NCHRP 9-55: Recycled Asphalt Shingles in Asphalt Mixtures with Warm Mix Asphalt Technologies

Randy West

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National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

92nd AAPT Annual Meeting and Technical Sessions

The 2017 Annual Meeting will be held March 19-22, 2017

The Island Hotel, Newport Beach, California USA

AAPT

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2017 Call for Papers

The Association of Asphalt Paving Technologists is actively soliciting paper offers for its 2017 Annual Meeting and Technical Sessions. Papers reporting on studies concerning any aspect of asphalt paving technology or related fields are considered. These can include research, design, construction and maintenance issues dealing with all types of asphalt binders, asphalt mixtures, and pavement applications – including innovative ideas and improvements to current practice. Papers will be considered for presentation at the Annual Meeting which is attended by specialists from academia, research organizations, material producers, contractors, national and state authorities, and consultants from around the world. Papers offered for the 2017 Annual Meeting must be submitted through the AAPT website.

Important dates

May 1, 2016 web site open for paper submission
August 15, 2016 - deadline for submitting papers
November 4, 2016 - notification of paper acceptance
December 2016 - registration open
March 19 to 22, 2017 - annual meeting and technical sessions

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Objectives

- Develop a mix design and evaluation procedure that provides acceptable performance for asphalt mixtures containing RAS and WMA
  - Determine RAS characteristics that relate to mix performance
  - Evaluate mixing efficiency of RAS with virgin binders over the range of asphalt mixture production temperatures

Existing Field Projects

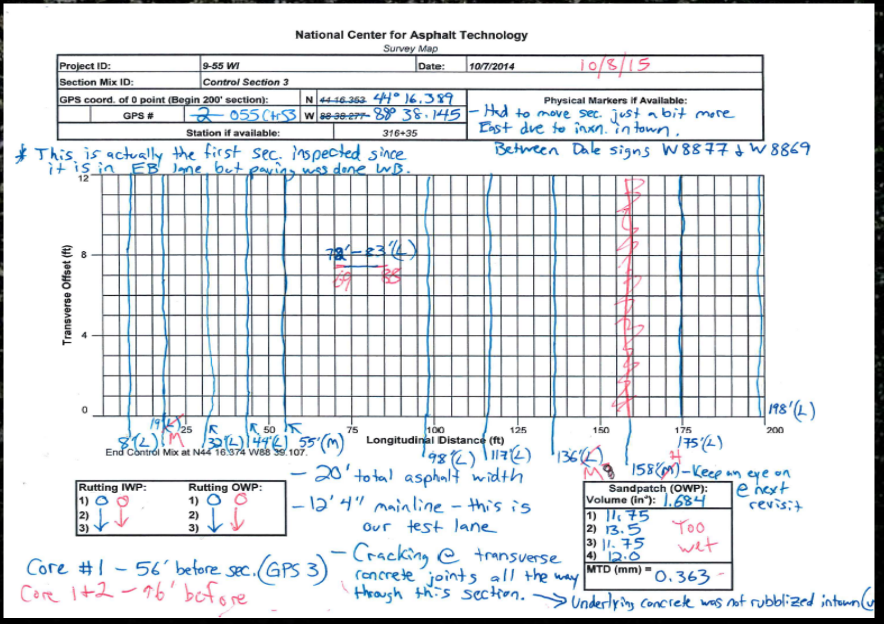
Location	Date Const.	RAS% RAP%	Mix Variables
US 287 Fort Worth, TX	Oct. 2012	5% 15%	HMA
			WMA (chem.)
FM 973 Austin, TX	Dec. 2011 Jan. 2012	3% 15%	HMA sect. 3
			WMA (chem.) sect. 9
		5%, 0%	HMA sect. 4
		3%, 15%	HMA w/ PG 58-28, sect. 6
I-88, IL Tollway Aurora, IL	Jun.-Aug. 2012	5% 13%	WMA (chem.), two agg. types

New Field Projects

Location	Date Const.	RAS % RAP %	Mix Test Sections	Prod. Temp.
SR 96 Larsen, WI	Sept. 2013	3% PC 14%	HMA	324
			Rediset	317
			Zycotherm	321
US 84 Enterprise AL	June 2014	5% PC 15%	HMA, low Pa	351
			HMA, adjusted Pa	350
			WMA (foam), low Pa	312
			WMA (foam), adjusted Pa	304
Union Valley Rd. Oak Ridge, TN	Oct. 2014	3% PC 10%	HMA	315
			WMA (chem.)	267
SR 58 Wilson, NC	June 2015	5% 20%	HMA w/ PCRAS	305
			WMA (chem.) w/ PCRAS	277
			HMA w/ MWRAS	297
			WMA (chem.) w/ MWRAS	276
SR 39 LaPorte, IN	Oct. 2015	2% MW 15%	HMA	318
			WMA (foam)	303

Field Performance Eval.

- Randomly selected three 200-ft sections for each mix
  - Rutting – Straight edge and wedge
  - Cracking – Visual Inspection and LTPP DIM
  - Raveling – ASTM E965 (sand patch)
- Collect five 6” cores from between wheelpaths
  - Determine in-place density
  - Binder properties
  - Laboratory test



US 287, Fort Worth, Field Performance @ 37 mos.

HMA

transverse (reflection) crack, low sev.

WMA

21 ft. low sev.

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FM 973, Austin, TX
Field Performance @ 47 mos.

		Wheelpath Longitudinal		Non-Wheelpath Longitudinal		Transverse		Block	
Mix	Severity	# of Cracks	Total Length, ft	# of Cracks	Total Length, ft	# of Cracks	Total Length, ft	# of Locations	Total Area, ft^2
WMA PG 64-22 15% RAP-3% RAS	Low	**6**	**113**	0	0	0	0	0	0
	Moderate	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0
HMA PG 64-22 15% RAP-3% RAS	Low	0	0	0	0	0	0	**3**	**7200**
	Moderate	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0
HMA PG 64-22 0% RAP-5% RAS	Low	**18**	**219**	0	0	1	1	0	0
	Moderate	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0
HMA PG 58-28 15% RAP-3% RAS	Low	**23**	**287**	1	7	**46**	**158**	0	0
	Moderate	**4**	**86**	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0

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Illinois Tollway Existing Project

- Gravel SMA:
  - 13% RAP/5% RAS
- Quartzite SMA:
  - 12% RAP/5% RAS
- Evotherm M1
- 2-2.25” thick over concrete

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Illinois Tollway
Field Performance @ 34 mos.

Mix	Severity	# Cracks	Total length, ft.
Gravel SMA	Low	13	126
	Moderate	6	72
	High	3	36
Quartzite SMA	Low	17	161
	Moderate	3	30
	High	6	72

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New Field Projects - Performance

Location	Mix Variables	Age	Field Performance
SR 96 Larson, WI	Control, Rediset, Zycotherm	25 mos.	Minor reflection cracking over unrubblized PCCP
US 84, Enterprise, AL	HMA & WMA – low Pa HMA & WMA – adj. Pa	17 mos.	No cracking or other distresses, last insp. pending
Union Valley Rd. Oak Ridge, TN	WMA & HMA	13 mos.	No cracking or other distresses, last insp. pending
SR 58 Wilson, NC	HMA & WMA w/ PCRAS, HMA & WMA w/ MSRAS	16 mos.	No cracking or other distresses
SR 39 LaPorte, IN	WMA & HMA		Pending 12 mo. insp. next month

LABORATORY TEST RESULTS

Plant Mix, Lab Compacted

No additional aging

Dynamic Modulus

- Temperatures: 4, 20 and 35 to 45°C
- Frequency range: 10 to 0.01 Hz
- Statistically assess mixture stiffness among mixtures
- Testing is completed on all mixtures

ANOVA + Tukey-Kramer test @ 10 Hz

Mixture	4 °C/10 Hz		20°C/10 Hz		40 °C/10 Hz	
	Average E*, ksi	Statistical Grouping	Average E*, ksi	Statistical Grouping	Average E*, ksi	Statistical Grouping
WI – Control	1881.0	**A**	804.2	**A**	221.7	**A**
WI – Rediset	1638.7	**A**	690.2	**A**	212.9	**A**
WI – Zycoth.	1678.4	**A**	719.9	**A**	210.4	**A**
AL – Low Pa WMA	2001.3	**A**	968.1	**A**	248.9	**A**
AL – Low Pa HMA	2114.8	**A**	1132.7	**B**	355.8	**B**
AL – Adj. Pa WMA	2181.9	**A B**	1167.6	**B C**	376.9	**B**
AL – Adj. Pa HMA	2367.6	**B**	1265.6	**C**	408.3	**B**

Mixtures from a project with the same letter table were statistically grouped together (no statistical difference among mixes at $\alpha = 0.05$).

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ANOVA + Tukey-Kramer test @ 10 Hz

Mixture	4 °C/10 Hz		20°C/10 Hz		40 °C/10 Hz	
	Average E*, ksi	Statistical Grouping	Average E*, ksi	Statistical Grouping	Average E*, ksi	Statistical Grouping
TN – HMA	2361.3	**A**	1249.4	**A**	330.3	**A**
TN – WMA	2178.5	**A**	974.3	**B**	208.5	**B**
NC – MW HMA	2072.7	**A**	1013.3	**A**	280.8	**A**
NC – MW WMA	1762.9	**B**	729.0	**B**	166.4	**B**
NC – PC HMA	1941.1	**A B**	981.8	**A**	292.5	**A**
NC – PC WMA	1789.2	**A B**	821.1	**B**	196.5	**B**
IN-HMA	2444.7	**A**	1423.0	**A**	494.1	**A**
IN-WMA	2415.6	**A**	1423.9	**A**	478.5	**A**

Mixtures from a project with the same letter were statistically grouped together (no statistical difference among mixes at $\alpha = 0.05$).

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Hamburg Wheel Tracking Test

- AASHTO T324
  - Assess rutting and stripping potential of mixtures
  - 50°C
  - All mixtures tested
  - Maximum 0.5 in (12.5 mm) @ 20,000 passes (NCHRP Report 673)

Hamburg Wheel Tracking Test

Mixture	Average Rut Depth at 20,000 passes, mm	Standard Deviation, mm	Stripping Inflection Point, cycles	Statistical Grouping
WI - Control	1.87	0.08	10,000+	**A**
WI - Rediset	2.49	0.75	10,000+	**A**
WI - Zycotherm	2.31	0.32	10,000+	**A**
AL – Low Pa WMA	4.02	0.30	10,000+	**A**
AL – Low Pa HMA	1.63	0.17	10,000+	**B C**
AL – Adj. Pa WMA	2.08	0.05	10,000+	**B**
AL – Adj. Pa HMA	1.35	0.22	10,000+	**C**

Hamburg Wheel Tracking Test

Mixture	Average Rut Depth at 20,000 passes, mm	Standard Deviation, mm	Stripping Inflection Point, cycles	Statistical Grouping
TN – HMA	2.52	0.42	20,000+	A
TN – WMA	4.98	1.48	18,100	A
NC – MW HMA	1.68	0.22	20,000+	A
NC – MW WMA	2.90	0.22	20,000+	B
NC – PC HMA	1.62	0.06	20,000+	A
NC – PC WMA	2.54	0.40	20,000+	B
IN – HMA	2.96	0.81	20,000+	A
IN - WMA	2.50	0.36	20,000+	A

There was no statistical differences between the types of RAS used.

Flow Number

- AASHTO TP 79-09
  - Test on E* specimens
  - Temperature: LTPP Bind 3.1 50% Reliability Temp 20 mm from surface
  - Unconfined testing
  - All mixtures tested

Current Flow Number Requirements

Traffic Level (Million ESALs)	NCHRP Report 673 (HMA)	NCHRP Report 691 (WMA)
< 3	---	---
3 to < 10	53	30
10 to < 30	190	105
≥ 30	740	415

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Flow Number Results

Mix	Temp, °C	Flow Number, cycles		Recommended ESAL Range, x10^6 ESALs	Grouping
		Ave.	St. Dev.		
WI – Control	48.5	**163**	51.5	10 to < 30	**A**
WI – Rediset		**120**	100.9		**A**
WI – Zycotherm		**117**	62.2		**A**
AL – Low Pa WMA	60.5	**28**	1.5	<3	**A**
AL – Low Pa HMA		**123**	28.3	10 to < 30	**B**
AL – Adj. Pa WMA		**106**	14.1		**B**
AL – Adj. Pa HMA		**119**	30.1		**B**

Flow Number Results

Mix	Temp, °C	Flow Number, cycles		Recommended ESAL Range, x10^6 ESALs	Grouping
		Ave.	St. Dev.		
TN – HMA	56.5	**195**	55.7	10 to < 30	**A**
TN – WMA		**46**	5.7	3 to <10	**B**
NC – MW HMA	58.0	**150**	49.0	3 to <10	**A**
NC – MW WMA		**18**	2.4	<3	**B**
NC – PC HMA		**124**	6.6	3 to <10	**A**
NC – PC WMA		**33**	1.3	3 to <10	**B**
IN-HMA	51.0	**593**	90.3	10 to < 30	**A**
IN-WMA		**530**	40.8	≥ 30	**A**

IN mixtures not statistically different, but IN-WMA @ higher traffic level?

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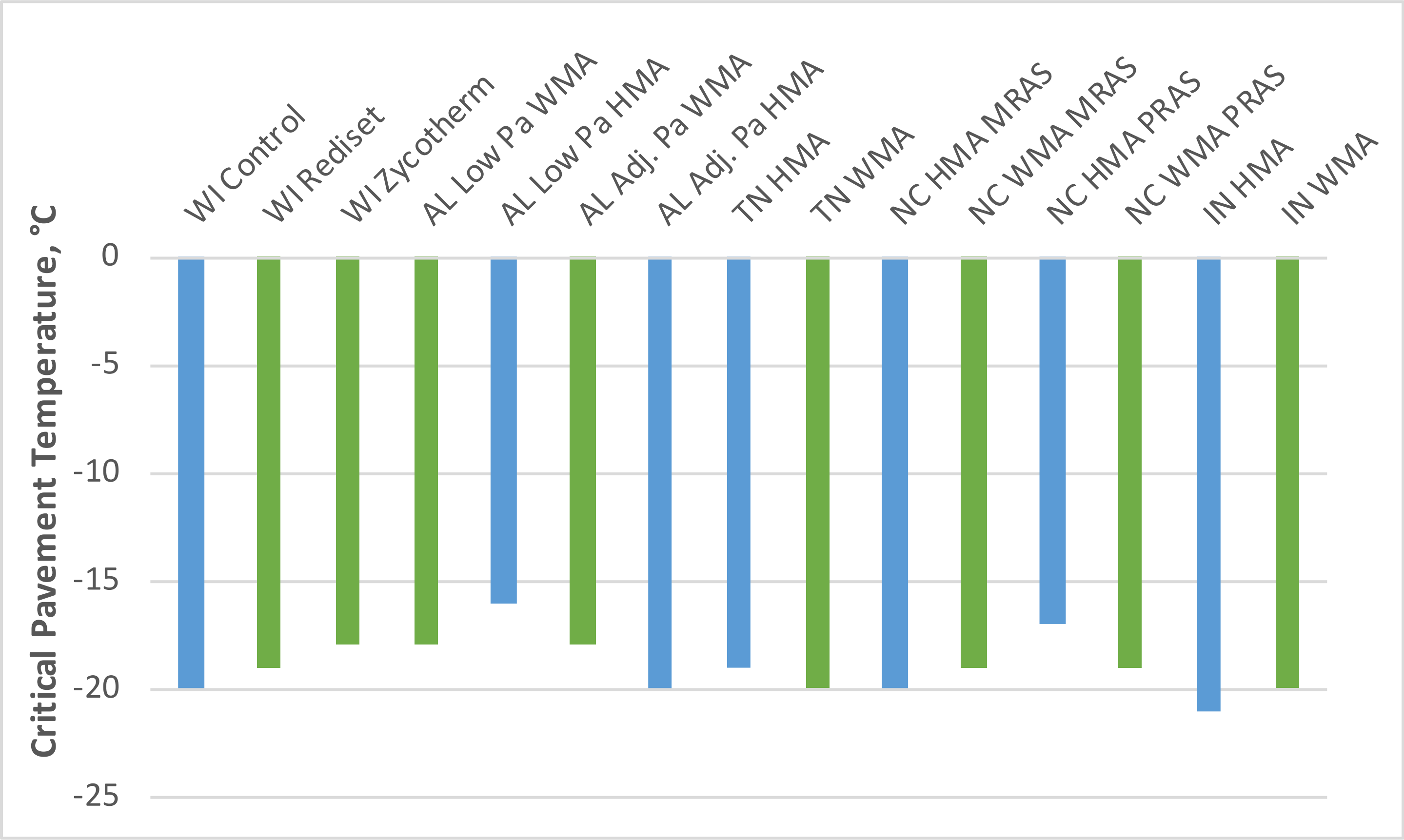
IDT Creep Compliance & Strength

- AASHTO T 322
  - Creep compliance at three temperatures
  - Tensile strength at one temperature
  - Predict the temperature at which the mix will crack due to thermal contraction
  - All mixtures tested

Critical Pavement Temperatures



Blue = HMA, Green = WMA

No statistical difference between HMA and WMA mixtures

Energy Ratio

- UF Method
  - Assess top-down cracking
  - Three IDT tests conducted @ 10°C
    - Resilient modulus
    - Creep
    - Tensile strength
  - Criteria developed by UF
  - All mixtures tested

Recommended Energy Ratio Criteria

Traffic: (ESALs/yr)	Minimum Energy Ratio
< 250,000	1
< 500,000	1.3
< 1,000,000	1.95

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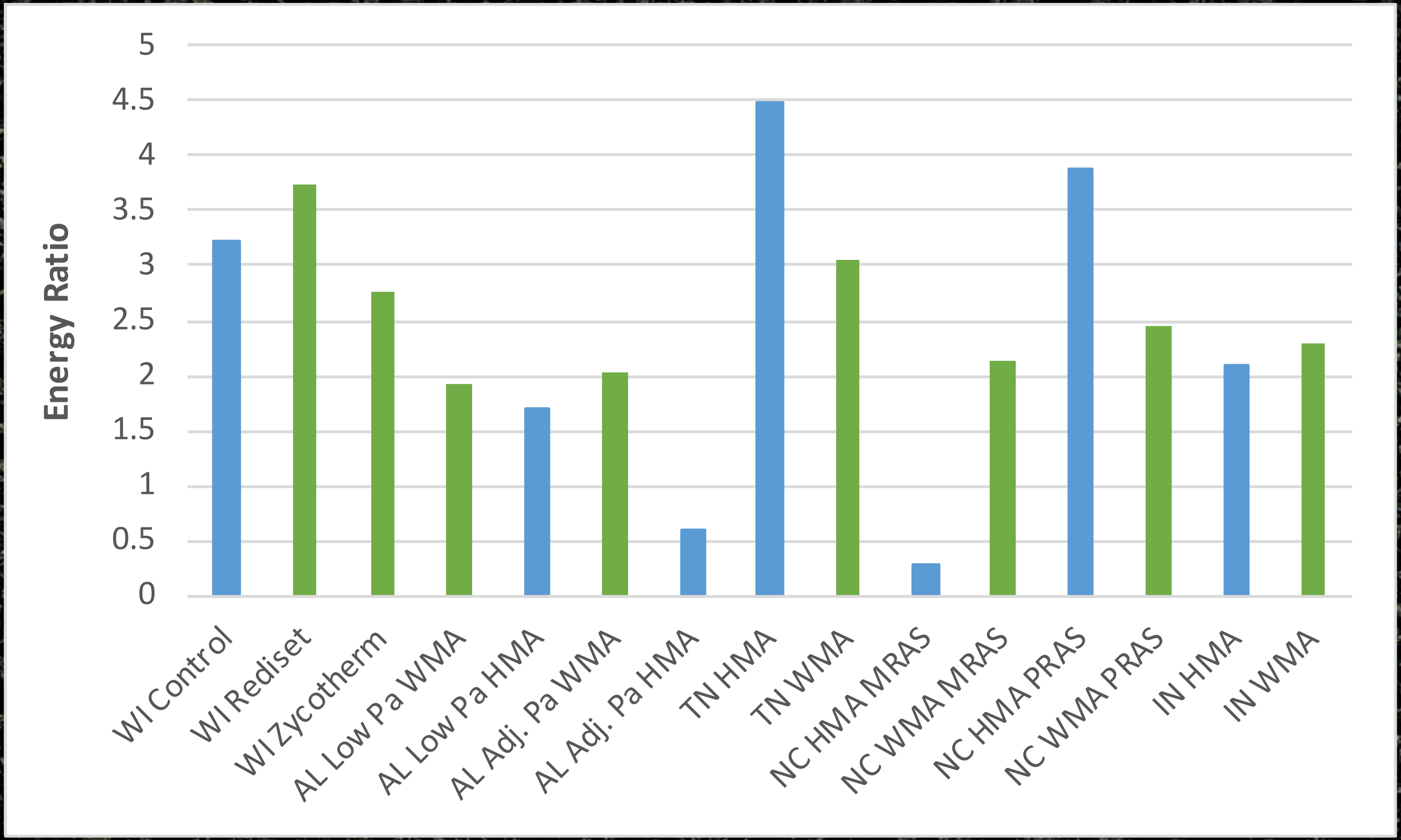
Energy Ratio Results



Blue = HMA, Green = WMA

No statistical difference between HMA and WMA mixtures

Bending Beam Fatigue

- AASHTO T324
  - Quantify number of cycles until failure at different strain levels
  - Frequency: 10 Hz
  - Temperature: 20°C
  - Determine fatigue endurance limit for mixtures
  - All testing completed

Beam Fatigue

New AASHTO Failure (Peak ModxCy)

Mix	Strain 1	Average Nf	Group	Strain 2	Average Nf	Group	Endurance Limit, με
WI – HMA*	500	287,530	**A**	250	126,510,069	**A**	258
WI – Redi*	500	258,840	**A**	250	81,180,843	**A**	241
WI – Zyco*	500	339,997	**A**	250	92,643,767	**A**	228
AL – Low Pa WMA	600	107,263	**A**	300	7,841,577	**A**	197
AL – Low Pa HMA	600	53,803	**A**	300	4,074,857	**A B**	169
AL – Adj. Pa WMA	600	76,497	**A**	300	4,453,407	**A B**	140
AL – Adj. Pa HMA	600	91,153	**A**	300	1,451,193	**B**	83

*Old AASHTO Failure Cycles (50%)

Beam Fatigue

New AASHTO Failure (Peak ModxCy)

Mix	Strain 1	Average Nf	Group	Strain 2	Average Nf	Group	Endurance Limit, με
TN – HMA	600	66,908	**A**	300	2,842,008	**A**	149
TN – WMA	600	59,745	**A**	300	1,105,585	**B**	94
NC – MW HMA	700	45,565	**A**	350	1,830,803	**A**	165
NC – MW WMA	700	38,264	**A B**	350	861,843	**A B**	113
NC – PC HMA	700	17,427	**A B**	350	954,994	**B**	139
NC – PC WMA	700	25,221	**B**	350	820,699	**B**	118
IN-HMA	600	59,437	**A**	300	2,245,642	**A**	143
IN-WMA	600	89,964	**A**	300	2,473,384	**A**	112

Overlay Tester

- TxDOT 248-F
  - Temperature specified: 25°C
  - Should temperature be based on mixture location
  - Displacement: 0.025 inches (32% strain)

Texas currently requires mixes ≥ 300 cycles while New Jersey requires ≥ 150 cycles.

OT Results

Mix	Temp, °C	Displacement, in	Cycles until Failure		Statistical Group
			Average	St. Dev.	
WI – Control	10	0.015	**792**	752.1	**A**
WI – Rediset			**1,320**	193.0	**A**
WI – Zycotherm			**1,903**	705.6	**A**
WI – Control	25	0.025	**241**	83.8	**A**
WI – Rediset			**285**	51.1	**A**
WI – Zycotherm			**436**	96.4	**A**
AL – Low Pa WMA	25	0.025	**214**	69.1	**A**
AL – Low Pa HMA			**19**	0.6	**B**
AL – Adj. Pa WMA			**44**	5.6	**B**
AL – Adj. Pa HMA			**24**	8.4	**B**

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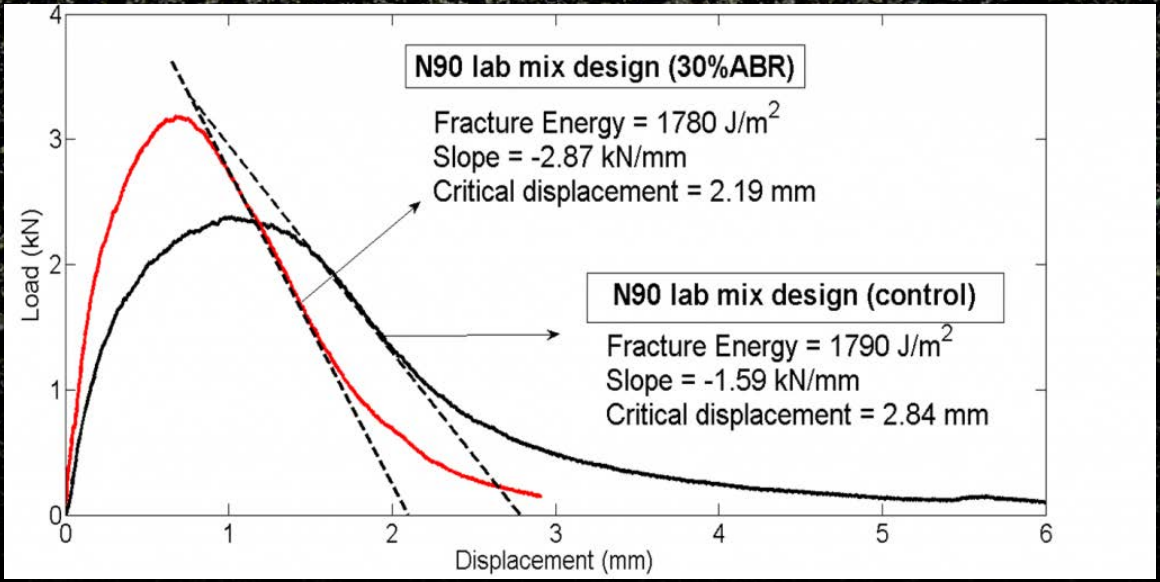
OT Results

Mix	Temp, °C	Displacement, in	Cycles until Failure		Statistical Group
			Average	St. Dev.	
TN – HMA	25	0.025	**226**	55.4	**B**
TN – WMA			**807**	148.2	**A**
NC – MW HMA			**125**	78.6	**A**
NC – MW WMA			**619**	88.4	**C**
NC – PC HMA			**215**	54.9	**A B**
NC – PC WMA			**333**	142.2	**B**
IN-HMA			**109**	30.3	**A**
IN-WMA			**158**	71.1	**A**

Illinois Flexibility Index Test

- SCB
- 25 °C
- Loading = 50 mm/min
- Flexibility Index = A*(Fracture Energy/Slope at inflection)
- Preliminary ILDOT criterion, minimum 8.0



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I-FIT Test Results

Mix	Average Flexibility Index (FI)	Std Dev of Flexibility Index (FI)	Statistical Group
WI Control	3.3	0.52	A
WI Rediset	5.8	1.76	B
WI Zycotherm	2.9	0.47	A
AL Low Pa WMA	2.9	0.65	A
AL Low Pa HMA	0.7	0.40	B C
AL Adj. Pa WMA	1.0	0.16	B
AL Adj. Pa HMA	0.2	0.05	C
TN HMA	3.3	0.90	A
TN WMA	4.9	0.73	B
NC HMA MW RAS	1.8	0.56	A
NC WMA MW RAS	7.3	0.56	B
NC HMA PC RAS	3.7	0.81	C
NC WMA PC RAS	4.7	0.52	C
IN HMA	1.1	0.39	A
IN WMA	1.7	0.17	B

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Correlations

Correlation R-value	Flex Index	Flow Number	E* Low (@ 4 °C)	E* Int (@ 20 °C)	E* High (@ 40 °C)	Critical Pavement Temperature (°C)	HWT Rutting	ER	OT Cycles to Failure
Flex Index	1								
Flow Number	-0.44	1							
E* Low (@ 4 °C)	-0.67	0.62	1						
E* Int (@ 20 °C)	-0.73	0.71	0.97	1					
E* High (@ 40 °C)	-0.79	0.80	0.85	0.94	1				
Critical Pavement Temperature (°C)	-0.02	-0.47	-0.35	-0.24	-0.20	1			
HWT Rutting	0.43	-0.09	0.02	-0.10	-0.28	-0.24	1		
ER	0.51	-0.02	-0.24	-0.24	-0.28	0.16	0.22	1	
OT Cycles to Failure	0.79	-0.38	-0.41	-0.55	-0.68	-0.16	0.69	0.35	1

Moderate correlation **Strong correlation**

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Correlations

- Moderate to strong inversely proportional correlation between Flexibility Index and E* values.
- Strong proportional correlation between Flexibility Index and OT cycles to failure.
- Moderate to strong proportional correlation between FN and E* values.

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Correlations

- Moderate inversely proportional correlation between OT cycles to failure and E* values.
- Moderate proportional correlation between OT cycles to failure and HWT rutting.
- Critical Pavement Temperature (°C) and Energy Ratio values did not correlate with any other test results.

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Performance Tests Conclusions

- At low temperatures, WMA has little effect on mix stiffness.
- At intermediate and high temperatures, WMA had lower E* values for 3 of 5 evaluated projects.
- No effect on E* due to type of RAS used.

Performance Tests Conclusions

- No statistical difference in Hamburg rutting was found for WMA vs HMA for WI, TN and IN mixtures. TN mixtures were statistically different for the FN test.
- For the AL mixtures, the low void WMA had statistically higher HWT rutting and lower FN. The adjusted void HMA had the least rutting.
- The two NC WMA mixtures had higher HWT rutting and lower FN than the HMA mixtures.

Performance Tests Conclusions

- No effect on rutting due to type of RAS used.
- All 15 mixtures passed the 0.5 in HWT criterion
- For the FN testing…
  - 2 of 15 had FN < 3 MESAL criteria
  - 4 of 15 mixtures met the 3 to <10 MESALs criteria
  - 8 of 15 mixtures met the 10 to < 30 MESALs criteria
  - 1 of 15 met the > 30 MESALs criteria

Performance Tests Conclusions

- All of the Wisconsin and Tennessee mixtures have ER values greater than 1.95.
- In total, 11 of 15 mixtures have ER values > 1.95 (highest traffic level).
- The AL adj. Pa HMA and the NC MW HMA had low ER results (below 1.0, lowest traffic level), suggesting susceptibility to top-down cracking
- HMA vs. WMA was not a sign. factor for ER

Performance tests Conclusions

- None of the tested mixtures meet the current preliminary I-FIT criterion of 8.0.
- A strong correlation was found between Flexibility Index and OT cycles to failure.
- Based on TxDOT specifications only 4 out of 15 mixtures passed the minimum 300 cycles criterion.

Field Performance

- All sections are performing well which makes it challenging to set some performance criteria.
  - Pass Hamburg = no rutting problems (not sure about the opposite)
  - Many mixes fail existing/preliminary criteria for cracking tests, but field cracking performance is good for first 2-3 years.

Currently working on

- Task 7: Assess response parameters and predict mixture performance
- Task 9: Cost-Benefit Analysis
- Task 10: Best Practices