8-30.9)	25%	0.26	17.7	3.8	1,882
	CG (66.2-28.6)	25%	0.26	21.2	2.6	1,685
	CG (65.8-30.9)	35%	0.37	18.5	3.7	1,829
	CG (66.2-28.6)	35%	0.37	21.5	2.6	1,700

IDEAL-CT Results @ 15°C

RAP Source	PG64-28 Virgin Binder Source	% RAP Specified by Weight	RAPBR	Blended Intermediate CG	CT_{Index}	FE (J/m^2)
Stiff RAP PG94-10 (99.3-11.0)	CG (65.8-30.9)	15%	0.16	23.0	15.2	10,378
	CG (66.2-28.6)	15%	0.16	23.0	9.7	8,543
	CG (65.8-30.9)	25%	0.27	21.3	15.5	11,241
	CG (66.2-28.6)	25%	0.27	24.7	6.4	8,398
	CG (65.8-30.9)	35%	0.38	23.5	9.9	10,416
	CG (66.2-28.6)	35%	0.38	26.5	2.8	7,468
Soft RAP PG76-22 (76.8-24.7)	CG (65.8-30.9)	15%	0.16	16.9	15.4	10,032
	CG (66.2-28.6)	15%	0.16	20.9	11.9	9,141
	CG (65.8-30.9)	25%	0.26	17.7	22.1	10,267
	CG (66.2-28.6)	25%	0.26	21.2	16.9	9,857
	CG (65.8-30.9)	35%	0.37	18.5	13.6	9,693
	CG (66.2-28.6)	35%	0.37	21.5	17.3	10,131

DC(T) Results @ -18°C

RAP Source	PG64-28 Virgin Binder Source	% RAP Specified by Weight	RAPBR	Blended Low Temperature CG	FE (J/m^2)
Stiff RAP PG94-10 (99.3-11.0)	CG (65.8-30.9)	15%	0.16	- 27.9	443
	CG (66.2-28.6)	15%	0.16	-26.0	333
	CG (65.8-30.9)	25%	0.27	-25.9	537
	CG (66.2-28.6)	25%	0.27	-24.2	418
	CG (65.8-30.9)	35%	0.38	-23.9	397
	CG (66.2-28.6)	35%	0.38	-22.4	360
Soft RAP PG76-22 (76.8-24.7)	CG (65.8-30.9)	15%	0.16	-30.0	479
	CG (66.2-28.6)	15%	0.16	-28.0	371
	CG (65.8-30.9)	25%	0.26	-29.4	474
	CG (66.2-28.6)	25%	0.26	-27.6	382
	CG (65.8-30.9)	35%	0.37	-28.7	478
	CG (66.2-28.6)	35%	0.37	-27.2	403

ANOVA Analysis Summary

Variable	FI Test FI	FI Test FE	IDEAL CT_{Index}	IDEAL FE	DC(T) FE
RAP Source	SIG	-	SIG	-	-
Virgin Binder Source	SIG	SIG	SIG	SIG	SIG
Percent RAP	SIG	SIG	SIG	-	-

ANOVA Discussion

- Virgin binder source had a significant effect on all three measures.
- RAP source and percent RAP also had a significant effect on the two intermediate cracking performance.
- The analyses showed an inconsistency among the cracking performance tests and measures except virgin binder sources has a significant effect.

Conclusions

- The current specification, which allows up to 15% RAP in surface mixtures by dry weight of the mixture without using a softer grade virgin binder or blending equations, was not valid based on blended binder properties.
- Utilizing the RAPBR for specifying RAP in lieu of the percent by dry weight of the mixture method produced similar results.

Conclusions

- A statistical analysis of the mixture test data indicated universally that virgin binder source significantly impacted all cracking performance measures.
- RAP source and percent RAP also had a significant effect on intermediate cracking measures being explored by MassDOT to incorporate in a BMD protocol.

Case Study of High RAP Content Surface Mixtures Placed on High-Volume Roads

Outline

- ❑ Problem Statement
- ❑ Objectives
- ❑ Methodology
- ❑ Results
- ❑ Conclusions

Problem Statement

- MassDOT specifications only allow up to 15% Reclaimed Asphalt Pavement (RAP) in surface course mixtures.

- Based on a UMass/MassDOT 2020 study entitled *"Influence of Reclaimed Asphalt Pavement (RAP) Source and Virgin Binder Source on RAP Specifications and Balanced Mix Design"* the following was concluded:

  - The RAP content could be increased over the 15% maximum based on the properties of the RAP, which is source dependent.

  - The RAP source has a significant effect on the cracking resistance of the asphalt mixture.

Problem Statement

MassDOT approved demonstration projects beginning in 2021 for high RAP surface mixtures with RAP contents between 25% and 30%.

These mixtures were placed on high-volume interstate projects to evaluate the RAP content specification limit and to document/evaluate their production, placement, and variability.

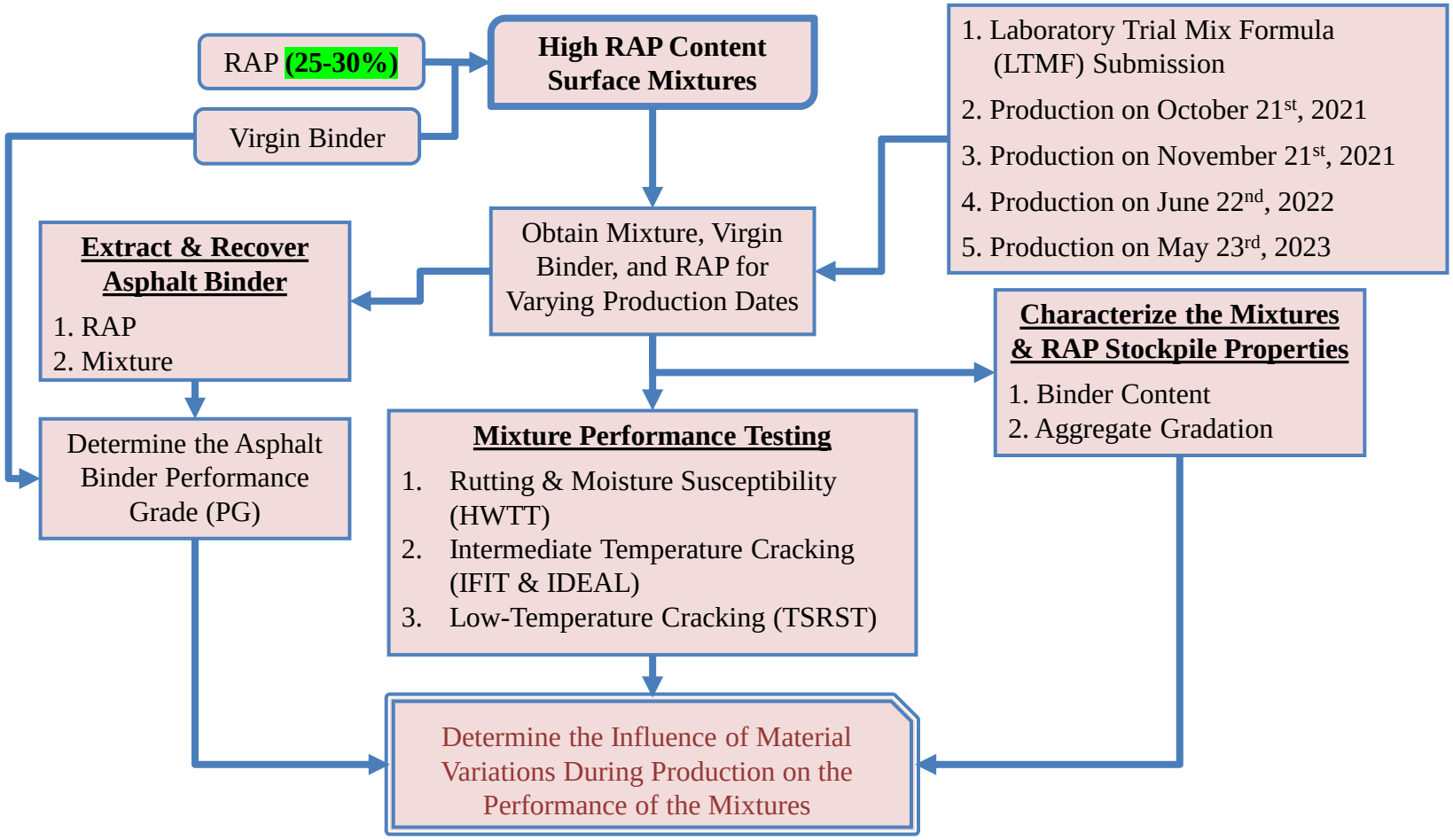
Objectives

1. Evaluate the variability of each high RAP content surface mixture, obtained on different production days, with respect to the properties of the virgin binder and RAP, and laboratory mixture performance (cracking and rutting).

2. Determine the effect of virgin binder and RAP properties on the laboratory performance of the mixtures.

3. Determine the influence of material variations during production on the performance of the mixtures.

Methodology - Experimental Plan



Results – RAP Binder Content & Aggregate Gradation

Mix ID	LTMF RAP (Control)	RAP for 10/21	RAP for 11/21	RAP for 6/22	RAP for 5/23	Standard Deviation	Suggested NCHRP 752 Standard Deviation Limits
Sieve Size	Percent Passing by Weight						
19 mm (3/4")	100	100	100	100	100	0	< 5.0
12.5 mm (3/4")	98.1	97.3	98.5	97.6	98.8	0.63	< 5.0
9.5 mm (3/4")	92.4	90.6	90.8	88.2	93.4	1.97	< 5.0
4.75 mm (No. 4)	69.7	71.9	63.5	61.2	73.7	**5.4 F**	< 5.0
2.36 mm (No. 8)	51.9	57.0	46.1	44.2	57.4	**6.05 F**	< 5.0
1.18 mm (No. 16)	39.0	44.0	33.8	32.7	44.1	**5.41 F**	< 5.0
0.6 mm (No. 30)	28.4	32.1	24.5	24.1	32.4	3.99	< 5.0
0.3 mm (No. 50)	18.8	21.7	16.7	17.1	21.8	2.46	< 5.0
0.15 mm (No. 100)	11.7	13.5	10.3	11.0	13.5	1.44	< 5.0
0.075 mm (No. 200)	7.5	8.7	6.5	7.1	8.5	0.93	< 1.5
Asphalt Content, %	4.88	5.37	5.15	5.00	5.46	0.24	< 0.5

Note: F= Standard deviation of measurements outside suggested NCHRP 752 limits

Results – Mixture Binder Content and Aggregate Gradation

Mix ID	LTMF Mixture	10/21 Mixture	11/21 Mixture	6/22 Mixture	5/23 Mixture	9.5 mm Superpave Specification	LEL**	UEL***
Sieve Size	Percent Passing by Weight							
19 mm (3/4")	100	100	100	100	100	100	100	100
12.5 mm (3/4")	100	**98.2 F**	**98.9 F**	**99.5 F**	**99.9 F**	100 min	100	100
9.5 mm (3/4")	94.0	92.6	93.3	95.2	96.4	90-100	90	100
4.75 mm (No. 4)	62.0	59.8	59.1	**68.2 F**	66	90 max	56	68
2.36 mm (No. 8)	40.0	39.7	39.1	**47.3 F**	43.1	32-67	35	45
1.18 mm (No. 16)	29.0	27.1	26.8	31.6	29	-	26	32
0.6 mm (No. 30)	20.0	18.4	18.5	21.2	19.5	-	17	23
0.3 mm (No. 50)	13.0	12.2	12.6	12.8	12.6	-	10	16
0.15 mm (No. 100)	8.0	7.6	8	7.6	7.4	-	6	10
0.075 mm (No. 200)	4.0	4.6	5.3	4.3	4.6	2-10	2.5	5.5
Asphalt Content, %	5.60	5.74	5.91	**6.1 F**	5.83	-	5.2	6.0
G_{mm}	2.471	2.474	2.473	**2.501***	2.479	-	-	-

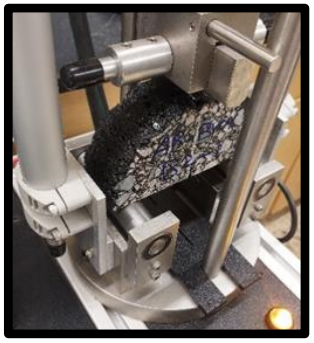
Note: F= Outside MassDOT acceptance limit

** Has a significantly different G_{mm} compared to the LTMF*

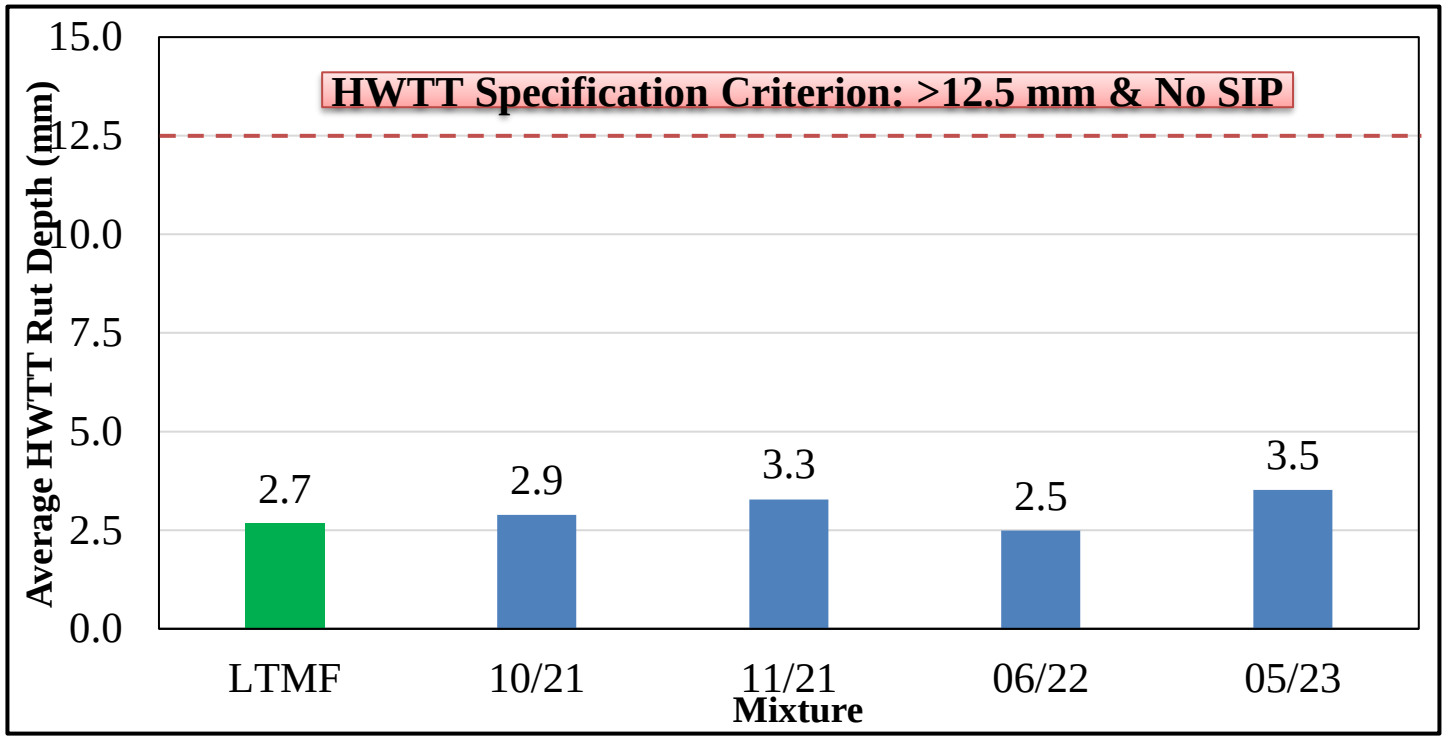
*** Lower quality engineering limit*

**** Higher quality engineering limits*

Mixture Performance Evaluation

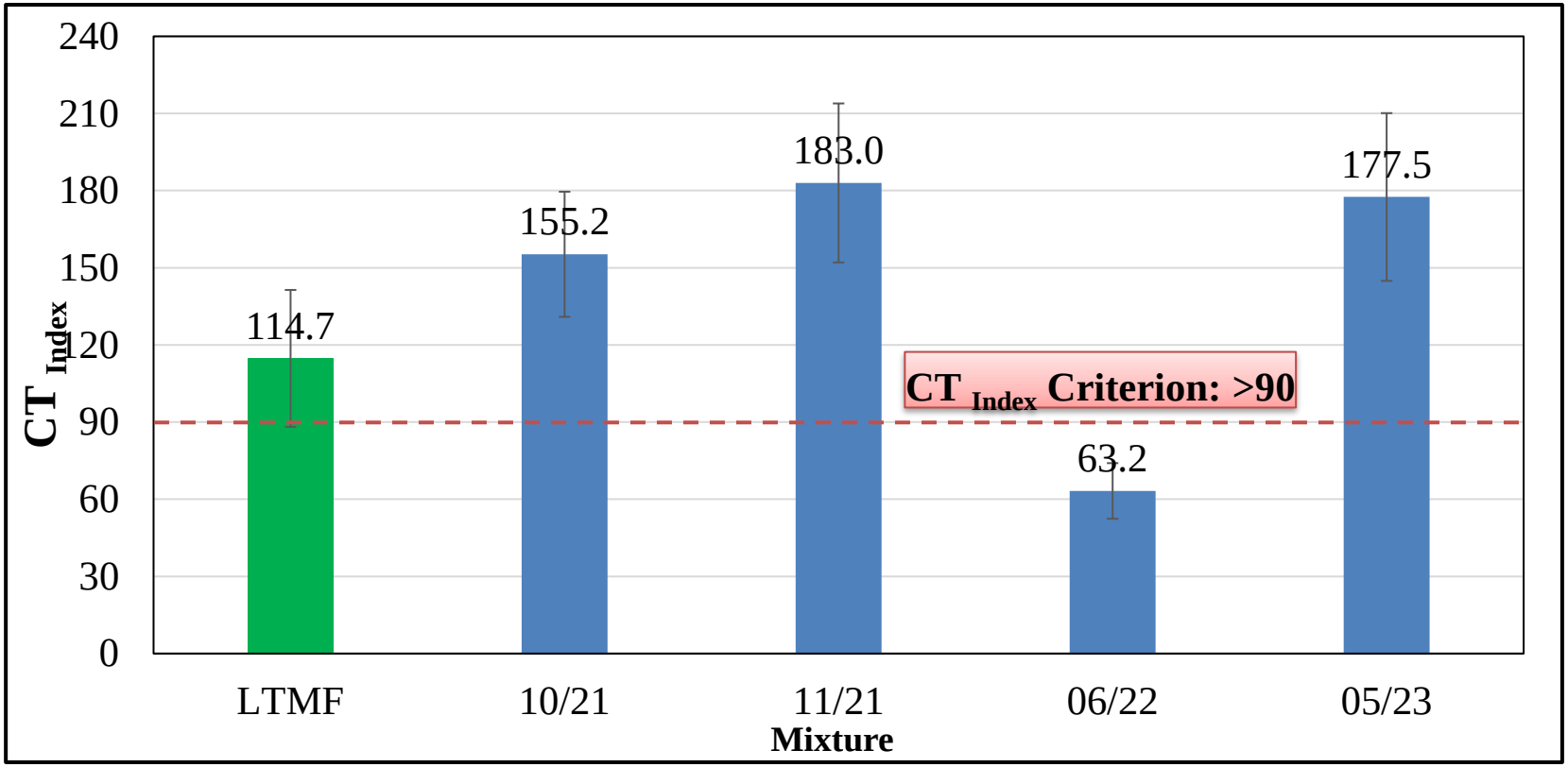
	Rutting & Moisture Susceptibility	Intermediate Temperature Cracking Tests		Low Temperature Cracking
Test	HWTT 	I-FIT 	IDEAL-CT 	TSRST 
Specification	AASHTO T 324	AASHTO T 393	ASTM D 8225	AASHTO TP 10-93
Test Temperature	45°C	25°C	25°C	n/a

Results – HWTT Rutting and Moisture Susceptibility

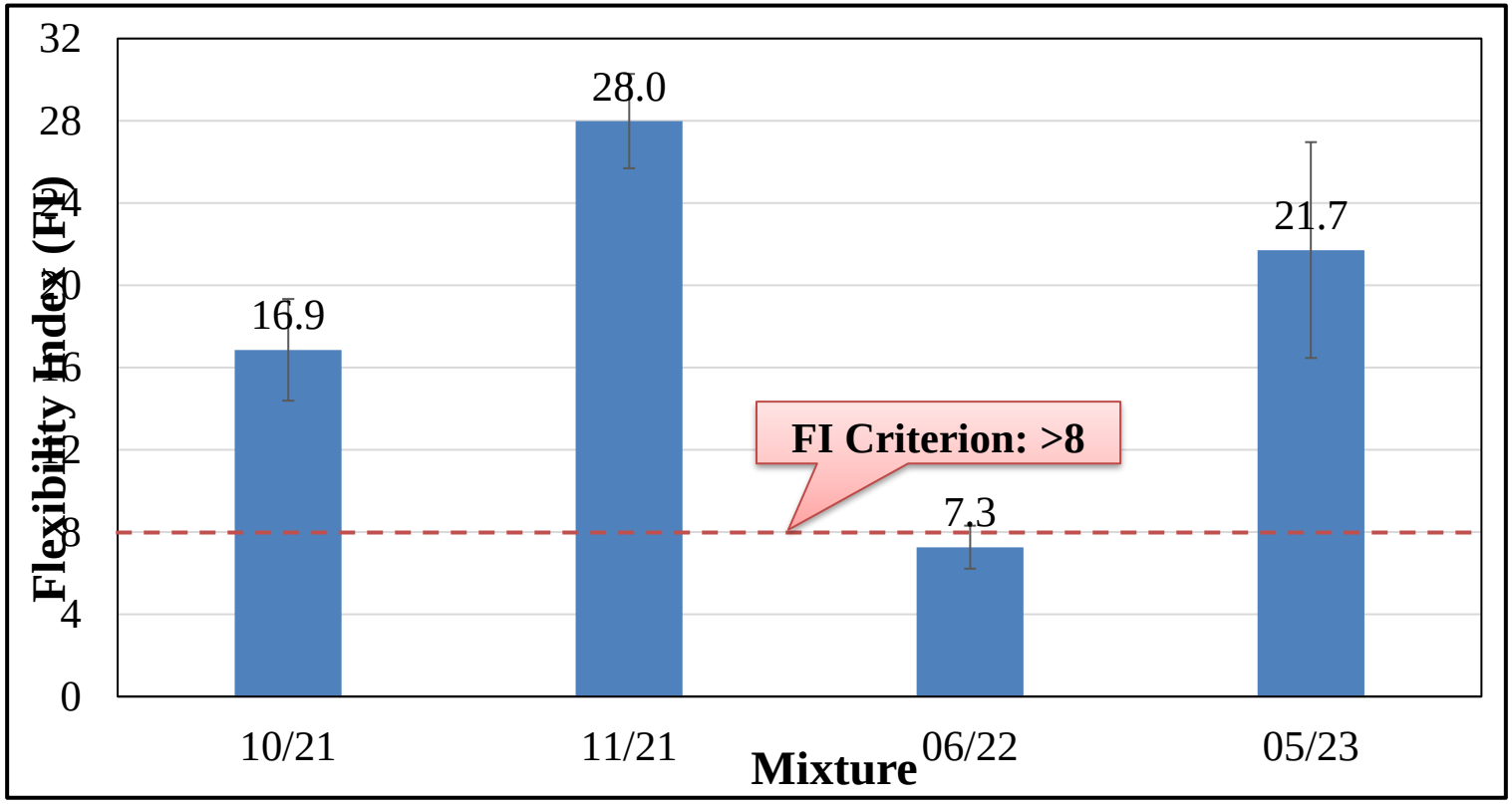


- All mixtures met the MassDOT specification criteria with all mixtures exhibiting very low rut depths and no stripping inflection point, which implies that rutting and moisture damage were not issues for these mixtures.

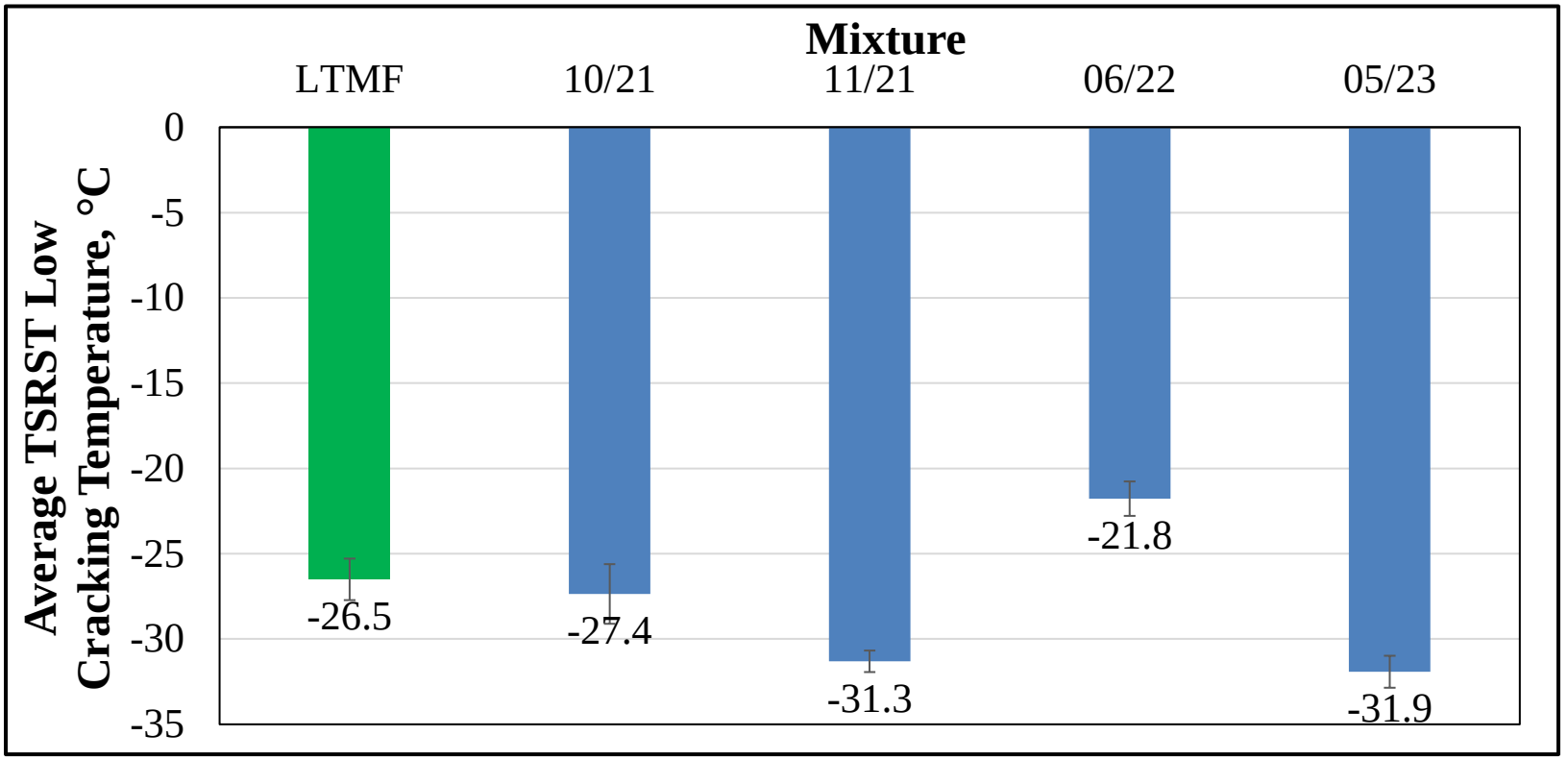
Results – IDEAL-CT Intermediate Temperature Cracking



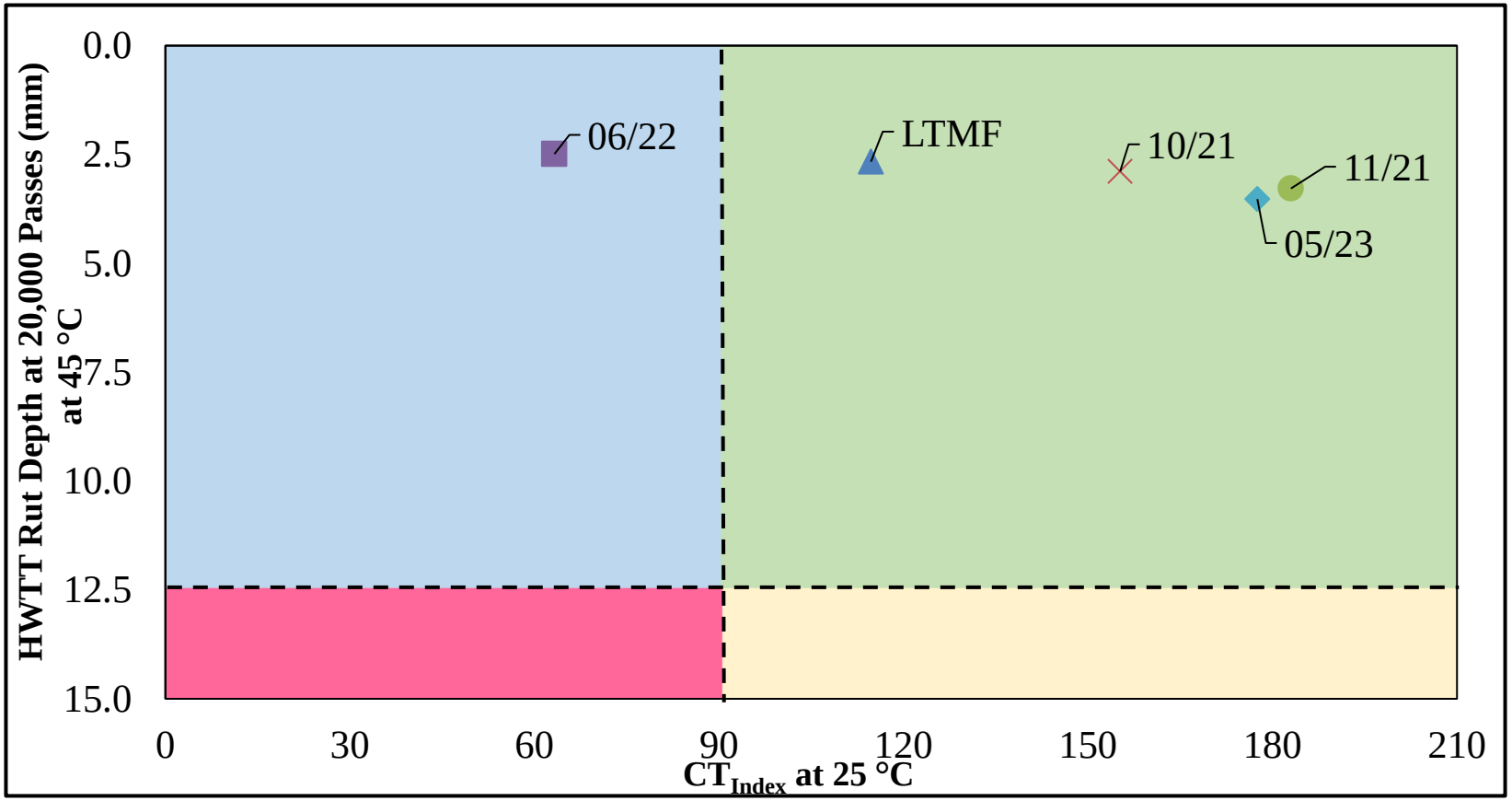
Results – IFIT Mixture Performance Evaluation



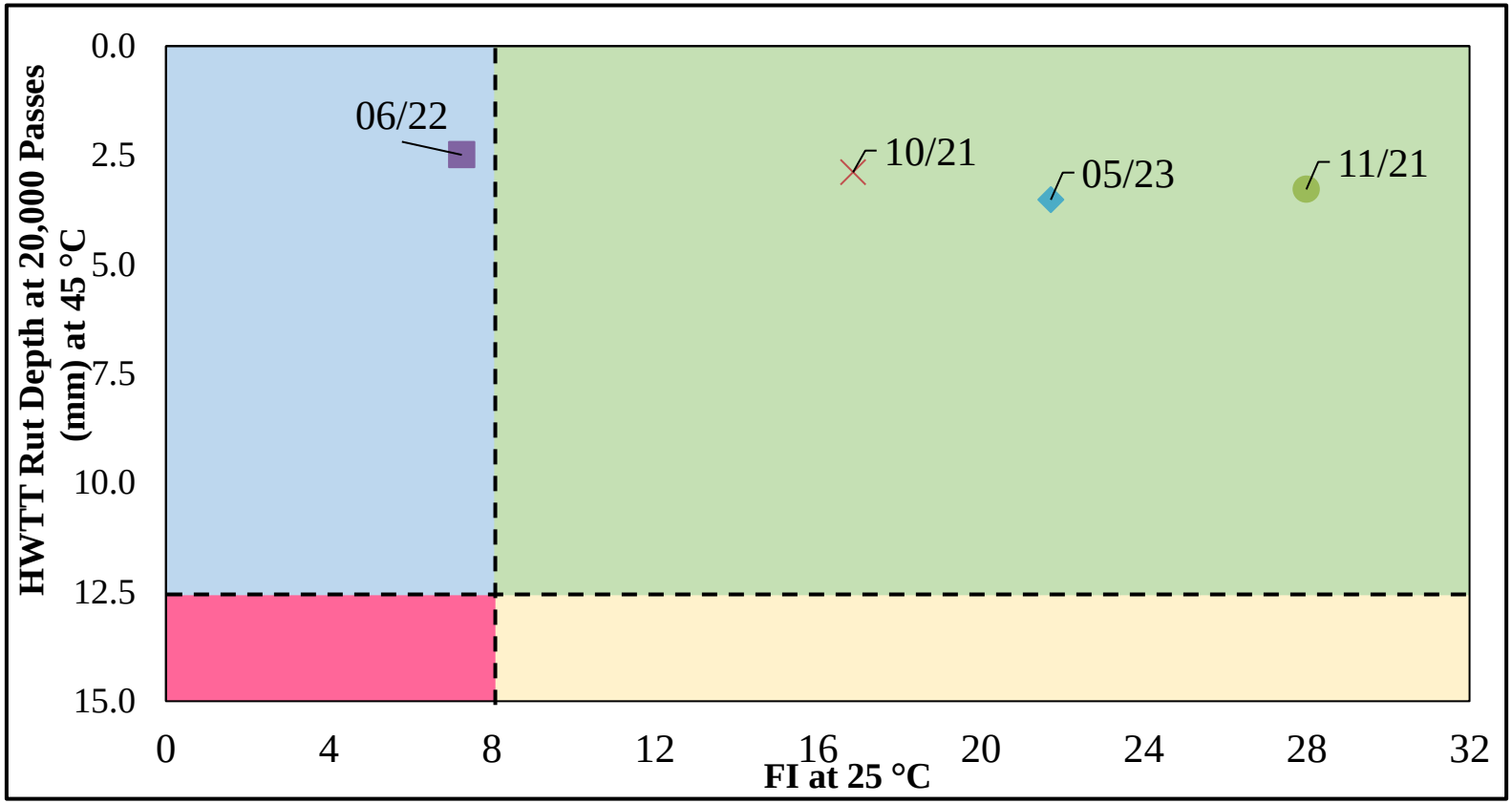
Results – TSRST Low Temperature Cracking



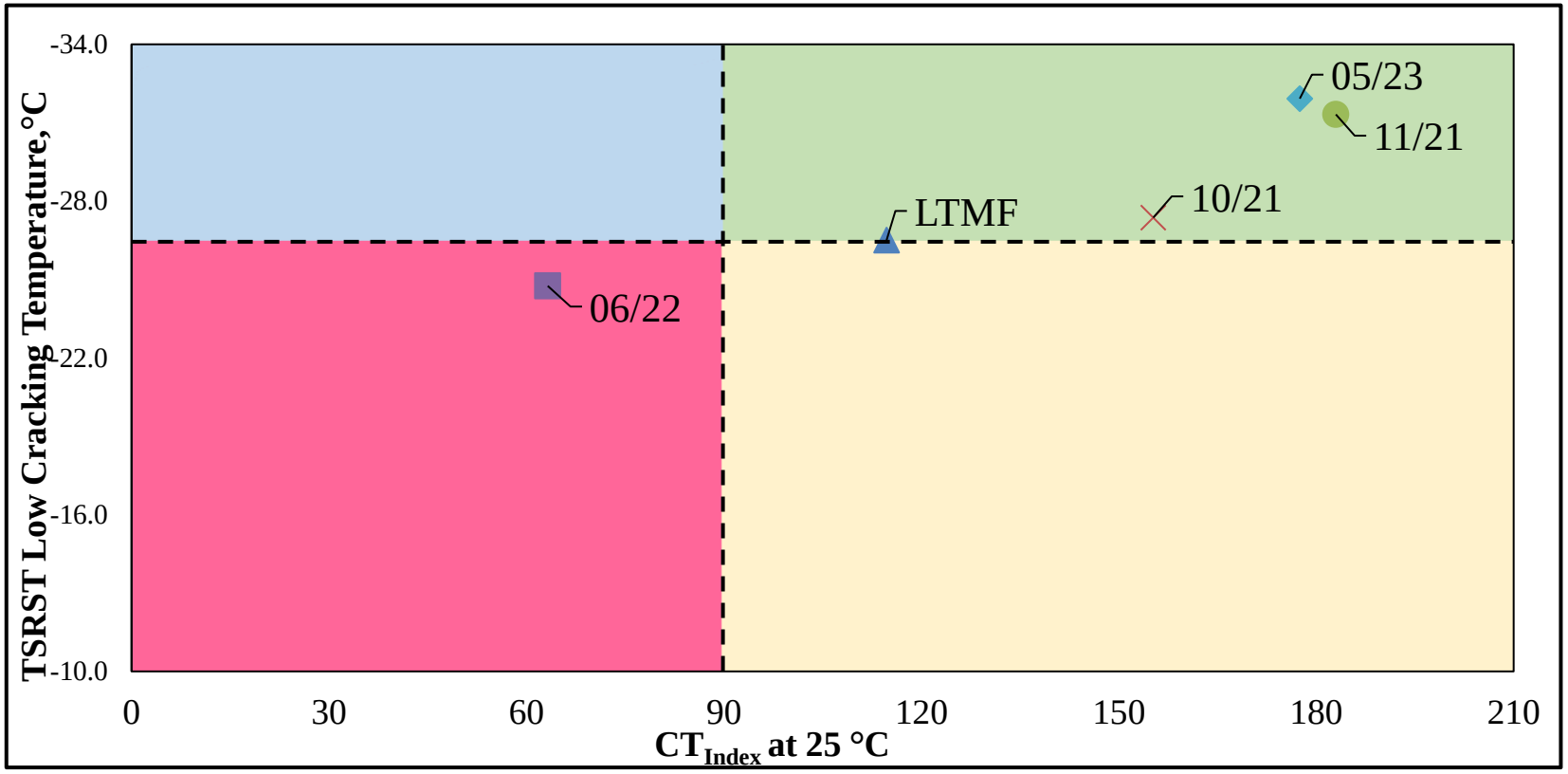
HWTT & CT_{Index} Mixture Performance Space Diagram



HWTT & FI Mixture Performance Space Diagram



CT_{Index} &TSRST Mixture Performance Space Diagram



Conclusions

- Three of four production mixture binders (extracted & and recovered from the mixture) did not meet the MassDOT specification criteria of a PG64E-28.

- Results indicated that RAP stockpile properties (binder grade) should be verified during production to ensure that the approved mix design will be maintained.

- Results indicated that rutting and moisture damage were not issues for these mixtures.

- Cracking performance test results showed the influence of material variations on performance with respect to when the mixture was produced. The material properties changed over time. This indicates the need for more comprehensive QC/QA testing for these mixtures to ensure that the approved mix design is maintained.

Conclusions

- Surface course mixtures with high RAP content (25-30%) can be produced and provide acceptable balanced performance in terms of rutting and cracking (intermediate and low temperature).

- Asphalt mixtures with high RAP content can be produced and provide an acceptable balanced performance for rutting, intermediate- and low- temperature cracking resistances.

- However, material characteristics should be rigorously validated during production to ensure that the approved mix design is obtained and adjusted if the material properties significantly change.


Thank You!