



Investigating the Influence of RAP Source Consistency on the Performance and Service Life of High-RAP Content Mixtures



NEAUPG

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Outline

- Background
- Objectives
- Experimental Plan
- Pilot Projects
- Results
- Pavement Performance Prediction

Background

- MassDOT's current specifications only allow up to 15% RAP in its surface asphalt mixture layer.
- Based on a 2020 MassDOT study entitled *Influence of 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 depends on its source.
 - For the same RAP content, RAP source has a significant effect on the cracking resistance of asphalt mixtures.

Background

- MassDOT approved demonstration projects using high RAP surface asphalt mixtures with RAP contents between 25% and 30%.
- Subsection 454 “Superpave High RAP Surface Course.”

Subsection 454 “Superpave High RAP Surface Course”

MassDOT Performance Testing Requirements for SSC-HR

Performance Characteristic	Test Method	Requirement
HWTD Maximum Rut Depth	AASHTO T 324 @ 45°C ⁽¹⁾	< 0.5 inch
Beam Fatigue Test Failure	AASHTO T 321 @ 25°C ⁽²⁾	For Information Only
Dynamic Modulus	AASHTO T 342	For Information Only
Semi-Circular Bend, Flexibility Index (FI)	AASHTO TP 124 @ 25°C	For Information Only
IDEAL-CT	ASTM E1169	For Information Only
TSRST	EN 12697-46	For Information Only

(1) Maximum rut depth after 20,000 passes.

(2) Test performed at a strain level of 500 microstrains.

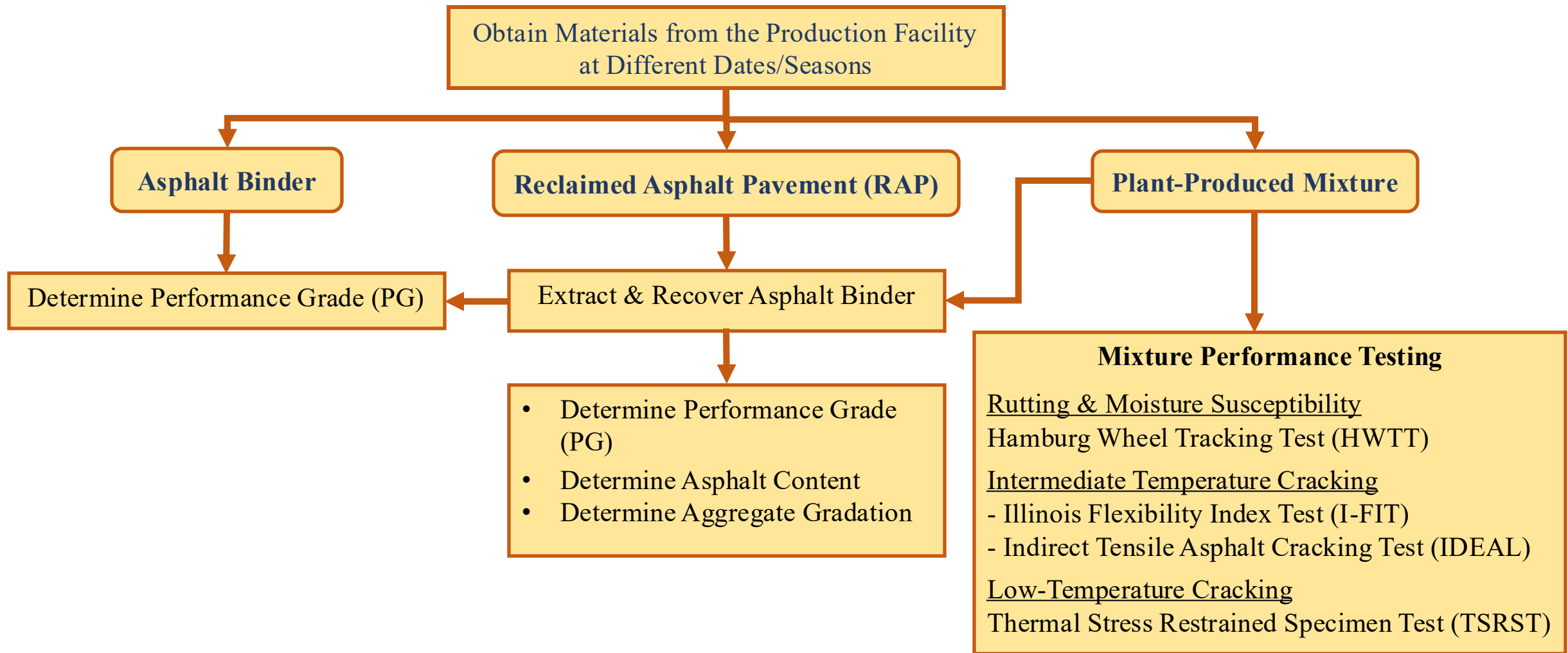
The final blended binder grade (RAP and Virgin) of the SSC-HR after extraction and recovery shall be a PG64E-28

Objectives

Across Different Seasons:

1. Document variability in virgin binder, RAP, and mixtures.
2. Characterize the impact of virgin binder and RAP properties on mixture performance, and
3. Evaluate the influence of material variations during production on the balanced performance of mixtures.

Experimental Plan



Pilot Projects

Contactor #	#1	#2	#3	#4	
NMAS (mm)	9.5	12.5	12.5	12.5	9.5
RAP Content (%)	25	28	27	30	
N _{des} (Gyrations)	100	100	100	75	
PG Binder	PG64E-34	PG64E-34	PG64E-34	PG64E-34	
Additives	WMA	WMA	WMA	WMA	
Sample Date	• LTMF • 10/21 • 11/21 • 06/22 • 05/23	• LTMF • 10/22 • 06/23 • 08/23	• LTMF • 06/24	• LTMF • 06/24	• LTMF

Asphalt Binder Test Results - Virgin Binders

Contractor #1		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG64(64E) -34	+0.8
10/21	PG70(64E) -28	-0.3
11/21	PG64(64E) -34	+0.7
06/22	PG70(64E) -34	+0.3
05/23	PG64(64E) -34	+0.5

Contractor #2		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG70(64E) -34	+0.1
10/22	PG70(64E) -34	+0.3
06/23*	PG64(64V) -28	+0.5
08/23	PG64(64V) -34	+0.7

* Virgin binder 64E-28 with recycling agent

Contractor #3		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG64(64E) -34	-0.6
06/24	PG70(64E) -34	-0.4

Contractor #4		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG64(64E) -34	+0.4
06/24	NT	

NT = Not Tested

The final blended binder grade (RAP and virgin) in the mixture should be a PG64E-28.

Asphalt Binder Test Results - RAP Binders

Contractor #1		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG88-16	-2.9
10/21	PG88-16	-2.8
11/21	PG82-22	-2.3
06/22	PG82-22	-1.1
05/23	PG88-16	-3.4

Contractor #2		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG88-16	-1.6
10/22	PG88-16	-1.9
06/23	PG88-16	0.0
08/23	PG88-16	-0.7

Contractor #3		
Sample Date	Binder PG	Average ΔT_C
LTMF	88-16	-2.8
06/24	88-16	-1.2

Contractor #4		
Sample Date	Binder PG	Average ΔT_C
LTMF	88-16	-1.3
06/24	NT	

NT=Not Tested

- The RAP binder high- and low-temperature grades changed by one grade from LTMF to production in some instances.
- This highlights the need to verify the RAP stockpile properties during production.

Asphalt Binder Test Results - Mixture Binders

Contractor #1		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG76(64E) -28	-1.1
10/21	PG70(64V) -28	-1.0
11/21	PG70(64E) -28	-2.2
06/22	PG70(64V) -22	-2.4
05/23	PG70(64V) -28	1.2

Contractor #2		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG88(64E) -22	-3.5
10/22	PG82(64E) -22	-1.0
06/23	PG82(64E) -22	-1.3
08/23	PG76(64V) -28	+0.2

Contractor #3		
Sample Date	Binder PG	Average ΔT_C
LTMF	PG70(64E) -28	0.0
06/24	PG70(64E) -28	+0.6

Contractor #4		
Sample Date	Binder PG	Average ΔT_C
LTMF (12.5 mm)	PG76(64E) -22	+1.4
LTMF (9.5 mm)	PG76(64E) -28	+0.2

Asphalt Binder Test Results - Mixture Binders

- Not all extracted and recovered mixture binders met the MassDOT specified criteria of a PG64E-28.

RAP Aggregate Gradation & Binder Content Results

Contractor #1 (25% RAP)							
	LTMF	10/21	11/21	06/22	05/23	Standard Deviation	Suggested NCHRP 752 Standard Deviation Limits
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	1.9	< 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
Binder 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

RAP Aggregate Gradation & Binder Content Results

Contractor #2 (28% RAP)						
	LTMF	10/21	11/21	06/22	Standard Deviation	Suggested NCHRP 752 Standard Deviation Limits
19 mm (3/4")	100.0	100.0	100.0	100.0	0	< 5.0
12.5 mm (3/4")	98.5	98.5	99.0	99.0	0.28	< 5.0
9.5 mm (3/4")	93.4	94.4	95.4	93.1	1.06	< 5.0
4.75 mm (No. 4)	65.7	71.1	70.8	73.3	3.22	< 5.0
2.36 mm (No. 8)	45.4	53.4	50.1	56.0	4.56	< 5.0
1.18 mm (No. 16)	33.3	41.4	37.7	40.9	3.74	< 5.0
0.6 mm (No. 30)	24.8	31.3	28.9	29.5	2.76	< 5.0
0.3 mm (No. 50)	17.8	22.2	21.3	20.9	1.95	< 5.0
0.15 mm (No. 100)	11.6	15.0	14.9	14.1	1.56	< 5.0
0.075 mm (No. 200)	7.7	10.7	10.7	9.5	1.41	< 1.5
Binder Content, %	6.08	6.16	6.06	6.04	0.05	< 0.5

RAP Aggregate Gradation & Binder Content Results

Contractor #3 (27% RAP)				
	LTMF	06/24	Standard Deviation	Suggested NCHRP 752 Standard Deviation Limits
19 mm (3/4")	100.0	100.0	n/a	< 5.0
12.5 mm (3/4")	99.2	99.9	n/a	< 5.0
9.5 mm (3/4")	92.2	92.3	n/a	< 5.0
4.75 mm (No. 4)	61.5	67.4	n/a	< 5.0
2.36 mm (No. 8)	42.1	50.3	n/a	< 5.0
1.18 mm (No. 16)	32.3	38.5	n/a	< 5.0
0.6 mm (No. 30)	25.2	29.1	n/a	< 5.0
0.3 mm (No. 50)	18.5	20.7	n/a	< 5.0
0.15 mm (No. 100)	12.1	13.4	n/a	< 5.0
0.075 mm (No. 200)	7.9	8.9	n/a	< 1.5
Binder Content, %	5.39	5.77	n/a	< 0.5

Note: n/a= not applicable.

RAP Aggregate Gradation & Binder Content Results

Contractor #4 (30% RAP)			
	LTMF	Standard Deviation	Suggested NCHRP 752 Standard Deviation Limits
19 mm (3/4")	100.0	n/a	< 5.0
12.5 mm (3/4")	99.8	n/a	< 5.0
9.5 mm (3/4")	95.6	n/a	< 5.0
4.75 mm (No. 4)	69.6	n/a	< 5.0
2.36 mm (No. 8)	50.9	n/a	< 5.0
1.18 mm (No. 16)	37.1	n/a	< 5.0
0.6 mm (No. 30)	25.4	n/a	< 5.0
0.3 mm (No. 50)	16.9	n/a	< 5.0
0.15 mm (No. 100)	11.4	n/a	< 5.0
0.075 mm (No. 200)	8.1	n/a	< 1.5
Binder Content, %	6.44	n/a	< 0.5

Note: n/a= not applicable.

Mixture Property Test Results

Contractor #1 (25% RAP)

	LTMF	10/21	11/21	06/22	05/23	9.5 mm Superpave Specification	Lower Engineering Limit (LEL)	Upper Engineering Limit (UEL)
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
Binder Content, %	5.60	5.74	5.91	6.1 F	5.60	-	5.2	6.0
G_{mm}	2.471	2.474	2.473	2.501*	2.471	-	-	-

F= Outside MassDOT acceptance limit

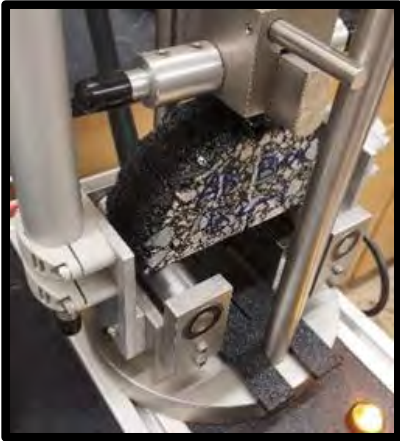
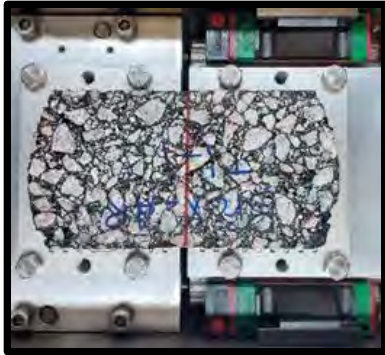
* Significantly different G_{mm} compared to the LTMF.

Mixture Property Test Results

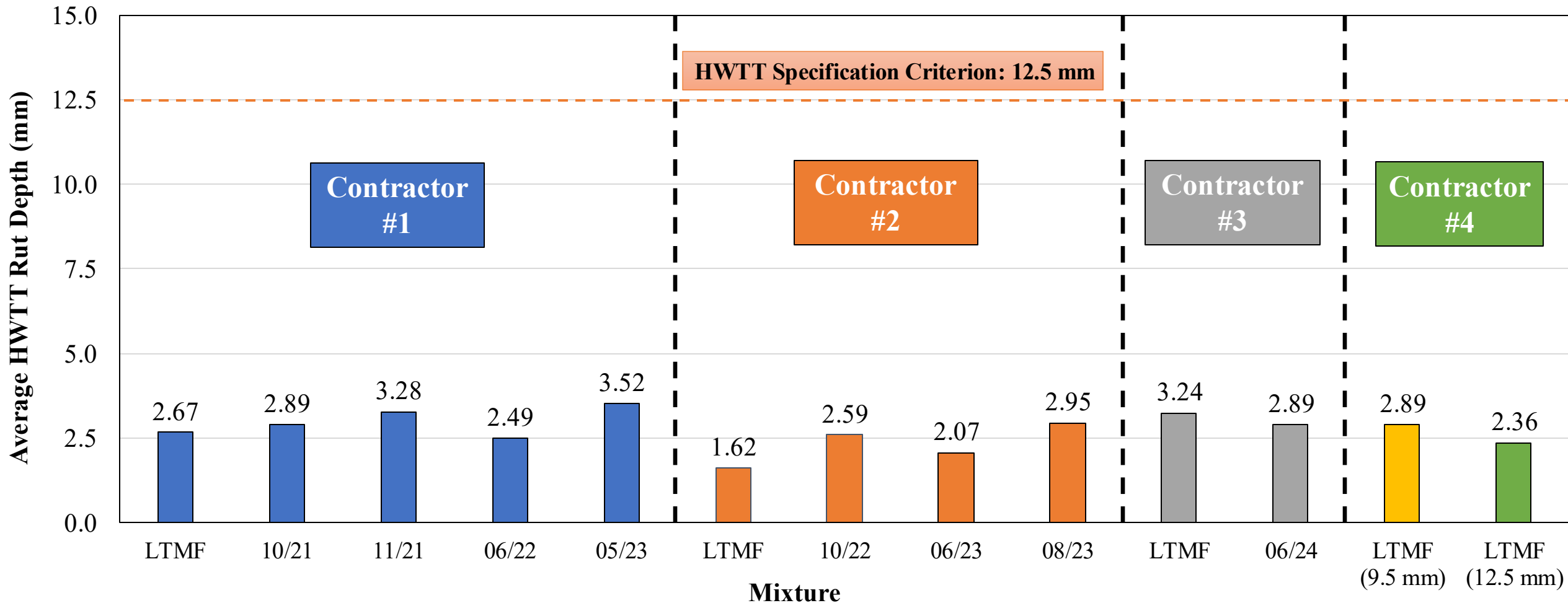
Contractor #2 (28% RAP)							
	LTMF	10/22	06/23	08/23	12.5 mm Superpave Specification	Lower Engineering Limit (LEL)	Upper Engineering Limit (UEL)
19 mm (3/4")	100	100	100	100	100	100	100
12.5 mm (3/4")	95.0	93.1	97.4	96.8	90-100	89	100
9.5 mm (3/4")	81.0	78.6	85.5	81.0	90 max	75	87
4.75 mm (No. 4)	51.0	47.7	53.8	49.9	-	45	57
2.36 mm (No. 8)	34.0	32.6	33.8	32.7	28-58	29	39
1.18 mm (No. 16)	26.0	24.2	24.2	23.8	-	23	29
0.6 mm (No. 30)	19.0	18.6	18.5	18.0	-	17	23
0.3 mm (No. 50)	14.0	14.2	14.3	13.7	-	11	17
0.15 mm (No. 100)	8.0	9.2	9.7	9.1	-	6	10
0.075 mm (No. 200)	4.3	5.6	5.9 F	5.5	2-10	2.8	5.8
Binder Content, %	5.20	5.26	5.60	5.20	-	4.8	5.6
G_{mm}	2.473	2.478	2.479	2.479	-	-	-

F= Outside MassDOT acceptance limit

Mixture Performance Evaluation

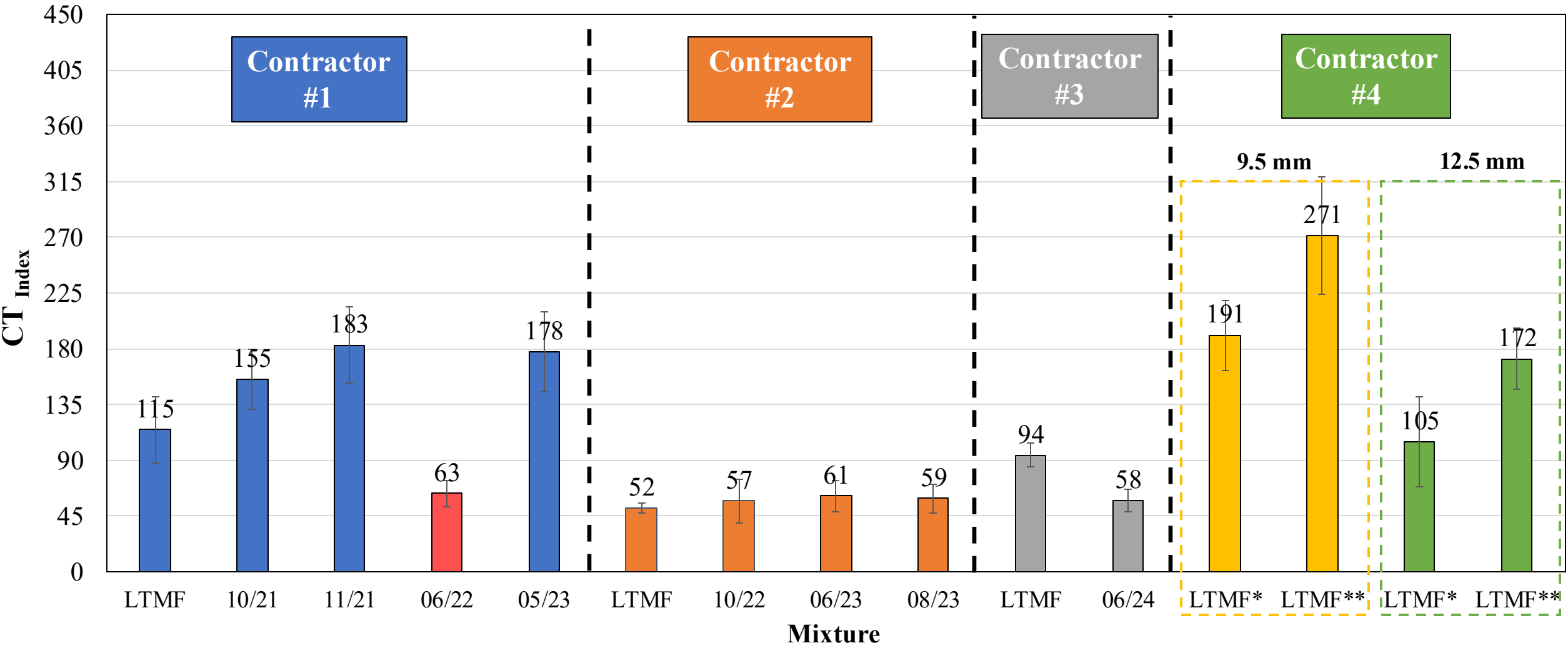
	Rutting & Moisture Susceptibility	Intermediate Temperature Cracking Tests		Reflective Cracking	Low Temperature Cracking
Test	HWTT 	I-FIT 	IDEAL-CT 	Overlay Test 	TSRST 
Specification	AASHTO T 324	AASHTO T 393	ASTM D 8225	Tex-248-F	AASHTO TP 10-93
Test Temperature	45°C	25°C	25°C	25°C	n/a

Mixture Rutting and Moisture Susceptibility Results



- All mixtures met the MassDOT specification criteria.
- Rutting and moisture damage were not issues for these mixtures.

Mixture Intermediate Temperature Cracking Results

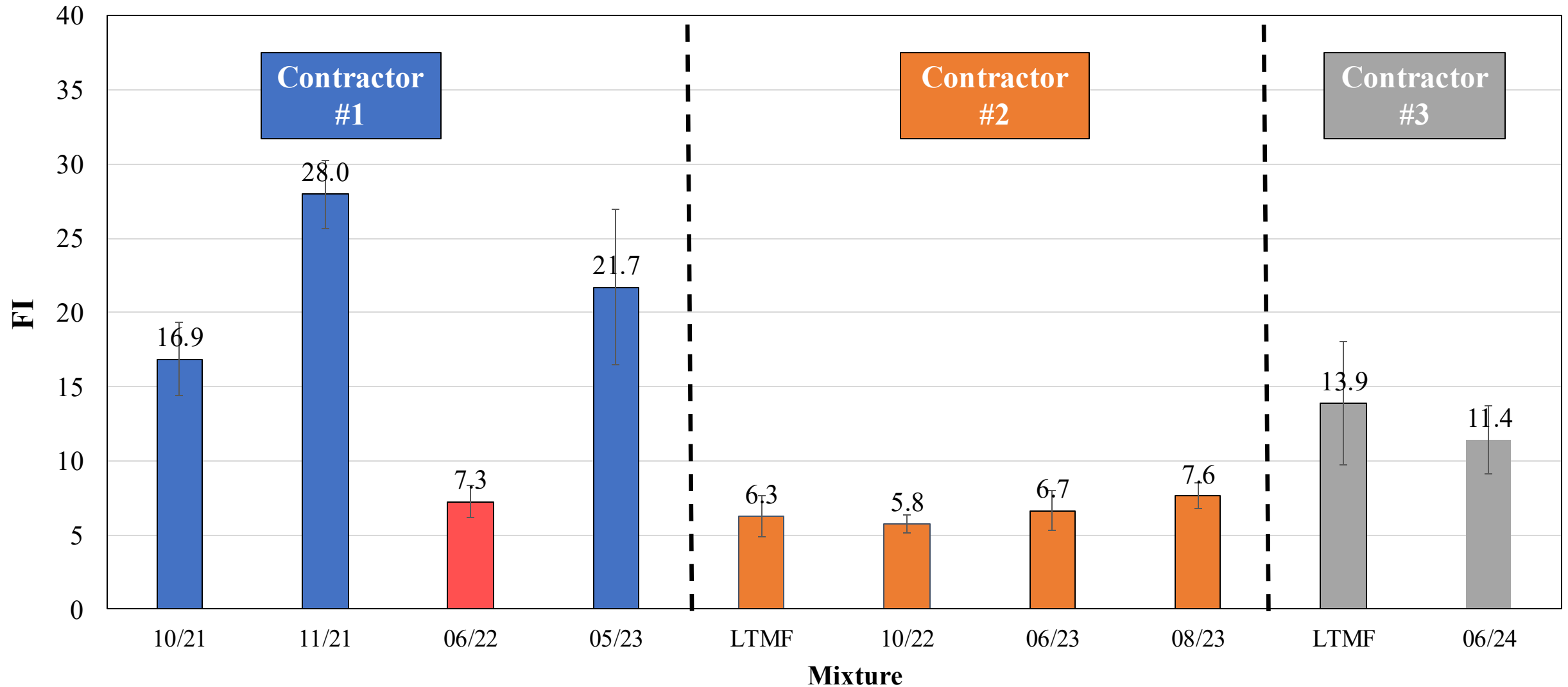


*Compacted specimens received from Contractor #4.

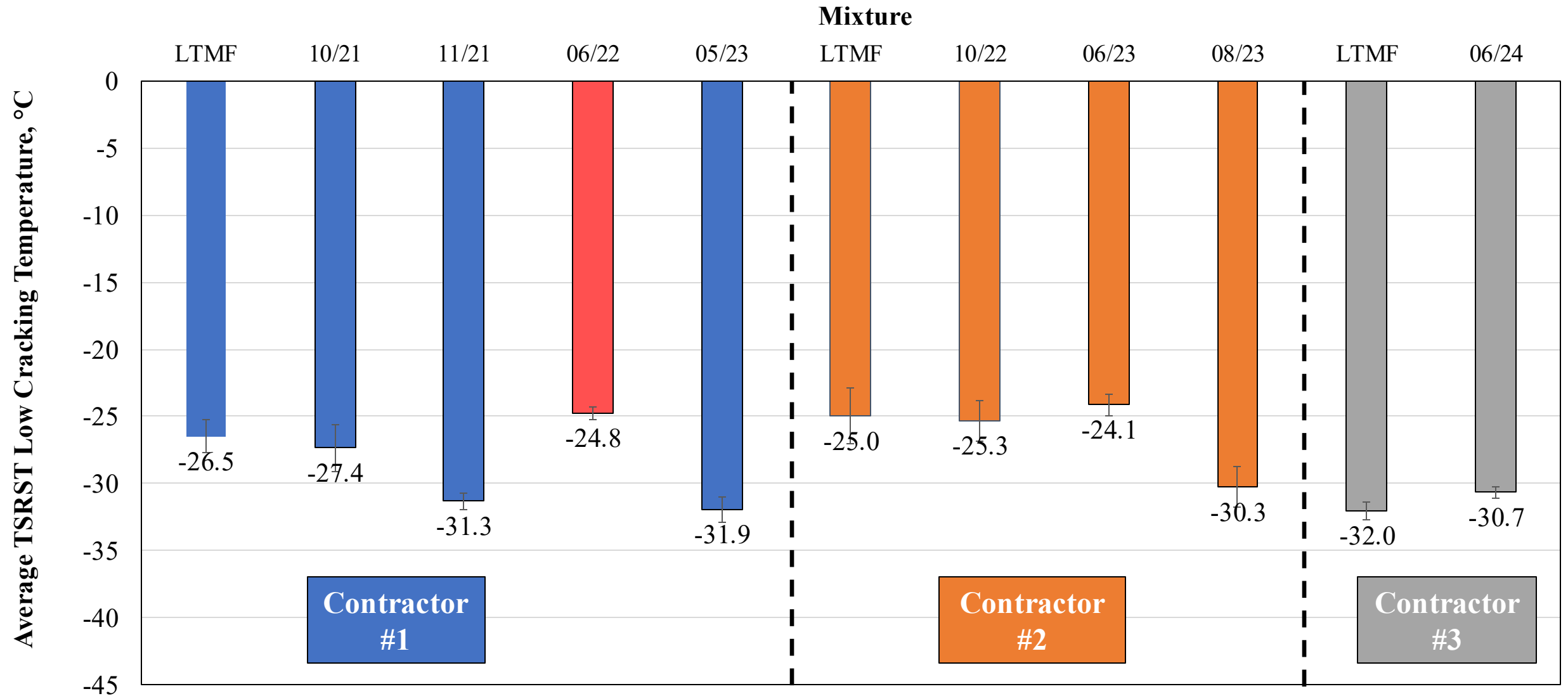
**Loose mixture received from Contractor #4 and reheated and compacted at the HSRC.



Mixture Intermediate Temperature Cracking Results

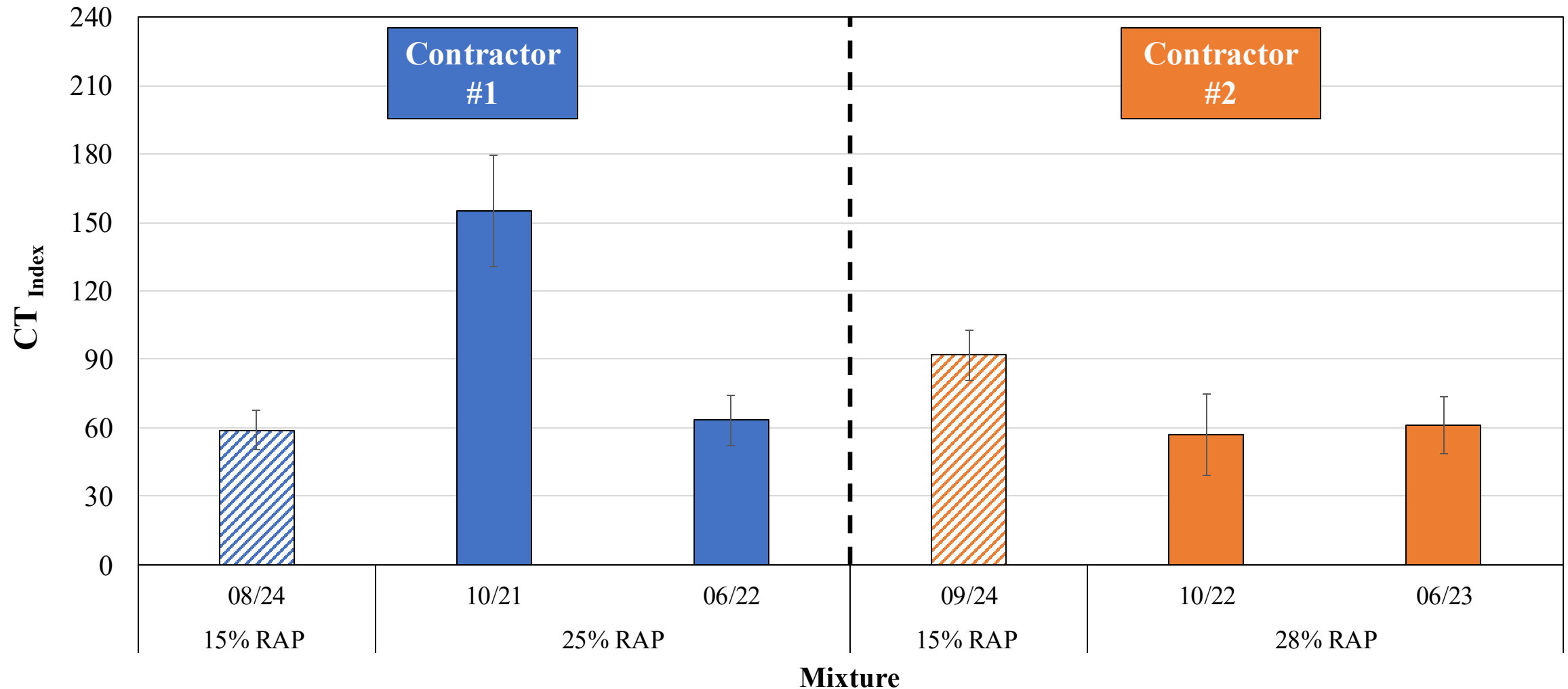


Mixture Low-Temperature Cracking Results



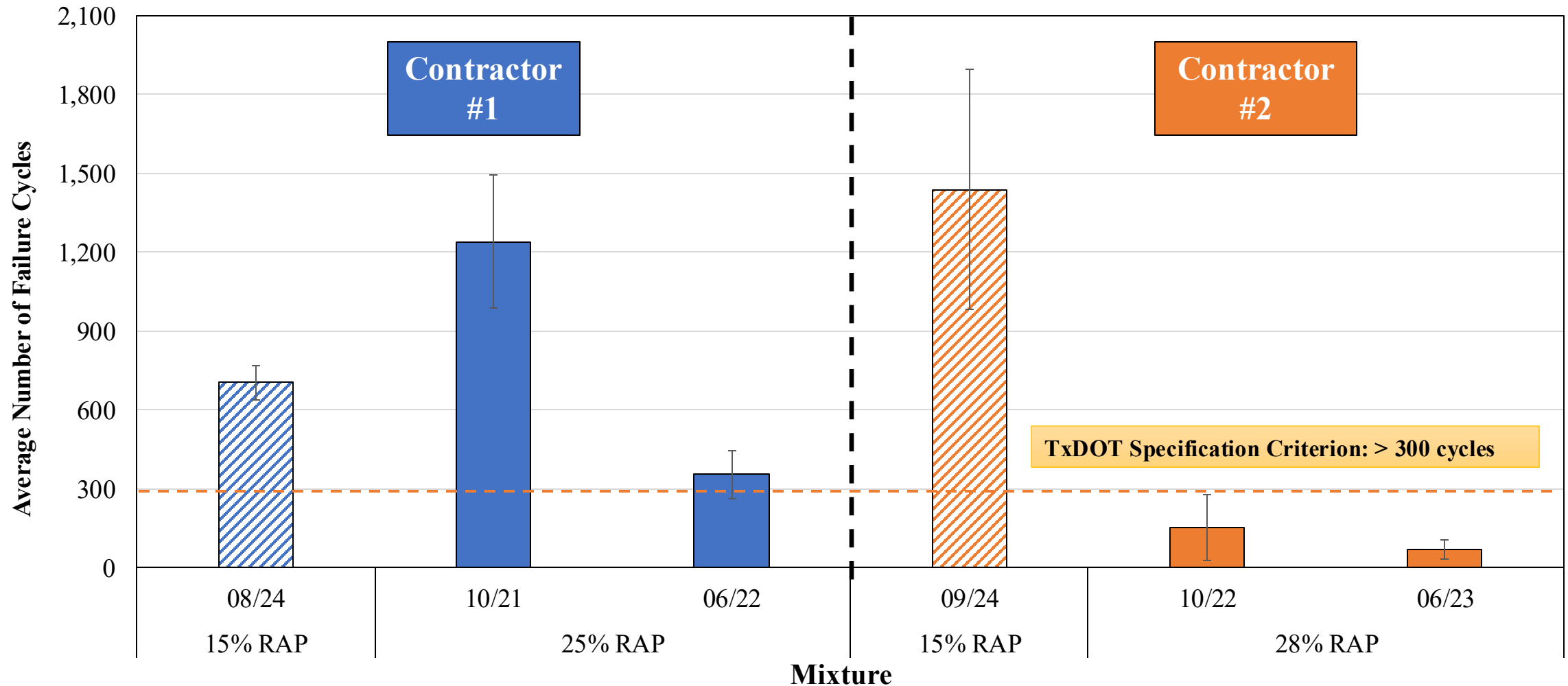
Mixture Intermediate Temperature Cracking Results

(15% RAP vs. High RAP)



Mixture Reflective Cracking Results

(15% RAP vs. High RAP)



Pavement Performance Prediction Using FlexPAVE™ Software

Asphalt Mixtures

Contractor #1:

- 15% RAP (08/24)
- 25% RAP (10/21)

Contractor #2:

- 15% RAP (09/24)
- 28% RAP (10/22)

AMPT Testing (Asphalt Mixtures)



Dynamic Modulus
AASHTO TP 132-19



Cyclic Fatigue Test
AASHTO TP 133-19



Stress Sweep Rutting(SSR)
AASHTO TP 134-22

FlexMAT (Mixtures Analysis Program)

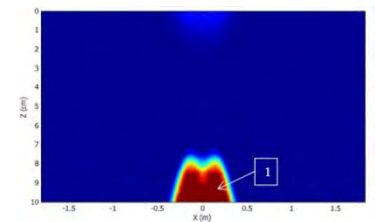
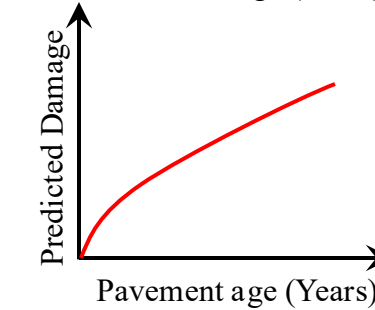
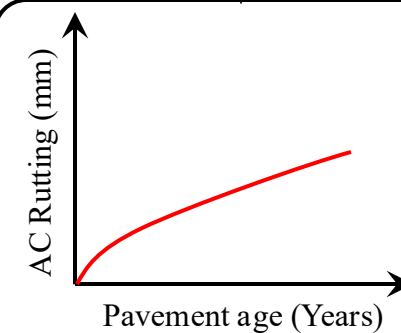
$|E^*|$ Dynamic
modulus master curve

Sapp (Cyclic Fatigue
Index Parameter)

RSI (Rutting Strain
Index)

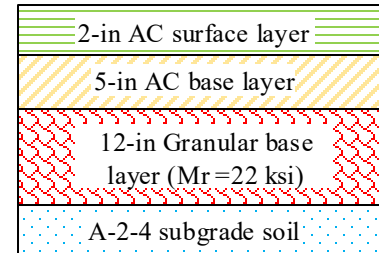
**Ongoing
Phase**

FlexPAVE (Pavement Performance Program)



Picture from: FHWA-HRT-21-093 Report

Pavement Structure



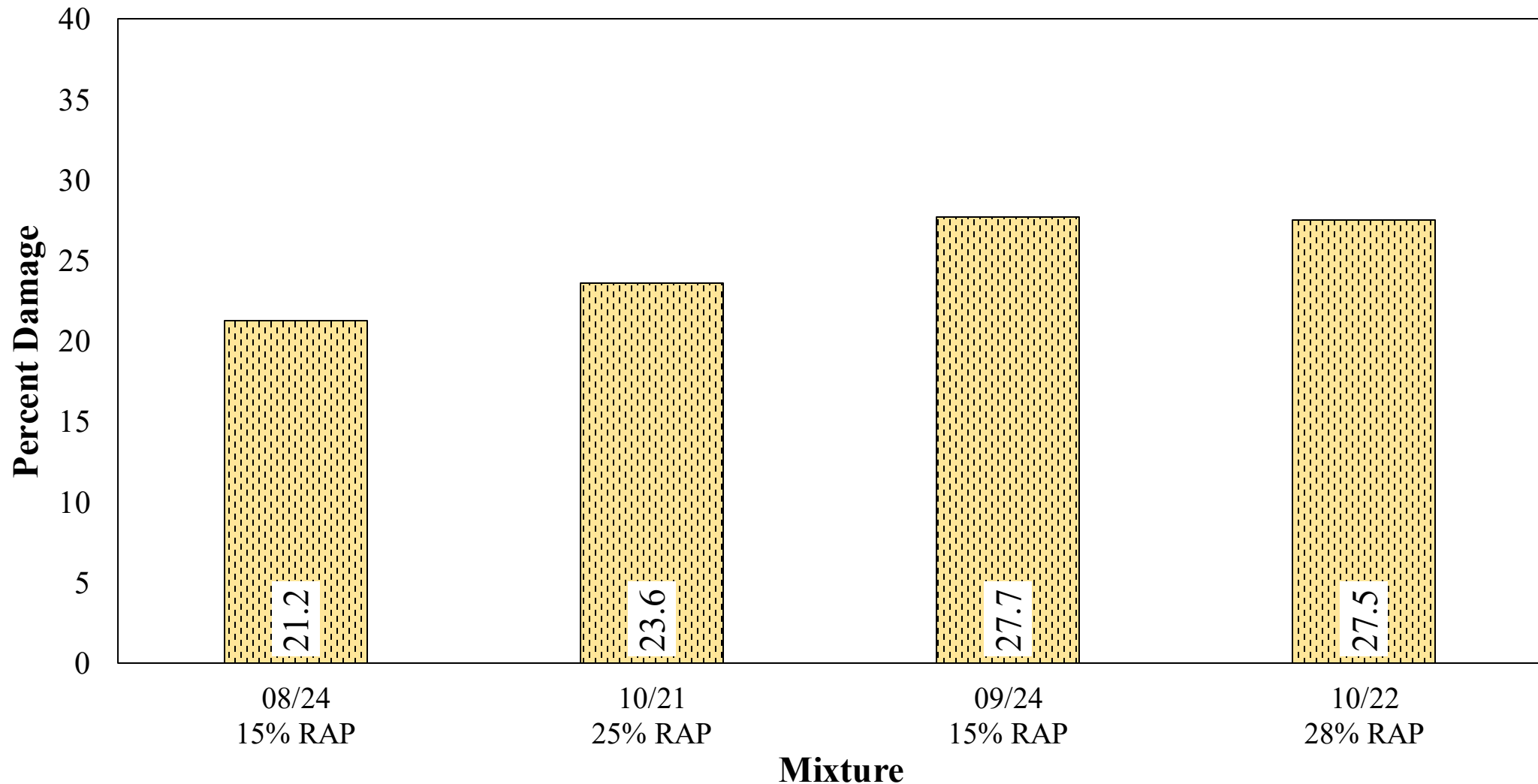
Climate Data



Traffic Data



Pavement Performance Prediction Using FlexPAVE™ Software



Predicted percent total damage after 20 years for the simulated pavement section

Discussion of Results

- RAP stockpile consistency proved critical to mixture performance.
- All SSC-HR mixtures satisfied MassDOT's rutting and moisture susceptibility.
- Low- and intermediate-temperature cracking resistances were generally acceptable when compared to corresponding control LTMF design mixture.
- SSC-HR mixtures can achieve balanced performance when RAP variability, binder grade, and mixture properties are adequately controlled.
- FlexMAT™ and FlexPAVE™ analyses indicated that SSC-HR mixtures can provide long-term rutting and fatigue performance comparable to conventional 15% RAP mixtures.

Thank You!





Association of Asphalt Paving Technologists

2026 Annual Meeting

Hyatt Regency
Boston, MA
March 23-26, 2026



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