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

Mix ETG Meeting

Bozeman, MT

September, 2017

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National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Objective

Develop a design and evaluation procedure that provides acceptable performance for asphalt mixtures with RAS and WMA

Unwritten objective

Does using ~~a lower mixing temperature (à la WMA)~~ affect the ~~"activation" of RAS binder and therefore the~~ performance of mixtures containing RAS?

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Panel's Concerns

- Allowable range of asphalt mixture production temperatures (i.e. WMA and HMA)
- Mixing efficiency of RAS with virgin binders
- Binder design and selection
- Evaluate type, source, quality, and RAS characteristics and relate to mix performance
- Minimize risk of poor construction, durability, and poor performance

AASHTO Standards for RAS

- MP-15-09
  - max. grind size: 100% pass ½" sieve
  - deleterious limits +#4: 3% max, 1.5% lightweight max.
- PP 53-09
  - assumed RAS aggregate gradation
  - solvent extraction for RAS asphalt content
  - determine Gse for RAS aggregate spec. gravity
  - estimate shingle availability factor
  - test composite binder if $Pb_{virgin} < 0.7\ Pb_{Total}$

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AASHTO Standards for RAS

- MP-25-14
  - grind size: 95% pass 3/8" sieve
  - deleterious limits +#4: 1.5% total, 0.5% non-metallic
- PP 78-14
  - eliminate assumed RAS aggregate gradation
  - RAS binder availability factor assumed to be between 0.70 and 0.85
  - virgin binder adjustment table with tiers like RAP

AASHTO Standards for RAS

- PP-78-17
  - solvent extraction or ignition method for Pb_{RAS}
  - eliminate shingle availability factor
  - increase VMA criteria by 0.1% for every 1% RAS
  - add criteria for ΔTc on binder recovered from mix
    - agency selected mix cracking test may be conducted in lieu of ΔTc requirement

9-55 Conclusions

- Using WMA with mixtures containing RAS does not appear to have a detrimental effect. Some cracking tests indicate WMA mixtures were better than corresponding HMA mix.
- All field sections are performing well which makes it challenging to validate performance test criteria.
- Longer term monitoring (5 years +) of field sections is recommended.

9-55 Conclusions

- The new ΔTc criteria will make it very difficult to use RAS in asphalt mixtures.
  - the research behind 40 hour PAV was based primarily on REOB and some rejuvenators. Only recently has work been done on RAS binders.
  - field aging was based on the top ½ inch of pavement. What about using RAS in lower layers (e.g. high modulus mixes)?
  - Several NCAT test sections call into question the validity of the Delta Tc criterion.

NCHRP 9-55 Project Overview

- The work plan focused on sampling, testing, and performance evaluation of asphalt mixtures containing RAS with and without the use of WMA technologies.
- 3 existing projects
- 5 new projects
- Mixtures evaluated using numerous laboratory "performance" tests

Existing Field Projects

Location	Date Const.	RAS% RAP%	Mix Variables
US 287 Fort Worth, TX	Oct. 2012	5% 15%	HMA
			WMA (Cecabase RT)
FM 973 Austin, TX	Dec. 2011 Jan. 2012	3% 15%	HMA Section 3
			WMA (Evotherm DAT) Section 9
		5%, 0%	HMA Section 4
		3%, 15%	HMA w/ PG 58-28, Section 6
I-88, IL Tollway Aurora, IL	Jun.-Aug. 2012	5% 13%	WMA (Evotherm M1), two aggregate types

Existing Field Projects - Performance

Location	Mix Variables	Age	Field Performance
US 287 Fort Worth, TX	HMA	37 mos.	Low-severity transverse cracking (reflective)
	WMA (Cecabase RT)	37 mos.	Low-severity transverse cracking (reflective) Low-severity longitudinal (edge) cracking
FM 973 Austin, TX	HMA PG 64-22 15% RAP-3% RAS	47 mos.	Low-severity transverse cracking Low-severity block cracking
	WMA (Evo. DAT)	47 mos.	Low-severity longitudinal cracking
	HMA PG 64-22 0% RAP-5% RAS	47 mos.	Low-severity longitudinal cracking
	HMA w/ PG 58-28	47 mos.	Low and medium-severity longitudinal cracking Low-severity transverse cracking
I-88, IL Tollway Aurora, IL	WMA (Evo. M1), two agg. types	46 mos.	Low, medium and high-severity transverse cracking (mostly reflective)

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 Va	351
			HMA, adjusted Va	350
			WMA (foam), low Va	312
			WMA (foam), adjusted Va	304
Union Valley Rd. Oak Ridge, TN	Oct. 2014	3% PC 10%	HMA	315
			WMA (Evotherm 3G)	267
SR 58 Wilson, NC	June 2015	5% 20%	HMA w/ PCRAS	305
			WMA (Evo. 3G) w/ PCRAS	277
			HMA w/ MWRAS	297
			WMA (Evo. 3G) w/ MWRAS	276
SR 39 LaPorte, IN	Oct. 2015	2% MW 15%	HMA	318
			WMA (foam)	303

As-Constructed In-Place Densities

Site	Mix ID	% Gmm	Standard Deviation	Sign. Diff.?
Larsen, WI SR 96	Control	91.6	0.6	N
	Rediset	90.7	1.0	
	Zycotherm	90.8	1.5	
Enterprise, AL US 84	Low Va HMA	94.1	0.6	N
	Low Va Gencor Foam	92.5	1.6	
	Adj. Va HMA	92.2	0.9	N
	Adj. Va Gencor Foam	90.9	1.7	
Oak Ridge, TN Racoon Valley Drive	HMA	88.8	2.0	N
	Evotherm 3G	87.0	1.2	
Wilson, NC SR 58	MWRAS HMA	92.4	0.1	N
	MWRAS Evotherm 3G	92.1	0.9	
	PCRAS HMA	93.8	0.5	N
	PCRAS Evotherm 3G	93.0	0.6	
LaPorte, IN SR 39	HMA	91.4	0.6	Y
	AQUABlack WMA	92.4	0.1	

Location	RAS % RAP %	RAPBR RASBR	Mix Test Sections	%Vbe	ΔTc 20 hr PAV
SR 96 Larsen, WI	3% PC 14%	0.11 0.14-0.15	HMA	11.4	-3.5
			Rediset	10.8	-3.8
			Zycotherm	11.6	-5.0
US 84 Enterprise AL	5% PC 15%	0.12-0.13 0.17-0.20	HMA, low Va	11.1	-7.7
			WMA, low Va	12.2	-8.1
			HMA, adj. Va	10.3	-10.8
			WMA, adj. Va	10.8	-8.6
Union Valley Rd. Oak Ridge, TN	3% PC 10%	0.10-0.11 0.09-0.11	HMA	9.9	-11.7
			WMA (chem.)	11.2	-5.5
SR 58 Wilson, NC	5% 20%	0.19-0.21 0.17-0.18	HMA w/ MWRAS	10.1	-2.7
			WMA (chem.) w MWRAS	10.9	-2.0
			HMA w/ PCRAS	11.6	-3.2
			WMA (chem.) w/ PCRAS	11.4	-2.9
SR 39 LaPorte, IN	2% MW 15%	0.15 0.07-0.10	HMA	9.9	-5.6
			WMA (foam)	10.1	-6.1

New Field Projects - Performance

Location	Mix Variables	Age	Field Performance
SR 96 Larson, WI	Control, Rediset, Zycotherm	24 mos.	Minor reflection cracking over unrubblized PCCP
US 84, Enterprise, AL	HMA & WMA – low Va HMA & WMA – adj. Va	29mos.	Low-severity transverse cracking
Union Valley Rd. Oak Ridge, TN	WMA & HMA	25 mos.	Low-severity transverse cracking. No other distresses
SR 58 Wilson, NC	HMA & WMA w/ PCRAS, HMA & WMA w/ MSRAS	14 mos.	Low-severity transverse cracking. No other distresses
SR 39 LaPorte, IN	WMA & HMA	16 mos.	No cracking or other distresses

Larson, WI

24 month inspection	Transverse (Reflection) Cracks (ft.)		
	Low	Med	High
Control	87	36	0
Rediset	0	0	0
Zycotherm	3	49	0

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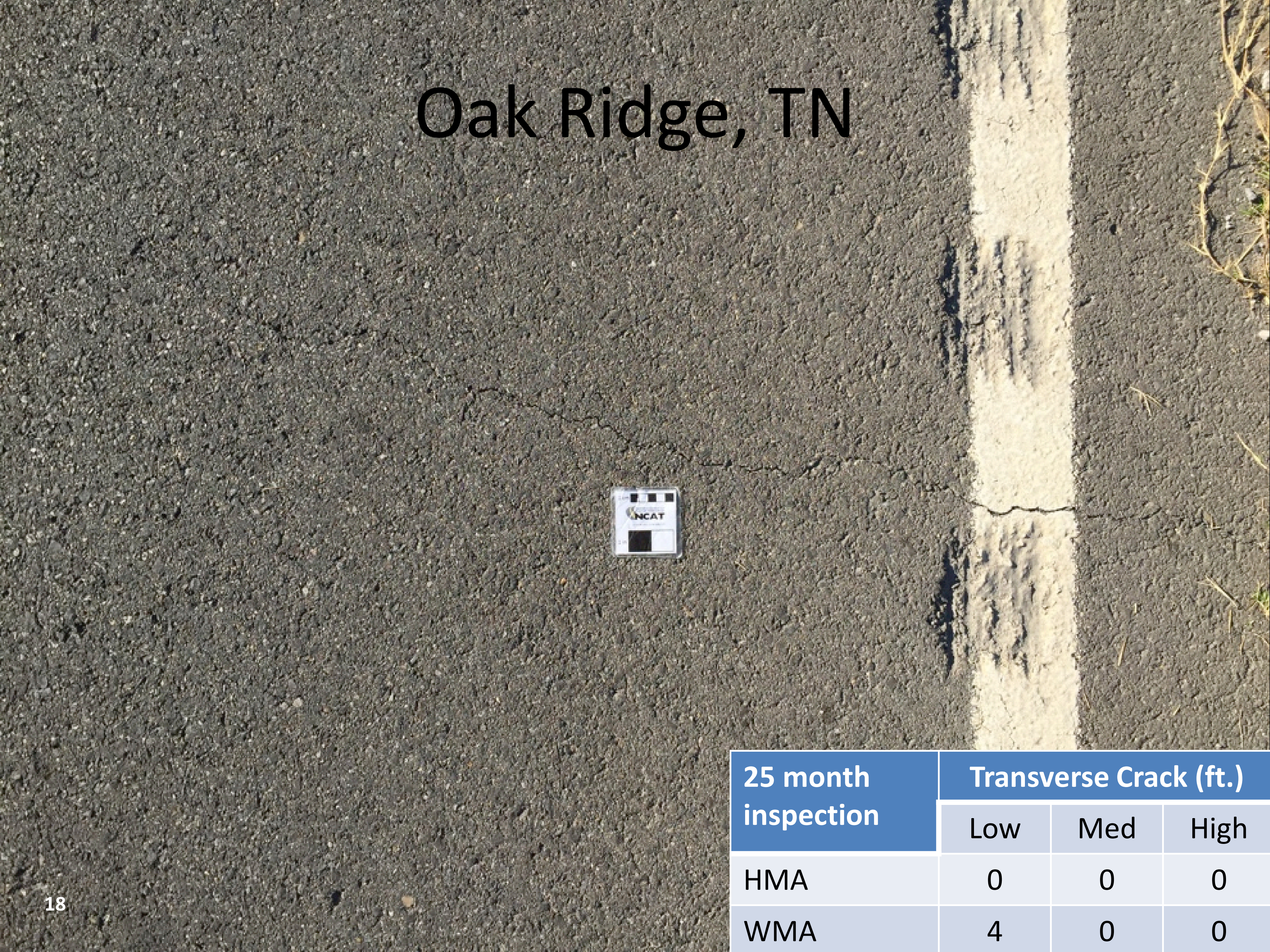
Enterprise, AL

29 month inspection	Longitudinal Cracks (ft.)		
	Low	Med	High
Low Va HMA	53	0	0
Low Va WMA	0	0	0
Adj. Va HMA	0	0	0
Adj. Va HMA	0	0	0

Oak Ridge, TN



25 month inspection	Transverse Crack (ft.)		
	Low	Med	High
HMA	0	0	0
WMA	4	0	0

Wilson, NC

14 month inspection	Transverse Cracks (ft.)		
	Low	Med	High
HMA PCRAS	4	0	0
WMA PCRAS	0	0	0
HMA MWRAS	0	0	0
WMA MWRAS	0	0	0

LaPorte, IN

16 month inspection	Cracking (ft.)		
	Low	Med	High
HMA	0	0	0
WMA	0	0	0

Laboratory Testing

- Recovered Binder: PG, ΔTc @ 20 hr PAV, MSCR, LAS
- Plant Mix, Lab Compacted (hot)
  - Stiffness: E*
  - Rutting: FN and HWTT
  - Cracking: BBF, OT, ER, and IDT Creep
  - Cracking (reheated mix): SCB-Jc and IFIT
- Lab Mix, Lab Compacted
  - mix design verification
    - 3 to 4 point AC volumetrics
    - ΔTc @ 40 hr PAV

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Caveats on the following slides

- OT tests were conducted using the first generation AMPT jig which have been found to have compliance issues. Comparing the results relative to the TxDOT criteria should be made with caution.
- LADOTD criteria for SCB-Jc are based on LTOA aged specimens. This study did not use any LTOA protocol, so comparing results to the LADOTD criteria should be made with caution.
- Reported V_{be} values are based on NCAT hot PMLC volumetric properties using NCAT G_{sb} values.

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Location	RAS % RAP %	Mix Test Sections	%Vbe	ΔTc 20 hr PAV	BBF M Nf @400
SR 96 Larsen, WI	3% PC 14%	HMA	11.4	-3.5	3.28
		Rediset	10.8	-3.8	2.58
		Zycotherm	11.6	-5.0	3.20
US 84 Enterprise AL	5% PC 15%	HMA, low Va	11.1	-7.7	0.96
		WMA, low Va	[illegible]	-8.1	1.88
		HMA, adj. Va	[illegible]	-10.8	0.58
		WMA, adj. Va	10.8	-8.6	1.15
Union Valley Rd. Oak Ridge, TN	3% PC 10%	HMA	9.9	-11.7	0.81
		WMA (chem.)	11.2	-5.5	0.42
SR 58 Wilson, NC	5% 20%	HMA w/ MWRAS	10.1	-2.7	1.10
		WMA (chem.) w MWRAS	10.9	-2.0	0.55
		HMA w/ PCRAS	11.6	-3.2	0.54
		WMA (chem.) w/ PCRAS	11.4	-2.9	0.50
SR 39 LaPorte, IN	2% MW 15%	HMA	9.8	-5.6	0.67
		WMA (foam)	10.1	-6.1	0.82

Paired t test: WMA & HMA **NSD**

Location	RAS % RAP %	Mix Test Sections	%Vbe	ΔTc 20 hr PAV	OT >300	T-K
SR 96 Larsen, WI	3% PC 14%	HMA	11.4	-3.5	241	A
		Rediset	10.8	-3.8	285	A
		Zycotherm	11.6	-5.0	436	A
US 84 Enterprise AL	5% PC 15%	HMA, low Va	11.1	-7.7	19	A
		WMA, low Va	12.[illegible]	[illegible]8.1	214	B
		HMA, adj. Va	[illegible]	-10.8	24	A
		WMA, adj. Va	10.8	-8.6	44	A
Union Valley Rd. Oak Ridge, TN	3% PC 10%	HMA	9.9	-11.7	226	A
		W[illegible]em.)	11.2	-5.5	807	B
SR 58 Wilson, NC	5%[illegible] 2[illegible]	[illegible]IA w/ MWRAS	10.1	-2.7	125	A
		WMA (chem.) w MWRAS	10.9	-2.0	619	C
		HMA w/ PCRAS	11.6	-3.2	215	A B
		WMA (chem.) w/ PCRAS	11.4	-2.9	333	B
SR 39 LaPorte, IN	2% MW 15%	HMA	9.8	-5.6	109	A
		WMA (foam)	10.1	-6.1	158	A

Paired t test: WMA > HMA p = 0.006

Location	RAS % RAP %	Mix Test Sections	%Vbe	ΔTc 20 hr PAV	ER >1.3
SR 96 Larsen, WI	3% PC 14%	HMA	11.4	-3.5	3.2
		Rediset	10.8	-3.8	3.7
		Zycotherm	11.6	-5.0	2.8
US 84 Enterprise AL	5% PC 15%	HMA, low Va	11.1	-7.7	1.7*
		WMA, low Va	[illegible]	-8.1	1.9
		HMA, adj. Va	[illegible]	-10.8	0.6*
		WMA, adj. Va	10.8	-8.6	2.0*
Union Valley Rd. Oak Ridge, TN	3% PC 10%	HMA	9.9	-11.7	4.5
		[illegible]	11.2	-5.5	3.1
SR 58 Wilson, NC	5% [illegible] 20%	[illegible] w/ MWRAS	10.1	-2.7	0.3*
		WMA (chem.) w MWRAS	10.9	-2.0	2.1
		HMA w/ PCRAS	11.6	-3.2	3.9
		WMA (chem.) w/ PCRAS	11.4	-2.9	2.4
SR 39 LaPorte, IN	2% MW 15%	HMA	9.8	-5.6	2.1
		WMA (foam)	10.1	-6.1	2.3

Paired t test: WMA & HMA **NSD**

Location	RAS % RAP %	Mix Test Sections	%Vbe	ΔTc 20 hr PAV	SCB-Jc >0.5
SR 96 Larsen, WI	3% PC 14%	HMA	11.4	-3.5	0.37
		Rediset	10.8	-3.8	0.41
		Zycotherm	11.6	-5.0	0.36
US 84 Enterprise AL	5% PC 15%	HMA, low Va	11.1	-7.7	0.41
		WMA, low Va	[illegible]	-8.1	0.68
		HMA, adj. Va	[illegible].3	-10.8	0.47
		WMA, adj. Va	10.8	-8.6	0.65
Union Valley Rd. Oak Ridge, TN	3% PC 10%	HMA	9.9	-11.7	0.64
		[illegible]em.)	11.2	-5.5	0.64
SR 58 Wilson, NC	5% [illegible] 20%	[illegible]MA w/ MWRAS	10.1	-2.7	0.32
		WMA (chem.) w MWRAS	10.9	-2.0	0.38
		HMA w/ PCRAS	11.6	-3.2	0.57
		WMA (chem.) w/ PCRAS	11.4	-2.9	0.40
SR 39 LaPorte, IN	2% MW 15%	HMA	9.8	-5.6	0.50
		WMA (foam)	10.1	-6.1	0.55

Paired t test: WMA & HMA **NSD**

Location	RAS % RAP %	Mix Test Sections	%Vbe	ΔTc 20 hr PAV	IFIT >8.0	T-K
SR 96 Larsen, WI	3% PC 14%	HMA	11.4	-3.5	3.3	A
		Rediset	10.8	-3.8	5.8	B
		Zycotherm	11.6	-5.0	2.9	A
US 84 Enterprise AL	5% PC 15%	HMA, low Va	11.1	-7.7	0.7	A B
		WMA, low Va	[illegible]	-8.1	2.9	C
		HMA, adj. Va	[illegible]	-10.8	0.2	B
		WMA, adj. Va	10.8	-8.6	1.0	A
Union Valley Rd. Oak Ridge, TN	3% PC 10%	HMA	9.9	-11.7	3.3	A
		[illegible]m.)	11.2	-5.5	4.9	B
SR 58 Wilson, NC	5% [illegible] 20%	[illegible]A w/ MWRAS	10.1	-2.7	1.8	A
		WMA (chem.) w MWRAS	10.9	-2.0	7.3	B
		HMA w/ PCRAS	11.6	-3.2	3.7	C
		WMA (chem.) w/ PCRAS	11.4	-2.9	4.7	C
SR 39 LaPorte, IN	2% MW 15%	HMA	9.3	-5.6	1.1	A
		WMA (foam)	9.7	-6.1	1.7	B

Paired t test: WMA & HMA **NSD**

Mix Design Verifications

Location	RAS % & Type	Opt. AC	Meet VMA?	Binder Ratios		ΔTc	
				RAP	RAS	20-hr PAV	40-hr PAV
WI	3% PC	+0.6	Y>>	0.15	0.13	-3.5	-6.5
AL - Low Va	5% PC	-0.1	N	0.14	0.19	-7.7	-10.6
AL – Adj. Va	5% PC	-0.5	Y	0.15	0.21	-10.8	-13.8
TN	3% PC	+0.3	Y>>	0.11	0.09	-11.7	-10.4
NC MRAS	5% MW	+0.2	Y	0.21	0.16	-2.7	-10.5
NC PRAS	5% PC	+0.4	Y	0.20	0.14	-3.2	-7.3
IN	2% MW	+0.3	Y	0.13	0.06	-5.6	-9.5

Production and Construction of RAS Mixtures

- Lower mix production temperatures associated with WMA did not cause plant issues or construction problems for any of the project sites evaluated in this study.
- Similar roller patterns resulted in statistically equivalent as-constructed densities for WMA mixes compared to the corresponding HMA.

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Short Term Field Performance

- All projects had less than 5 mm rutting after 2-3 years.
- No project had any evidence of moisture damage.
- Cracking is very minor at 1 to 2 years. Reflection cracking is the most common type of cracking.
- All test sections had similar surface texture depths.
- Density increased over time for most projects, however, the use of WMA did not appear to affect density changes compared to HMA.

Performance Tests

- WMA mixtures tend to have lower E* values than those of corresponding HMA mixtures in most cases.
- Fn and HWT results indicate WMA mixtures are more susceptible to rutting, but still met suggested criteria.
- Most WMA mixtures were slightly more resistant to cracking based on OT, IFIT, and Jc.

Performance Tests

- IDT creep compliance & strength test results indicate WMA and HMA mixtures had similar thermal cracking critical temperatures.
- E* parameters generally agree with results obtained from laboratory performance tests and may provide an additional tool to evaluate cracking susceptibility.

Mix Design Verification

- Slight differences in the optimum asphalt content were found for all mixtures. Most of the verified mixtures had higher asphalt contents.
- RAS G_{sb} results were within between lab reproducibility.
- All verified mixes failed the new ΔTc requirement. This criterion is very restrictive and may eliminate RAS.

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In General

- Using WMA with mixtures containing RAS does not appear to have a detrimental effect.
- Some cracking tests indicate WMA mixtures were better than corresponding HMA mix.
- Early performance of all projects is good which makes it challenging to validate performance test criteria.
- Longer term monitoring (5 years) of field sections is recommended.

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Projects Worth Monitoring

- Dallas, TX, I-30, SMA with RAS and Advera (July, 2011)
- Muscatine, IA, Hwy. 61, RAP, RAS & Evotherm (Oct. 2010)
- SR 19, Nappanee, IN, 3% RAS HMA, 3%RAS WMA, 15% RAP over concrete (Aug. 2009)
- SR 10, Pauline, IA, 0, 4, 5, & 6% RAS over concrete (Jun.-Jul. 2010)
- King County, WA, SE 416th Street (Sept. 2009)
- MnROAD, RAS transitions & shoulders

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Projects Worth Monitoring

- Austin, TX, FM 973, SMA with RAP, RAS, with & w/o WMA, sections 3 & 9 (Dec. 2011)
- Ft. Worth, TX, US 287, Dense-graded with RAP, RAS, with & w/o WMA (Cecabase)
- Larson, WI
- Wilson, NC
- LaPorte, IN

Other NCAT Projects Involving RAS

- 2012 experiment dealing a RAS mix prepared at mixing temperatures from 225 to 350°F.
  - *unable to distinguish aging effect from RAS activation effect*
- 2012 experiment on Test Track for FDOT
  - *Willis et. al. TRR No. 2590, pp. 65-73, 2016.*
- 2015 Cracking Group Experiment on Test Track
- 2015 Rejuvenator RAP & RAS mix test section

FHWA Accelerated Loading Facility

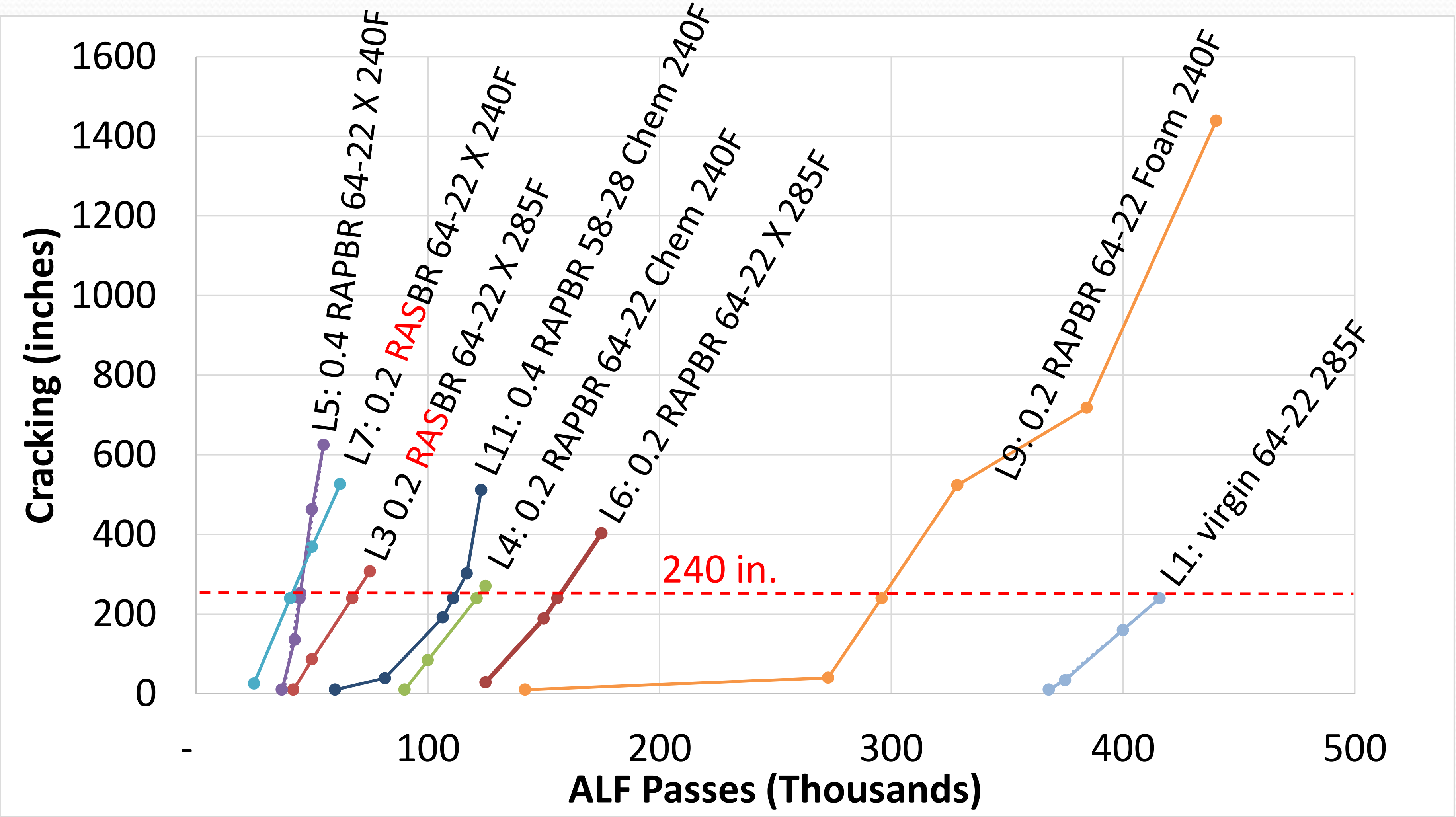
- Controlled 20°C @ 20-mm
- 425 Super Single Tire
- 100 psi inflation
- 14,200 lb. load
- Loading only one direction
- Lateral Wander
- Two approx. 2-in. asphalt lifts
- approx. 22-in. thick agg. base

Mixes in FHWA 2013 ALF Experiment

Lane	WMA Type	RAP Binder Ratio	RAS Binder Ratio	Virgin Binder PG	Prod. Temp. (F)
1	n/a	0	0	64-22	285
2	foam	0.4	0	58-28	240
3	n/a	0	0.2	64-22	285
4	chem.	0.2	0	64-22	240
5	n/a	0.4	0	64-22	285
6	n/a	0.2	0	64-22	285
7	n/a	0	0.2	64-22	240
8	n/a	0.4	0	58-28	285
9	foam	0.2	0	64-22	240
11	chem.	0.4	0	58-28	240

Lanes were tested one at a time beginning in Fall 2013 and completed in Fall 2015. Lanes 2 and 8 were not included in this paper.

ALF Cracking Performance Measured…



Issues with Loading of Lane 2 and 8

4. Adjusting ALF Passes to 240-in. of Cracking

Lane	Obs. ALF Passes to 240-in. of Cracking	*Nf* *from step 3*	Ratio of Lane 1 to Lane n	Adjusted ALF Passes to 240-in. of Cracking
1	416,000	4.32E5	1.00	416,000
3	67,000	5.33E5	0.81	54,307
4	121,000	2.64E5	1.64	198,080
5	45,000	1.20E5	3.61	162,551
6	156,000	5.96E5	0.73	113,110
7	41,000	2.36E5	1.83	75,143
9	296,000	2.10E5	2.06	609,361
11	111,000	1.01E5	4.25	472,289

Recommendations

- Move toward BMD ASAP.
  - Biggest gaps are
  1. selection of aging protocol
  2. selection of cracking test(s)
  3. identifying appropriate cracking test criteria for mix design and QA.

Other thoughts

- Time and temperature effects on interaction of binder components (virgin, RAP, RAS, rejuvenators) is significant. it seem unlikely that a single lab protocol will simulates all mix production situations.
- WMA didn't significantly affect volumetric mix; but it will affect BMD
- Japan may have it right on the best way to produce high RAP content mixes.

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