NCHRP 9-49A Project
Performance of WMA Technologies: Stage II Long-term Field Performance

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Asphalt Mixture ETG Meeting

Fall Rivers, MA

April 8, 2015

Project Information

- Project Duration: 05/2011-05/2016
- Project Team:
  - Haifang Wen, PI
  - Shihui Shen, Co-PI (PSU-Altoona)
  - Louay Mohammad, Co-PI (LTRC)
  - Bloom Companies – Field Distress Survey
  - Braun Intertec – Field Cores, FWD

Outline

- Background & Objectives
- Projects Overview & Tests
- Field Performance & Significant Determinants
  - Transverse cracking
  - Top-down longitudinal cracking
  - Rutting
- Summary and Future Work

Background

- **WMA categories:**
  - Wax additives: e.g. Sasobit
  - Chemical additives: e.g. Evotherm
  - Foaming: Water-based (Astec DBG, Ultrafoam)
    Water containing (Aspha-min, Advera, Rediset)
- **How about the long-term field performance?**
  - Potential issues (rutting, moisture susceptibility, etc)
  - Lack of sufficient data
- **Significant material and engineering property (determinants) to characterize WMA long-term performance?**

Research Objectives

- To identify the material and engineering properties of WMA pavements that are *significant determinants* of their long-term field performance, and

- To recommend *best practices* for the use of WMA technologies.

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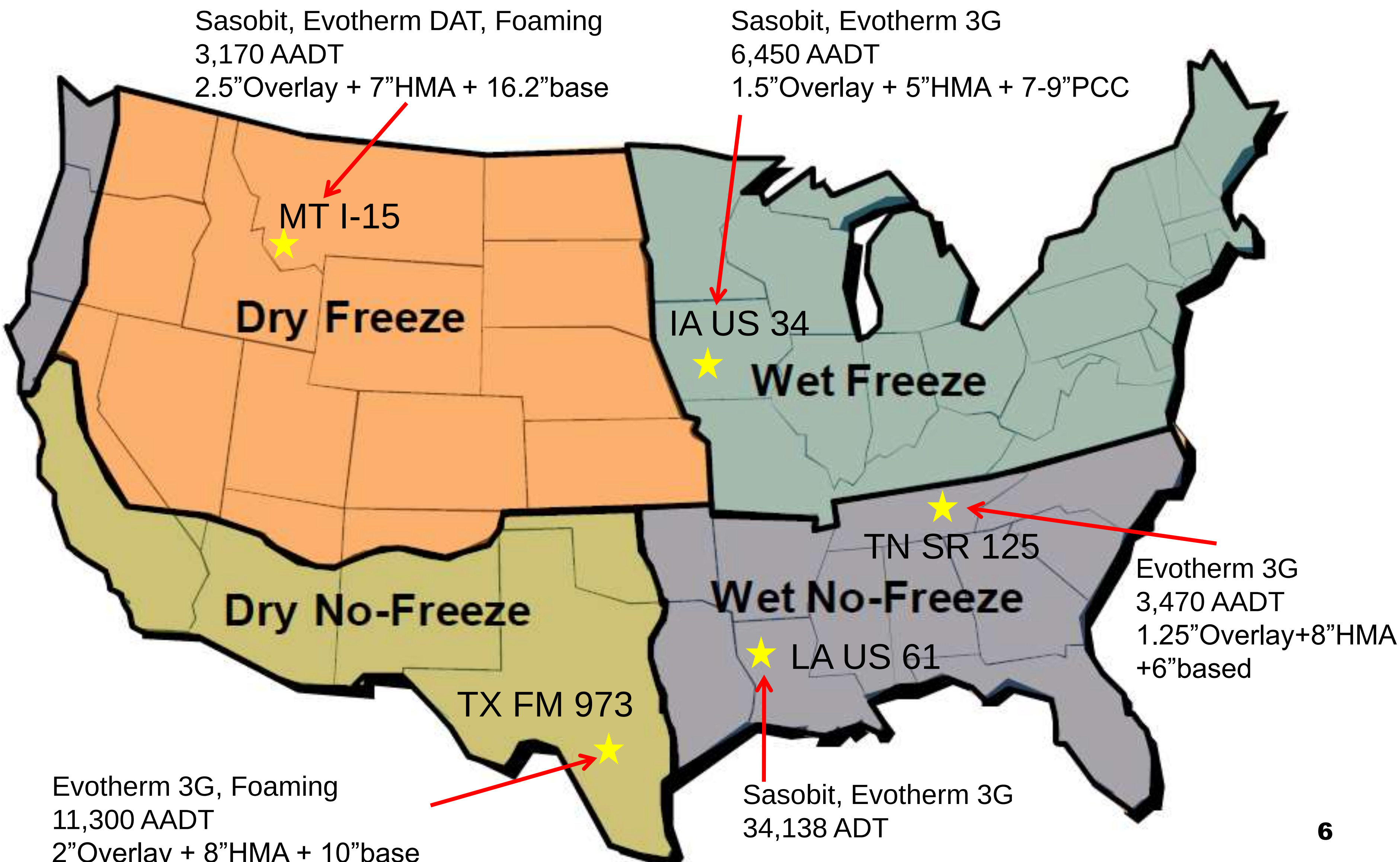
New Pavement Project (2011/2012)

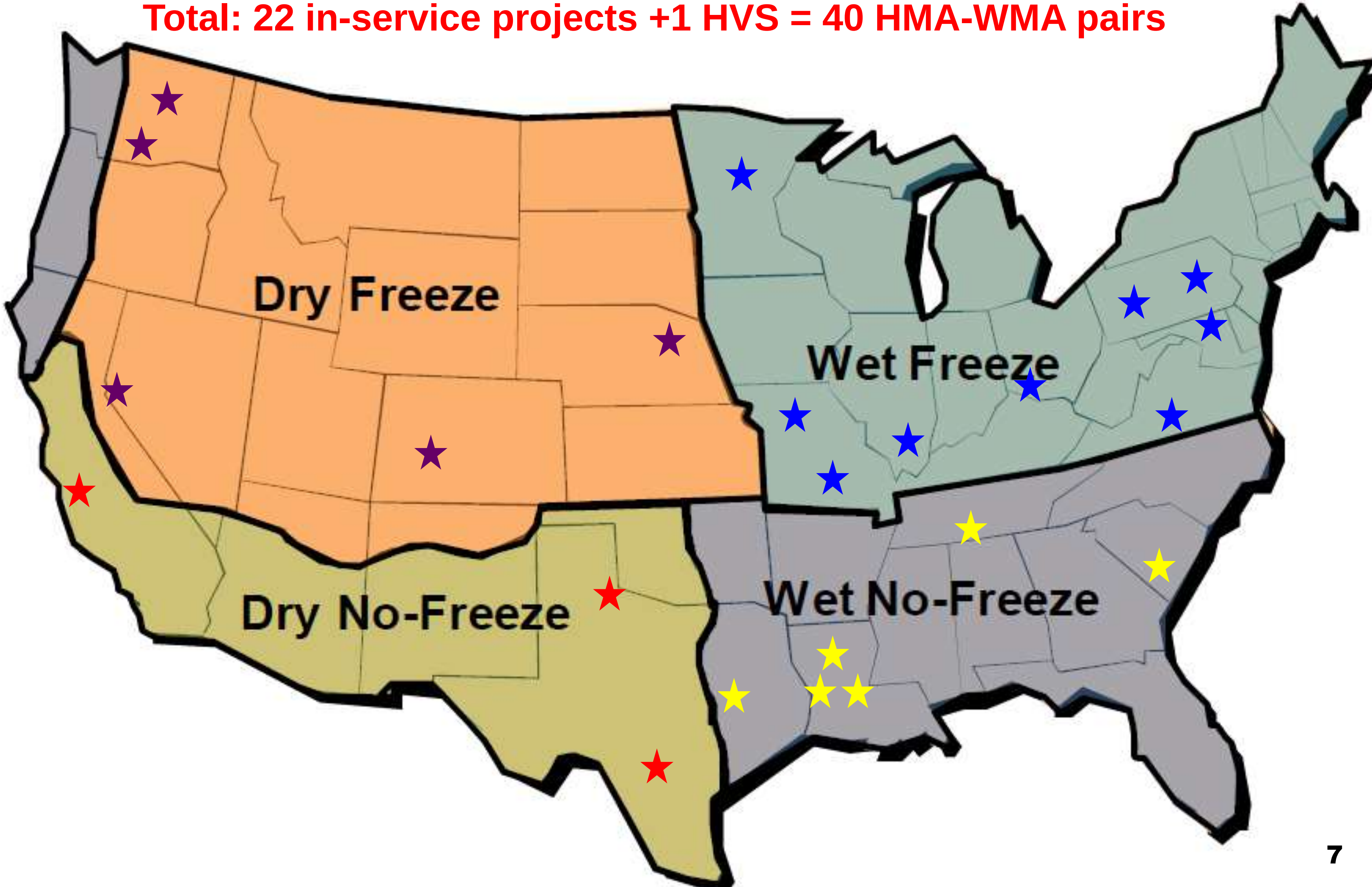
5 Projects = 10 HMA-WMA pairs



In-service Pavement Project

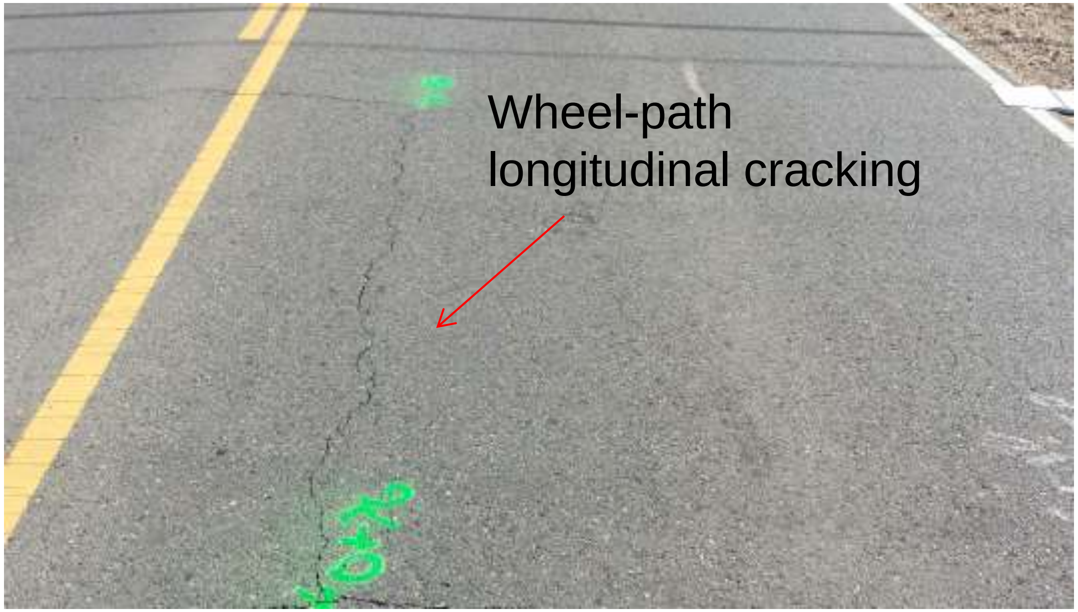
Different Ages, structures, traffic, material types, RAP content

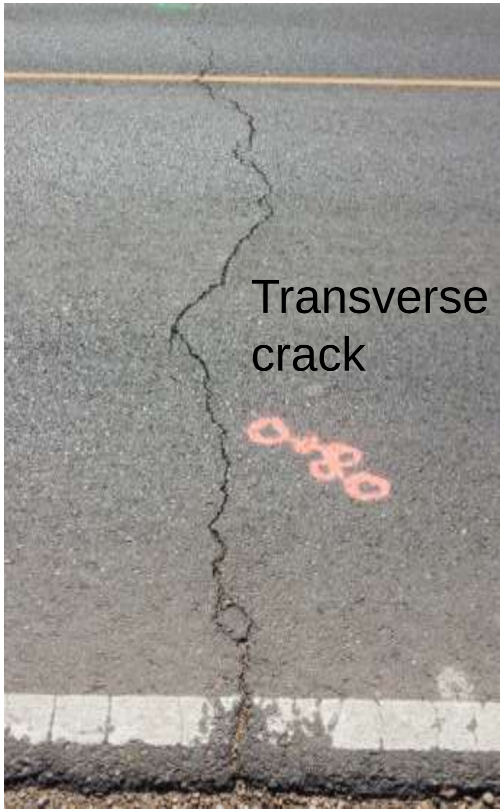
Total: 22 in-service projects +1 HVS = 40 HMA-WMA pairs



Field Distress Survey

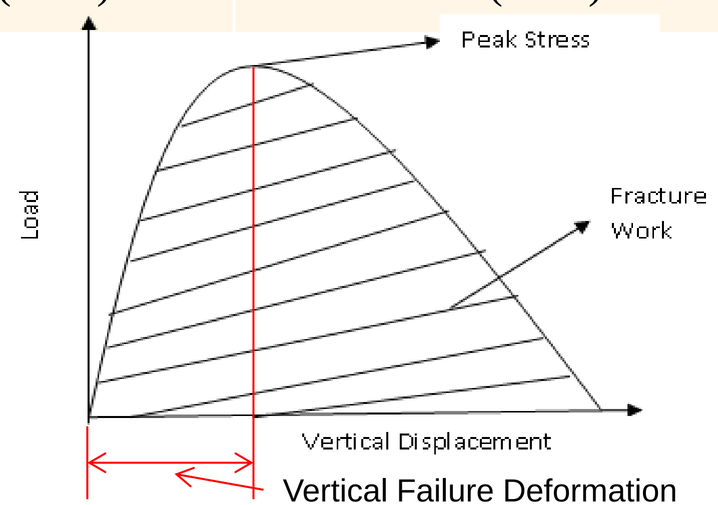
- 1st round (2012), 2nd round (2014/2015)
- LTPP distress identification manual: cracks, rut depth
- Cores taken at the tip of crack
- Three 200-feet segments





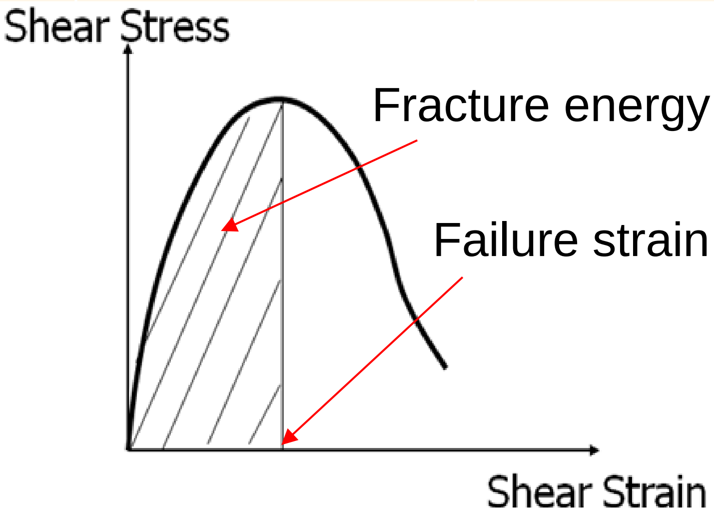
Field Cores Test Summary

Mixture Test	IDT Dynamic Modulus/Creep Compliance	Fatigue- IDT Fracture at Room Temp	Thermal Cracking-IDT Fracture at Low Temp	Rutting/Moisture- Hamburg
Testing Conditions	Temp.: −4, 14, 32, 50, 68, 86°F; Frequency: 20, 10, 5, 1, 0.1, 0.01 Hz Duration: 100s	Temp.: 68°F Loading rate: 2 in./min	Temp.: 14°F Loading rate: 0.1 in./min	Temp.: 122°F Wet condition
Material Properties	Dynamic modulus; Creep compliance	IDT strength; Fracture work density; Vertical failure deformation; Horizontal failure strain	IDT strength; Fracture work density; Vertical failure deformation; Horizontal failure strain	Rut depth; Stripping inflection point (SIP)
References	Wen & Kim (2002) AASHTO T322	Wen (2012)	Wen (2012)	AASHTO T324



Binder Test Summary

Binder Test	PGs	Rutting: MSCR	Fatigue: Monotonic at Room Temp	Thermal Cracking: Monotonic at Low Temp
Testing Conditions	Different temp depending on the test (DSR, BBR)	Load: 0.1, 3.2kPa Temp.: high pavement temp 98% reliability	Temp.: 68°F Shear strain rate: 0.3 s^{-1}	Temp.: 41°F Shear strain rate: 0.01s^{-1}
Material Properties	PG; BBR stiffness; m-value	$Jnr_{0.1}$, $Jnr_{3.2}$; $R_{0.1}$, $R_{3.2}$	Maximum stress; Fracture energy; Failure strain	Maximum stress; Fracture energy; Failure strain
References	AASHTO MP1/T240/T313	AASHTO T350	Wen et al. (2010)	Wen (2010)



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Transverse Crack Length Comparison

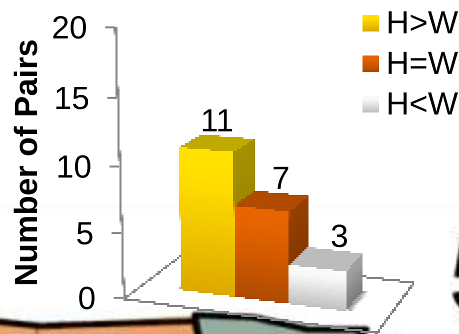
- Weighted or Unweighted? (consider crack severity)
  - Use weighted factor (Wu et al. 2010 FHWA report)

$$TotalCrack = 1.0 \times Crack_{low} + 3.4 \times Crack_{medium} + 7.7 \times Crack_{high}$$

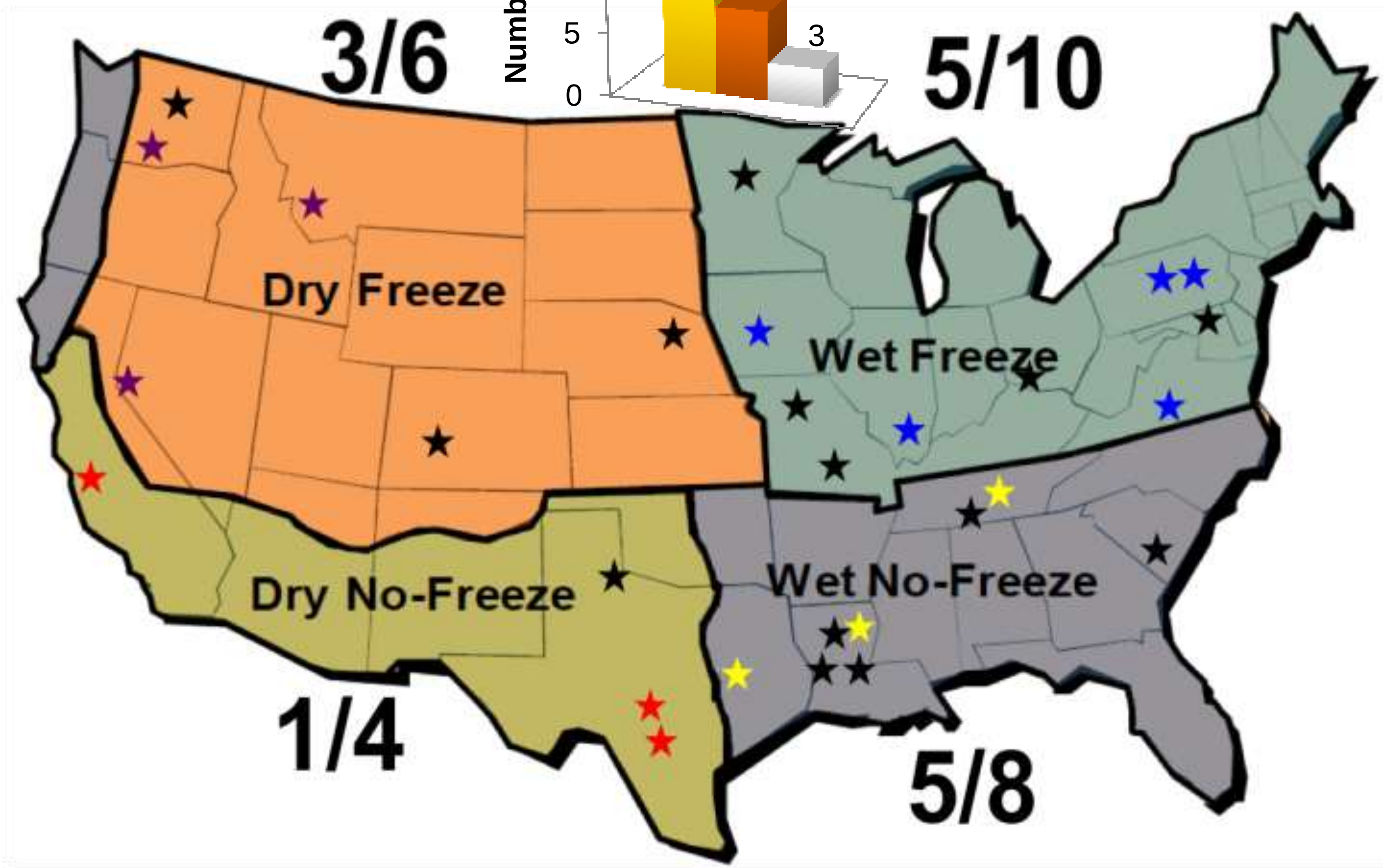
High (>5")

HMA/WMA Transverse Cracking Comparison (1st Survey)

14 out of 24 projects exhibited transverse cracking (21 H-W pairs)

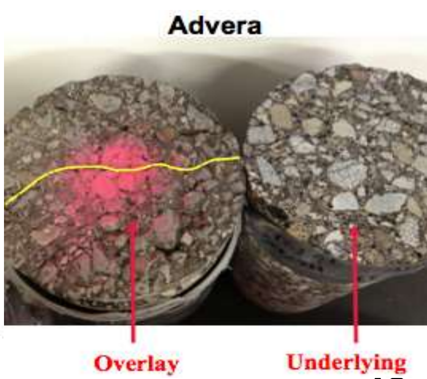


WMA better or comparable in transverse cracking performance



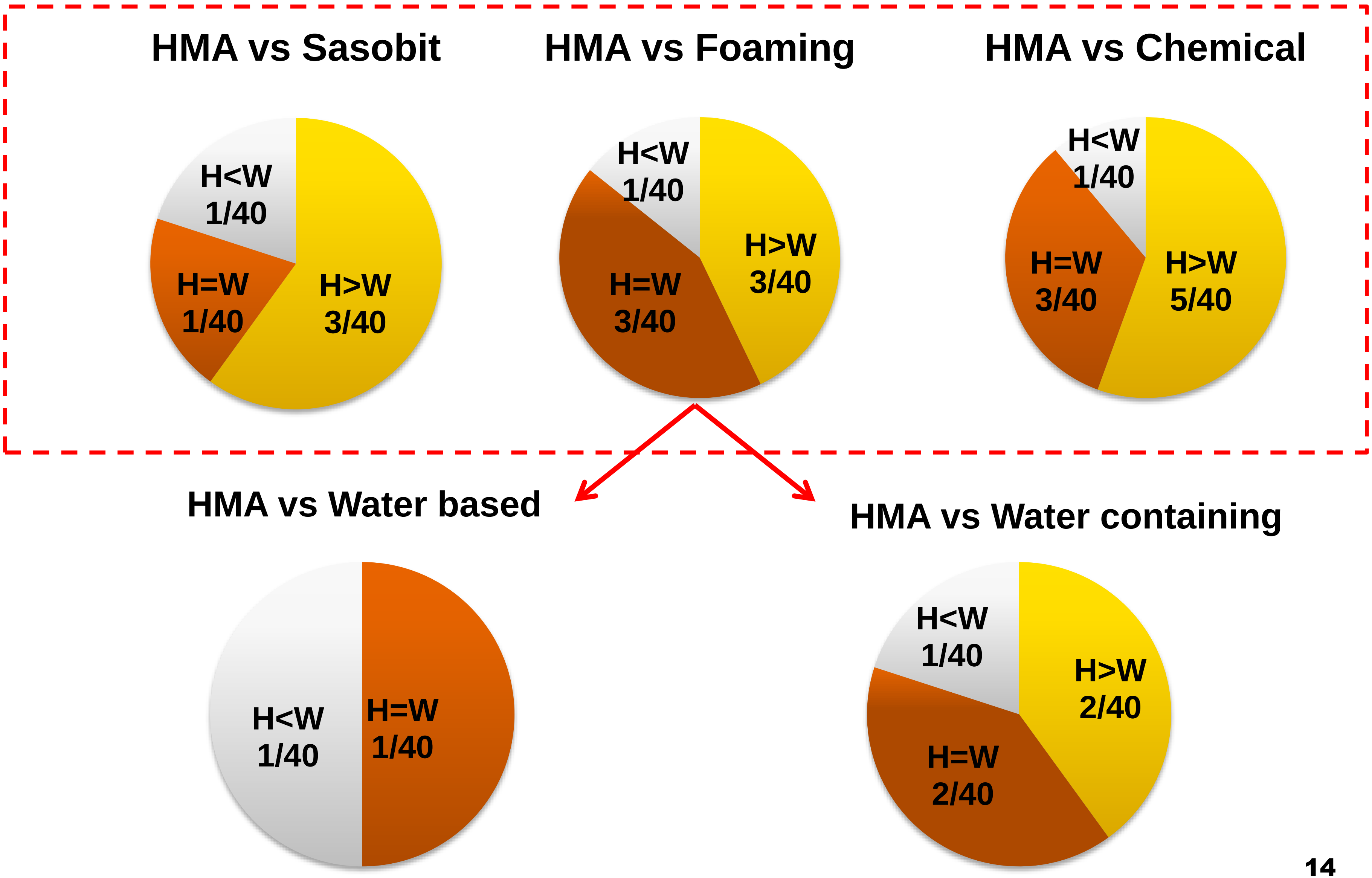
Reflective

Surface-initiated

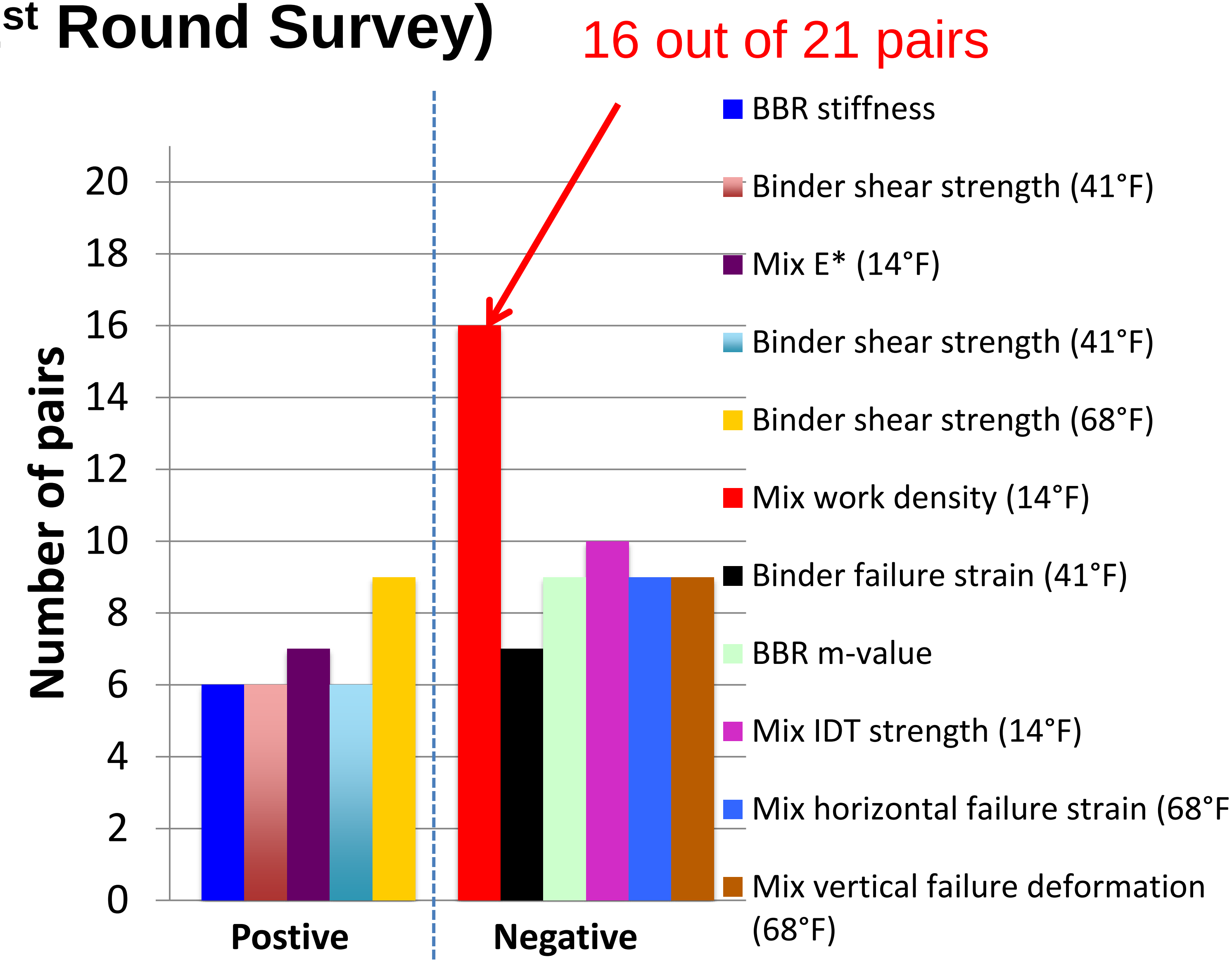


Note: H>W: HMA has more cracking than WMA

Transverse Cracking Comparison in terms of WMA Technology



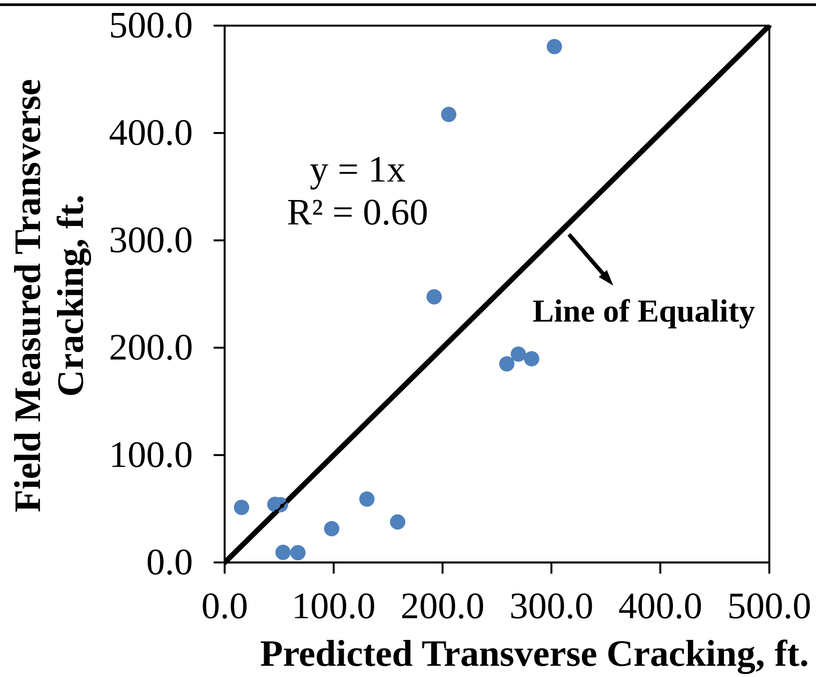
Significant Determinants for Transverse Cracking (1st Round Survey)



Transverse Cracking Regression Model

$TC = 540.64 - 1846.17FWD + 0.019T_{low} - 185.00D_{OL} + 0.29D_{HMA}$

TC	Transverse cracking length, ft/200ft segments
FWD	Mixture fracture work density tested at 14ºF, MPa
T_{low}	8-year low temperature hour, (the total hours of low temperature below 15ºF, direct output from Pavement ME based on the location of the site)
D_{OL}	Overlay thickness, in.
D_{HMA}	Total HMA thickness, in.

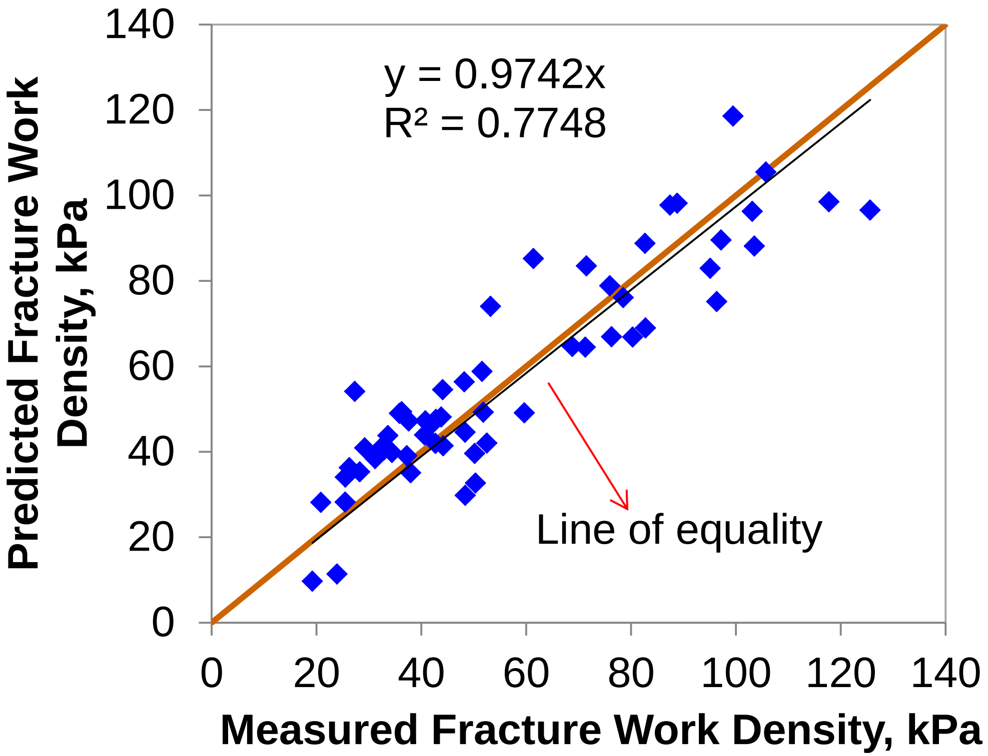


Implementation of the Use of Significant Determinants in Mix Design

FWD = -291.38+0.387VFA+66.74G_{se}+8.08ε_b+15.76P_b+2.97P_{50}

Parameter	**Description**	**P-value**
FWD	mixture fracture work density 14ºF, kPa	
VFA	Voids filled with asphalt	0.006
G_{se}	aggregate effective specific gravity	0.006
ε_b	binder failure strain tested at 41ºF	0.000
P_b	asphalt content, %	0.000
P_{50}	percentage passing No. 50 sieve size	0.000

Measured Vs Predicted Fracture Work Density



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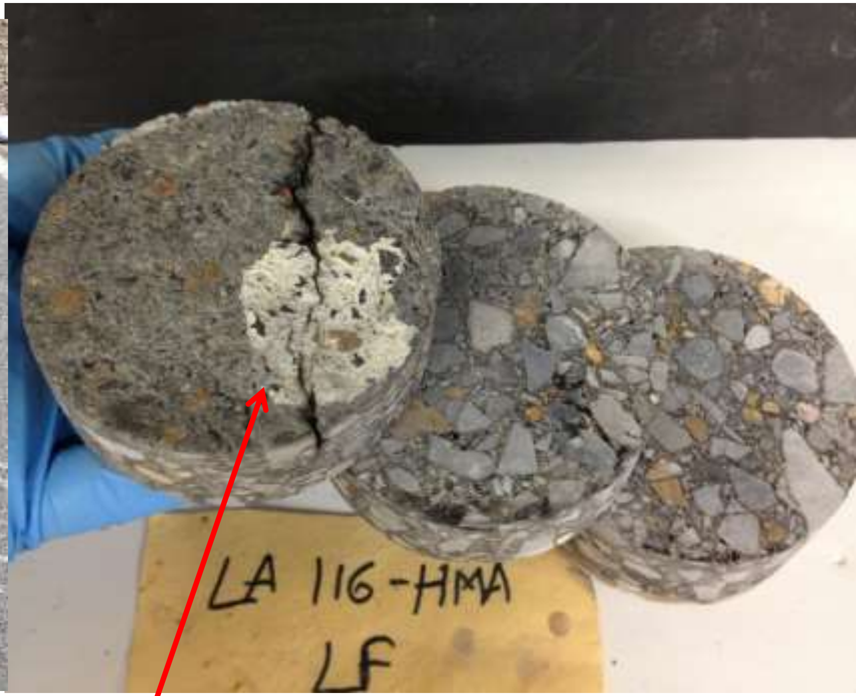
Top-down Longitudinal Cracking (Wheel-path)

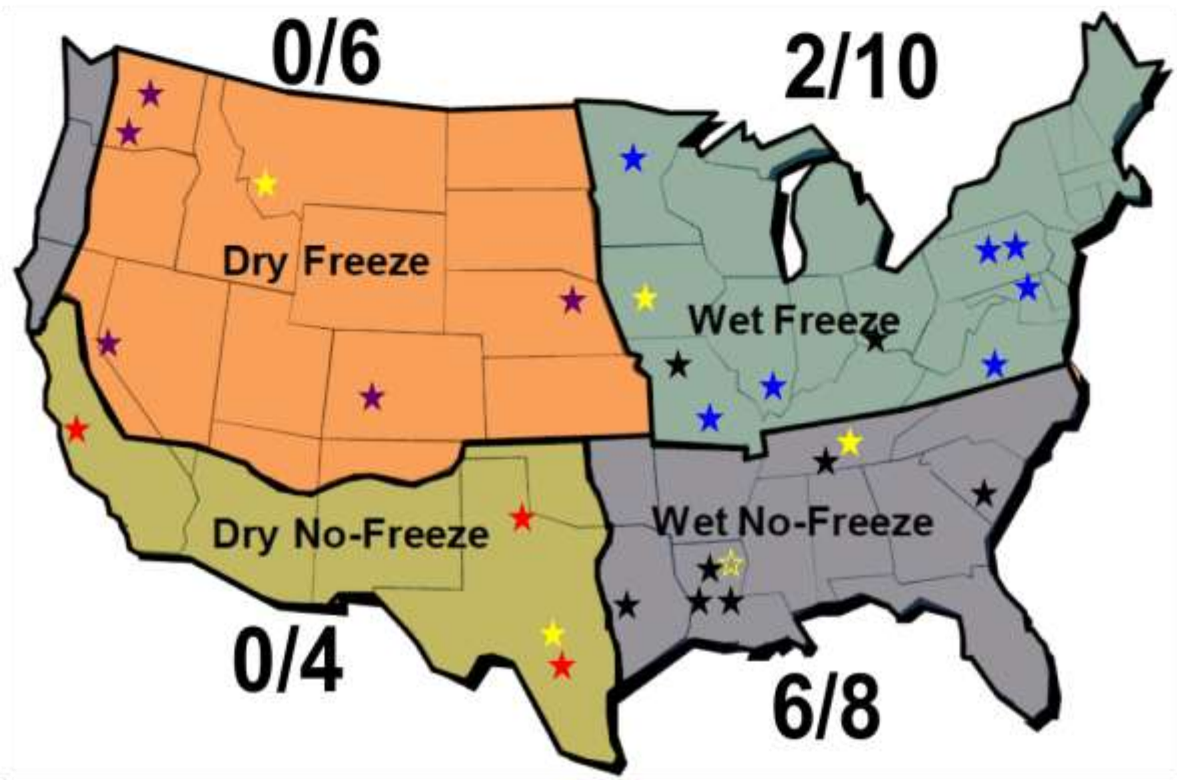


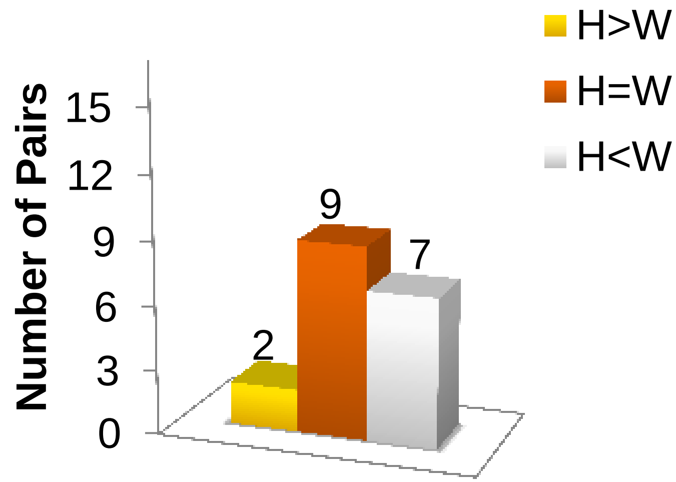
Surface-initiated

HMA/WMA Top-down Cracking Comparison (1st Round)

8 out of 24 projects exhibited top-down longitudinal cracking (18 H-W pairs).

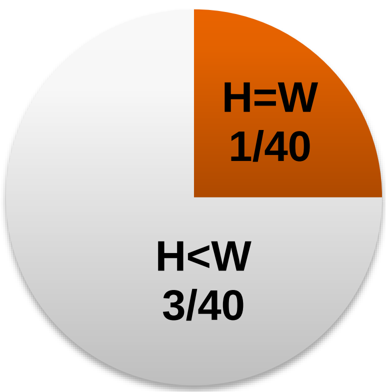
HMA better or comparable in top-down fatigue cracking performance



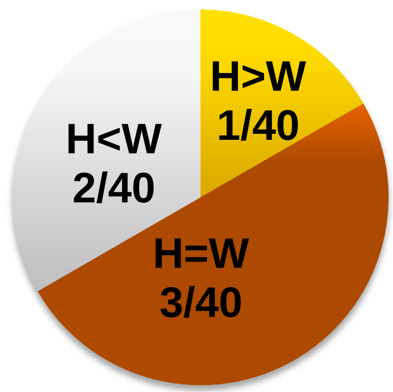


Top-down Longitudinal Cracking Comparison in terms of WMA Technologies (1st Round)

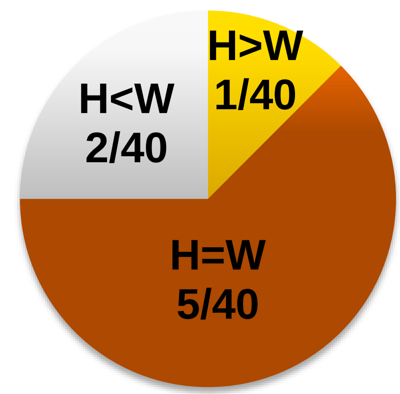
HMA vs. Sasobit



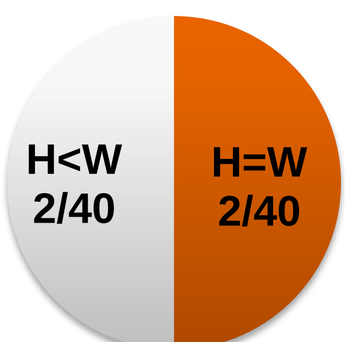
HMA vs. Foaming



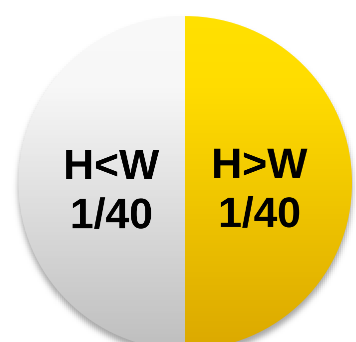
HMA vs. Chemical



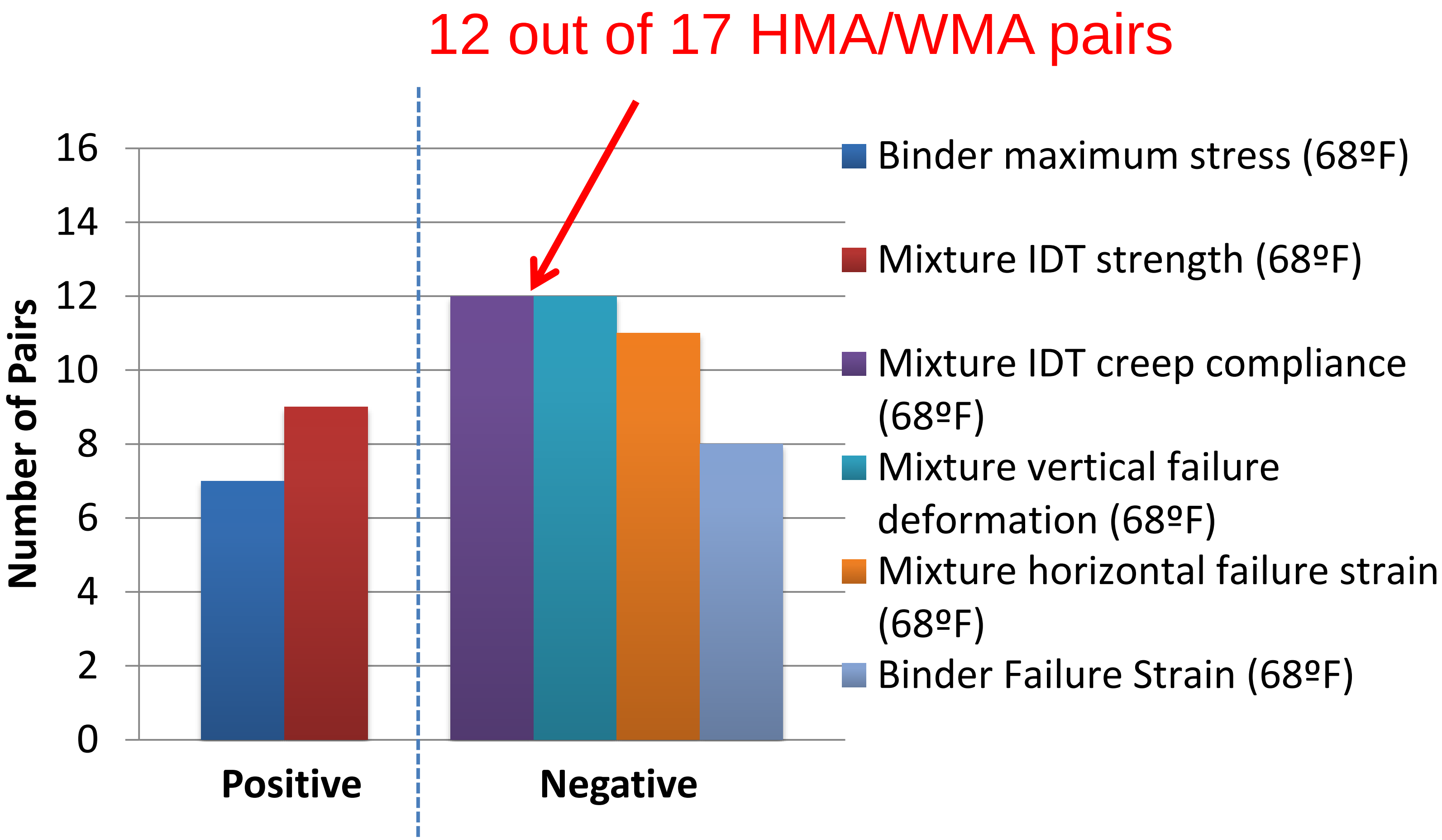
HMA vs. Water based



HMA vs. Water containing



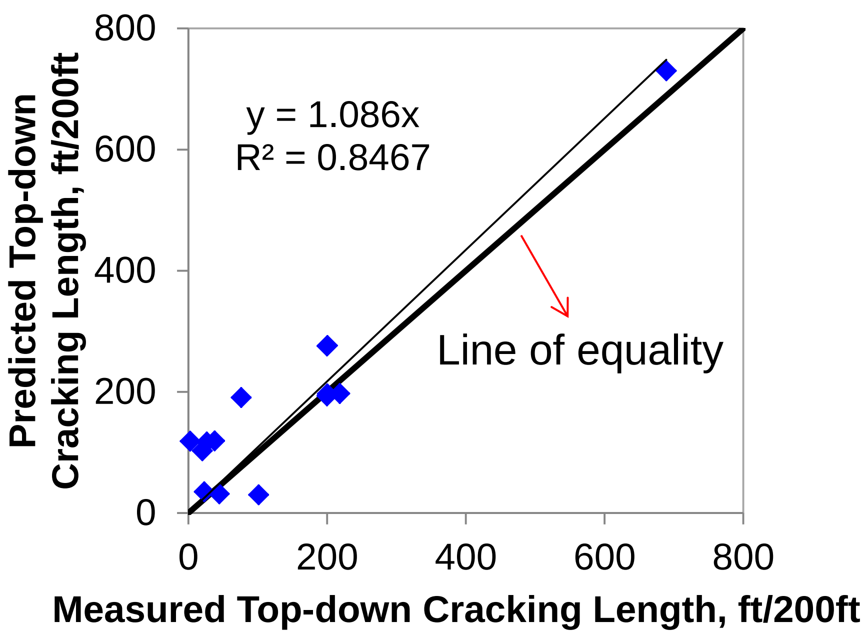
Significant Determinants for Top-down Longitudinal Cracking (1st Round)



Top-down Cracking Regression Model

LC = -1514.14 + 129.86Age - 16.55VFD + 107.84 DOL + 0.012AADT + 0.075UV

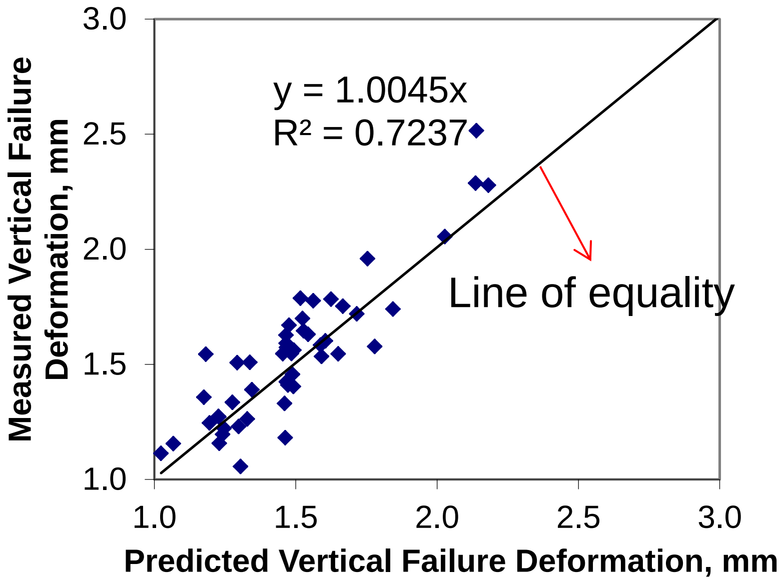
LC	top-down longitudinal crack length, ft/200-ft segment
Age	Service years
VFD	vertical failure deformation of mix tested at 68ºF, mm
D_{OL}	Overlay thickness, in.
AADT	Average annual daily traffic
UV	cumulative UV index during the service period, obtained from the National Oceanic and Atmospheric Administration (NOAA).



Implementation of the Use of Significant Determinants in Mix Design

$$VFD = 1.65 - 0.034PG_{inter} + 0.01VFA + 0.009P_{16}$$

Parameter	Description	P-value
VFD	Mixture vertical failure deformation 68ºF, mm	
PG_{inter}	Binder intermediate temperature PG	0.000
VFA	Void filled with asphalt	0.013
P_{16}	Percentage passing No. 16 sieve size	0.027



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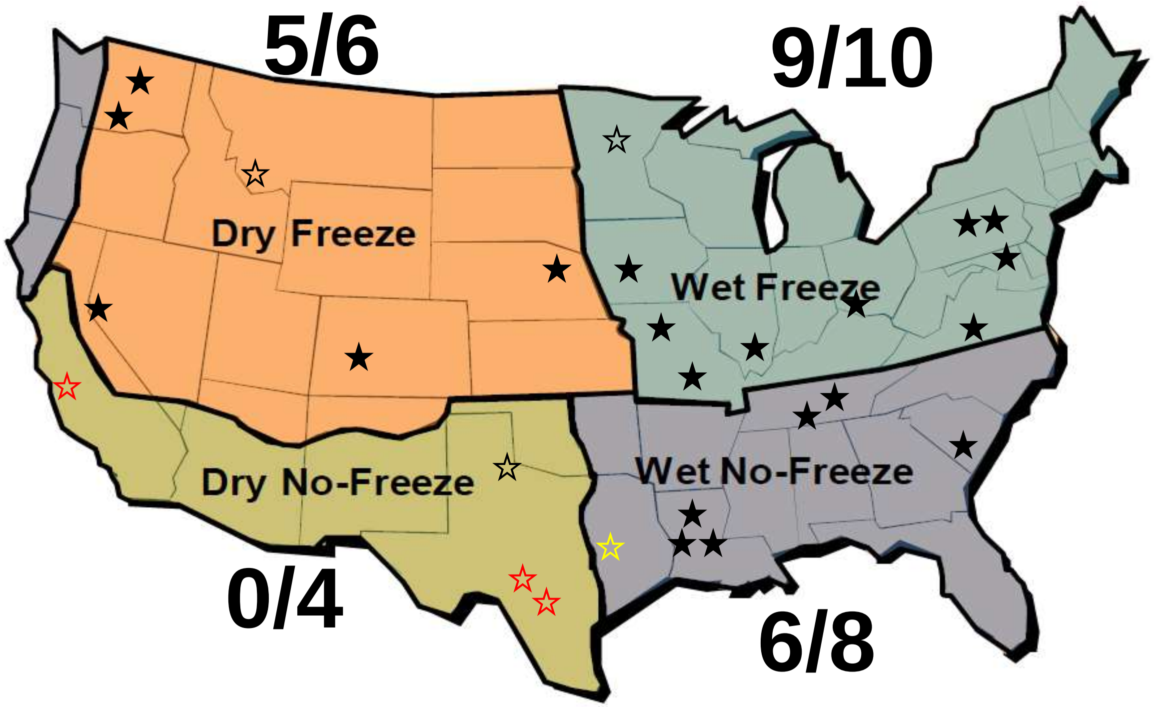
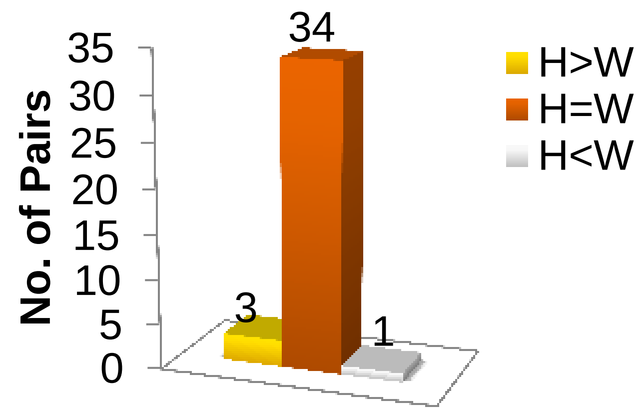
HMA/WMA Rut Depth Comparison (2nd Round)

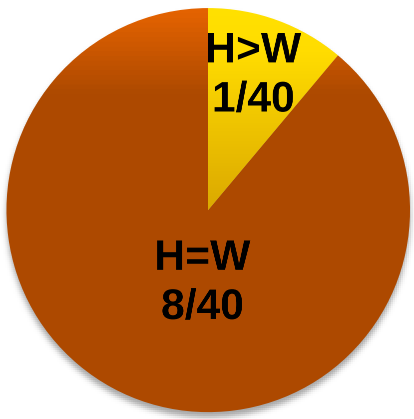
- Use 1/16” to compare averaged rut depth of HMA and WMA pavements



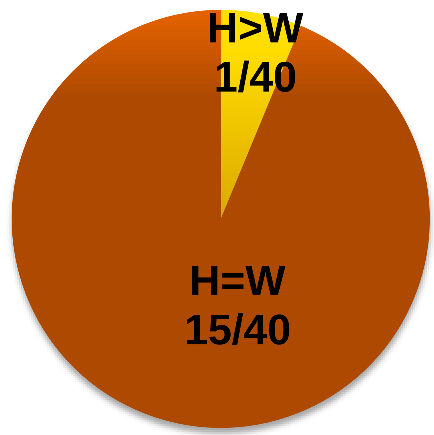


Rut Depth Comparison in terms of WMA Technologies (2nd Round)

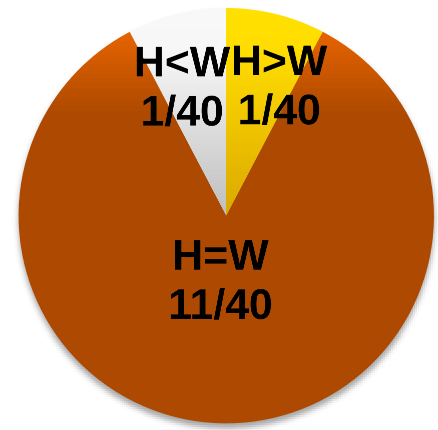
HMA vs. Sasobit



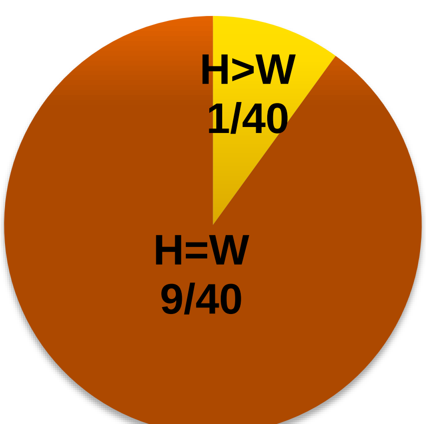
HMA vs. Foaming



HMA vs. Chemical



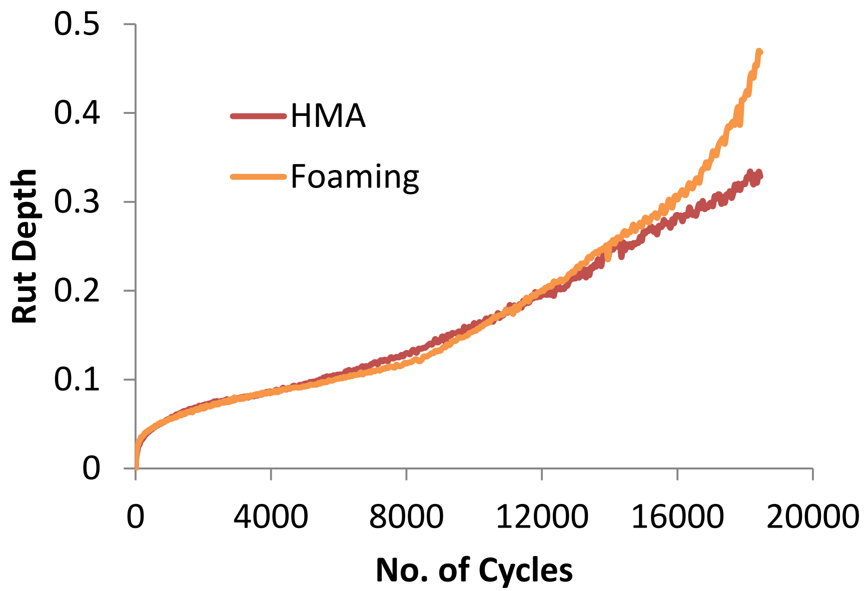
HMA vs. Water-based



HMA vs. Water containing

Rutting Resistance Index (RRI)

RRI = No. of Cycles $\times$ (1- Rut Depth)



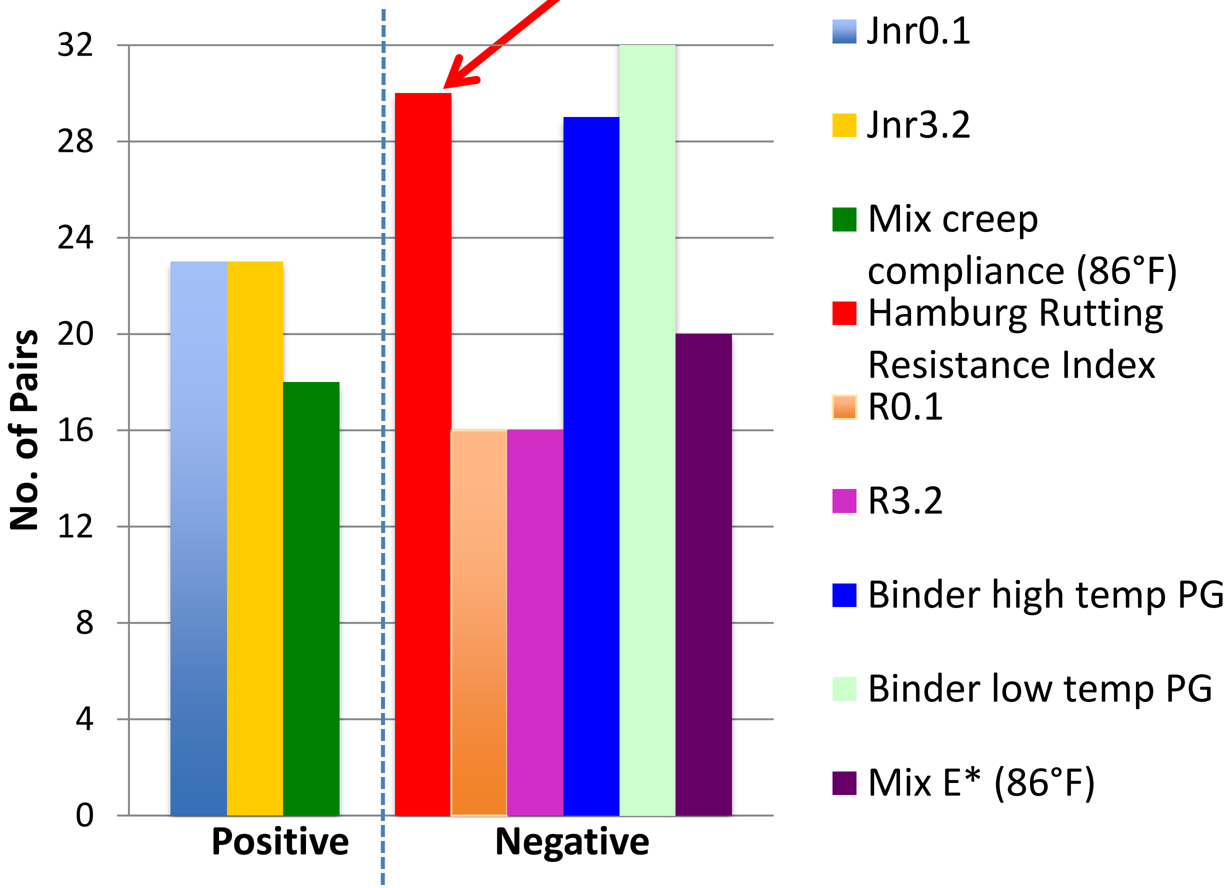
(1) Good rutting performance: 0.1 in. @ 20,000 cycles, RRI=18,000

(1) Average rutting performance: 0.5 in. @ 20,000 cycles, RRI=10,000

(1) Poor rutting performance: 0.5 in. @10,000 cycles, RRI=5,000

Significant Determinants for Rutting Performance (2nd Round)

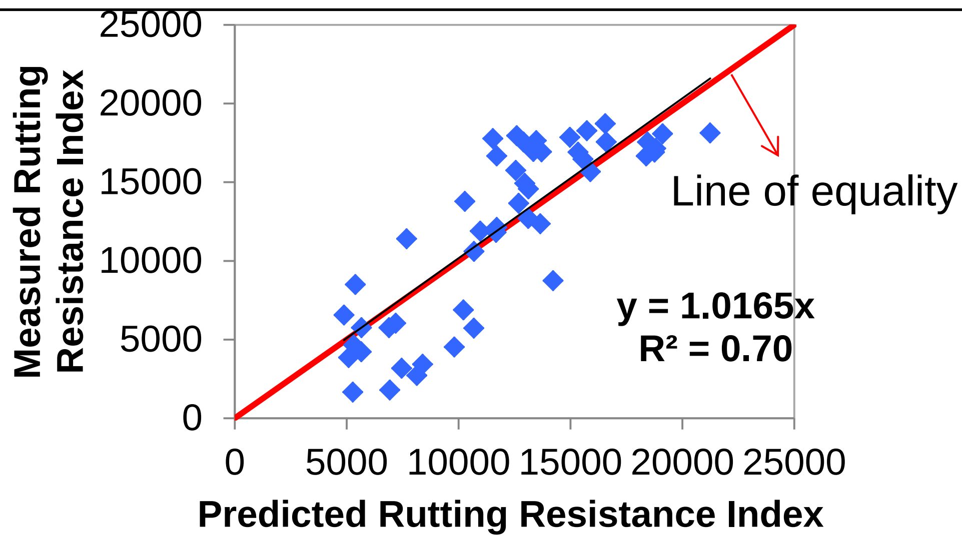
30 out of 32 HMA/WMA pairs



Implementation of the Use of Significant Determinants in Mix Design

$$RRI = 3700.555 + 2187.602P_{100} + 122.027R_{3.2} - 323.71P_{16} - 73.374VFA + 2054.665P_{ba}$$

Parameter	**Description**	**P-value**
RRI	Rutting resistance index	
P_{100}	Percentage passing No. 100 sieve	0.000
$R_{3.2}$	Binder percent recovery of binder @3.2 kPa	0.000
P_{16}	Percentage passing No. 16 sieve size	0.000
VFA	voids filled with asphalt	0.003
P_{ba}	asphalt binder absorption	0.013



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Conclusions:
Transverse Cracking

- Transverse crack may result from a combination of thermal cracking and reflective cracking.
- WMA shows better or comparable transverse cracking performance than HMA.
- Mixture work density (14ºF) is found to be a significant determinant of transverse cracking in overlay.
- For implementation, if a mix has a ductile binder, relatively more asphalt, contain more aggregate passing No.50 sieve, and hard aggregate, the mix is more crack resistance.

Conclusions: Top-down cracking

- Most of the cracks in the wheel path are surface-initiated, indicating that these cracks are top-down fatigue cracking.
- HMA shows better or comparable top-down cracking performance than WMA.
- The mixture vertical deformation obtained from IDT tests (68ºF) are found to be the significant determinants of top-down fatigue cracking.
- For implementation, if a mix has relatively lower intermediate PG, higher VFA, and more % passing No.16 sieve, the mix has better top-down cracking resistance.

Conclusions:
Rutting

- HMA and WMA show comparable rutting performance.
- Mixture rutting resistance index is a good indicator for rutting performance.
- If a mix has a rutting-resistant binder (higher $R_{3.2}$), relatively lower VFA (dry mix), less aggregate passing No.16 and more passing No.100 (like SMA), a relatively higher binder absorption rate, the mix is more rutting resistance.

Future Work

- Data analysis on the 2nd round field distress survey results
- Testing on new-pavement project (2nd round sampling)
- Validation of previous findings

Acknowledgements

- NCHRP (09-49A) for Sponsoring the Study
- Team Members
  - Haifang Wen - Washington State University (Prime)
  - Louay Mohammad - Louisiana State University
  - Shihui Shen - Penn State University at Altoona
  - Braun Intertech
  - Bloom Companies
- State Highway Agencies

Thank You!

Any questions?

- How to compare based on what criteria?
  - High variation of crack in three segments
  - t-test may overshadows the difference
  - Dual criterion

(1) Absolute difference: 18.9ft/ 200ft
(2) Difference ratio: 15%

For example:
HMA: 114.7 ft/200ft
WMA: 71.7 ft/200ft

(1) Absolute difference = 114.7-71.7=43 > 18.9
(2) Difference ratio = (114.7-71.7)/93.2*100=46.2% > 15%

Crack length: HMA > WMA

Significant Determinants of Transverse Cracking

Compare Material Properties

- H>W, H=W, H<W
- Effect size (d = 1.6)

Compare Field Performance

- H>W, H=W, H<W
- 15% and 18.9ft/200ft Transverse
- 15% and 10ft/200ft Top-down

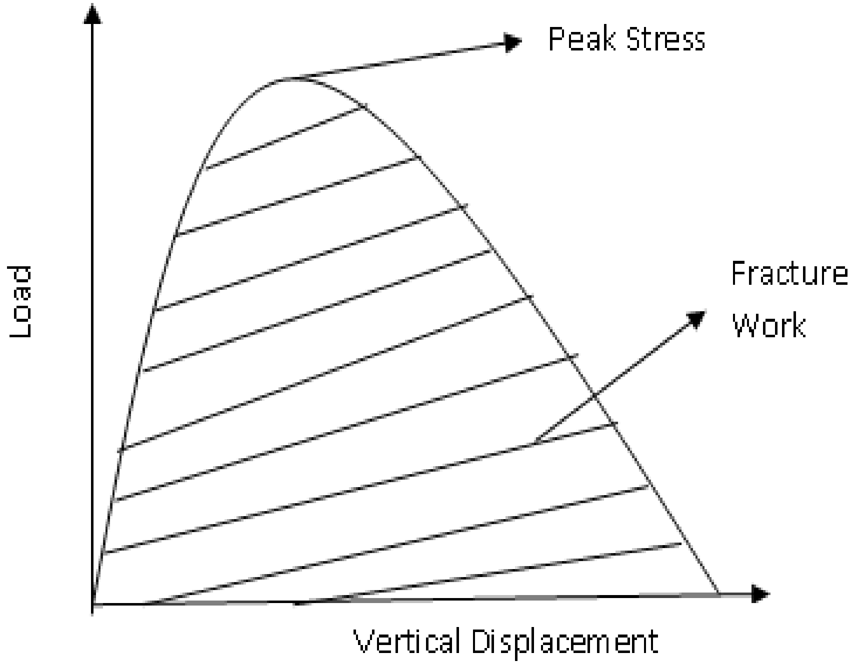
Compare the two rankings

- Consistent trend
- No consistent trend

- Summarize the number of pairs with consistent trend and determine the promising indicator;
- Evaluate other possible influencing factors

Fracture Work Density

$$Fracture\ Work\ Density = \frac{Fracture\ Work}{Volume\ of\ \ Specimen}$$



The higher fracture work density, the better transverse cracking resistance.

Significant Material Properties Determination Procedure

Compare Material Properties

- H>W, H=W, H<W
- Effect size (d = 1.6)

Compare Field Performance

- H>W, H=W, H<W
- 15% and 18.9ft/200ft Transverse
- 15% and 10ft/200ft Top-down

Compare the two rankings

- Consistent trend
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- Summarize the number of pairs with consistent trend and determine the promising indicator;
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