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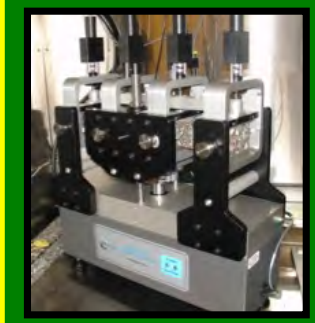
Innovative Research in Asphalt Pavements



PERFORMANCE OF PLANT-PRODUCED HIGH-RECLAIMED ASPHALT PAVEMENT CONTENT WARM MIX ASPHALTS

NEAUPG

Northeast Asphalt User Producer Group Meeting

October 19th, 2017 • Hartford, CT

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Civil & Environmental Engineering

Highway Sustainability Research Center

University of Massachusetts Dartmouth

Acknowledgements

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  - Mr. Denis Boisvert, New Hampshire Department of Transportation, Chairperson
  - Mr. Bryan Engstrom, Massachusetts Department of Transportation
  - Mr. David Kilpatrick, Connecticut Department of Transportation
  - Mr. Michael Byrne, Rhode Island Department of Transportation
  - Mr. Richard Bradbury, Maine Department of Transportation
  - Mr. Mladen Gagulic Vermont Agency of Transportation

Research Team

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Special Thanks to Industry for Producing Mixtures:

Aggregate Industries - Wrentham, MA

Palmer Paving Corp. - Palmer, MA

Project Scope

Plant #1

12.5mm Mixture

Plant #2

=

PG64-28 Asphalt Binder

+

Virgin Coarse Aggregates

+

Virgin Fine Aggregates

+

15% RAP

OR

15 to >30% RAP

OR

>30% RAP

+

SonneWarmix™ (Wax Based WMA)

OR

Evotherm® (Chemical Based WMA)

OR

ACCU-SHEAR™ *(Foaming WMA)*

Research Objective

Expand on existing laboratory research by using plant-produced mixtures incorporating various WMA technologies and RAP contents.

Understand the influence of RAP, WMA and moisture on performance in terms of moisture susceptibility, fatigue cracking and thermal cracking.

Internet Based Survey

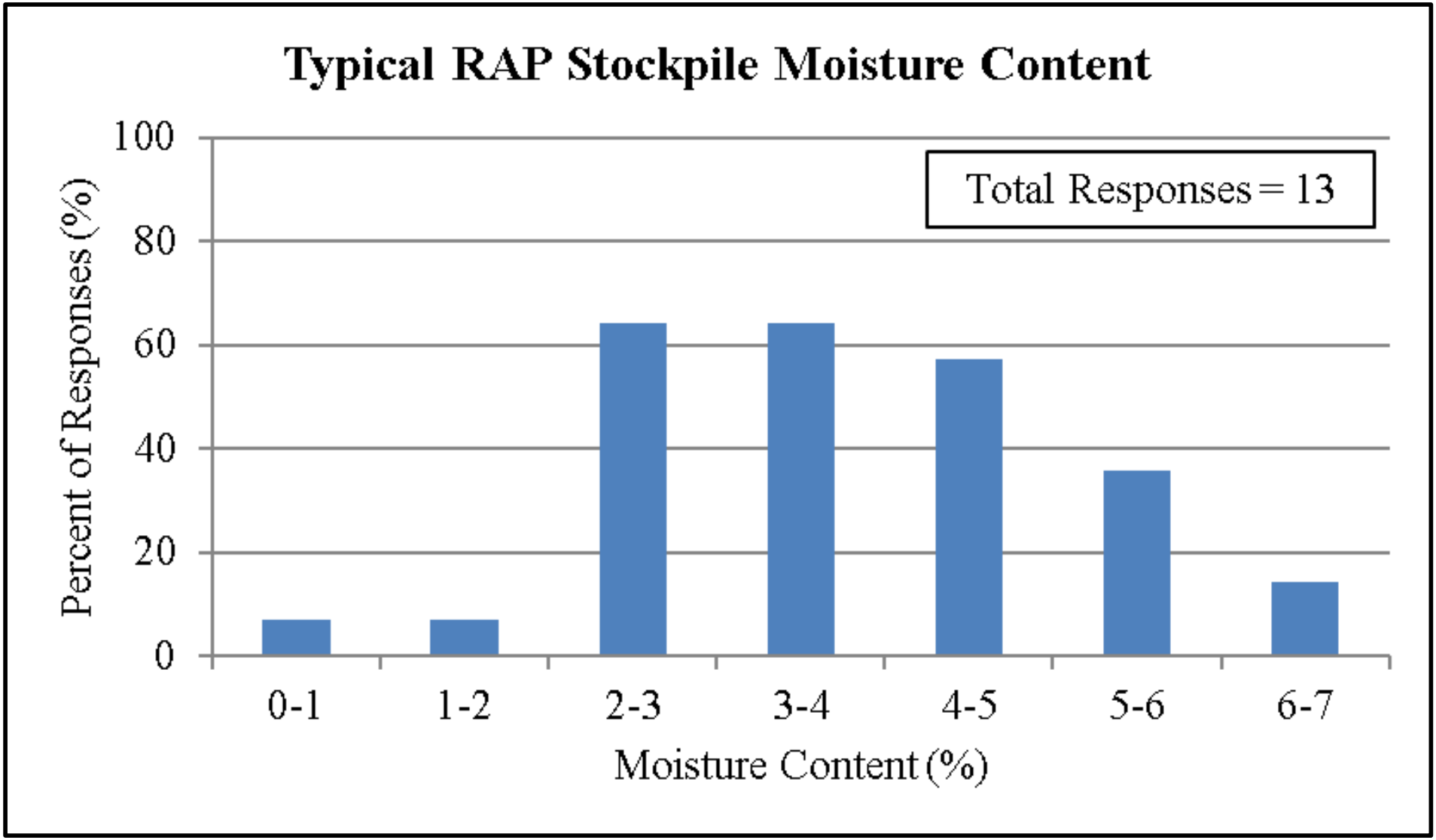
- Two internet based surveys were developed.
- One survey for state agencies and one for industry.
- Survey designed to assess current state-of-practice regarding RAP and WMA use in mixtures, specification requirements, and testing requirements.

Internet Based Survey Results

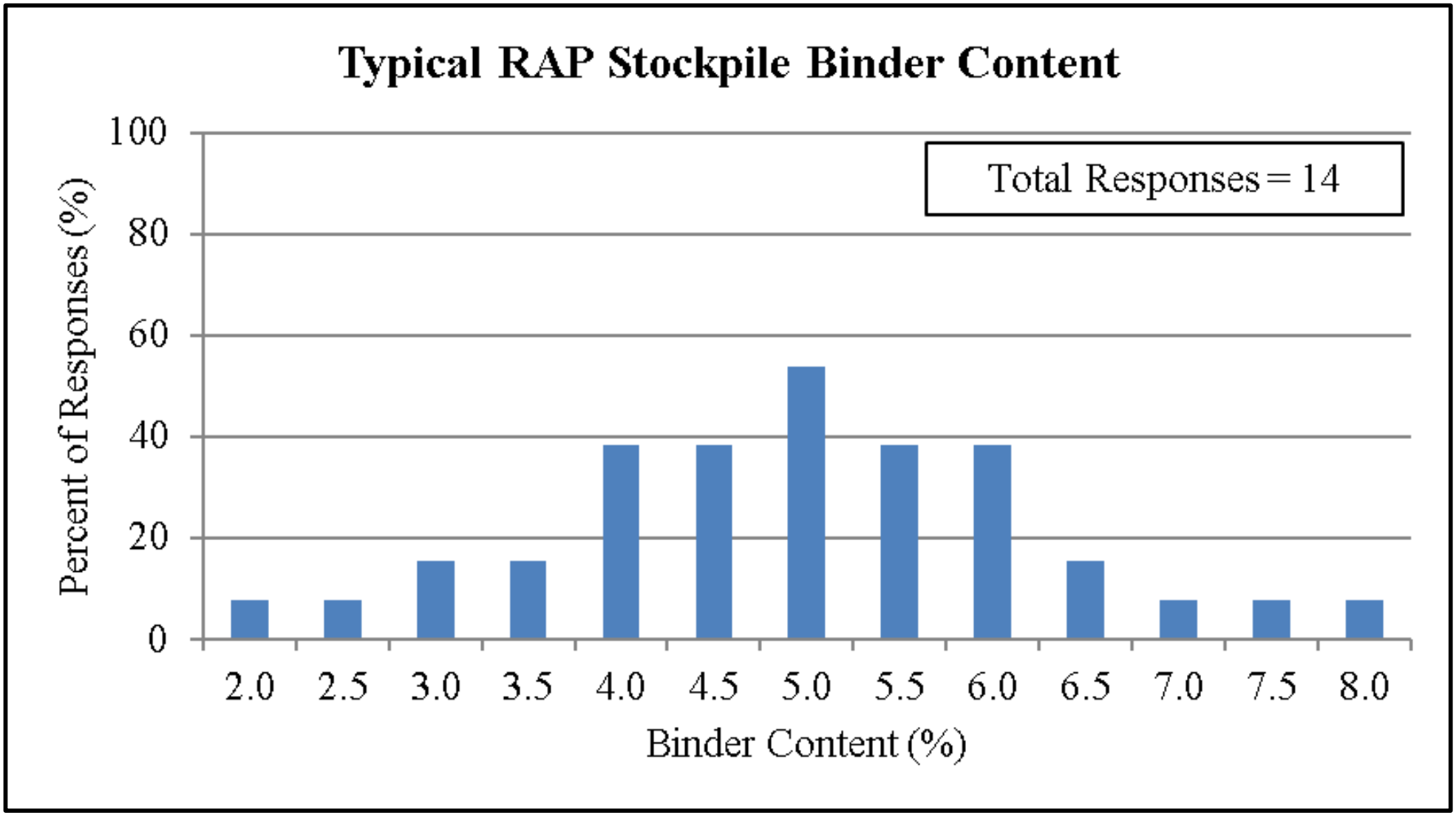
- The most commonly used WMA technologies were SonneWarmix™ (wax based) and Evotherm® (chemical based). Foaming/moisture-based processes were not common.

- Typical RAP binder contents varied from 2-8% while typical RAP moisture contents vary from 0-7%.

Internet Based Survey Results



Internet Based Survey Results



Research Approach

- Plant-produced mixtures incorporating three WMA technologies and three RAP contents were tested for performance in terms of moisture susceptibility, fatigue cracking and thermal cracking.

- Two drum plants were used to produce the mixtures.

WMA Technology Selection

- SonneWarmix™ (wax based), Evotherm® (chemical based), and Stansteel ACCU-SHEAR™ (foaming process) were selected from the Northeast Asphalt User Producer Group (NEAUPG) approved list of WMA technologies.

- SonneWarmix™ and Evotherm® were utilized at a dosage of 0.5% per weight of binder per manufacturer's recommendations.

- The Stansteel ACCU-SHEAR™ foaming process utilized a water content of 3% by weight of binder.

Drum Plant #1 Mixtures

- A 12.5-mm 100 gyration mixture produced using SonneWarmix™.
- Mixture produced with RAP contents of 15% (low), 27.8% (medium) and 46.3% (high).
- The RAP content of 27.8% and 46.3% corresponded to 1.5% and 2.5% of the mixture virgin binder content being replaced, respectively.
- The binder content of the RAP was 5.4% and the moisture content of the RAP was 1.6%.
- The production temperature was 134ºC (271ºF).

Drum Plant #2 Mixtures

- A 12.5-mm mixture 75 gyration mixture using Evotherm® and Stansteel ACCU-SHEAR™.
- Six mixtures, three for each WMA technology, were produced with RAP contents of 29% (medium), 39% (high) and 48% (high).
- RAP contents corresponded to 1.5%, 2.0% and 2.5% of the mixture virgin binder content being replaced, respectively.
- Binder content of the RAP was 5.0-5.9% and the moisture content of the RAP was 2.9-4.1%.
- The production temperatures ranged from 135-143ºC (275-290ºF).

Moisture Content After Production

- The moisture contents of all mixtures were measured immediately after production, with no silo storage, in accordance with AASHTO T329.

- The highest amount of moisture after production in any mixture was 0.16%. This indicates that nearly all of the moisture in the RAP and aggregate was eliminated during plant production.

Quality of Binder Blending Analysis

- Lower WMA production temperatures might negatively impact the quality of blending between the virgin and aged RAP binders and thus impact mixture performance.

- To assess blending, first the mixture dynamic modulus (E*) was measured using the AMPT. Next, the binder was extracted and recovered from each mixture and tested to determine shear modulus (G*) and phase angle using the DSR.

- The Hirsch model was used to predict mixture E* using the recovered binder G* and phase angle. This predicted E* was then compared to the measured E* of the mixture.

Quality of Blending Analysis - Discussion

- Based on the method used, blending was poor for the majority of mixtures.

Mixture Performance

Moisture Susceptibility

AASHTO T283

ESR Ratio

HWTD

Fatigue Cracking

IFIT SCB

Thermal Cracking

TSRST

DC(T)

Moisture Susceptibility – AASHTO T283

	AASHTO T283 Tensile Strength Ratio (TSR)	
	TSR (%)	Area Stripped (%)
Drum Plant #1 - 12.5-mm Mixture with 0.5% SonneWarmix™		
15% RAP Mixture	92.0	<10%
27.8% RAP Mixture	88.7	<10%
46.3% RAP Mixture	93.9	<10%
Drum Plant #2 - 12.5-mm Mixture with 0.5% Evotherm®		
29% RAP Mixture	82.2	<10%
39% RAP Mixture	77.5 **F**	<10%
48% RAP Mixture	85.9	<10%
Drum Plant #2 - 12.5-mm Mixture with ACCU-SHEAR™ Foaming		
29% RAP Mixture	94.8	<10%
39% RAP Mixture	90.1	<10%
48% RAP Mixture	86.8	<10%

F = Failed the specification. The minimum passing TSR is 80%.

Moisture Susceptibility – AASHTO T283

- All mixtures passed except for the 39% RAP mixture with Evotherm® which had a borderline but failing TSR of 77.5%. However, this mixture easily passed HWTD.

- None of the mixtures exhibited visual stripping that was more than 10% of the total area.

Moisture Susceptibility - ESR Ratio

- The ESR is the ratio of the E* of the conditioned specimens to the E* of the unconditioned specimens which was computed at each frequency.

- A minimum ESR in the range of 70% to 80% is generally considered acceptable.

Moisture Susceptibility - ESR Ratio

	Dynamic Modulus Stiffness Ratio (ESR)		
	10 Hz (%)	1 Hz (%)	0.1 Hz (%)
Drum Plant #1 - 12.5-mm Mixture with 0.5% SonneWarmix™			
15% RAP Mixture	101.4	99.8	96.5
27.8% RAP Mixture	95.2	92.0	89.9
46.3% RAP Mixture	95.1	93.3	91.6
Drum Plant #2 - 12.5-mm Mixture with 0.5% Evotherm®			
29% RAP Mixture	90.4	89.2	81.7
39% RAP Mixture	**77.8**	**73.2**	**74.7**
48% RAP Mixture	92.3	90.4	88.4
Drum Plant #2 - 12.5-mm Mixture with ACCU-SHEAR™ Foaming			
29% RAP Mixture	94.6	94.7	98.0
39% RAP Mixture	92.4	89.3	94.8
48% RAP Mixture	92.3	90.4	88.4

F = Failed the specification. The minimum passing ESR is 70%.

Moisture Susceptibility - ESR Ratio

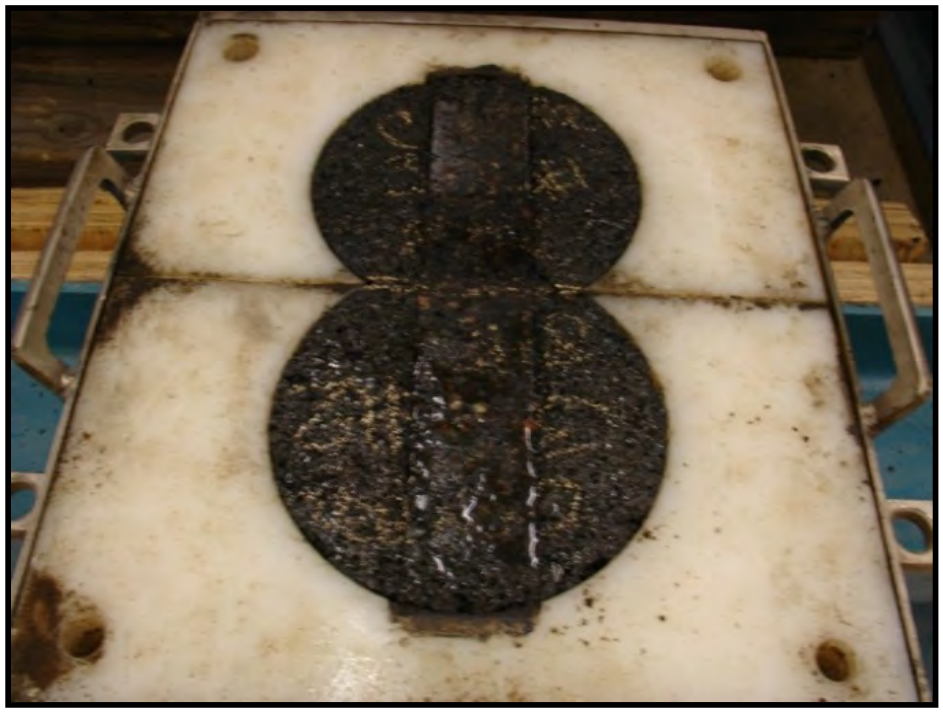
- All ESR values were above 70%, suggesting good performance.

- The ESR may have further identified the 39% RAP mixture with Evotherm® to be slightly susceptible to moisture damage, having ESR between 73 and 78%. The TSR for this mixture failed at 77.5%. The mixture easily passed the HWTD.

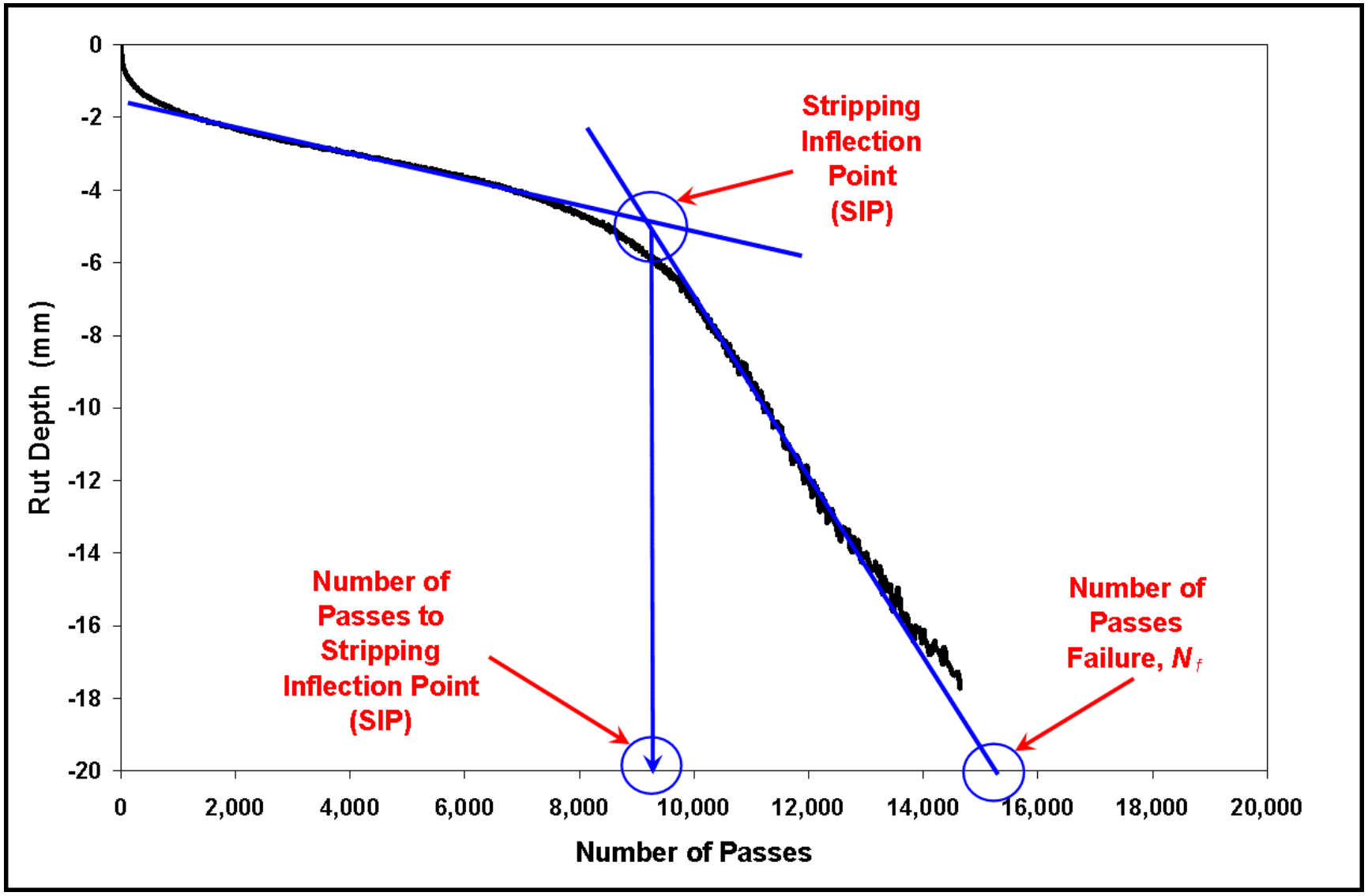
Moisture Susceptibility - HWTD

- Water temperature of 45ºC (113ºF)
- Test duration of 20,000 passes

- HWTD testing conducted in accordance with AASHTO T324



Moisture Susceptibility - HWTD



Moisture Susceptibility - HWTD

	AASHTO T324 Hamburg Wheel Tracking Device	
	Stripping Inflection Point	Rut Depth at 20,000 Wheel Passes (mm)
Drum Plant #1 - 12.5-mm Mixture with 0.5% SonneWarmix™		
15% RAP Mixture	11,766 **F**	13.4 **F**
27.8% RAP Mixture	NONE	5.1
46.3% RAP Mixture	NONE	4.4
Drum Plant #2 - 12.5-mm Mixture with 0.5% Evotherm®		
29% RAP Mixture	NONE	2.8
39% RAP Mixture	NONE	2.1
48% RAP Mixture	NONE	2.3
Drum Plant #2 - 12.5-mm Mixture with ACCU-SHEAR™ Foaming		
29% RAP Mixture	NONE	3.0
39% RAP Mixture	NONE	2.4
48% RAP Mixture	NONE	1.7

F = Failed the specification. SIP ≥ 15,000 Passes and Rut Depth ≤ 12.5 mm at 20,000 Passes.

Moisture Susceptibility - HWTD

- All mixtures passed the HWTD criteria for moisture susceptibility except for the 15% RAP mixture with SonneWarmix™. However, the mixture easily passed the other two tests (TSR & ESR) for moisture susceptibility.

- All rut depths were low except for the mixture which failed from moisture damage.

Fatigue Cracking – IFIT SCB

- I-FIT testing conducted in accordance with AASHTO TP124.
- Test temperature of 25ºC (77ºF).
- Load applied along the vertical diameter of the specimen at a displacement rate of 50 mm/min.
- Flexibility Index (FI) was calculated and recorded for each mixture.

Fatigue Cracking – IFIT SCB

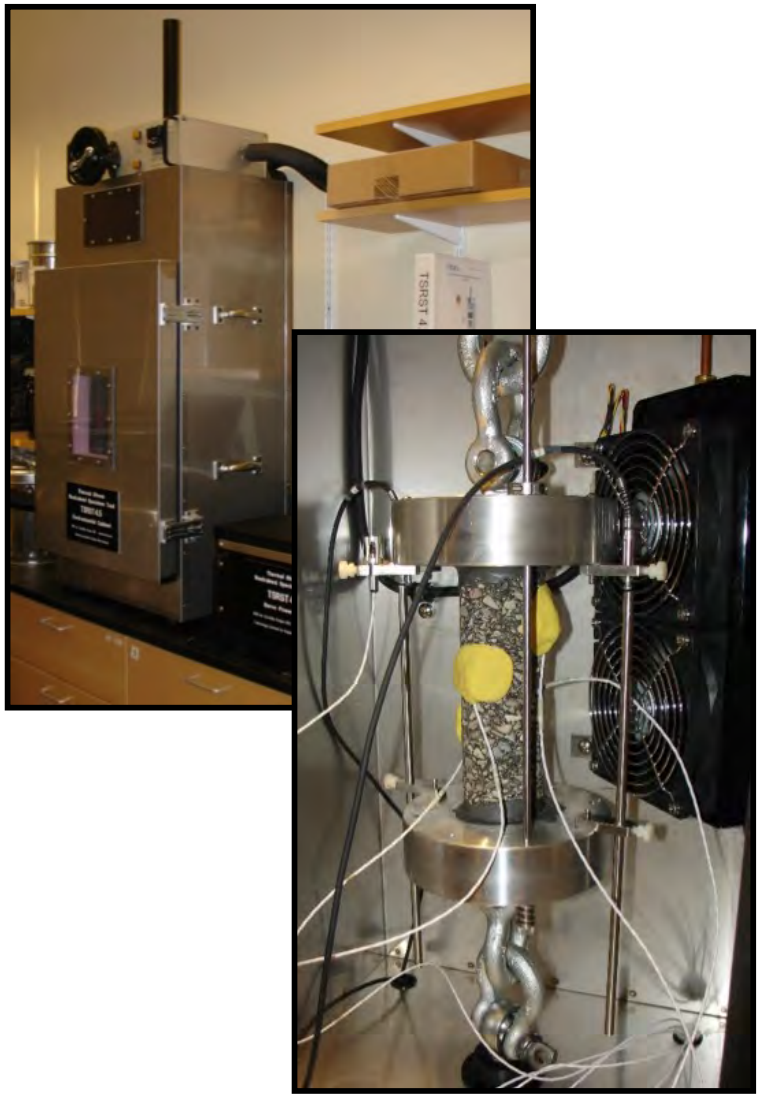
	AASHTO TP124 Semi-Circular Bending Test (SCB)
	Average Flexibility Index (FI)
Drum Plant #1 - 12.5-mm Mixture with 0.5% SonneWarmix™	
15% RAP Mixture	10.6
27.8% RAP Mixture	16.2
46.3% RAP Mixture	15.8
Drum Plant #2 - 12.5-mm Mixture with 0.5% Evotherm®	
29% RAP Mixture	6.1 F
39% RAP Mixture	5.4 F
48% RAP Mixture	3.7 F
Drum Plant #2 - 12.5-mm Mixture with ACCU-SHEAR™ Foaming	
29% RAP Mixture	8.4
39% RAP Mixture	6.7 F
48% RAP Mixture	4.4 F

F = Failed the specification. FI values less than 8.0 were shown to belong to mixtures with poor field and laboratory performance (Al-Qadi, et al. 2015).

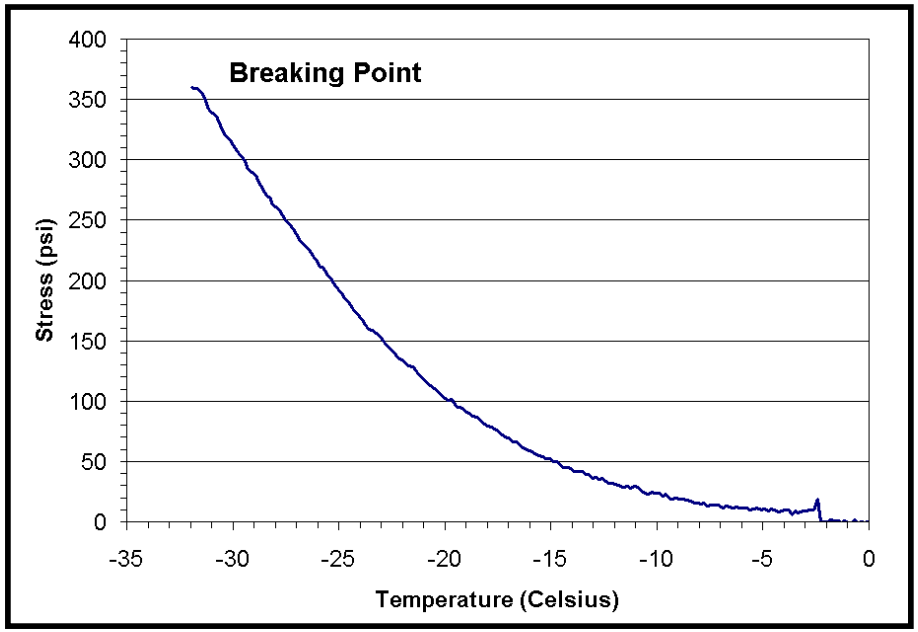
Fatigue Cracking – IFIT SCB

- Four of nine mixtures passed the test.
- An analysis of variance showed that the FI was a function of both the WMA technology and the RAP content FI.

Thermal Cracking – TSRST



- Superpave gyratory specimens utilized.
- Cooling Rate of -10ºC/hour.
- Testing in accordance with AASHTO TP10-93.



Thermal Cracking – TSRST

	AASHTO TP10 Thermal Stress Restrained Specimen Test (TSRST)
	Average Failure Temperature (°C)
Drum Plant #1 - 12.5-mm Mixture with 0.5% SonneWarmix™	
15% RAP Mixture	-27.0
27.8% RAP Mixture	-27.3
46.3% RAP Mixture	-26.6
Drum Plant #2 - 12.5-mm Mixture with 0.5% Evotherm®	
29% RAP Mixture	-25.5
39% RAP Mixture	-26.2
48% RAP Mixture	-26.8
Drum Plant #2 - 12.5-mm Mixture with ACCU-SHEAR™ Foaming	
29% RAP Mixture	-26.9
39% RAP Mixture	-25.8
48% RAP Mixture	-23.0

Thermal Cracking – TSRST

- The TSRST often provides a temperature that is warmer than the low-temperature PG, usually in the range of -26 to -28℃ for a PGXX-28 binder.

- The TSRST cracking temperatures ranged from -23.0 to -27.3℃. The thermal cracking performances of the mixtures would be acceptable at temperatures down to -28℃ except for one mixture.

Thermal Cracking – DC(T)

- Disc Shaped Compact Tension DC(T) testing conducted in accordance with ASTM D7313.
- Test temperature of -18ºC which is 10ºC warmer than low temperature PG grade.
- Preliminary DC(T) fracture energy thresholds for low, medium, and high traffic asphalt pavement mixtures were set at 400, 460, and 690 J/m^2 respectively based on FHWA Pooled Fund Study.

Thermal Cracking – DC(T)

	ASTM D7313 Disk-Shaped Compact Tension DC(T) Test
	Average Fracture Energy (J/m^2)
Drum Plant #1 - 12.5-mm Mixture with 0.5% SonneWarmix™	
15% RAP Mixture	499
27.8% RAP Mixture	518
46.3% RAP Mixture	474
Drum Plant #2 - 12.5-mm Mixture with 0.5% Evotherm®	
29% RAP Mixture	504
39% RAP Mixture	562
48% RAP Mixture	562
Drum Plant #2 - 12.5-mm Mixture with ACCU-SHEAR™ Foaming	
29% RAP Mixture	548
39% RAP Mixture	517
48% RAP Mixture	582

Thermal Cracking – DC(T)

- The 100 gyration mixtures from drum plant #1 passed the medium traffic criteria.
- The 75 gyration mixtures from drum plant #2 passed the medium traffic criteria.
- Note that the previous TSRST does not consider traffic level. Thus, the TSRST and DC(T) tests might not always provide an identical conclusion.

Conclusions and Recommendations

- The residual moisture contents of the mixtures in this study after plant production were negligible, which means that moisture had no effect on mixture performance.

- The three moisture susceptibility tests generally indicated acceptable performance regardless of the WMA technology or RAP content.

Conclusions and Recommendations

- Four of nine mixtures had acceptable fatigue cracking performance based on FI.

- The TSRST provided acceptable thermal cracking performances. The DC(T) showed that all mixtures would have acceptable thermal cracking performances for pavements with low or medium traffic levels.

Conclusions and Recommendations

- Field trials or full-scale pavement accelerated tests with rigorous pavement monitoring are needed to confirm the findings of this study.

- Studies are also needed to determine the applicability of the recommended minimum allowable FI of 8.0 to Northeast states.

Thank you!

Drum Plant #1 Mixture – 0.5% SonneWarmix

Sieve Size (mm)	% Passing by Weight		
	15% RAP Mixture	27.8% RAP Mixture	46.3% RAP Mixture
19.0	100	100	100
12.5	98.4	98.2	98.1
9.5	85.9	84.9	83.4
4.75	61.0	60.6	60.2
2.36	41.8	42.0	42.9
1.18	28.2	28.9	31.0
0.60	18.4	18.8	21.1
0.30	11.8	12.0	13.6
0.15	6.7	6.9	8.2
0.075	3.5	3.5	4.3
Total Mixture Binder Content (%)	5.5	5.5	5.5
Mixture Air Voids (%)	4.1	3.4	2.8
Voids in Mineral Aggregate (VMA), %	14.0	14.2	13.7
Voids Filled with Asphalt (VFA), %	71.0	76.1	79.8
Production Temperature (°C)	133°C	133°C	134°C

Drum Plant #2 Mixture – 0.5% Evotherm

Sieve Size (mm)	% Passing by Weight		
	29% RAP Mixture	39% RAP Mixture	48% RAP Mixture
19.0	100	100	100
12.5	97.4	98.5	99.0
9.5	84.1	85.0	88.2
4.75	59.7	59.7	63.5
2.36	47.1	46.7	50.5
1.18	39.9	39.1	38.2
0.60	32.9	32.1	34.0
0.30	21.4	20.9	22.2
0.15	9.8	9.8	11.3
0.075	4.1	4.2	4.8
Total Mixture Binder Content (%)	5.0	5.0	5.0
Mixture Air Voids (%)	4.4	4.3	4.2
Voids in Mineral Aggregate (VMA), %	14.1	14.2	14.4
Voids Filled with Asphalt (VFA), %	69.0	69.6	71.1
Production Temperature (°C)	138°C	135°C	143°C

Drum Plant #2 Mixture – ACCU-SHEAR™ Foaming

Sieve Size (mm)	% Passing by Weight		
	29% RAP Mixture	39% RAP Mixture	48% RAP Mixture
19.0	100	100	100
12.5	97.4	98.5	99.0
9.5	84.1	85.0	88.2
4.75	59.7	59.7	63.5
2.36	47.1	46.7	50.5
1.18	39.9	39.1	38.2
0.60	32.9	32.1	34.0
0.30	21.4	20.9	22.2
0.15	9.8	9.8	11.3
0.075	4.1	4.2	4.8
Total Mixture Binder Content (%)	5.0	5.0	5.0
Mixture Air Voids (%)	3.4	3.5	3.8
Voids in Mineral Aggregate (VMA), %	14.1	14.2	14.4
Voids Filled with Asphalt (VFA), %	76.2	75.6	73.5
Production Temperature (°C)	138°C	135°C	143°C