NCHRP 9-49A Project

Long-Term Field Performance of Warm Mix Asphalt Technologies

NCHRP Report 843

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Presented to the Asphalt Mixture ETG
Ames, IA

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Acknowledgements

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- State DOTs and local agencies
- Past NCHRP WMA project teams, universities, graduate students, ……

Outline

- Introduction & Objectives
- Project Scope and Research Approach
- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture Susceptibility
- Findings

Introduction

- Rapid growth in the use of WMA

- Limited research on long-term performance of WMA
  - How WMA compares with HMA in terms of specific performance
  - What are the critical material properties that could have significant impact on the long-term performance of WMA

- Better understanding of WMA technologies for full implementation

Long-term Performance

Research Objectives

- Investigate the long-term field performance of WMA as compared to its control HMA:
  - Transverse cracking
  - Wheel-path longitudinal cracking
  - Rutting and moisture damage

- Identify the material and engineering properties of WMA pavements that are significant determinants of their long-term field performance

- Recommend best practices for the use of WMA technologies.

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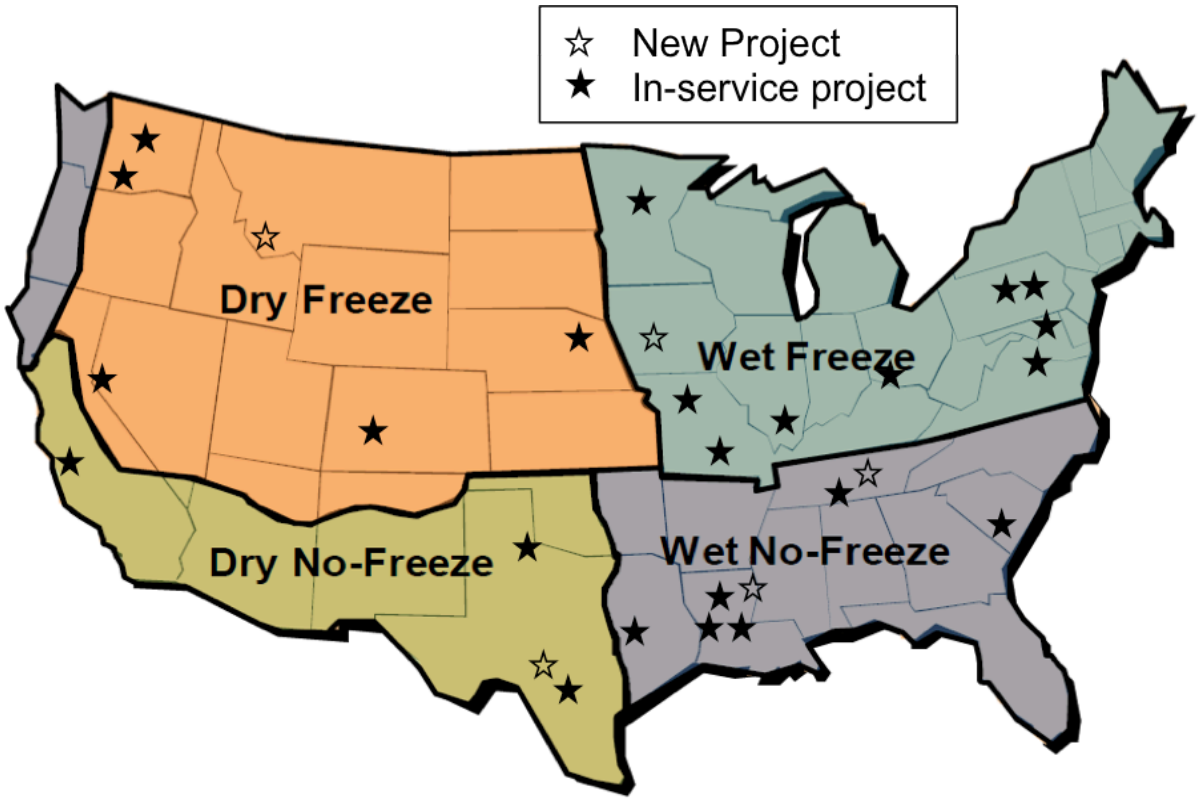
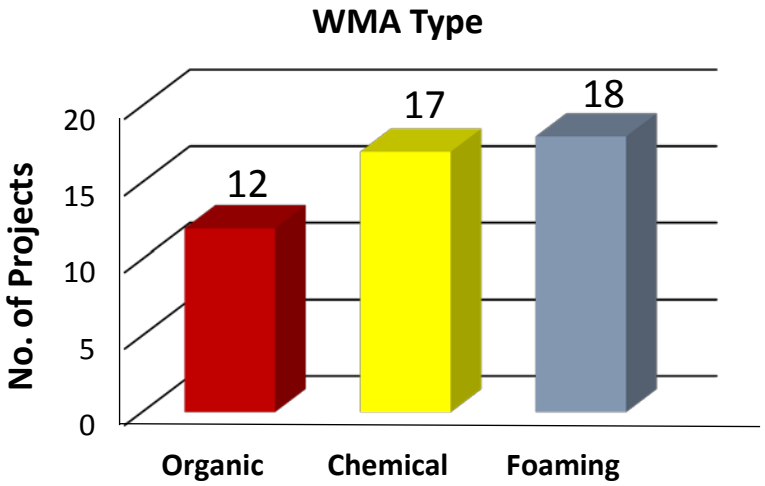
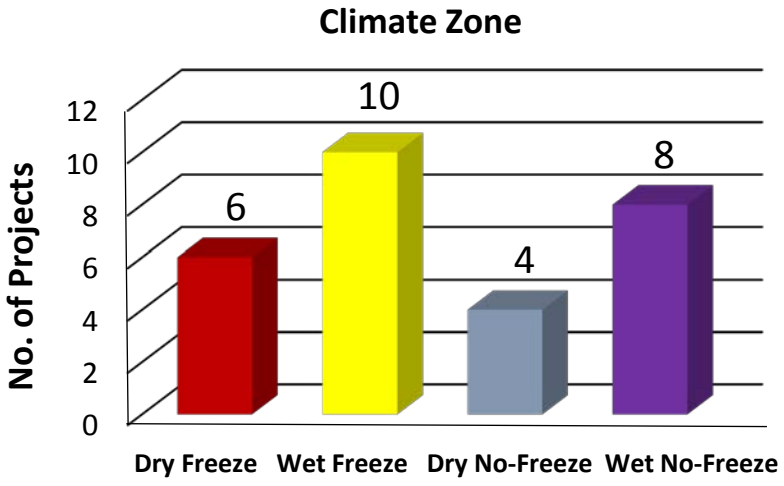
Project Scope

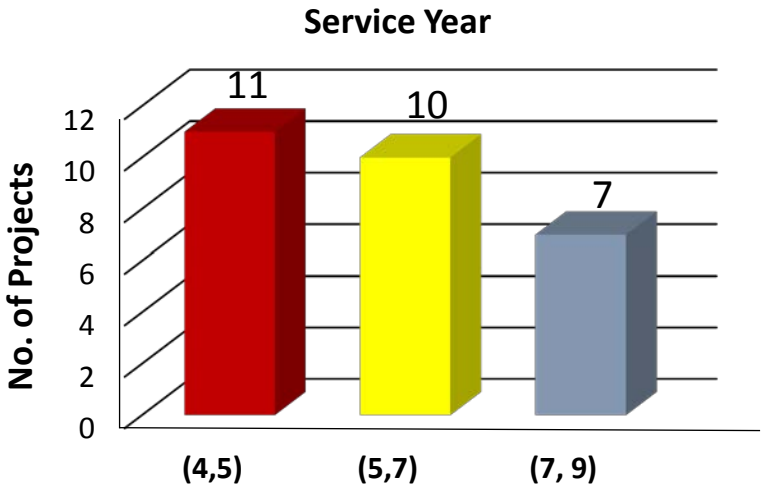
- 28 pavement projects
  - 22 in-service projects +1 HVS = 40 HMA-WMA pairs
    - ✓ 4-9 years service life
  - 5 newly constructed in 2011/2012 = 8 HMA-WMA pairs
- 3 WMA categories: organic, chemical, foaming

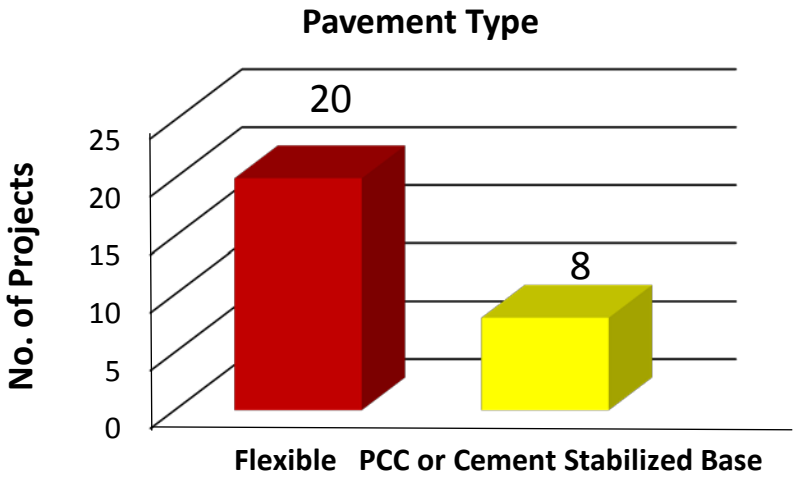


Scope: *Project Distribution*









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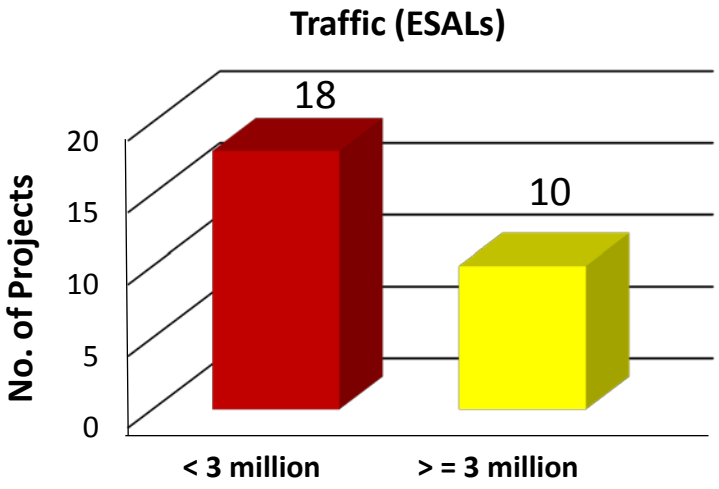
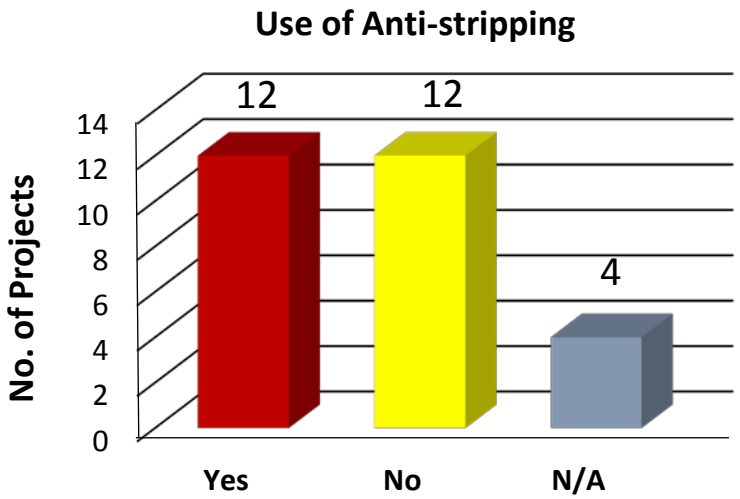
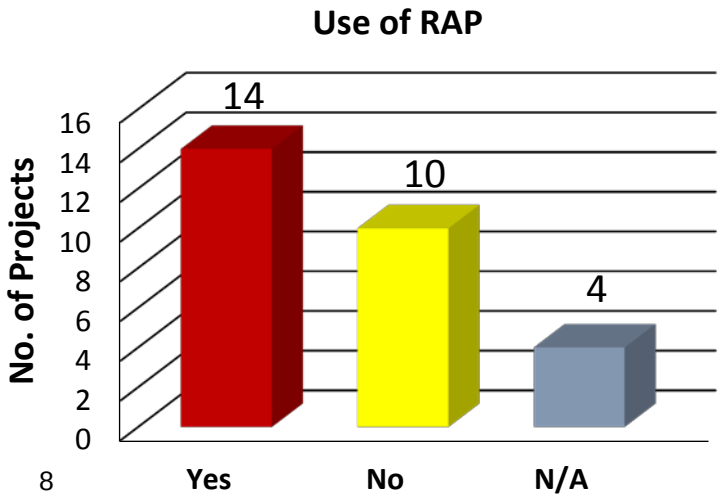
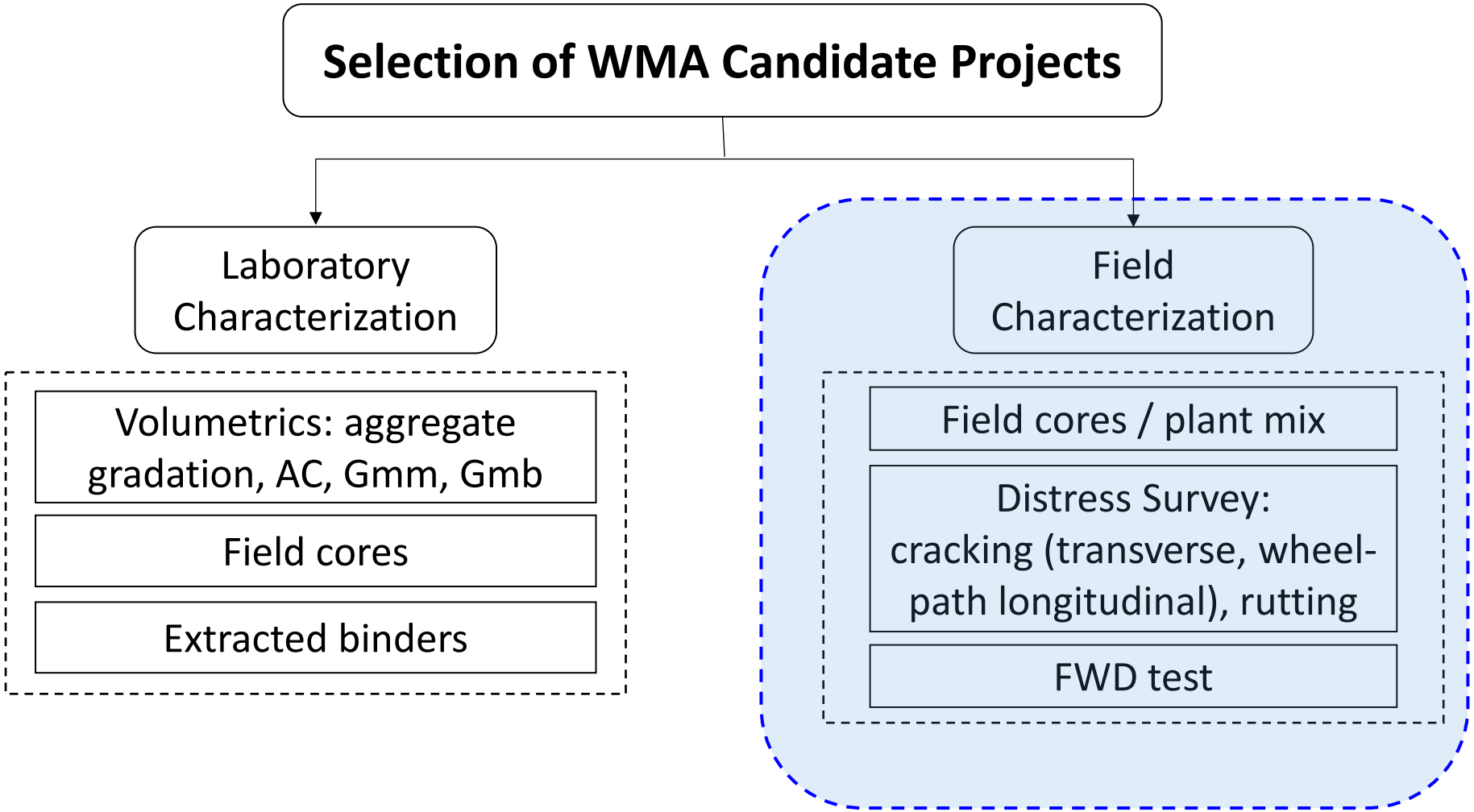




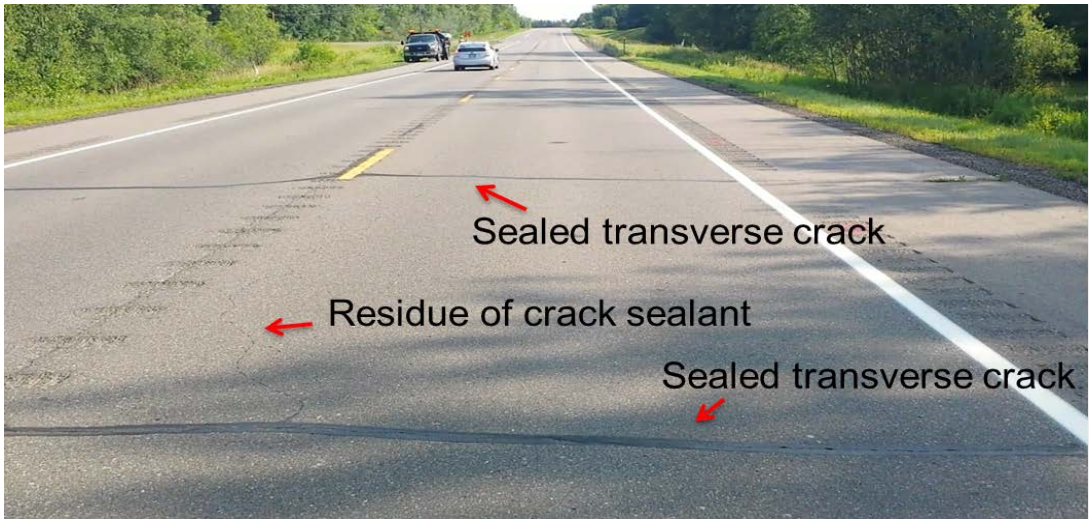


Research Approach



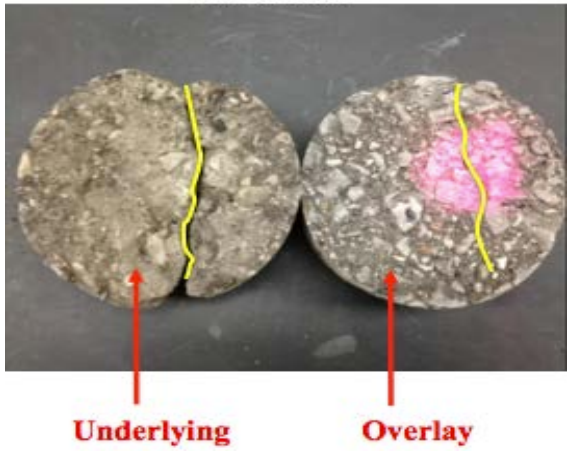
Field Characterization: Two-Rounds of Distress Survey

Transverse Cracking



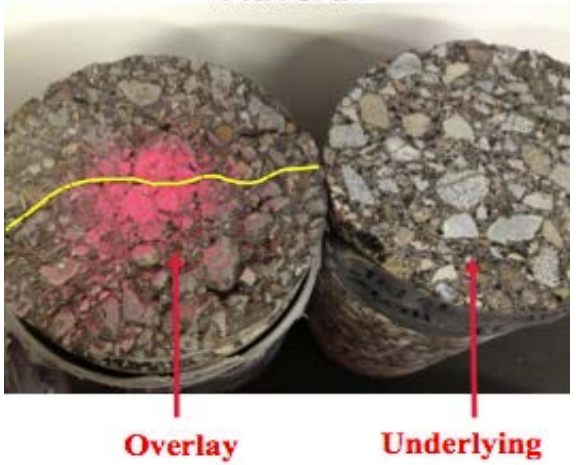
Reflective

Evotherm



Surface-initiated

Advera



Field Characterization: Two-Rounds of Distress Survey

Wheel-path Longitudinal Cracking

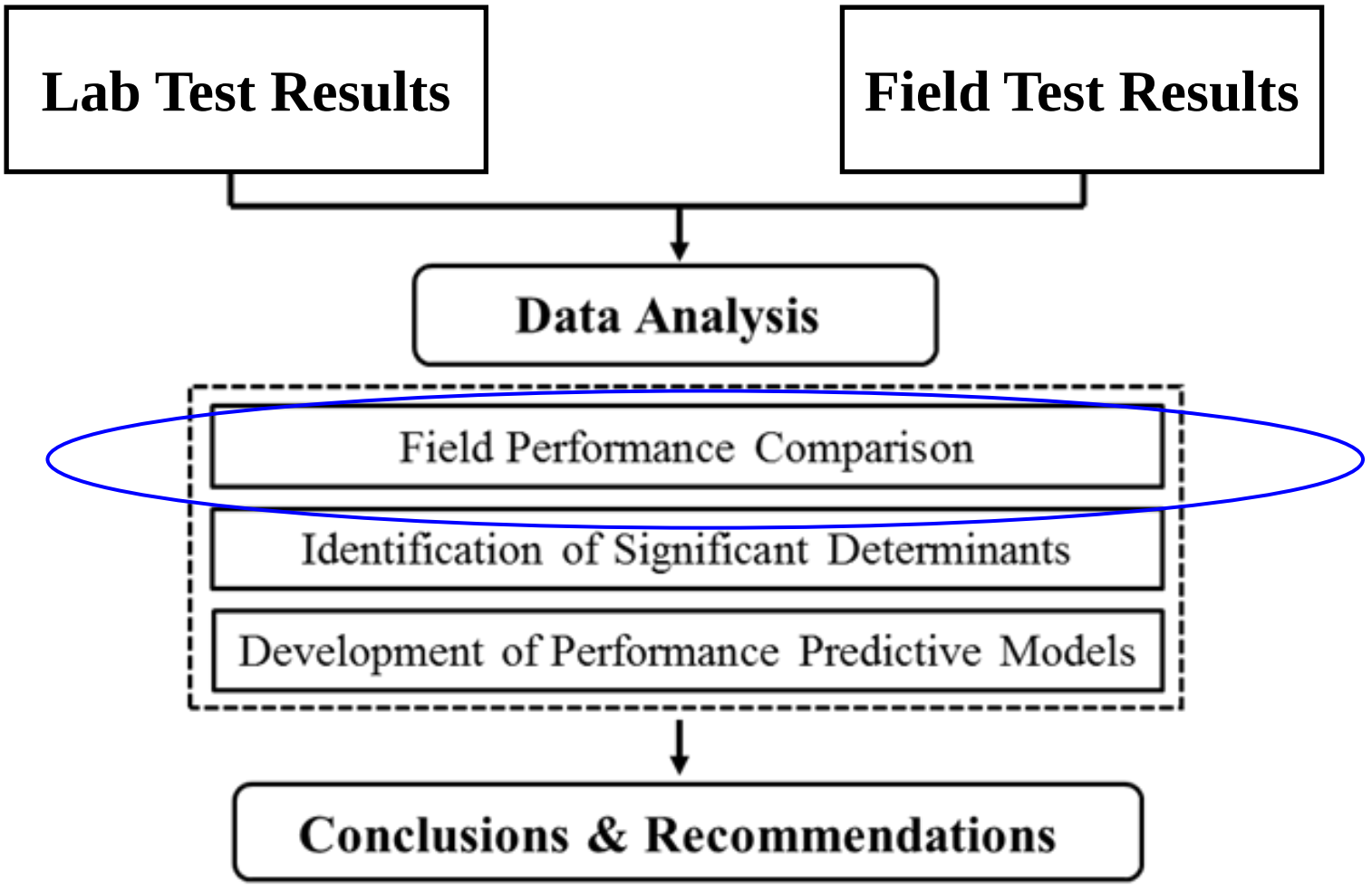
Observation:

- 2 to 4 feet away from the shoulder or centerline.
- Field cores indicate top-down fatigue cracks.

Field Characterization: Two-Rounds of Distress Survey

Rut Depth

Research Approach



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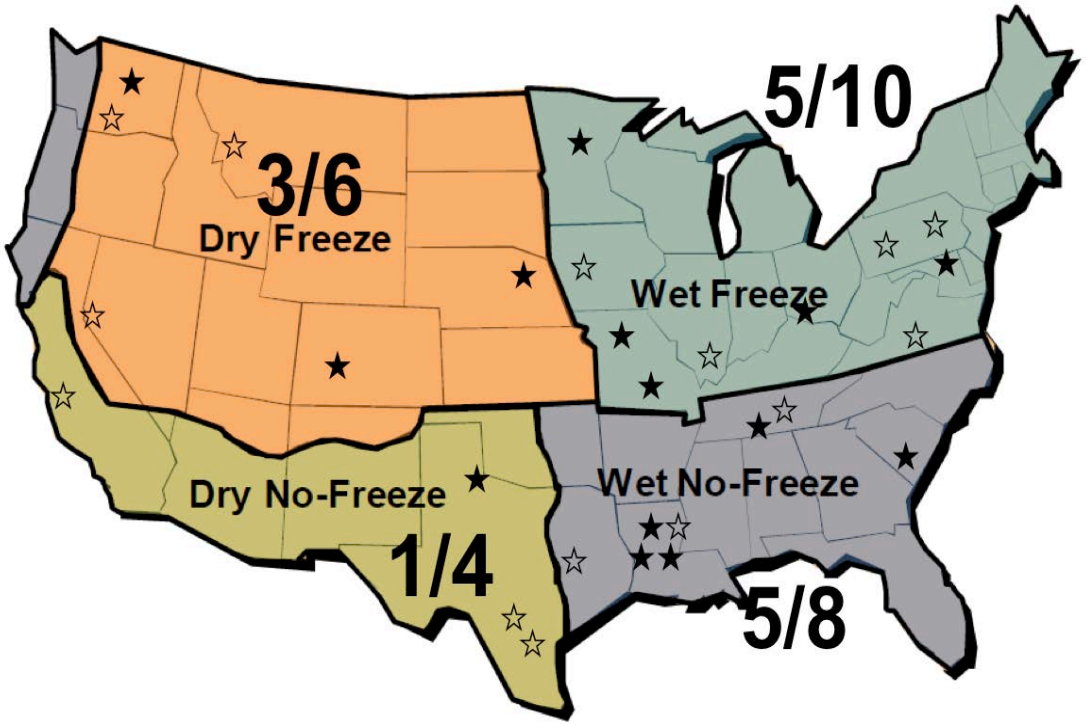
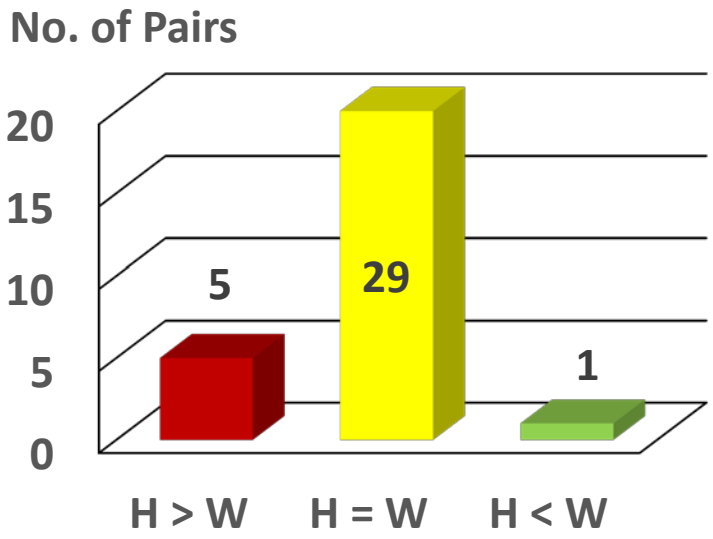
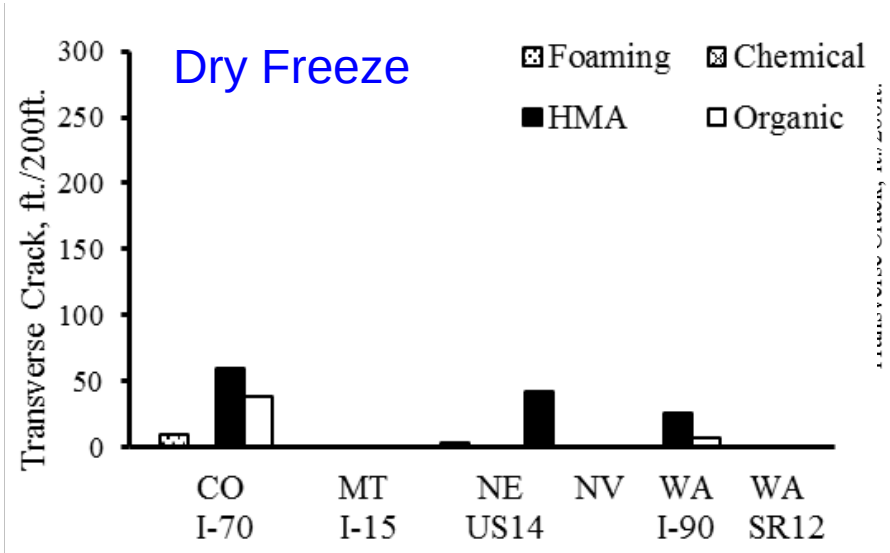
1st-Round Field Transverse Cracking

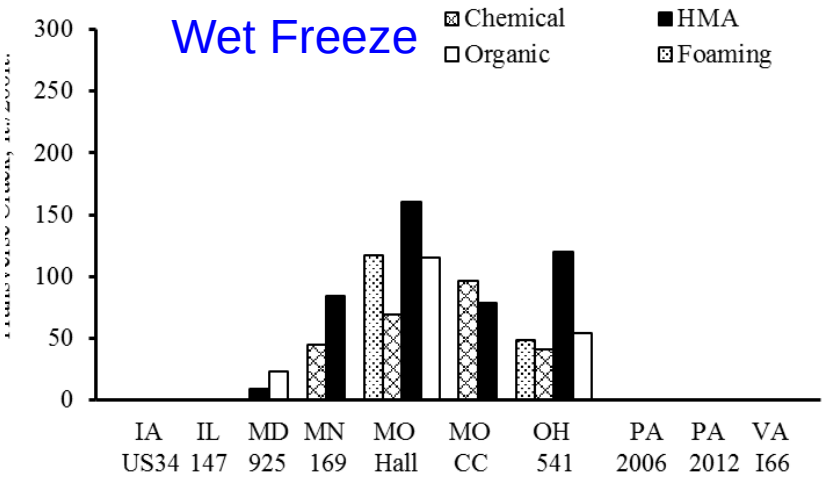
HMA vs. WMA, Y 2011/2012

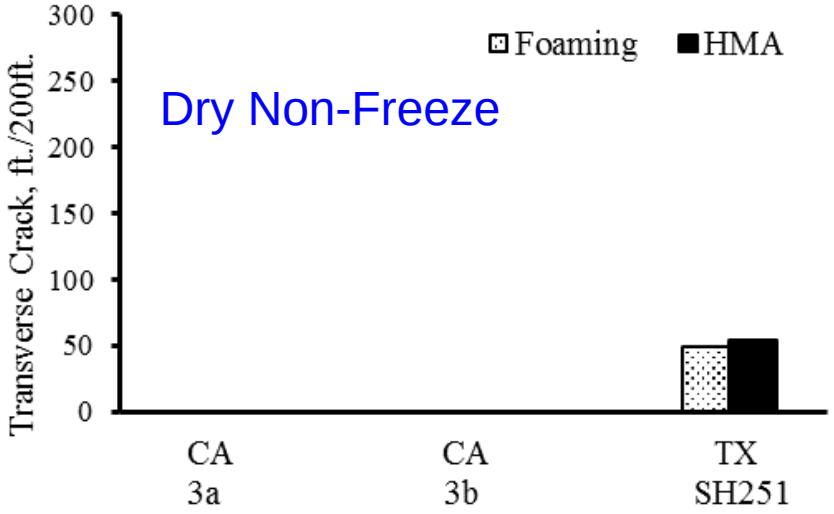


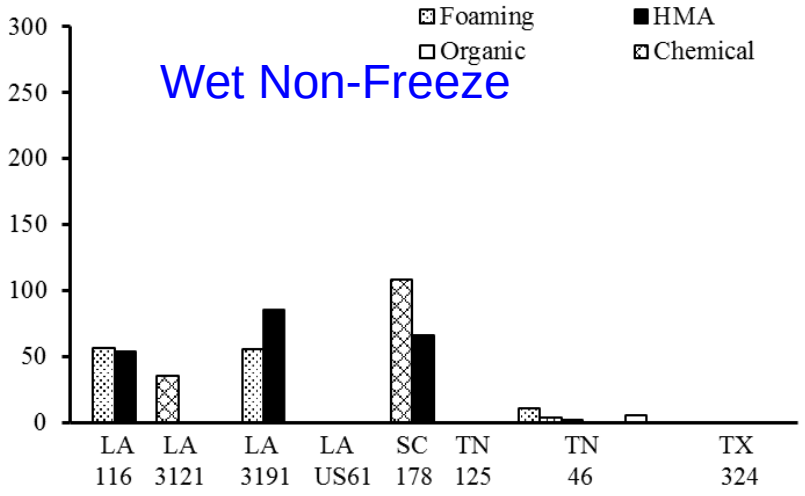


1st Round Transverse Cracking
Y 2011/2012



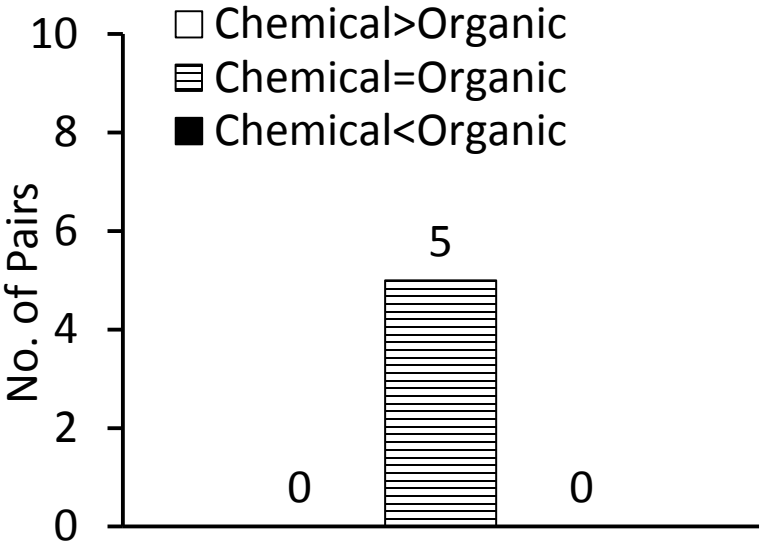


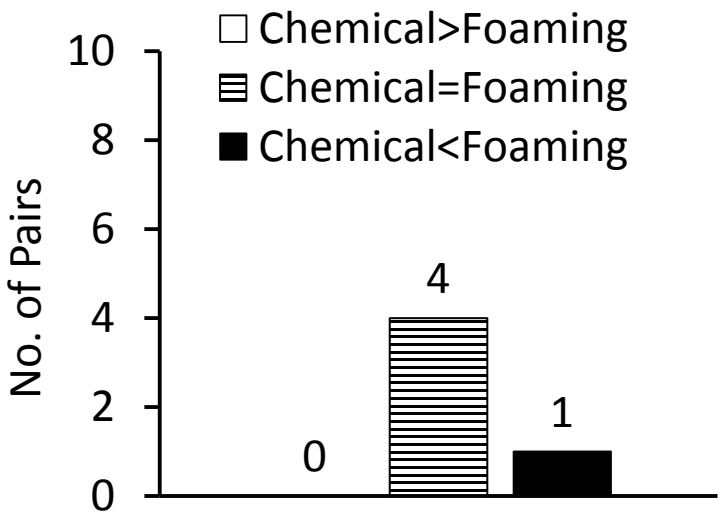


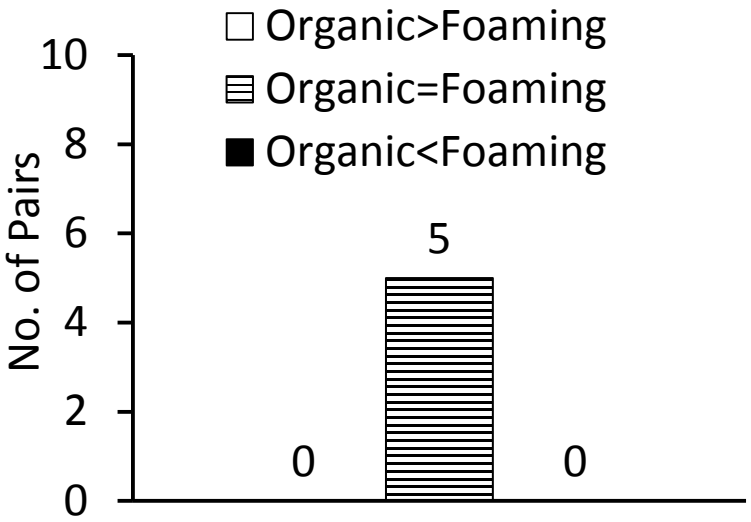


1st Round Transverse Cracking

Comparison Among WMAs



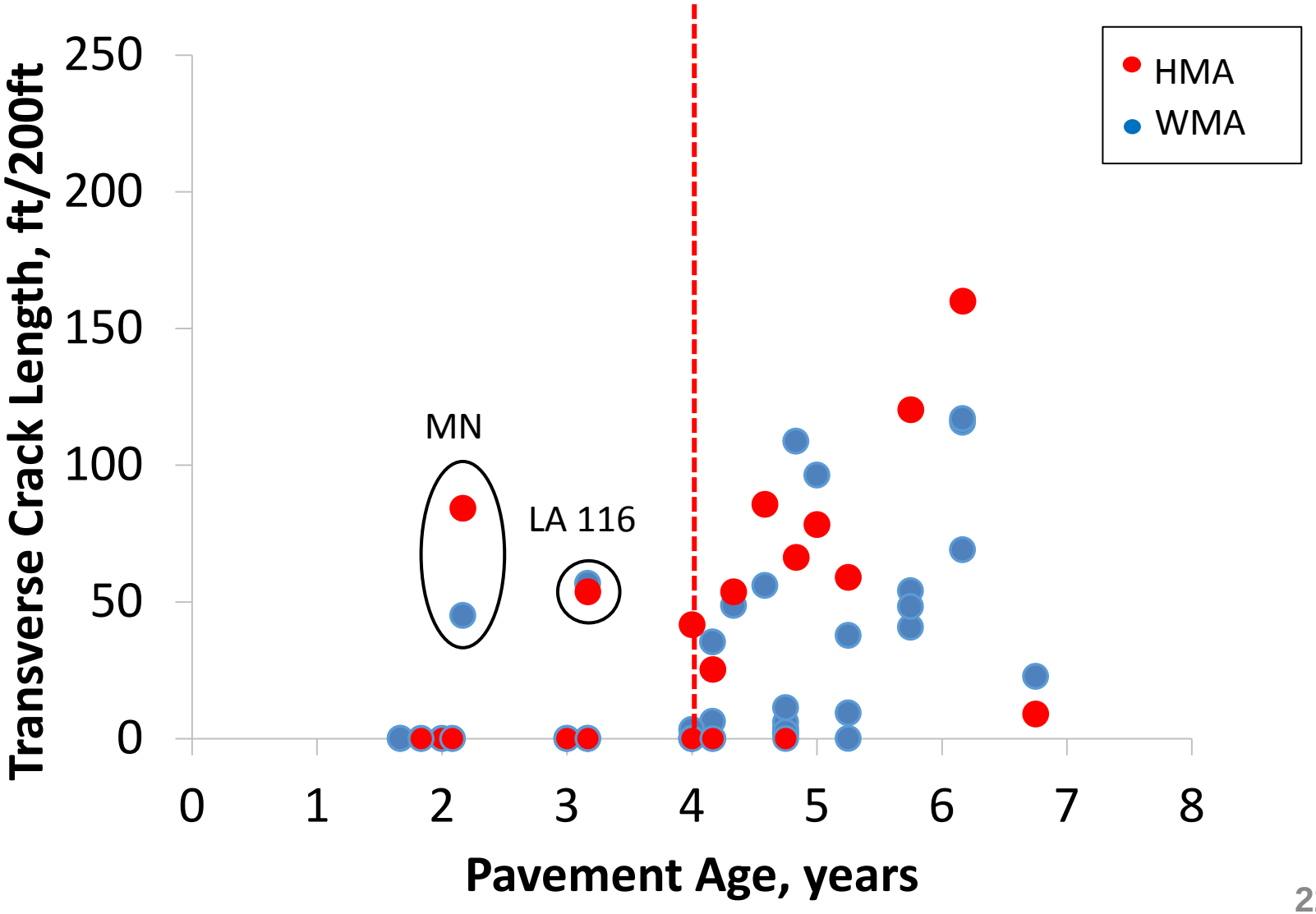




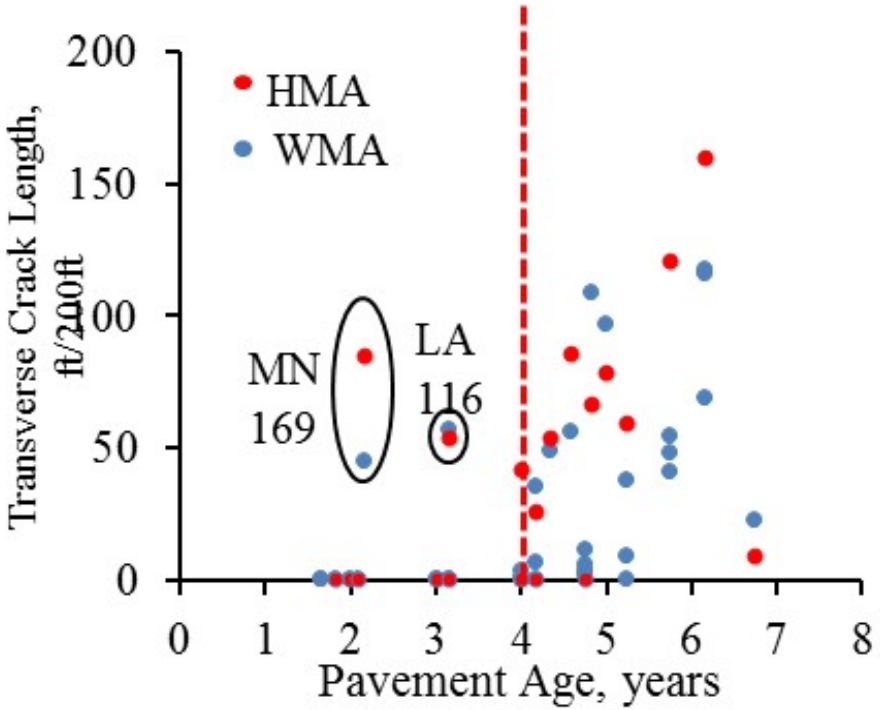
All technologies behave similarly in trans. cracking

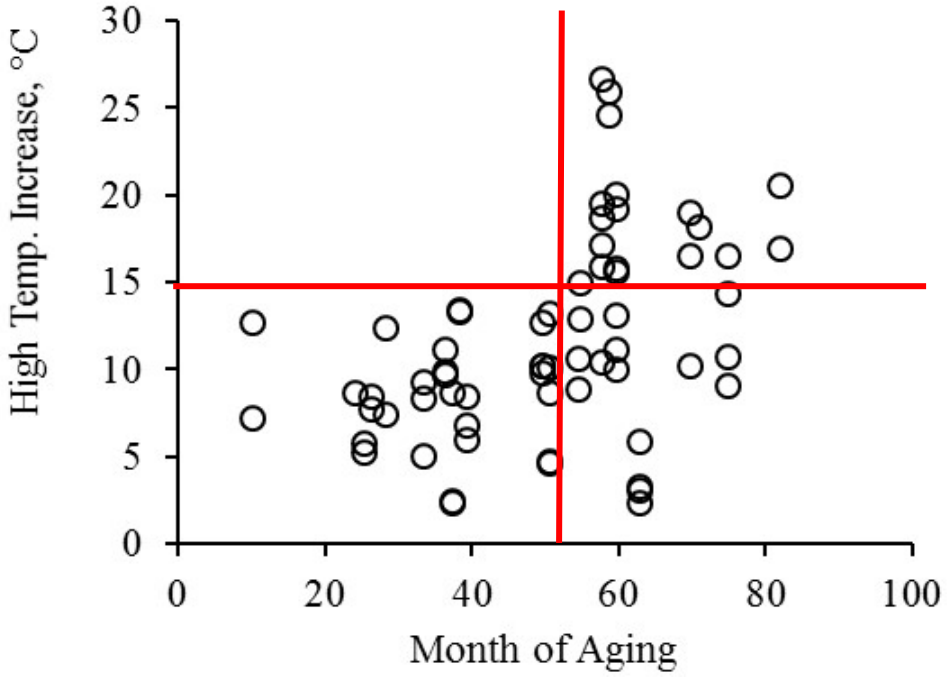
1st Round Field Transverse Cracking

Effect of Pavement Age

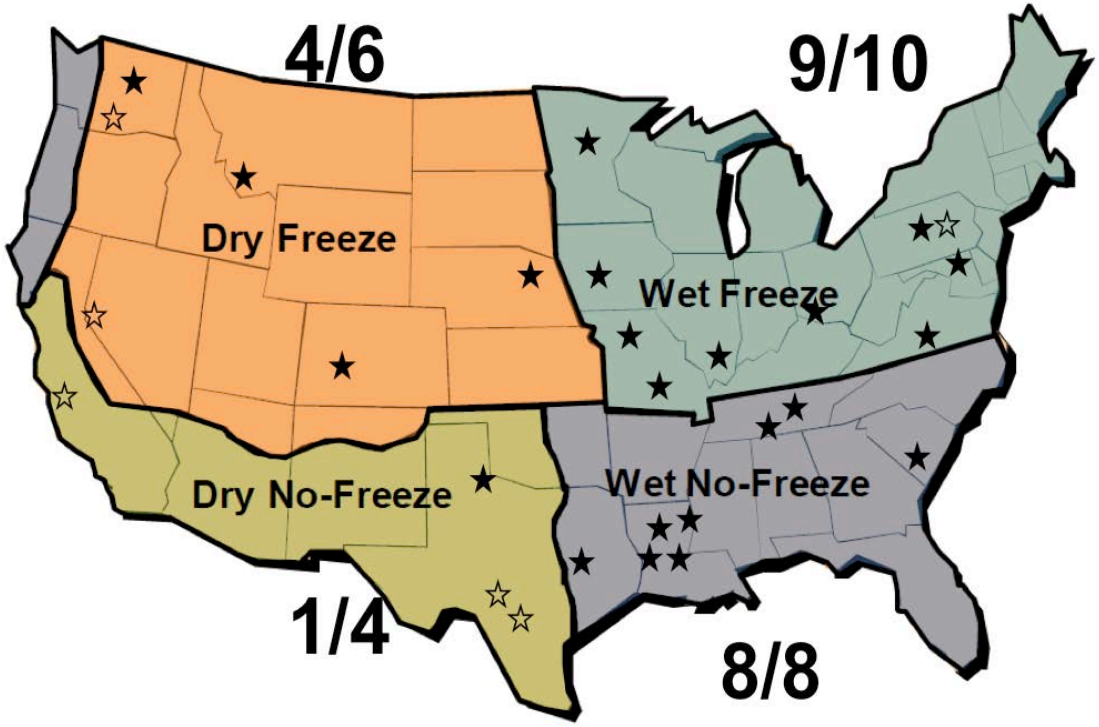


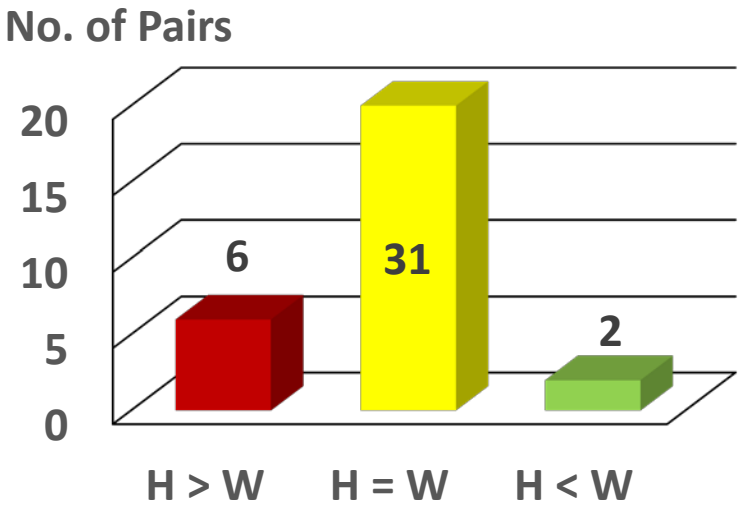
Effect of Aging on Pavement Performance



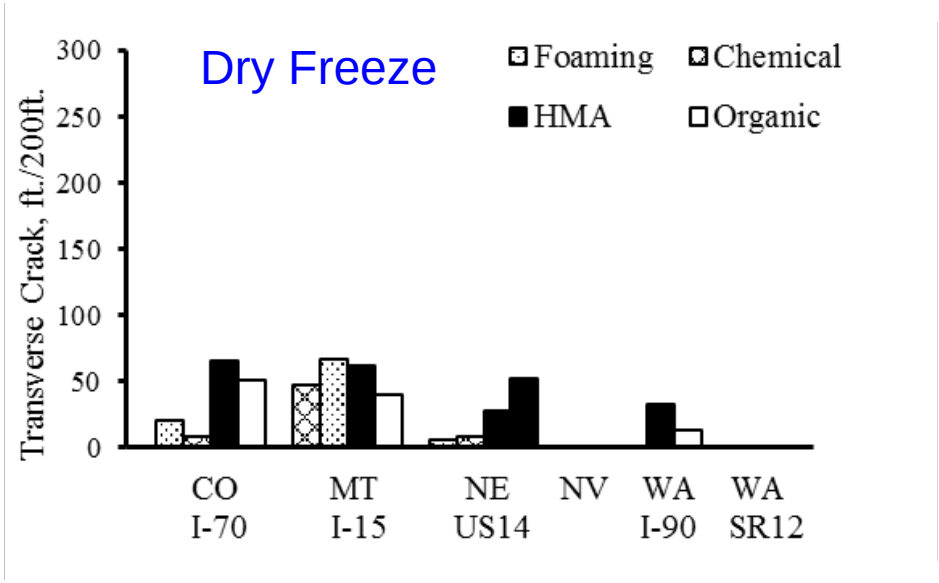


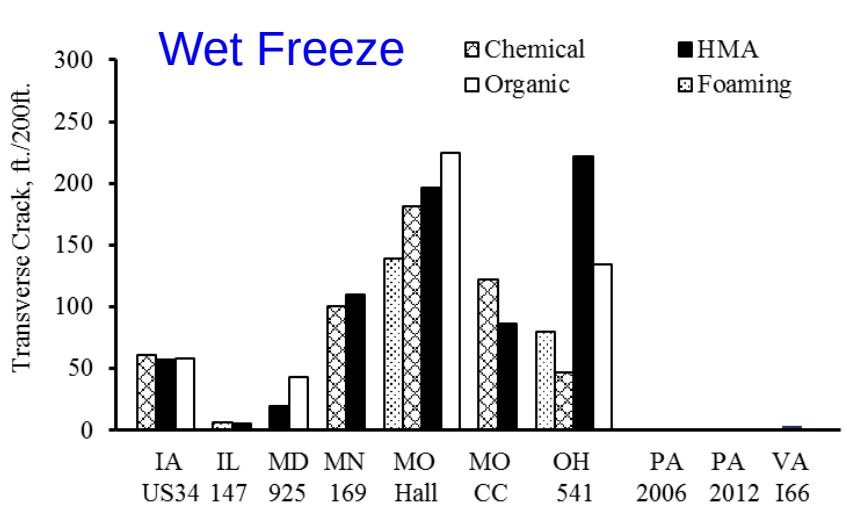
2nd Round Field Transverse Cracking
HMA vs. WMA, Y 2014/2015

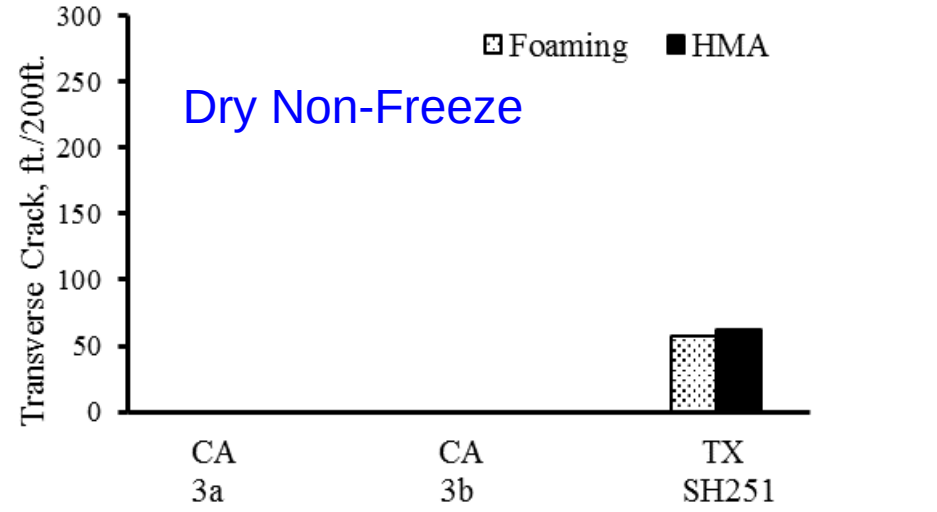


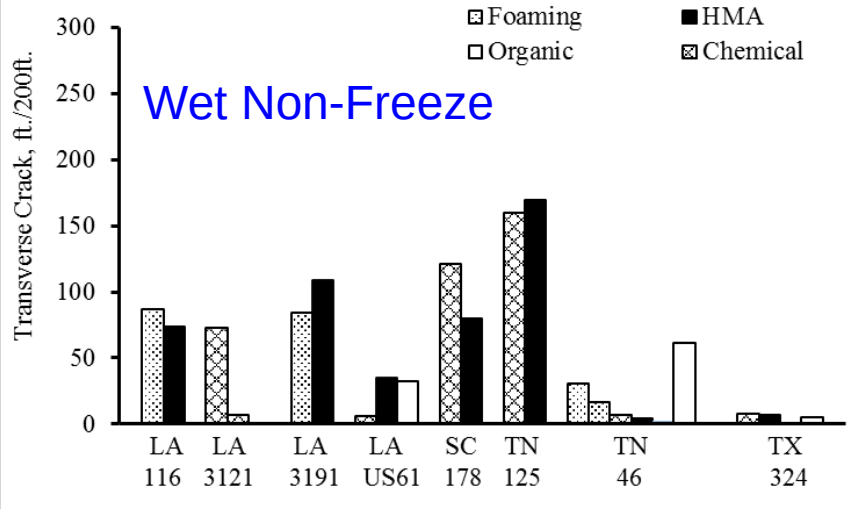


2nd Round Transverse Cracking
Y 2014/2015









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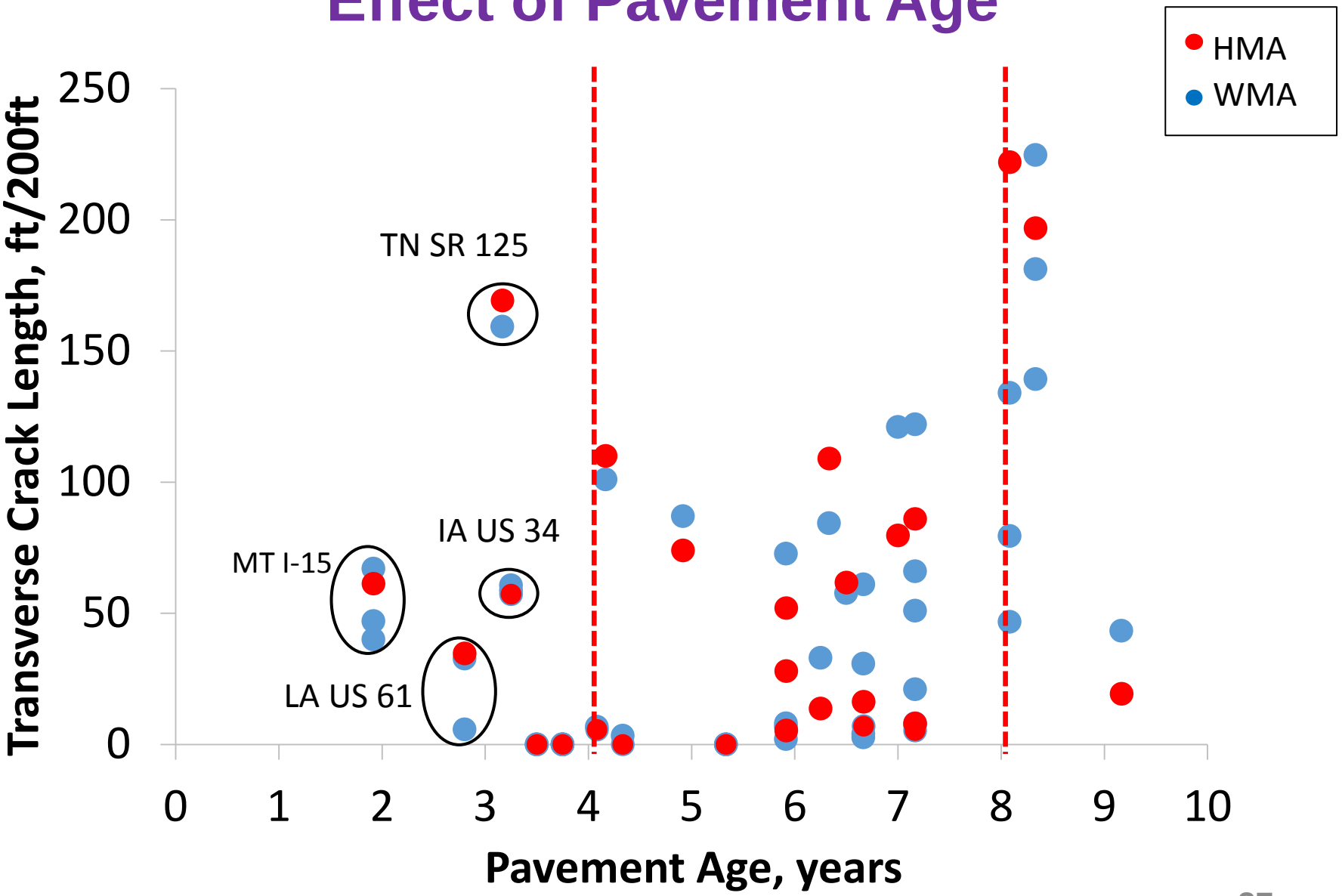
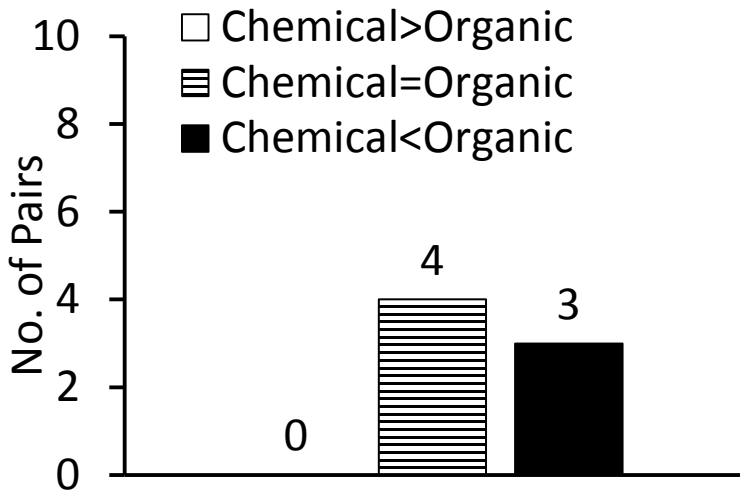
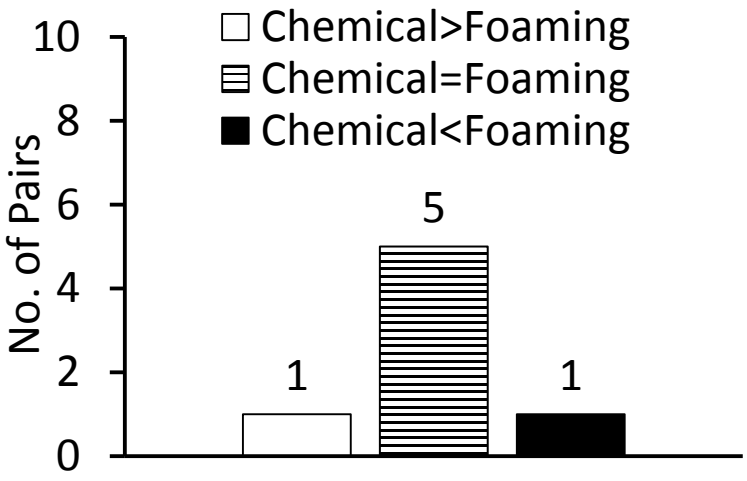
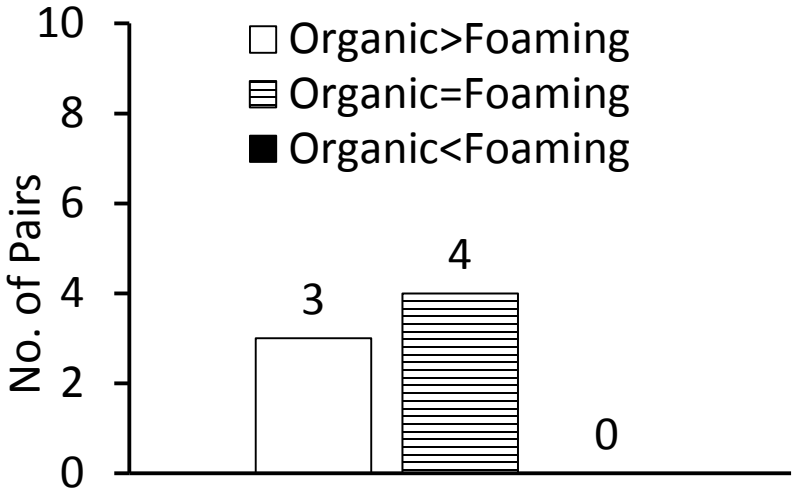


2nd Round Transverse Cracking

Comparison Among WMAs







Organic starts to show more cracks than Chemical and Foaming

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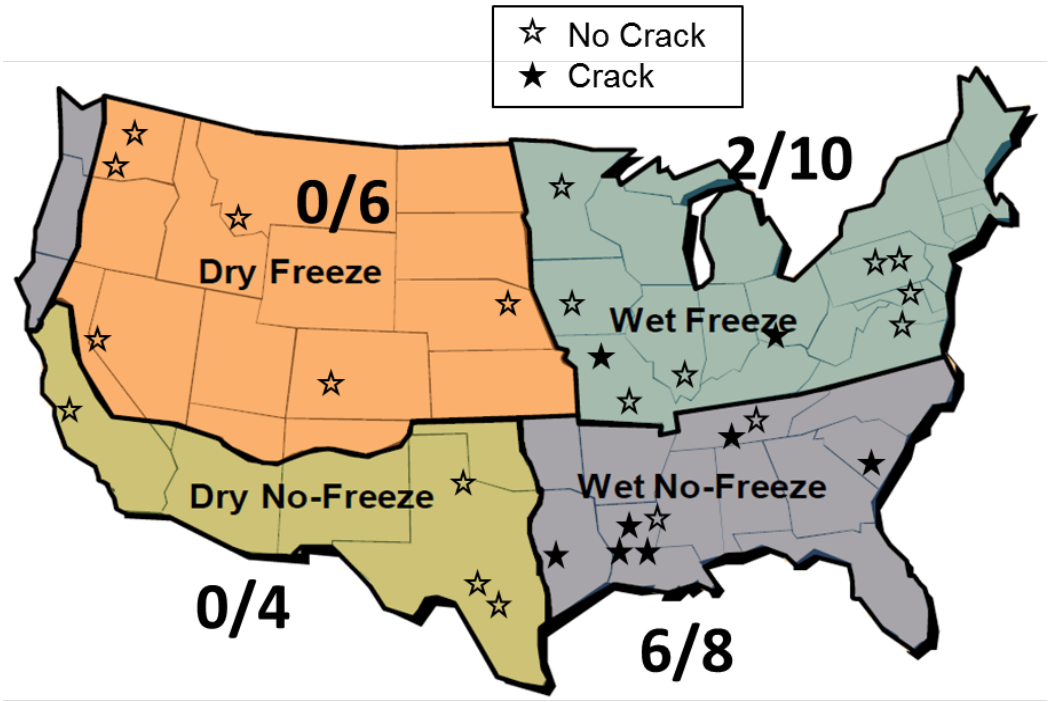
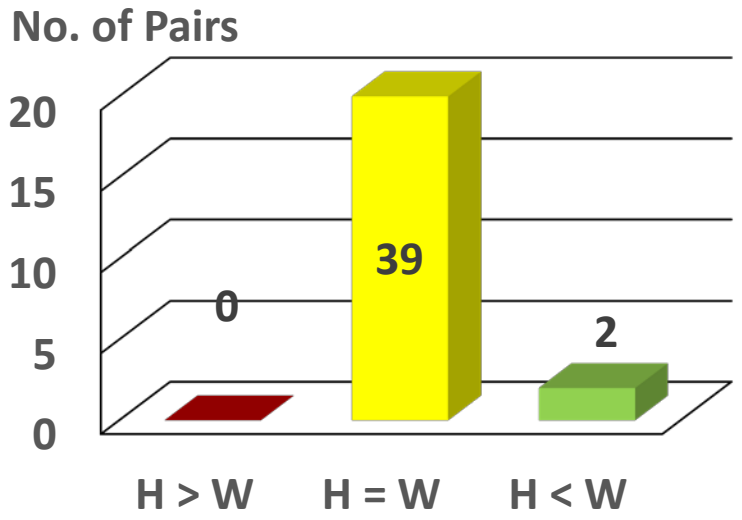
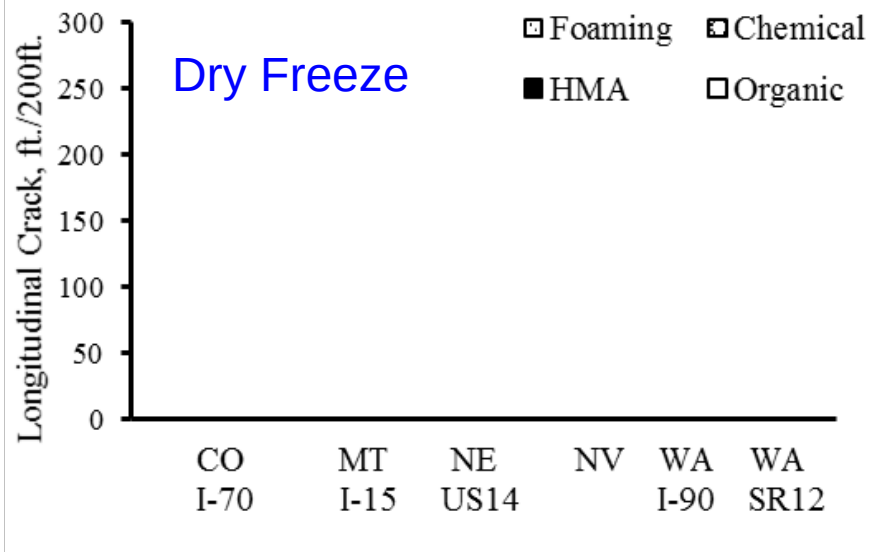
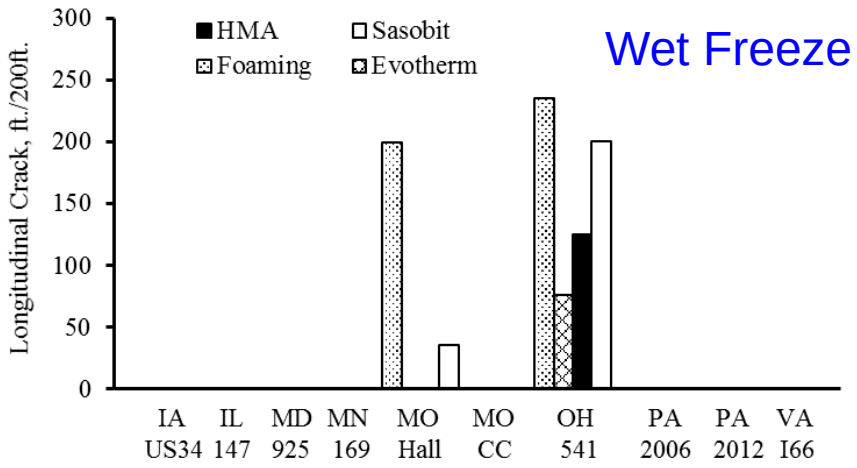
1st Round Wheel-path Longitudinal Cracking
HMA vs. WMA, 2011/2012

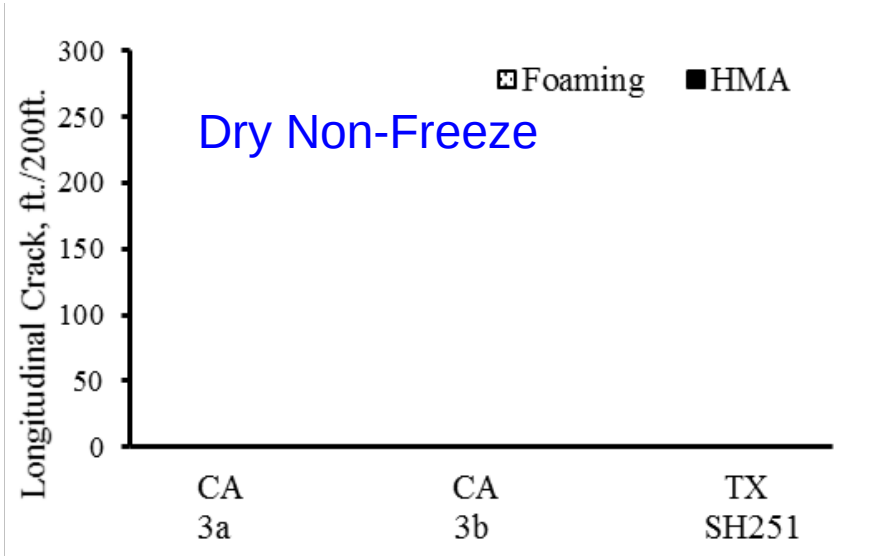


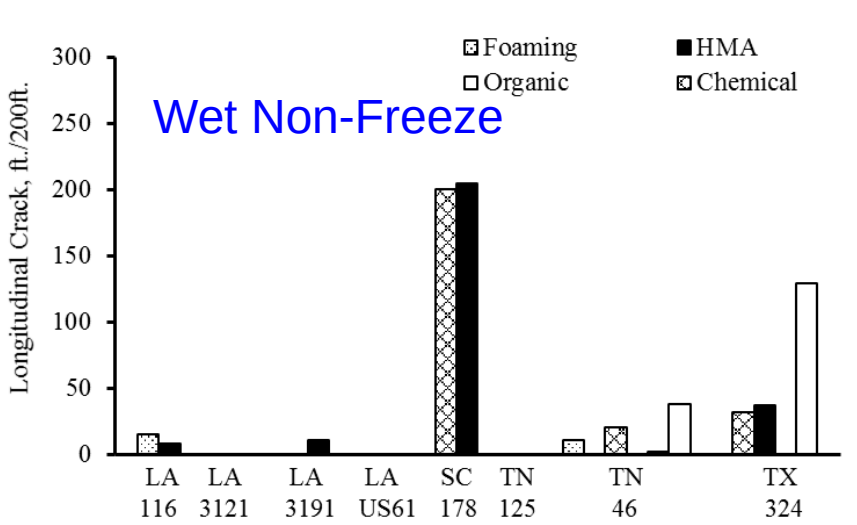


1st Round Longitudinal Cracking 2011/2012



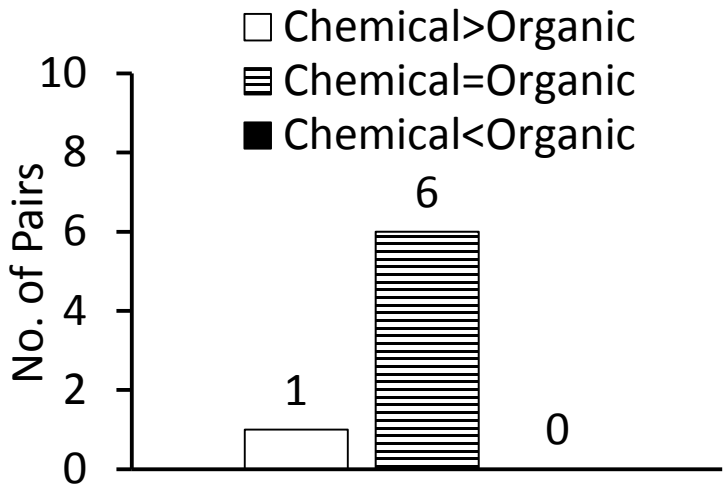


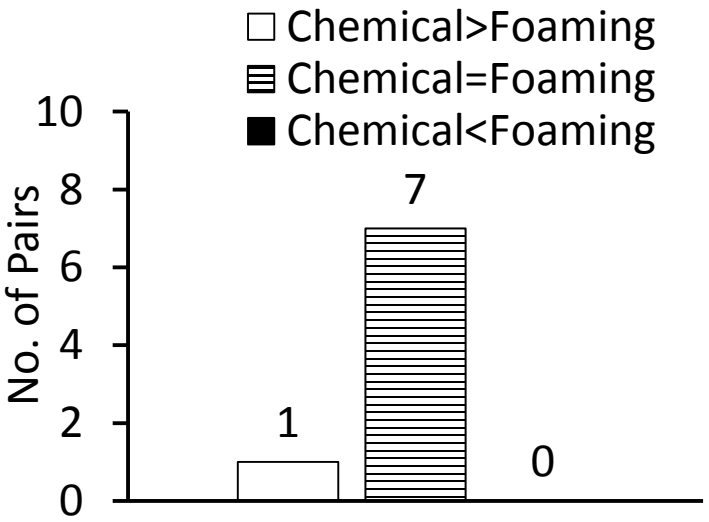


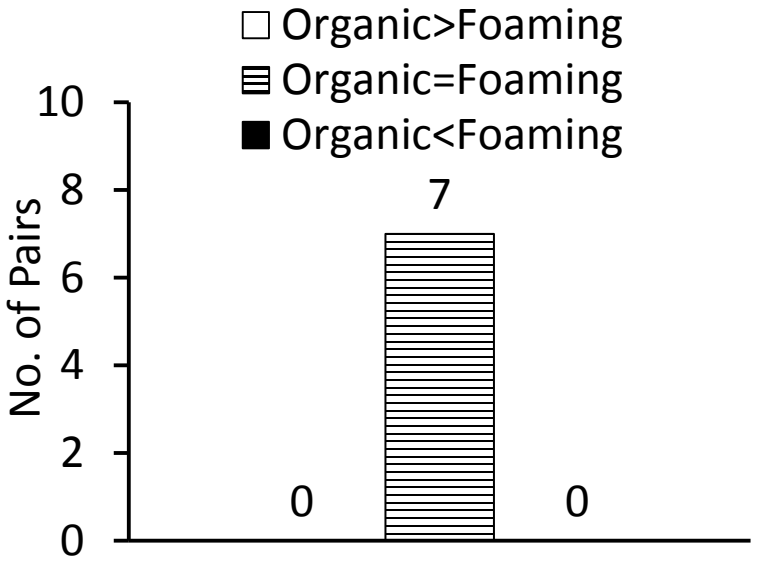


1st Round Wheel-path Longitudinal Cracking

Comparison Among WMAs

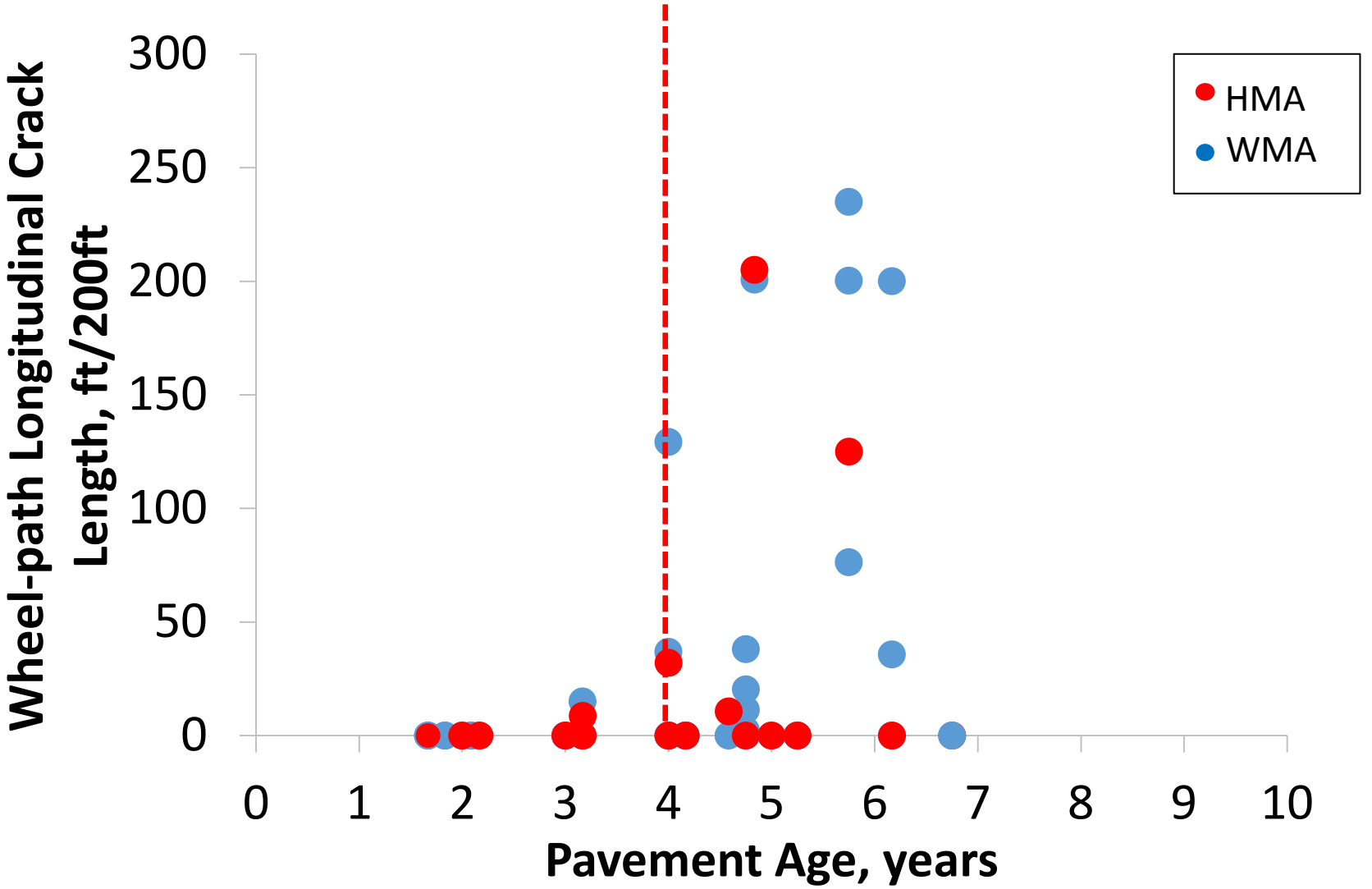




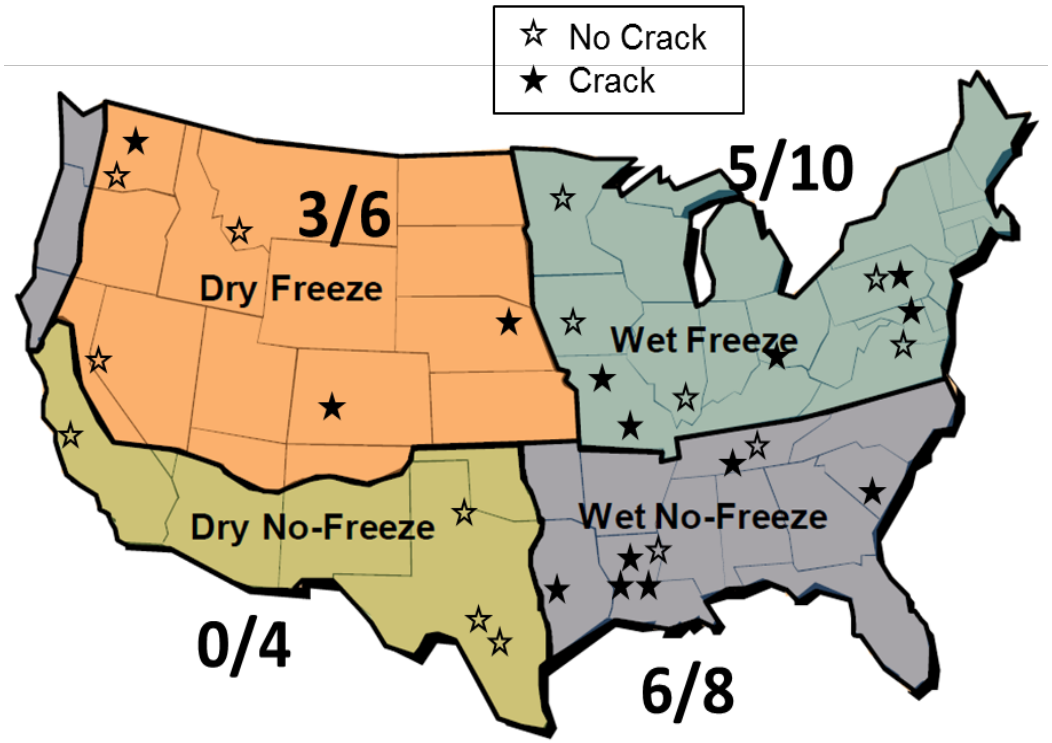


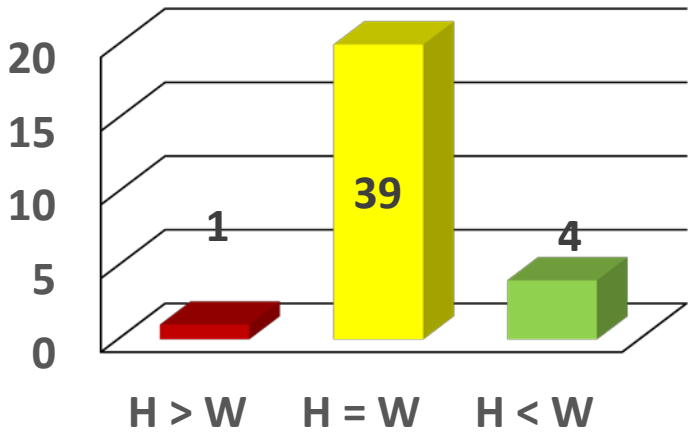
All technologies behave similarly in long. cracking

1st Round Wheel-path Longitudinal Cracking
Effect of Pavement Age



2nd Round Wheel-path Longitudinal Cracking
Y 2014/2015





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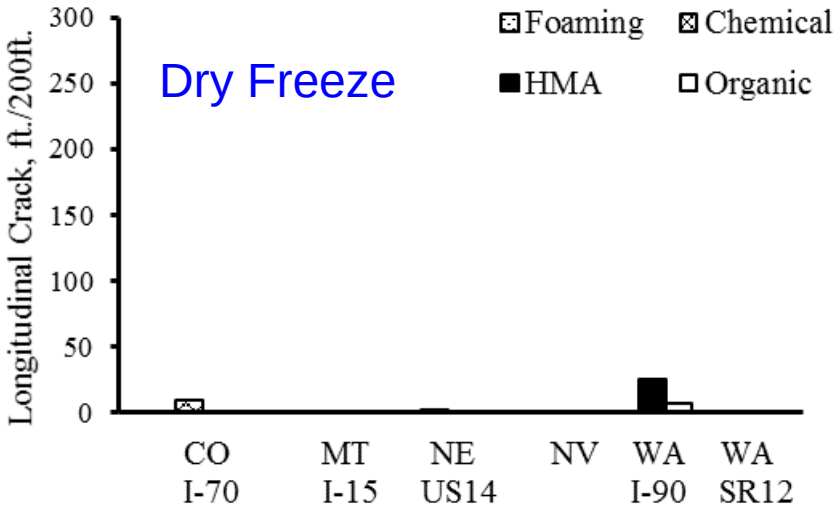
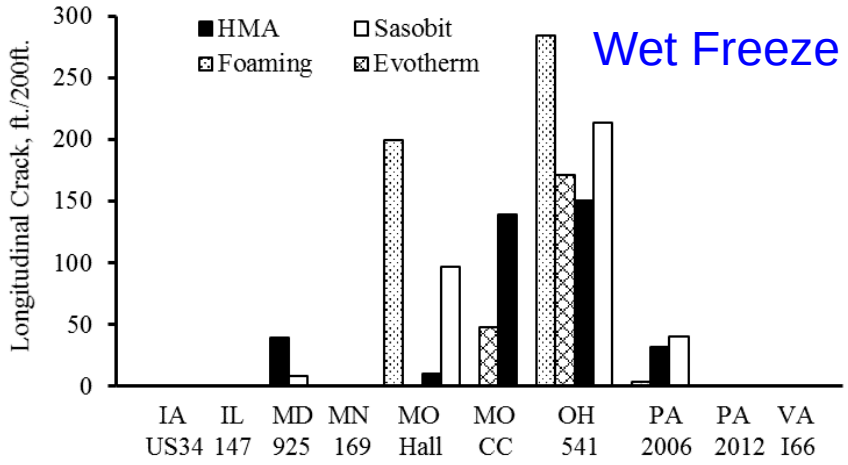
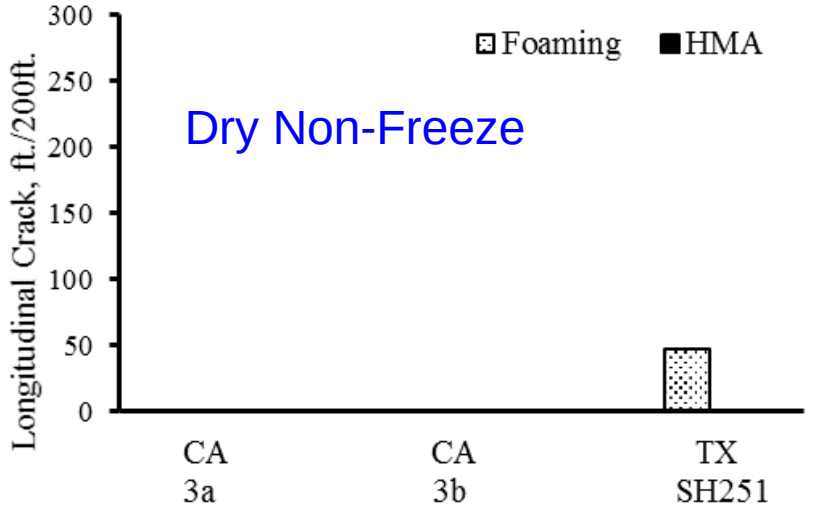
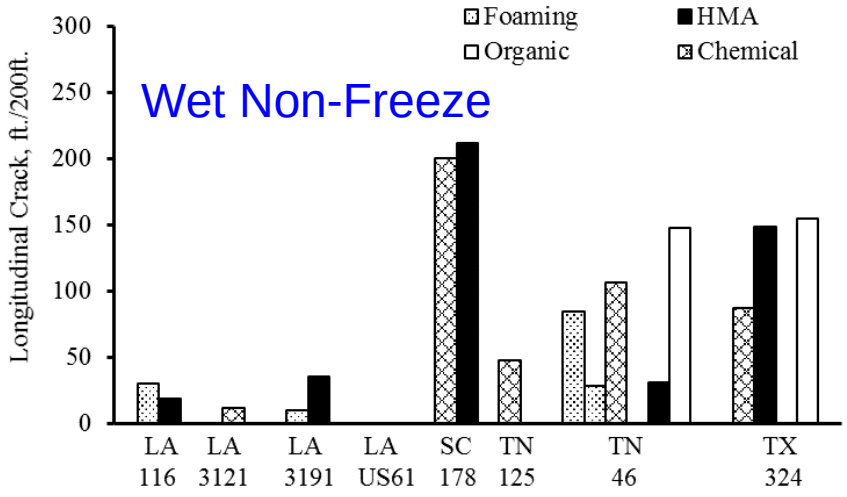
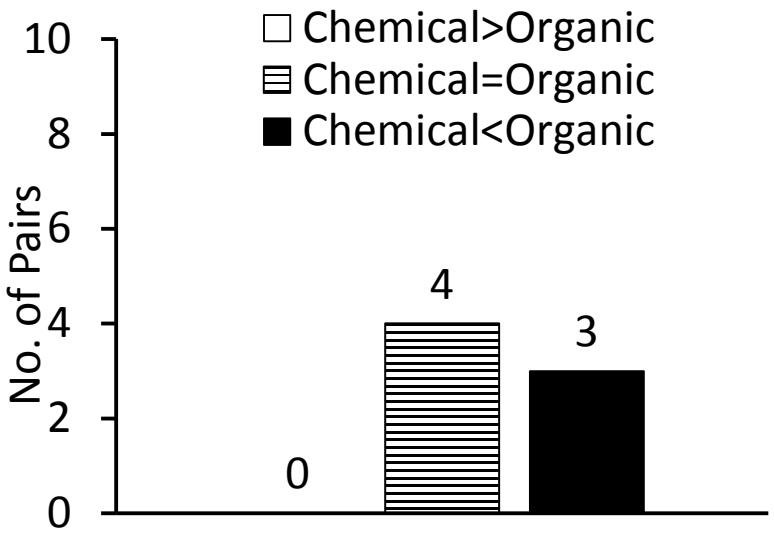


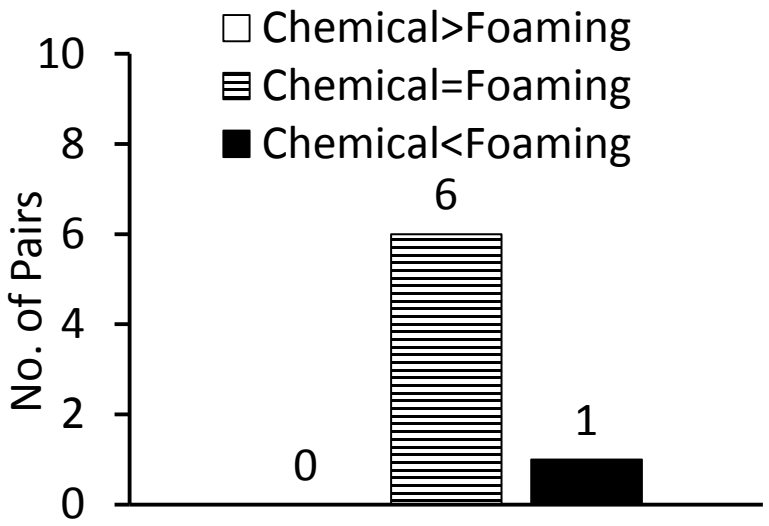


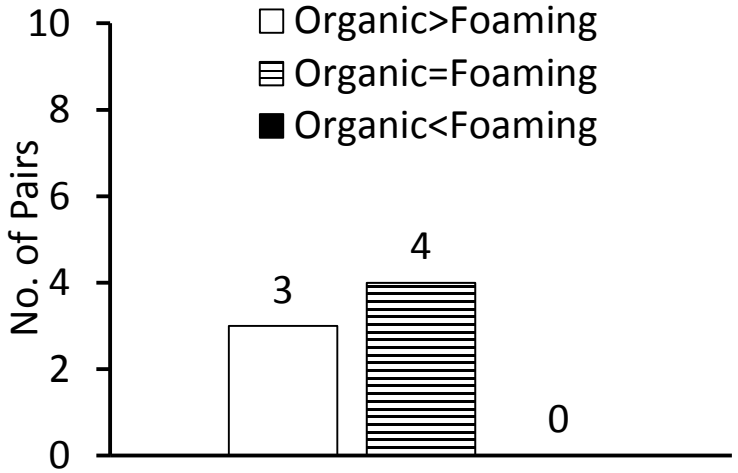




2nd Round Wheel-path Longitudinal Cracking
Comparison Among WMAs







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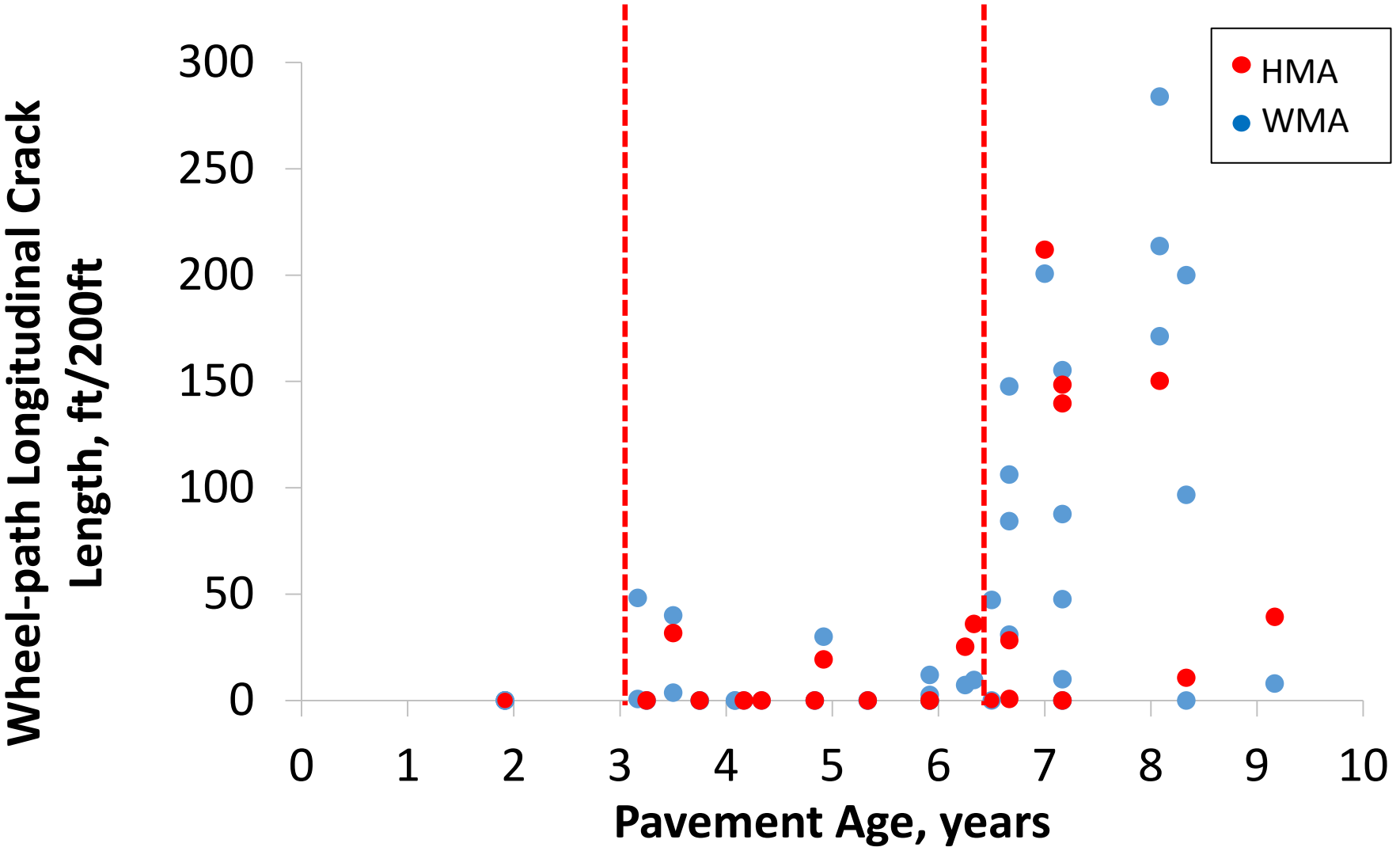
2nd Round Wheel-path Longitudinal Cracking
Effect of Pavement Age

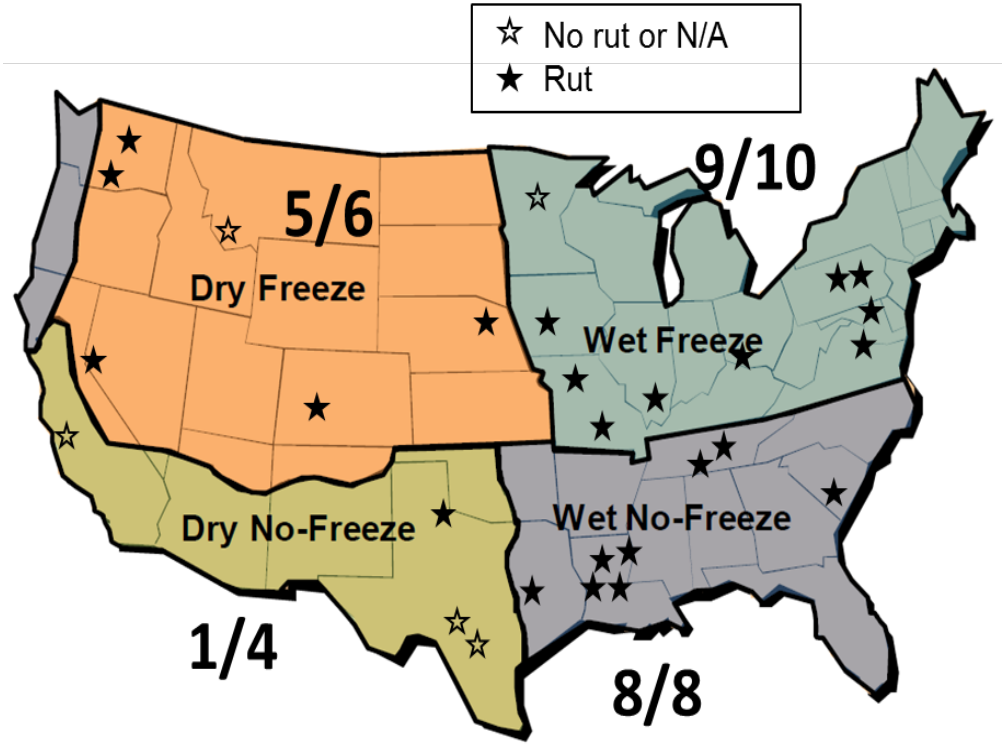


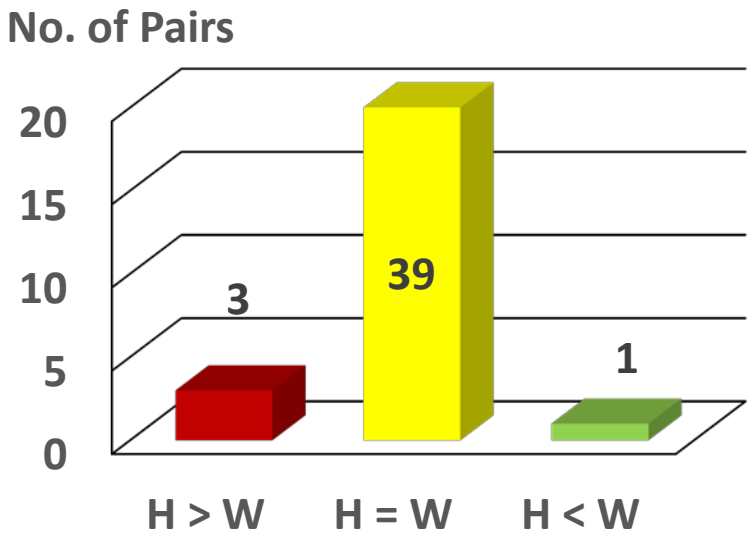
Outline

- Introduction & Objectives
- Project Scope and Research Aproach
- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture Susceptibility
- Findings

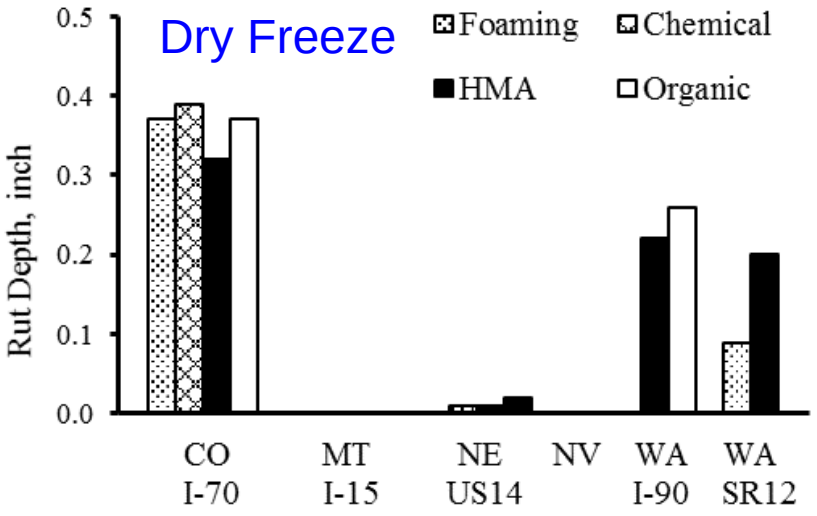
Field Rutting Performance

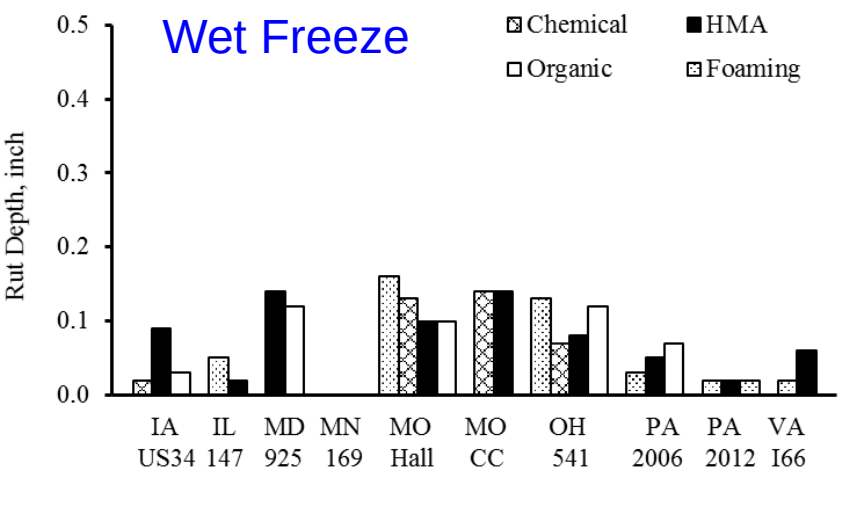
- Rut depth is less than 1/16” for the 1st round survey;
- Use 2nd round survey results to compare;

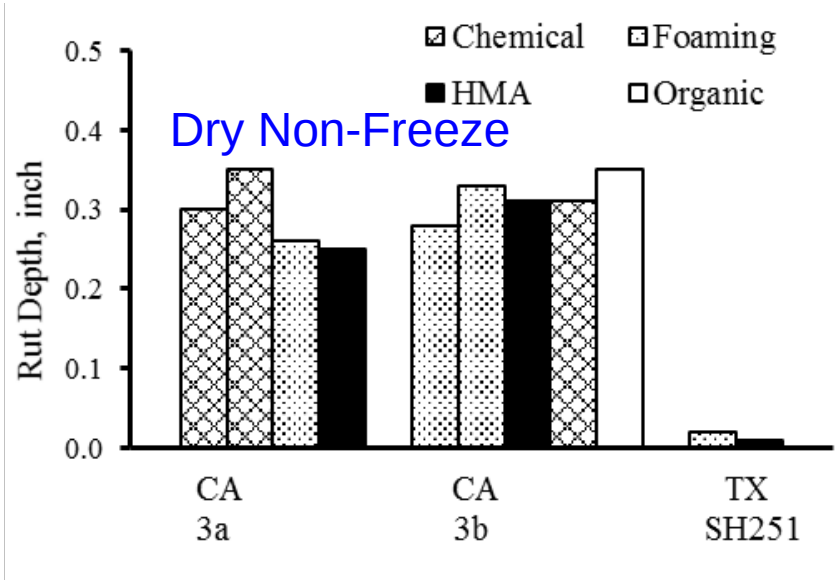


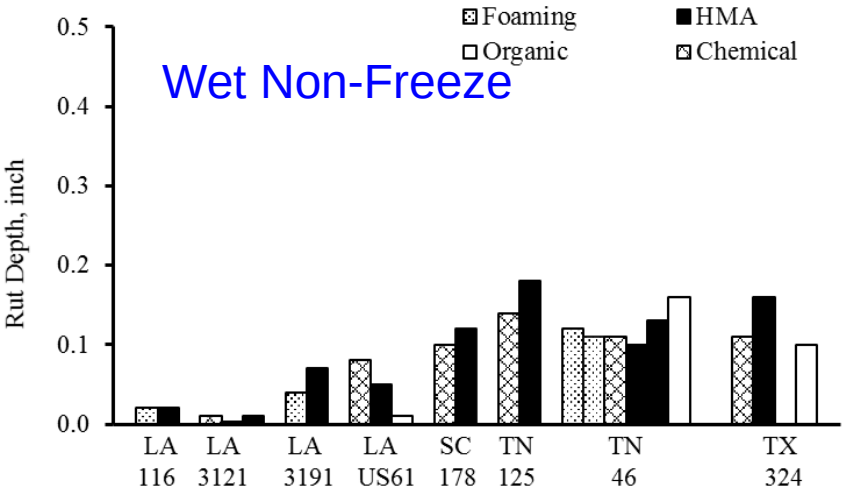


2nd Round Rut Depth
Y 2014/2015



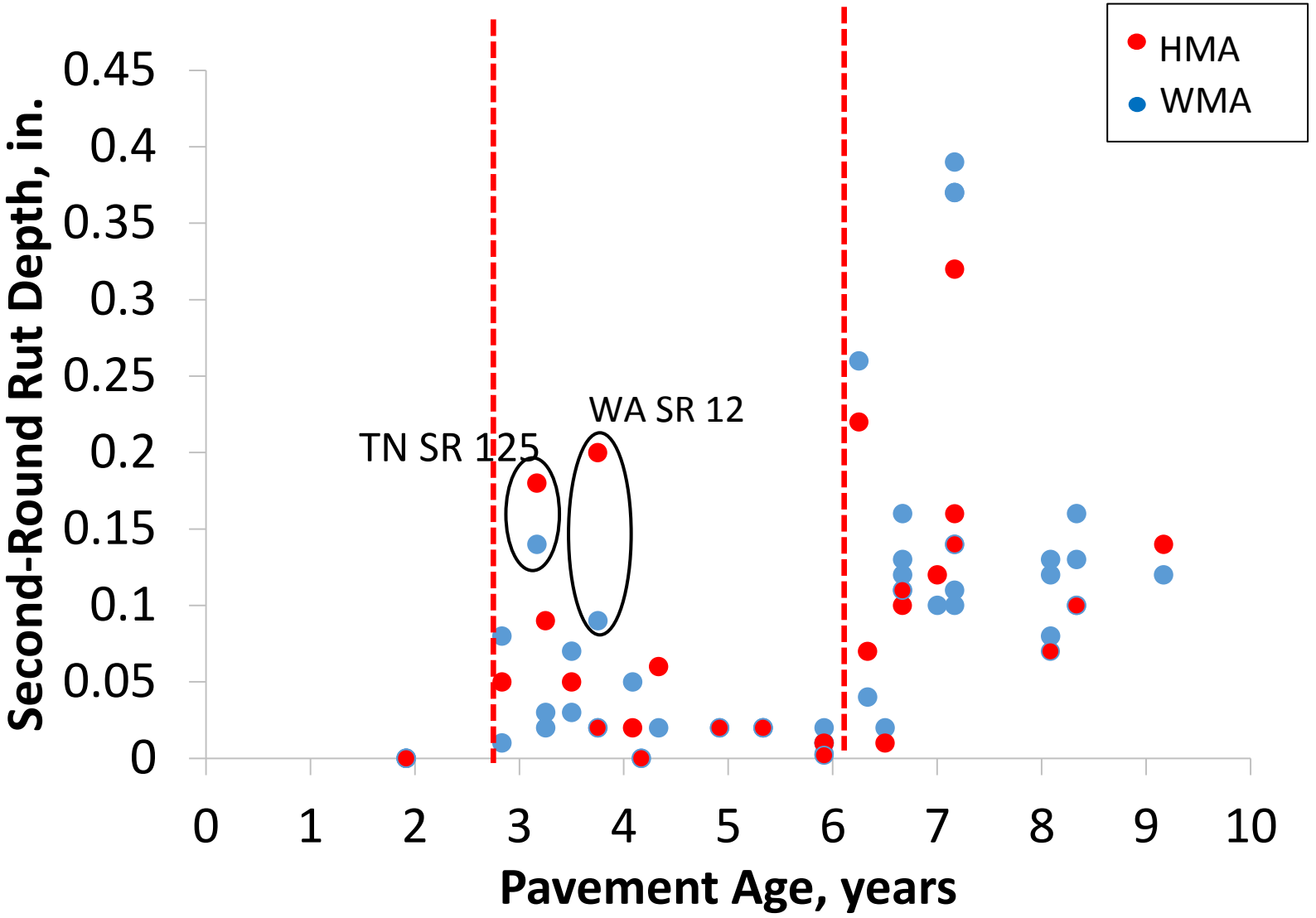




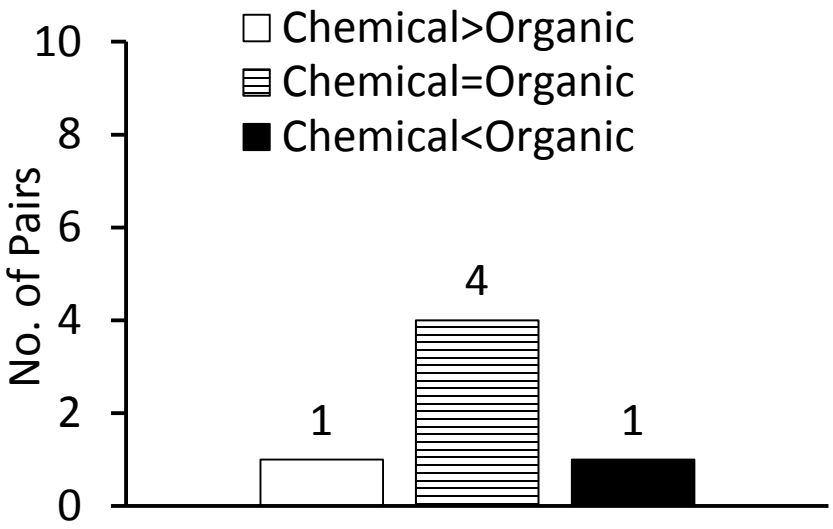


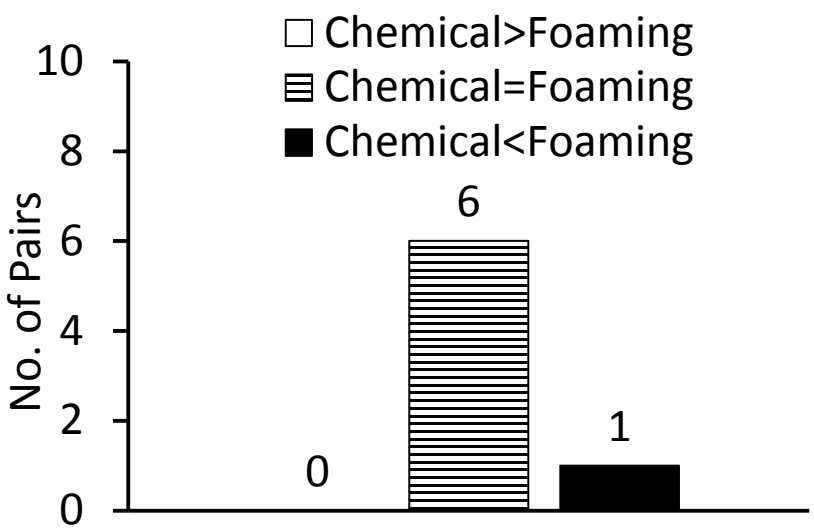
2nd Round Rut Depth

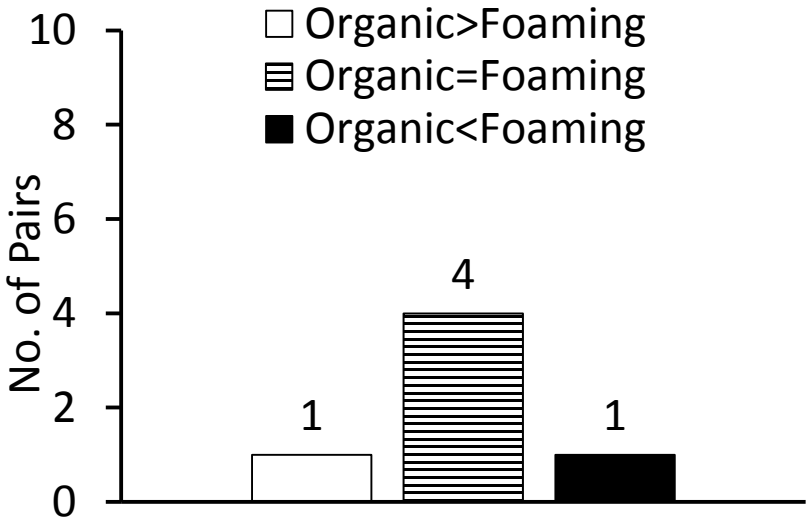
Effect of Pavement Age



2nd Round Rut Depth
Comparison Among WMA





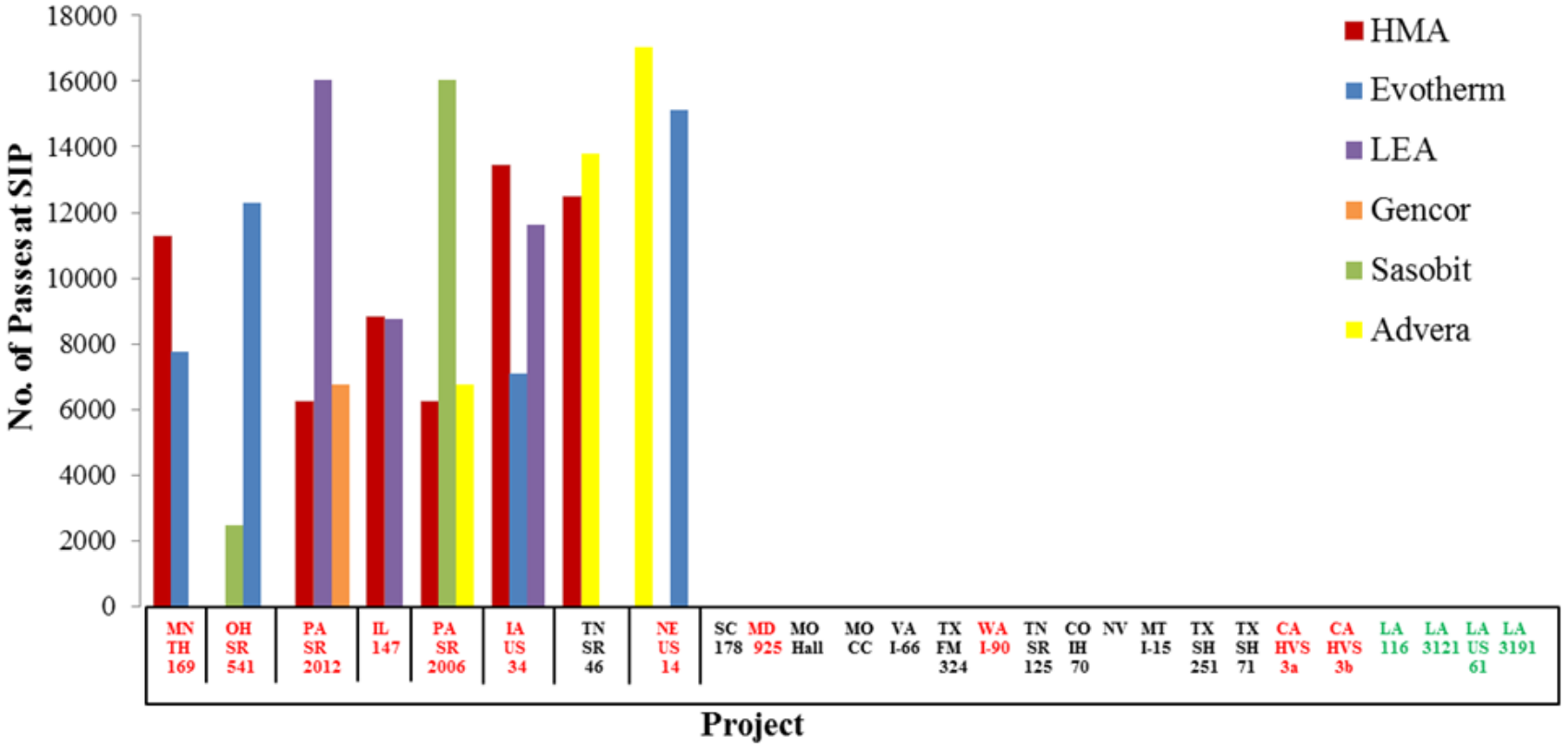


All technologies behave similarly in rut depth

Moisture Susceptibility
Field Performance

- Moisture damage was not observed
  - Both WMA and HMA pavements
  - Consistent with NCHRP 9-49 findings

Moisture Susceptibility
Lab Hamburg Wheel Track Test Results

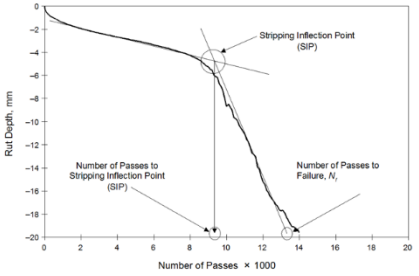


Projects

Red : No anti-strip agent

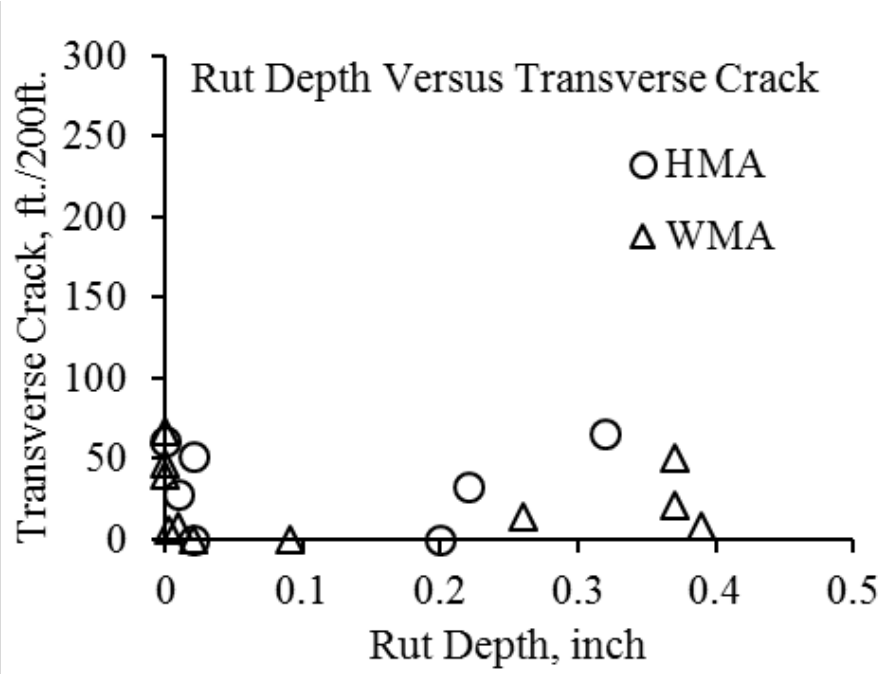
Black : W/ anti-strip agent

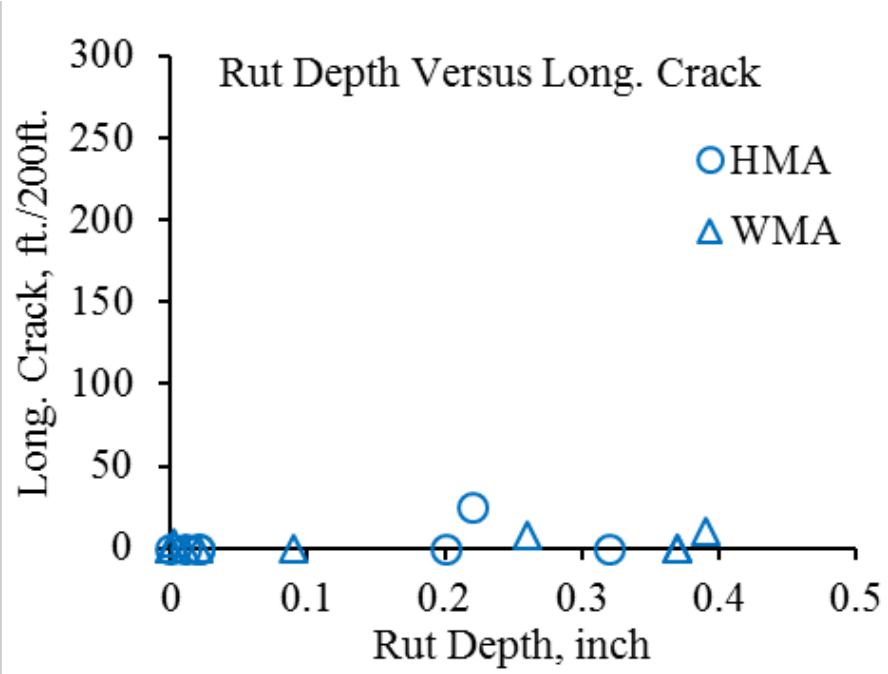
Green : Info not available



Relationship between Rutting and Cracking Performance

Dry Freeze Climatic Zone

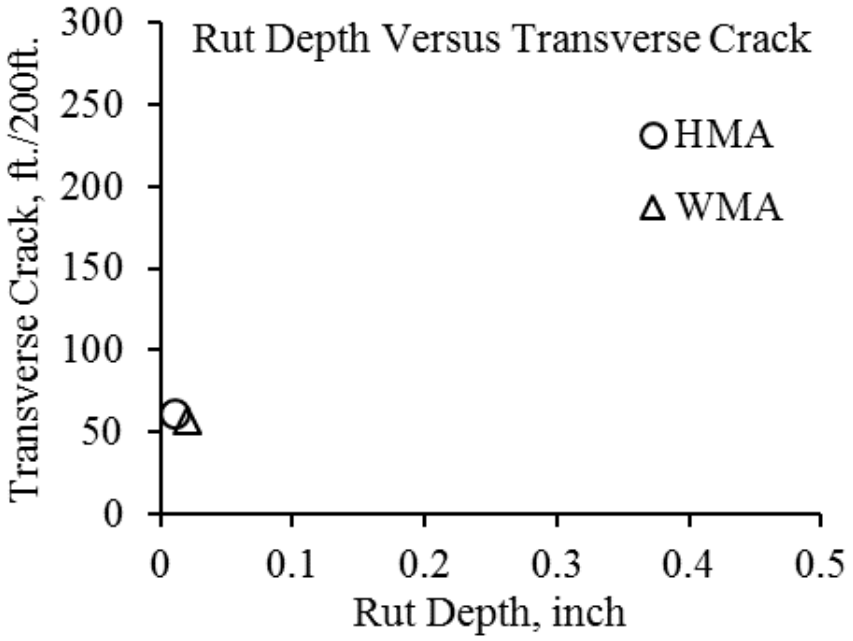


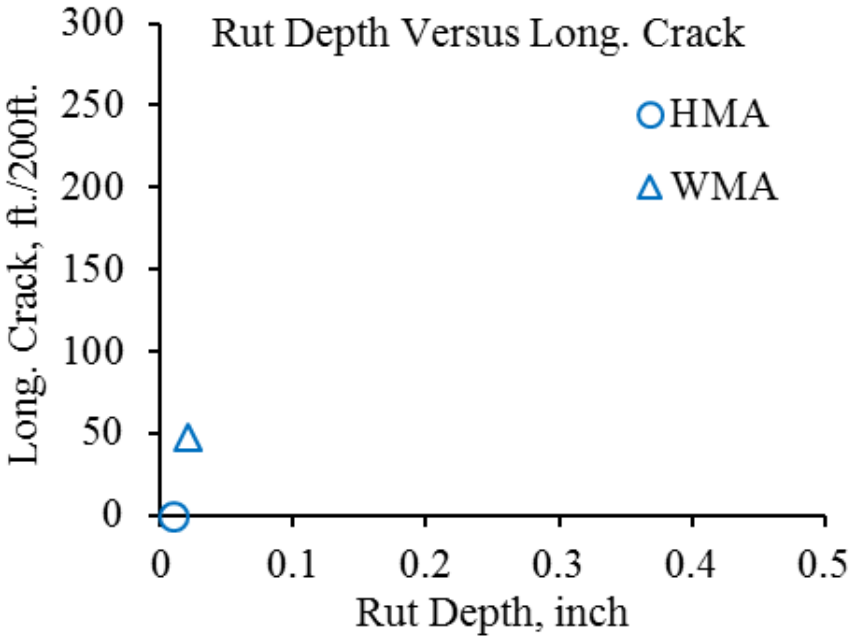


Rutting Dominates

Relationship between Rutting and Cracking Performance

Dry Non-Freeze Climatic Zone

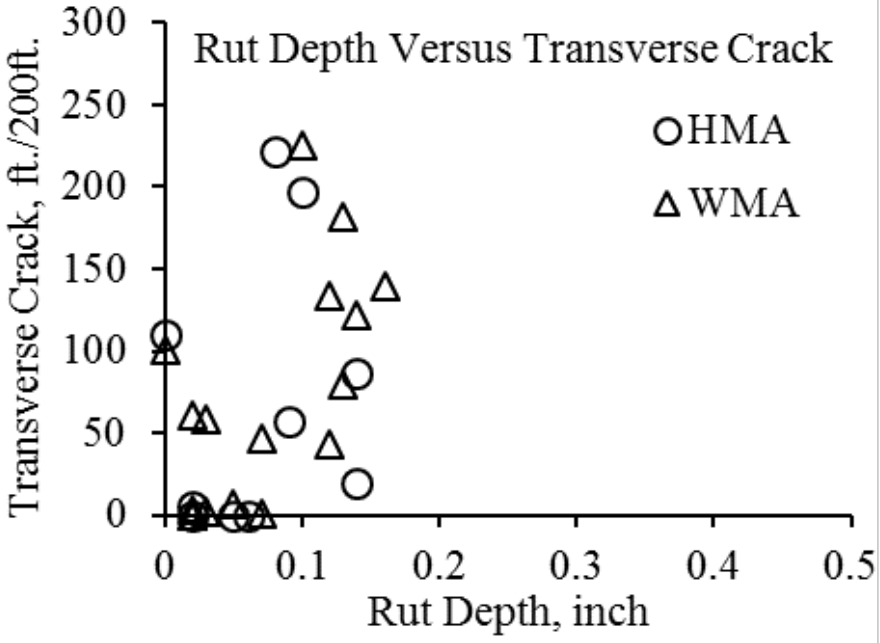


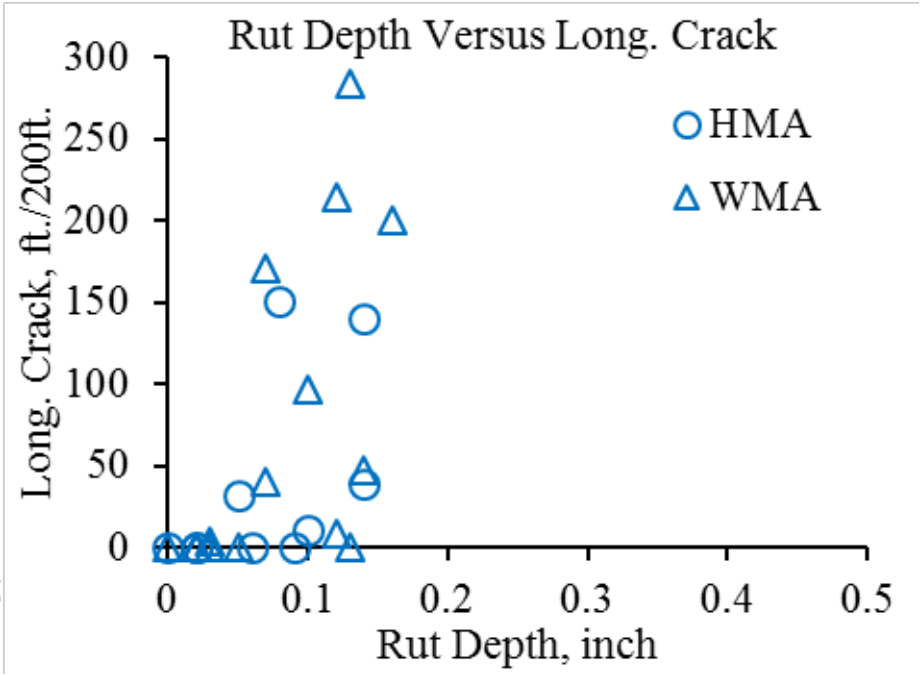


Not Conclusive

Relationship between Rutting and Cracking Performance

Wet Freeze Climatic Zone

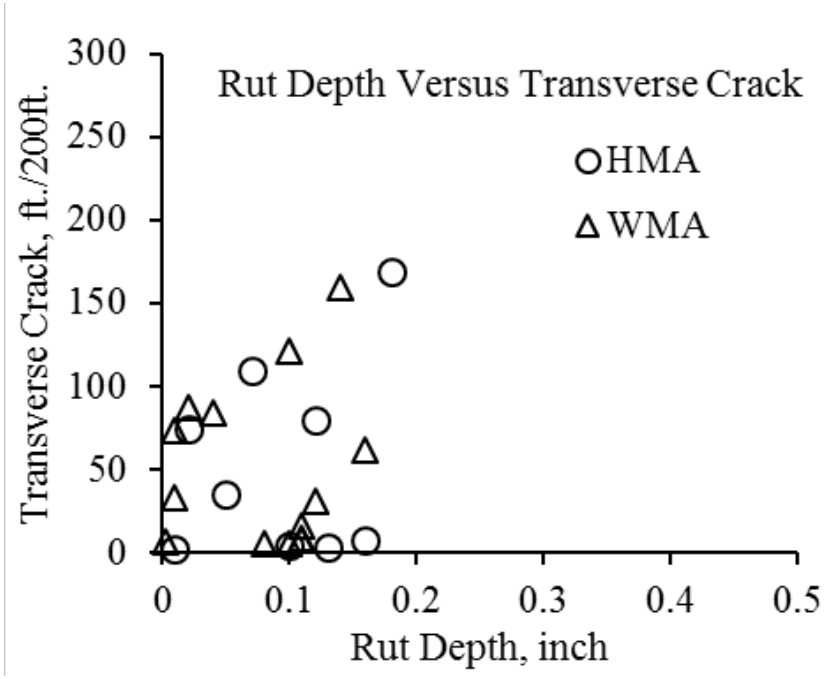


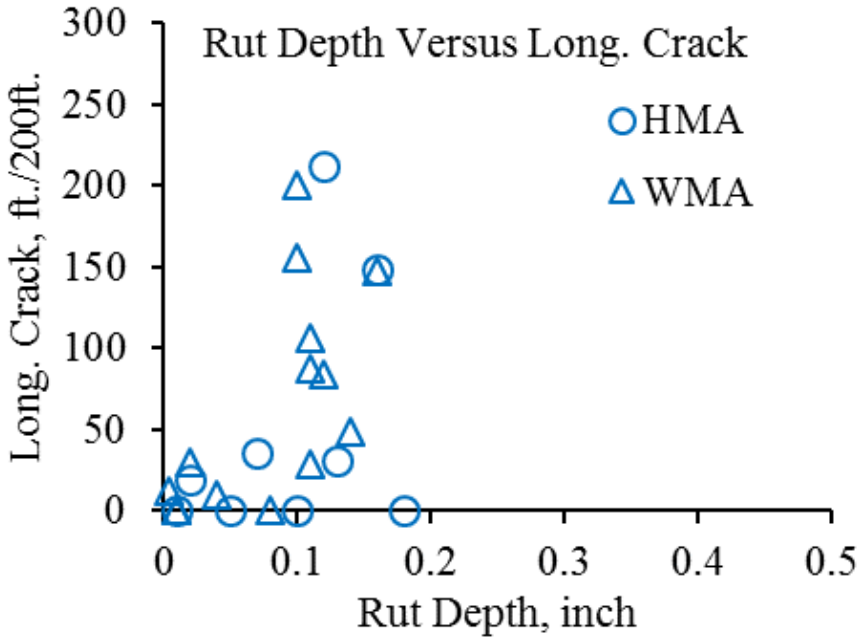


Cracking Dominates

Relationship between Rutting and Cracking Performance

Wet Non-freeze Climatic Zone





Cracking & Rutting

Outline

- Introduction & Objectives
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  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture Susceptibility
- Findings

Findings: Transverse Cracking

- *Transverse cracks* were found to initiate from the top surface of the pavement, but often overlapped with transverse cracks in existing asphalt layer
  - transverse cracking could be a combination of *thermal* and *reflective* cracking.

- *Transverse cracking* performance between HMA and WMA
  - comparable for the majority of HMA and WMA pavements
  - mostly seen in pavements with four or more years of age

- *Transverse cracking* performance among WMAs
  - short-term: comparable for the three WMA technologies
  - longer term: *chemical* and *foaming* appear to be comparable or better than *organic*

Findings: Wheel-path Longitudinal Cracking

- Cracks were found to initiate from surface of pavement
  - may be indicative of top-down fatigue cracking

- Performance comparison between HMA and WMA
  - comparable for the majority of HMA and WMA pavements
  - cracks start to develop mostly at age of 3-4 years; more cracking is seen with 6+ years.

- Performance among WMAs
  - short-term: comparable for the three WMA technologies
  - longer term: *chemical* and *foaming* appear to have comparable or better performance than *organic*

Findings: Rutting & Moisture Susceptibility

- Rutting performance between HMA and WMA pavements, and among WMA technologies is mainly comparable
- Field rut depth starts to build up as early as 3 years; and becomes more differentiable (more than 0.1”) with 6 or more years service.
- Based on field investigation, no moisture-related distress was found in both HMA and WMA pavements.
- Based on laboratory HWT test results, most of mixes without an anti-stripping agent exhibited SIPs
  - The use of anti-stripping agent may be beneficial overall for both HMA and WMA mixtures.

Findings: Overall

- Distress distribution appears to be climatic related.
  - Within dry freeze zone, rutting appears to be the major type of distress, regardless of HMA or WMA
  - Within wet freeze zone, cracking appears dominant
  - Within wet non-freeze zone, cracking and rutting can both happen.

Effect of moisture on cracking ?

List of Publications

1. Zhang, W., S. Shen, Shenghua Wu, Louay Mohammad (in press). Prediction Model for Field Rut Depth of Asphalt Pavement based on Hamburg Wheel Tracking Test Properties, *ASCE Journal of Materials in Civil Engineering*.
2. Wu, S., Zhang, W., Shen, S., Muhunthan, B., & Mohammad, L. N. (in press). Case Study: Evaluation of the Effect of Extraction Temperature on WMA Binder Containing Sasobit Additive. *ASTM Journal of Testing and Evaluation*.
3. Zhang, W., S. Shen, A. Faheem, R. Basak, S. Wu, and L. Mohammad (in press). Predictive Quality of the Pavement ME Design Program for Field Performance of Warm Mix Asphalt Pavement, *Journal of Construction and Building Materials.*
4. Zhang, W., S. Shen, S. Wu, L. Mohammad (2017). Long-term Field Aging of Warm Mix and Hot Mix Asphalt Binders, *Transportation Research Record: Journal of Transportation Research Board (TRB).*
5. Wu, S., W. Zhang, S. Shen, L. Mohammad, B. Muhunthan (2017). Case Study: Short-term Performance and Material Property Evolution of Warm Mix Asphalt and Hot Mix Asphalt Pavements, *Transportation Research Record: Journal of Transportation Research Board (TRB),* No. 2631.
6. Wu, S., H. Wen, W. Zhang, S. Shen, L. Mohammad, A. Faheem, B. Muhunthan (2016). Field Performance of Top-down Fatigue Cracking for Warm Mix Asphalt Pavement, *International Journal of Pavement Engineering*.
7. Shen, S., W. Zhang, L. Shen, H. Huang. (2016). A Statistical Based Framework for Predicting Field Cracking Performance of Asphalt Pavements: Application to Top-down Cracking Prediction, *Journal of Construction and Building Materials, Vol. 116*, Pages 226–234.
8. Haifang Wen, Shenghua Wu, Louay N. Mohammad, Weiguang Zhang, Shihui Shen (2016). Long-term Field Rutting and Moisture Susceptibility Performance of Warm Mix Asphalt Pavement. *Transportation Research Record: Journal of Transportation Research Board (TRB),* No. 2575, pp. 103-112.
9. Shenghua Wu, Haifang Wen, Weiguang Zhang, Shihui Shen, Ahmed Faheem, Louay N. Mohammad (2016). Long-term Field Performance of Transverse Cracking for Warm Mix Asphalt Pavement and Identification of Significant Material Property for Transverse Cracking. *Transportation Research Record: Journal of Transportation Research Board (TRB).*
10. Shen, S., W. Zhang, H. Wang, H. Huang (2016). Numerical evaluation of surface-initiated cracking in flexible pavement overlays with field observations, *Journal of Road Materials and Pavement Engineering*, pp. 1-14.
11. Zhang, W., Shihui Shen, Prasanta Basak, Haifang Wen, Shenghua Wu, Ahmed Faheem, Louay N. Mohammad (2015). Development of Predictive Models for the Initiation and Propagation of Field Transverse Cracks. Transportation Research Record: Journal of Transportation Research Board (TRB), No. 2524, Transportation Research Board, Washington, D.C., pp.92-99.

Thank You!
Any questions?

New Projects

Project	MT I-15	TN SR 125	IA US 34	TX FM 973	LA US 61
Construction Year	2011	2011	2011	2011	2012
Warm Mix Type	Sasobit, Evotherm DAT, Foaming	Evotherm 3G	Sasobit, Evotherm 3G	Evotherm 3G, Foaming	Sasobit, Evotherm 3G
Mixing Temp., °F	H (315-320) W (283-300)	H (320-350) W (290-320)	H (330-340) W (265-280)	H (310-340) W (249-290)	H (325) W (295)
Compaction Temp., °F	H (290-300) W (269-285)	H (311-335) W (275-290)	H (253-265) W (220-239)	H (268-291) W (221-268)	H (277-316) W (245-250)
Design Thickness, in.	2.5	1.25	1.5	2.0	2.0
Traffic	3 million ESALs (3,170 AADT, 26.3% truck)	0.39 million ESALs (3,470 AADT, 13% truck)	3 million ESALs (6,450 AADT, 10.9% truck)	3 million ESALs (11,300 AADT, 4.3% truck)	9 million ESALs (34,138 ADT, 14% truck)
Aggregate	Siliceous	Gravel & Sand	Limestone, Quartzite & Sand	Gravel, Limestone & Dolomite	Granite & Limestone
NMAS, in.	3/4	1/2	1/2	3/4	1/2
Asphalt Binder	PG 70-28	PG 70-22	PG 58-28	PG 70-22	PG 76-22
Anti-stripping Agent	Hydrated Lime, 1.4%	ARR-MAZ, 0.3%	None	None	0.6%
Polymer-modified	SBS	Yes	None	N/A	SBS
Asphalt Content, %	4.6	6.0	5.44	5.2	4.7
Maximum Specific Gravity (G_{mm})	HMA (2.458) Sasobit (2.466) Evotherm (2.459) Foaming (2.453)	HMA (2.352) Evotherm (2.355)	HMA (2.423) Sasobit (2.428) Evotherm (2.429)	HMA (2.406) Evotherm (2.405) Foaming (2.420)	HMA (2.464) Sasobit (2.468) Evotherm (2.464)
Sampling Date	Sep. 15-17, 2011	Oct. 24-31, 2011	Sep. 6, 2011	Dec. 1, 2011	May 16-June 6, 2012
RAP or RAS	None	10% RAP	17% RAP	None	15% RAP
Structure	2.5'' overlay + 7'' existing HMA + 16.2'' base (non-stabilized) + infinite subgrade	1.25'' overlay + 8'' bituminous base + 6'' min. aggregate base + infinite subgrade	HMA & Sasobit: 1.5'' overlay + 5'' existing HMA + 7'' PCC + subgrade Evotherm: 1.5'' overlay + 3'' existing HMA + 9'' PCC + subgrade	2'' overlay + 8'' existing HMA + 10'' base + 141.1'' subgrade (lean clay)	2'' overlay + 8'' existing HMA + 8'' PCC + 6'' cement-treated soil subgrade

In-service Projects – Wet Freeze Zone

Project	MD 925	MO Hall St.	MO Rte. CC	MN TH 169	OH SR 541	PA SR 2012	VA I-66	IL 147	PA SR 2006
Construction Month/Year	9/2005	5/2006	2007	7/2010	9/2006	5-6/2009	7/2010	6/2010	5/2009
Warm Mix Type (content, %, by weight of binder)	Sasobit	Sasobit (1.5); Evotherm ET; Aspha-min (0.3)	Evotherm DAT	Evotherm 3G	Sasobit (1.5); Evotherm ET (5.3 by mix); Aspha-min (0.3)	LEA, Gencor (0.5)	Astec DBG	Astec DBG	Sasobit, Advera
Production Temp., °F	HMA (310-350); Sasobit (270-310)	HMA (320); Sasobit (240); Evotherm (225); Aspha-min (275)	HMA (320); Evotherm (280-290)	HMA (300); Evotherm (265)	HMA (320), Sasobit (260); Evotherm (235); Asphamin (245)	HMA (290-310); Gencor (250-265); LEA (240-260)	HMA (317); Astec DBG (288)	HMA (300); Astec DBG (270)	HMA (310), Sasobit (265); Advera (260)
Traffic (AADT)	10,480	21,000	8618	12,600	650	254	57,000	775	523
Aggregate	N/A	Limestone Steel Slag	Limestone	N/A	Limestone	Limestone	N/A	Limestone	Limestone
NMAS, in.	3/8	1/2	1/2	3/4	3/8	3/8	1/2	1/2	3/8
Asphalt Binder	64-22	70-22	64-22	58-28	70-22	64-22	76-22	64-22	64-22
Anti-stripping Agent	None	ARR MAZ, 0.25%	Pave Bond Lite, 0.25%	None	None	None	Pave Bond Lite, 0.5%	None	None
Asphalt Content, %	5.0	5.3	5.4	4.2	6.1	5.9	H (5.0); W (5.4)	5.0	6.0
G_{mm}	2.519	2.451	2.469	2.549	2.429	2.476	H (2.62); W (2.605)	H (2.450); W (2.47)	H (2.467); Sasobit (2.462); Advera (2.469)
Sampling Date	6/28/12	7/16-18/12	7/17/12	8/28/12	6/18/12	6/26/12	6/26/12	7/19/12	6/21/12
RAP	15%	10%	20%	N/A	15%	None	N/A	10%	None
Structure	2" + 5" HMA + 8" Macadam stone	1.75" + 12" PCC + 0-3" base	3.75" + 7" PCC + 6" base	2" + 8" HMA + 6" base	1.25" + 6.75" HMA + 9" granular base	1.5" + 5" HMA + 4" aggregate base	1.5" + 5" HMA + 9" + 10" base	1.5" + 9" HMA	1.5" + 5" HMA + 4" stone base

In-service Projects – Wet Non-Freeze Zone

Project	SC US 178	TN SR 46	TX FM 324	LA 116	LA 3191	LA 3121
Construction Month/Year	9/2007	10/2007	2-3/2008	3/2010	11/2008	3/2009
Warm Mix Type	Evotherm DAT	Sasobit, Evotherm DAT, Astec DBG, and Advera	Sasobit, Evotherm DAT, Rediset, Advera	Foam	Astec Foam	Evotherm 3G
Production Temp., °F	HMA (295); Evotherm (240)	HMA Danley (320-350); HMA Franklin (320-350); Sasobit (250); Evotherm DAT (240); Advera (250); DBG (260)	H (330); W (240)	N/A	N/A	N/A
Traffic (AADT)	3880	4440	1450	2600	ADT 200	ADT 400
Aggregate	N/A	Limestone	Limestone	N/A	N/A	N/A
NMAS, in.	3/8	1/2	3/8	1/2	1/2	1/2
Asphalt Binder	64-22	70-22	64-22	70-22	70-22	70-22
Anti-stripping Agent	N/A	Franklin (AD-Here 77-00, 0.3%); Astec DBG (Pavegrip 650, 0.3%)	1% Lime	N/A	N/A	N/A
Asphalt Content, %	H (5.3); W (5.4)	5.3	4.6	4.4	5.2	5.1
G_{mm}	H (2.460) W (2.463)	HMA Danley (2.428); Sasobit (2.411); Evotherm (2.410); Astec DBG (2.444); Advera (2.422); HMA Franklin (2.425)	HMA, Sasobit, Evotherm (2.508); Advera Rediset (2.498)	H (2.525) W (2.541)	H (2.453) W (2.486)	H (2.507) W (2.490)
Sampling Date	07/27/12	07/24/12	2/6-8/13	05/21/13	05/21/13	05/20/13
RAP	N/A	None	None	15	15	15, 30
Structure	2" overlay + 5.7" HMA + 7.1" PCC + sand clay base	1.25" overlay + 4.26" HMA + 6" crushed stone	1.5" overlay + 5.7" HMA + 10" base	1.5" overlay + 5" HMA + 8.5" base	2" HMA + 6" HMA + 7" PCC	2" overlay + 12" cement-treated base

In-service Projects – Dry Freeze Zone

Project	WA I-90	WA SR 12	CO IH 70	NE US 14	NV
Construction Month/Year	6/2008	4/2010	7-8/2007	2008	8/2010
Warm Mix Type	Sasobit	Aquablack	Sasobit (1.5% by mass of binder); Evotherm DAT (0.5% of binder); Advera (0.3% of mixture)	Advera, Evotherm DAT	Ultrafoam
Production Temp., °F	HMA (330), Sasobit (276)	HMA (325), Aquablack (275)	HMA (mixing 310, compaction 280); Sasobit (255, 235); Evotherm (250, 230); Advera (255, 235)	H (330), W (275)	H (330), W (275)
Traffic (AADT)	13,000	6,550	30,000	2,140	5,000
Aggregate	Basalt	Basalt	Crushed River Rock	Limestone, Gravel	N/A
NMAS, in.	1/2	1/2	1/2	1/2	1/2
Asphalt Binder	76-28	64-28	58-28	64-28	64-28
Anti-stripping Agent	None	Superbond (0.25%)	Hydrated Lime (1% by mass of aggregate blend)	None	Hydrated Lime, 1.5%
Asphalt Content, %	5.5	5.2	6.3	5.0	4.6
G_{mm}	2.601	2.596	2.45	H-Adv (2.439), H-Evo (2.441)	2.451
Sampling Date	8/27/12	8/28/12	10/18/12	10/14/12	10/19/12
RAP, %	15-20	20	None	<15	15
Structure	3" overlay + 11.28" HMA + 6.5" base (HMA)/5" base (Sasobit)	3" overlay + 7.8" HMA + 9" base	2.5" overlay + 10-11" HMA	3" overlay + 4" HL slurry stabilization + 1.5" existing asphalt + 4" bit sand base	6" HMA + 9" aggregate base

In-service Projects – Dry Non-Freeze Zone

Project	TX SH 251	TX SH 71	CA HVS 3a	CA HVS 3b
Construction Month/Year	8/2008	6/2008	9/2009	9/2009
Warm Mix Type	Astec DBG	Evotherm DAT	Gencor, Evotherm DAT, Cecabase	Sasobit, Advera, Astec DBG, Rediset
Production Temp., °F	H (310) W (270)	H (330) W (240)	HMA (320), Gencor (284), Evotherm (248), Cecabase (266)	HMA (335, 279), Sasobit (300,279), Advera (295,266), Astec DBG (295,257), Rediset (285,258)
Traffic (AADT)	2,300	57,000	HMA (74,000), Gencor (159,000), Evotherm and Cecabase (160,000)	HMA, Sasobit, Astec DBG and Rediset (160,000), Advera (50,000)
Aggregate	Limestone	Limestone	Granite	Reed
NMAS, in.	3/8	3/8	1/2	1/2
Asphalt Binder	70-22	76-22	64-16	64-16
Anti-stripping Agent	1% Akzo	0.8% Liquid	None	None
Asphalt Content, %	5.1	4.8	7.0	8.3
G_{mm}	H (2.45), W (2.4)	2.416	H (2.503)	H (2.505)
Sampling Date	2/5/13	2013	2012	2012
RAP, %	None	N/A	Rubber (18% of binder)	Rubber (18% of binder)
Structure	2.0" overlay + 4.3" HMA	2" overlay + HMA	2.5" gap-graded rubberized HMA + 2.5" HMA + 15.6" base	2.5" gap-graded rubberized HMA + 2.5" HMA + 15.6" base