NCHRP 20-44(01)
Increasing WMA Implementation by Leveraging the State-of-the-Knowledge Overview

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Increasing WMA Implementation by Leveraging the State-of-the-Knowledge

- Background
- Defining WMA
- Objectives
- Webinars
- Workshop

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Background

- Industry Scan Tour
- Industry, state and national level research
- Various WMA technologies developed including foam, waxes and other specialty chemicals

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NCHRP Studies

- 9-43 - Mix Design Practices for WMA
- 9-47- Engineering Properties, Emissions and Field Performance of WMA Technologies
- 9-47A - Properties and Performance of WMA Technologies
- 9-49 - Performance of WMA Technologies: Stage I-Moisture Susceptibility
- 9-49A - Performance of WMA Technologies: Stage II-Long Term Field Performance
- 9-52 - Short Term Laboratory Conditioning of Asphalt Mixtures

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NCHRP Studies (Cont)

- 9-53 - Properties of Foamed Asphalt for Warm Mix Asphalt Applications
- 9-54 - Long Term Aging of Asphalt Mixtures for Performance Testing and Prediction
- 9-55 - Recycled Asphalt Shingles in Asphalt Mixtures with WMA Technologies
- 9-58 - Effects of Recycling Agents on Asphalt Mixtures w/High RAS & RAP Binder Ratios
- 20-07/311 - Development of a WMA Tech. Evaluation Program
- TOTAL COST - $7,504,5012

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Defining WMA

The use of foams, waxes and other specialty chemicals to:

- Lower production temperatures
- Reduce emissions
- Reduce energy consumption
- Extend construction seasons and days
- Opportunity for more uniform and higher density extended to higher quantity RAP/RAS mix designs (density of stiffer mixes)

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Project Objectives

- Identify barriers encountered by state DOTs where WMA technologies remain to be implemented
- Assist those agencies who have yet to embrace WMA
- Identify continuing knowledge gaps
- Establish and update implementation performance indicators to provide a better picture of WMA implementation nationwide
- Develop a series of webinars to provide common ground for understanding and a two-day workshop to identify barriers and provide peer leadership for lagging states

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Webinars

Provide a series of topical Webinars to deliver NCHRP Study products to reach common background knowledge.

- Overview of WMA History, Development and Usage
- Mix Design Properties of WMA
- Laboratory Conditioning of WMA for Short and Long Term Ageing
- Inclusion of Recycled Materials and other Additives with WMA Technologies
- Successful Implementation and Field Performance of WMA

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Workshop

Provide a two-day workshop for lead states, lagging states and industry partners

- Workshop will be structured to provide two or more breakout sessions each composed of 5-6 topic areas. Barriers and impediments will be identified
- Targeted to showcase successful implementation activities so barriers and risk can be lowered for those states using limited or no WMA
- Provide sufficient detail for modification of specifications and construction practices
- Identify Performance Measures/Indicators

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Warm Mix Brief 1-1
Overview of NCHRP Project 20-44(01)

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NCHRP Project 20-44(01)
Principal Investigator

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OUTCOMES

By the end of Warm Mix Brief 1-1, you will:

- Understand the purpose of the 2-day workshop for NCHRP project 20-44
- Be able to identify how this project will support the implementation of WMA

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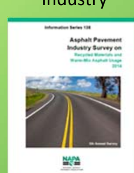
WARM MIX BRIEF 1-1

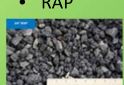
- State

Industry



NCHRP

- RAP



Additives & recycling agents

RAS

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WARM MIX BRIEF 1-1

- A common definition of Warm Mix Asphalt - - a key outcome of 2-day Workshop
- FHWA Long Term Pavement Performance (LTPP) defines WMA as:

“asphalt mixtures produced at either 275^{o}F or less, or at 30^{o}F below HMA production temperature”

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WARM MIX BRIEF 1-1

NCHRP Project 20-44(01): *Increasing WMA Implementation by Leveraging the State-of-Knowledge*

OBJECTIVES

- Identify barriers to broader use and implementation of WMA
- Review definitions for WMA and details of WMA specifications
- Update performance criteria for WMA based on agencies and industry feedback
- Improve and expand tracking mechanisms for WMA usage

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WARM MIX BRIEF 1-1

NCHRP Project 20-44(01): *Increasing WMA Implementation by Leveraging the State-of-Knowledge*

Project Team

Dr. Leslie Myers McCarthy

Dr. Jo Daniel

Ms. Lee Friess

Project Panel Members

Dr. Edward Harrigan, NCHRP
Dr. Nelson Gibson, TRB
Mr. Harold (Skip) Paul, Consultant
Dr. Audrey Copeland, NAPA
Mr. Tim Aschenbrener, FHWA
Dr. Rebecca McDaniel, Purdue Univ.
Dr. Ervin Dukatz Jr., Mathy Construction
Mr. Frank Fee, Consultant

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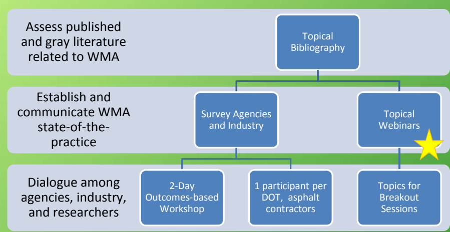
WARM MIX BRIEF 1-1

NCHRP 20-44(01) Elements: *Project Approach*



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WARM MIX BRIEF 1-1

NCHRP 20-44(01) Elements: *Survey of Agencies and Paving Industry*

Purposes of Survey:

- Definitions of WMA
- Update 2010 Survey for AASHTO NTPEP and 2014 FHWA-NAPA Survey
- Identify barriers to better adoption of tools for WMA implementation
- Identify observed or perceived challenges with increased usage of WMA

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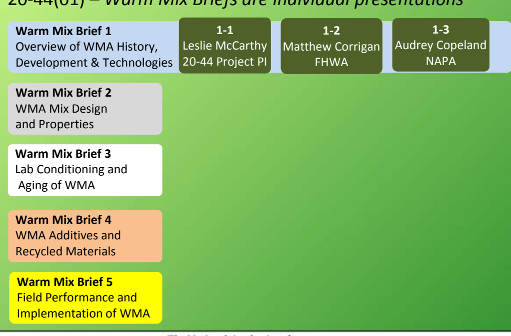
WARM MIX BRIEF 1-1

NCHRP 20-44(01) – *Warm Mix Briefs are individual presentations*



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WARM MIX BRIEF 1-1

NCHRP 20-44(01) *Topical Webinars – Warm Mix Briefs*

Purposes of Warm Mix Briefs:

- Each standalone presentation provides the audience with a common knowledge basis and background on WMA
- Each presentation may spark ideas to bring forward to the 2-day workshop (please consider taking notes)

After this webinar, please complete the assessment for Warm Mix Brief #1 on Survey Gizmo:

http://www.surveygizmo.com/s3/3316133/NCHRP20-44-WarmMixBrief-1

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WARM MIX BRIEF 1-1

NCHRP 20-44(01) Elements: *2-Day Outcomes-based Workshop*

★ May 8 and 9, 2017 ★
Tentative Location:
★ Irvine, California ★

State DOT travel and lodging costs will be sponsored by NCHRP

Outcomes will relate to:

- Updated methodology for WMA usage
- Updated tools for tracking WMA performance

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WARM MIX BRIEF 1-1

NCHRP 20-44(01) Elements: *Post-Workshop Activities*

Products Outcomes of 2-Day Workshop:

- Workshop proceedings, including results and a vision for the future of WMA
- Sample specifications for implementation of WMA
- Suggestions for establishing a WMA Community of Practice
- Develop research needs statements for TRB, AASHTO, NAPA and FHWA

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OUTCOMES REVIEW

- Explain the purpose of the 2-day workshop for NCHRP project 20-44(01)

Jot down 2 ideas of how you can contribute to the goals of the 2-day workshop

- Identify needs that must be met to support further implementation of WMA

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Warm Mix Brief #1-2

History of WMA and Initiatives in the U.S.

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matthew.corrigan@dot.gov

OUTCOMES

By the end of this Warm Mix Brief 1-2, you will be able to:

- Name the general WMA technology categories
- Identify the national efforts made to-date in the US to further WMA implementation
- Compare the statistics relating WMA production to total asphalt production in the US over the past decade

WMA: Where have we been?

2004-05	**2014-16**
Number of named WMA technologies in the U.S.?	Number of named WMA technologies in the U.S.?
3	30+

WMA Technology Market in US**

- EUROVIA
- EVOTHERM / Ingevity
- MEEKER
- PQ Corporation
- sasol
- AESCO MADSEN
- Shell
- KOLO VEIDEKKE
- Mathy Tech. & Eng. Services and Paragon Technical Services, Inc
- sonneborn
- Thiopave
- CECA ARKEMA GROUP
- ASTEC
- Stansteel
- tea-co
- M'CONNAUGHAY
- AKZO NOBEL
- ITERCHIMICA
- GENCOR INDUSTRIES INC.
- ASPHALT INNOVATIONS A MeadWestvaco Business
- Lake Asphalt of Trinidad and Tobago
- MAXAM
- TEREX Roadbuilding
- TARMAC INTERNATIONAL, INC.

Other named technologies are also available in the market.

General Technology Categories

- Material Processing
  - Ex. LEA (Hot Coated Coarse Agg + Moist Fine Agg + Additives)
- Organic Additives
  - Waxes, Zeolite
- Chemical Additives
  - Surfactants
- Foaming Processing
  - Water Injection, Zeolite
- Hybrid Systems
  - Ex. H_20 + Surfactant

Commercially-Available Laboratory Foaming Devices

WMA Efforts: A Look Back

2004-05

No. of WMA Technical Working Groups?

0

2014-16

No. of WMA Technical Working Groups?

0

Stakeholder Engagement: WMA Technical Working Group

Established in 2005
Adjourned in 2012

Co-Chairs:
Matthew Corrigan

Ron White

Dissemination of Information on WMA

2004-05

No. of WMA International Conferences?

0

2014-16

No. of WMA International Conferences?

2

International WMA Conferences

1st Conference on November 11-13, 2008 in Nashville, TN

Processes, Mix Production & Placement, Energy consumption, Mix Design, Material Properties

2nd Conference October 11-13, 2011 in St. Louis, MO

Lab & Field Properties, Design & Performance, Health & Environment, RAP w/ WMA, Binder & Mix Properties, Moisture Susceptibility, Construction, etc.

FHWA International WMA Scan Tour

- Joint Program with FHWA, AASHTO, NCHRP, and Industry
- Publication FHWA-PL-08-007
- Scan Final Report
  - .pdf available at http://international.fhwa.dot.gov/pubs/pl08007/index.cfm

National Research Efforts on WMA

2004-05	Feb 2017
Number of WMA NCHRP Research Projects?	Number of WMA NCHRP Research Projects?
0	12

NCHRP Projects Funded as a Result of WMA TWG Efforts

9-43	-Mix Design Practices for WMA	$522,501	Completed
9-47	-Engineering Properties, Emissions, and Field Performance of WMA Technologies	$79,000	Completed
9-47A	-Properties and Performance of WMA Technologies	$1,121,000	Completed
9-49	-Performance of WMA Technologies: Stage I--Moisture Susceptibility	$450,000	Completed
9-49A	-Performance of WMA Technologies: Stage II--Long-Term Field Performance	$900,000	Completed
9-52	-Short-Term Laboratory Conditioning of Asphalt Mixtures	$800,000	Completed
9-53	-Properties of Foamed Asphalt for Warm Mix Asphalt Applications	$700,000	Completed
9-54	-Long-Term Aging of Asphalt Mixtures for Performance Testing and Prediction	$800,000	Phase 2 Underway
9-55	-Recycled Asphalt Shingles in Asphalt Mixtures with WMA Technologies	$600,000	Phase 2 Underway
9-58	-Effects of Recycling Agents on Asphalt Mixtures w/High RAS & RAP Binder Ratios	$1,500,000	Oct 2017
20-07(311)	-Development of a WMA Tech. Evaluation Program	$50,000	Completed
20-44(01)	-Increasing WMA Implementation by Leveraging State-of-Knowledge	$150,000	Jan 2018

NCHRP Projects Funded as a Result of WMA TWG Efforts

9-43	-Mix Design Practices for WMA	$522,501	Completed
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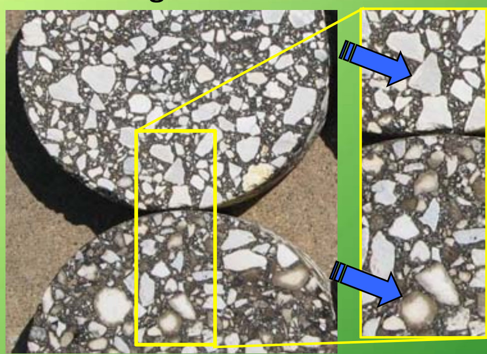
9-58	-Effects of Recycling Agents on Asphalt Mixtures w/High RAS & RAP Binder Ratios	$1,500,000	Oct 2017
20-07(311)	-Development of a WMA Tech. Evaluation Program	$50,000	Completed
20-44(01)	-Increasing WMA Implementation by Leveraging State-of-Knowledge	$150,000	Jan 2018

Total $7,672,501

Mix Design Considerations

WMA

240°F



HMA

330°F

NTPEP National Transportation Product Evaluation Program

- NCHRP 20-07/ Task 311 **Development of a Warm Mix Asphalt Technology Evaluation Program**
  - Myers McCarthy Consulting Engineers, LLC
  - http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3075
- AASHTO NTPEP Program for evaluating WMA technologies was developed www.ntpep.org

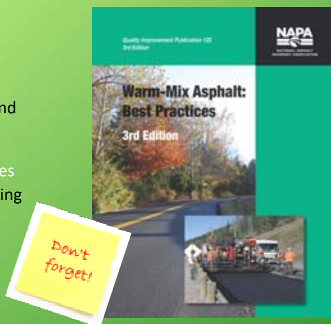
Publications: WMA Best Practices

2004-05	2014-16
Number of WMA Best Practices Publications?	Number of WMA Best Practices Publications?
0	3

Quality Improvement Series 125

3rd Edition

- Stockpile Moisture Management
- Burner Adjustments and Efficiency
- Aggregate Drying and Baghouse Temperatures
- Drum Slope and Flighting
- Combustion Air
- RAP usage
- Placement Changes



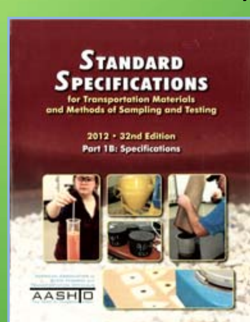
AASHTO: Test Standards on WMA

2004-05	**2014-16**
Number of AASHTO Standards on WMA?	Number of AASHTO Standards on WMA?
0	2

AASHTO R35 Appendix: Commentary

"Special Mixture Design Considerations and Methods for WMA"

Approved by AASHTO Subcommittee on Materials and published: *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* (32nd Edition, 2012)



AMPT Flow Number Standardization

Published as Appendix within AASHTO TP 79-13

X1. EVALUATE RUTTING RESISTANCE USING THE FLOW NUMBER TEST

X1.1 *Scope:*

X1.1.1 This procedure establishes a method to evaluate the rutting resistance of asphalt paving mixtures using the TP 79, Flow Number test in the AMPT.

X1.2 *Procedure:*

X1.2.1 Input the test parameters listed in Table X1.2.1 Ito the AMPT control software for the Flow Number test.

Table X1.2.1 – TP 79 Flow Number Test Conditions

Test Parameter	HMA	WMA
Test Temperature	1-	1-
Deviator Stress	87 psi (600 kPa)	87 psi (600 kPa)
Contact Stress	5% of deviator stress	5% of deviator stress
Confining Stress	0 psi (0 kPa)	0 psi (0 kPa)

1- Determine the project design temperature using LTPPBind version 3.1; computed using 50% reliability, at a 20 mm depth for surface courses and the top of the pavement layer for intermediate and base courses.

X1.2.2 Determine the flow number for each specimen, and average the results. Compare the average flow number with the criteria in Table X1.2.2.

Table X1.2.2 – Minimum Flow Number Requirements

Traffic Level, million ESAL's	HMA, minimum Flow Number	WMA, minimum Flow Number
< 3	---	---
3 to < 10	50	30
10 to < 30	190	105
> 30	740	415

WMA Production: How Has It Grown?

2004-05

Number of WMA tons produced annually?

0

2015

Number of WMA tons produced annually?

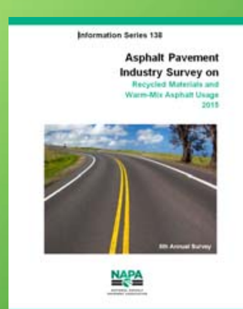
120 million

Information Series 138

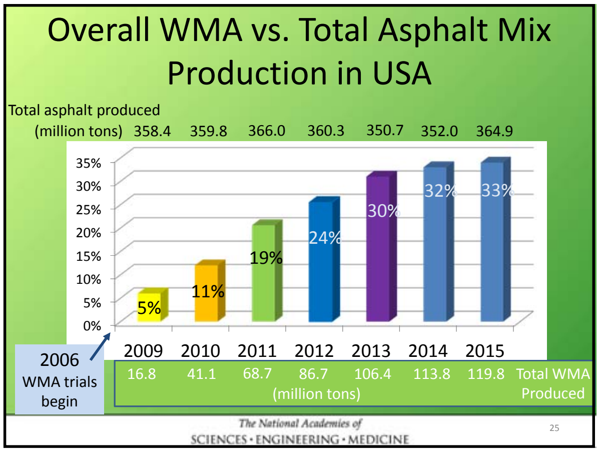
6th Annual Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2015

(release pending)

Product of FHWA & NAPA Cooperative Agreement Contract



www.asphaltpavement.org/recycling


Overall WMA vs. Total Asphalt Mix Production in USA
Total asphalt produced (million tons) 358.4 359.8 366.0 360.3 350.7 352.0 364.9
35% 30% 25% 20% 15% 10% 5% 0%
5% 11% 19% 24% 30% 32% 33%
2009 2010 2011 2012 2013 2014 2015
2006 WMA trials begin
16.8 41.1 68.7 86.7 106.4 113.8 119.8 Total WMA Produced
(million tons)
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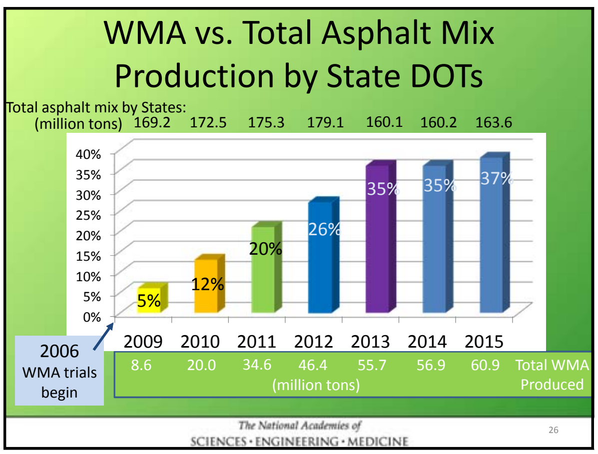
WMA vs. Total Asphalt Mix Production by State DOTs
Total asphalt mix by States: (million tons) 169.2 172.5 175.3 179.1 160.1 160.2 163.6
40% 35% 30% 25% 20% 15% 10% 5% 0%
5% 12% 20% 26% 35% 35% 37%
2009 2010 2011 2012 2013 2014 2015
2006 WMA trials begin
8.6 20.0 34.6 46.4 55.7 56.9 60.9 Total WMA Produced
(million tons)
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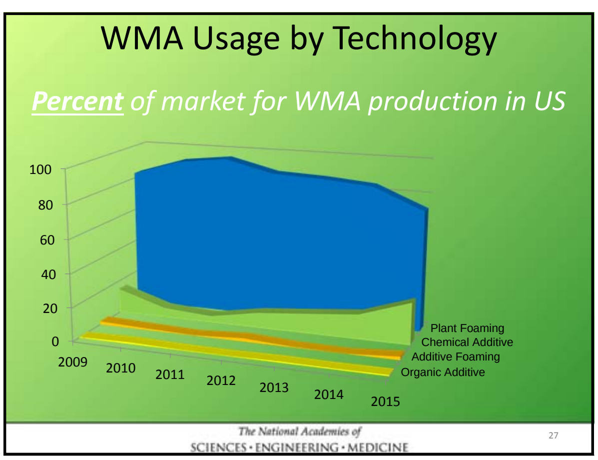
WMA Usage by Technology
Percent of market for WMA production in US
100 80 60 40 20 0
2009 2010 2011 2012 2013 2014 2015
Plant Foaming
Chemical Additive
Additive Foaming
Organic Additive
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FHWA Efforts: Focus on WMA Projects

2004-05

Number of WMA projects evaluated by FHWA?

0

2014-16

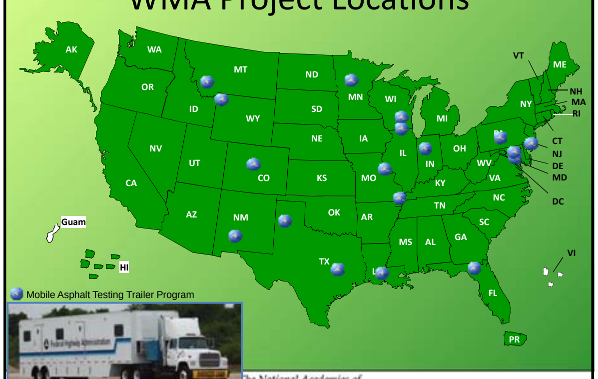
Number of WMA projects evaluated by FHWA?

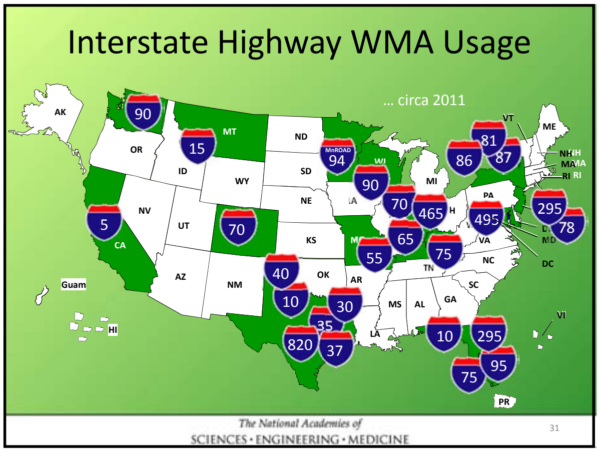
18

FHWA Field Technology Support

- Mobile Asphalt Pavement Testing Trailer (MATT)
  - Site Visits to WMA Construction Projects
  - Field Data Collection and Testing
  - Use and Demonstration of Emerging Test Devices
  - Contact: Matthew Corrigan, P.E.

WMA Project Locations




Interstate Highway WMA Usage
… circa 2011
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WMA Project
Yellowstone
National Park


WMA Project
Big Bend
National Park

"The collective efforts from highway agencies and industry partners to advance warm mix asphalt technologies as a standard practice has been tremendous."
- U.S. DOT Federal Highway Administration

"[We] support the development and implementation of warm-mix asphalt … this will inevitably become the standard practice for asphalt mixture production."
- Global Asphalt Pavement Alliance

"WMA is the future of flexible pavements in the U.S. … lowering our production and paving temperatures promises improved energy consumption, operations, and quality."
-Mike Acott, President, NAPA

"WMA technology provides an important tool to the pavement engineer … designers and contractors alike now have a great opportunity to learn more about this promising practice which is revolutionizing the paving industry in North America."
-Pete Grass, President, Asphalt Institute

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OUTCOMES REVIEW

- Name the general WMA technology categories
- Identify the national efforts made to-date in the US to further WMA implementation
- Compare the statistics comparing WMA to total asphalt production in the US over the past decade

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Warm Mix Asphalt Project

Questions? Please contact us

WMAPROJECT.20.44@gmail.com

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Warm Mix Brief #1-3
National Perspectives & Initiatives

Audrey Copeland, PhD, PE
National Asphalt Pavement Association
Audrey@asphaltpavement.org


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OUTCOMES

By the end of this Warm Mix Brief 1-3, you will understand:

- The state-of-practice of the industry influencing WMA use
- The benefits of WMA
- Benchmarks, improvement efforts, & resources for WMA use
- Technologies for expanding use of WMA

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U.S. PRACTICE & CHALLENGES

- Volumetric Mix Design
- Higher RAP Contents
- Contractors Fractionating
- Use of Reclaimed Asphalt Shingles
- More states specifying binder replacement (or equivalent)
- No consensus on cracking performance testing
- WMA use continues to grow
  - (in most areas)

Warm-Mix Asphalt

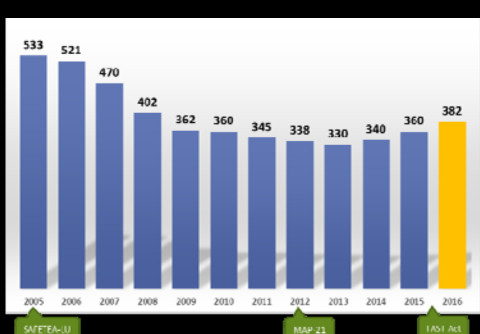
- **Reduced Mixing temperatures (50º-100º F)**

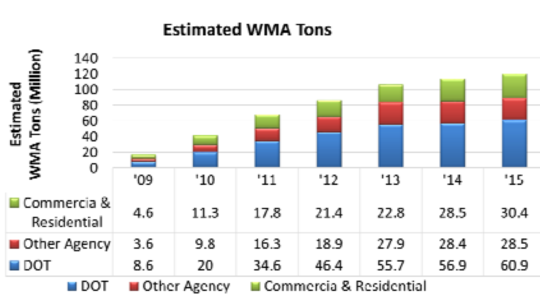
AMERICA RIDES ON US Asphalt.

Benefits of Warm Mix Asphalt

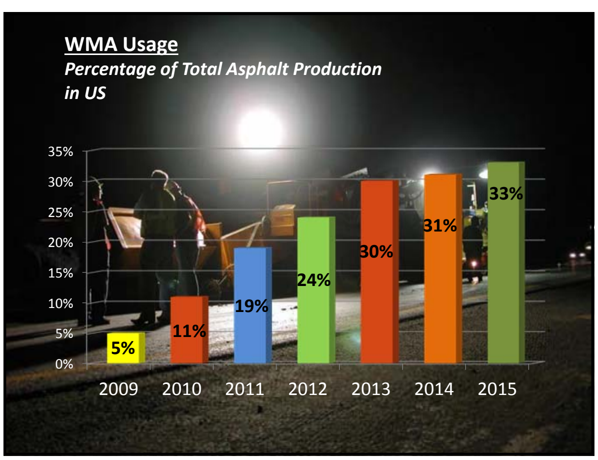
Tons of HMA/WMA Produced Nationally

(in millions)

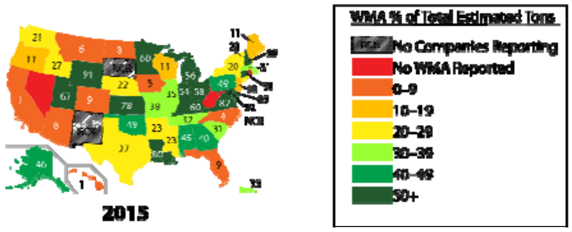




	'09	'10	'11	'12	'13	'14	'15
Commercia & Residential	4.6	11.3	17.8	21.4	22.8	28.5	30.4
Other Agency	3.6	9.8	16.3	18.9	27.9	28.4	28.5
DOT	8.6	20	34.6	46.4	55.7	56.9	60.9



Percent WMA Used by State



Where to find the latest survey report:

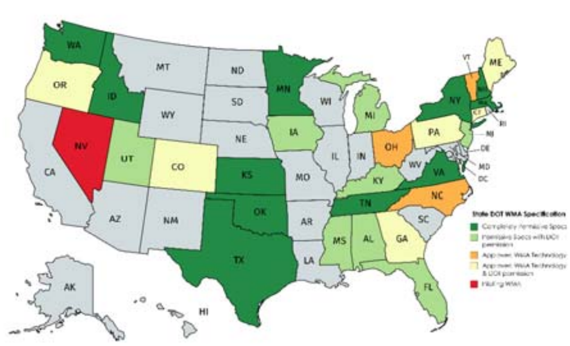
Information Series 138

Asphalt Pavement Industry Survey on
Recycled Materials and Warm-Mix Asphalt Usage 2014

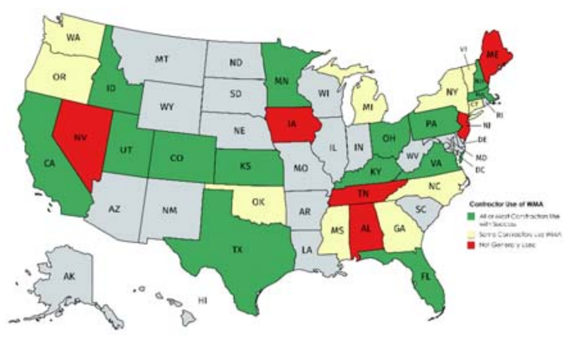
NAPA

www.asphaltpavement.org/recycling

State DOT WMA Specifications



Contractor Use of WMA



U.S. Department of Transportation
Federal Highway Administration

NAPA

Working Together…

- Expert Task Groups
- Benchmarking
- Research & Pooled Fund Studies
- Standards and Specifications
- Resources

Towards the Future…

As of 2013, 49 State DOTs support use of WMA (FHWA).

When WMA is fully implemented, U.S. will save 150 million gallons of No. 2 fuel oil per year – cutting carbon dioxide emissions by an equivalent of 210,000 cars annually.

USDOT estimates by 2020, use of WMA will save more than $3.5 million by reducing fuel needed to produce asphalt mixtures.

U.S. Department of Transportation
Federal Highway Administration

LTPP WMA Study

- Short & Long-Term Performance of WMA & HMA
- Several WMA technologies considered
- Field performance, lab test data
- Benefits and performance prediction
- RAP included and some RAS
- TRB Papers

16

TRB Transportation Research Board NCHRP Research

- 9-43, WMA Mix Design (completed)
- 9-47 WMA Emissions, Properties (complete)
- 9-47A, Properties and Performance of WMA (complete)
- 9-49, WMA Moisture Susceptibility (complete)
- 9-49A, Long-Term Field Performance (2016)
- 9-53, Properties of Foamed WMA (complete)
- 9-55, Shingles and RAP/RAS in WMA (2016)
- 20-07(311) Development of a WMA Technology Evaluation Program (complete)
- 20-44(01) Increasing WMA Implementation by Leveraging State-of-Knowledge (2018)

Over $5 million devoted to WMA research!

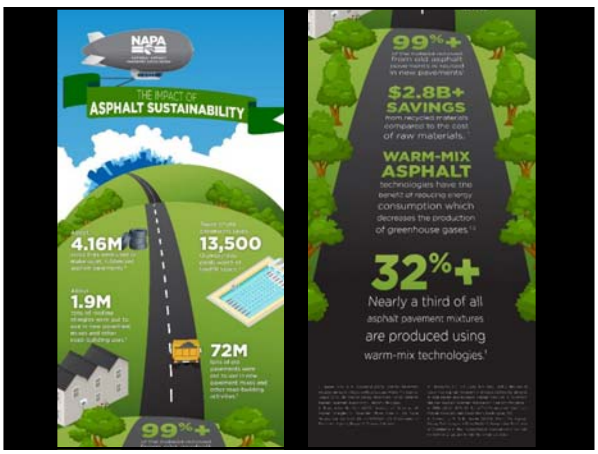
19

AASHTO R 35 for Sup
include considerations

http://www.ct.gov/dot/AASHTO-R35

Web Based Training


NCHRP
REPORT 763
Evaluation of the Moisture Susceptibility of WMA Technologies
NCHRP
REPORT 807
Properties of Foamed Asphalt for Warm Mix Asphalt Applications
NCHRP
REPORT 779
Field Performance of Warm Mix Asphalt Technologies


NAPA
THE IMPACT OF
ASPHALT SUSTAINABILITY
4.16M
13,500
1.9M
72M
99%+
99%+
$2.8B+
SAVINGS
WARM-MIX
ASPHALT
32%+
Nearly a third of all asphalt pavement mixtures are produced using warm-mix technologies.


RESEARCH PROJECT SUMMARY
January 2017
NAPA
THINLAY
PaveXpress
IRI Explorer
Environmental Product Declaration

Quantifying the Asphalt Industry's Environmental Impact

Environmental Facts

Functional Unit: 1 metric ton of Asphalt Cement

Primary Energy Demand (MJ)	4.0×10^3
Non-Renewable Energy (MJ)	3.9×10^3
Renewable Energy (MJ)	5.5×10^1
Global Warming Potential (kg CO_2eq)	79
Acidification Potential (kg SO_2eq)	0.23
Eutropication Potential (kg Neq)	0.012
Ozone Depletion Potential (kg CFC-11eq)	7.3×10^{-9}
Smog Potential (kg O_3eq)	4.4

Boundaries: Cradle-to-Gate
Company: XYZ Asphalt
RAP: 10%

General Program Instructions for Environmental Product Declarations (EPD) Program National Asphalt Pavement Association

Version 1
September 15, 2014

www.AsphaltPavement.org/EPD

Emerald ECO LABEL

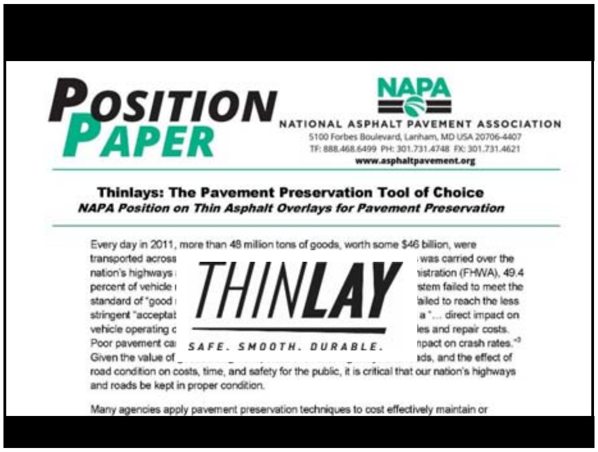
Quantify potential environmental impacts of an asphalt mixture

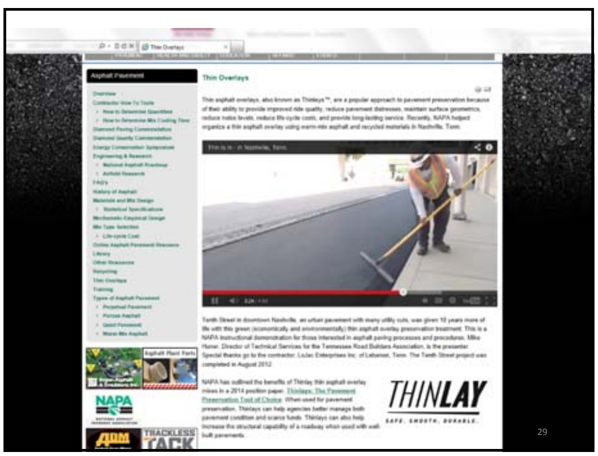
- Meet material credit requirements of green rating systems affordably
- Meet public agency requirements to quantify a pavement's sustainability
- Identify opportunities to improve operational efficiencies
- Streamline collection process for corporate sustainability reporting
- Ensure an even playing field in the green construction sector
- Tool available beginning April 1, 2017

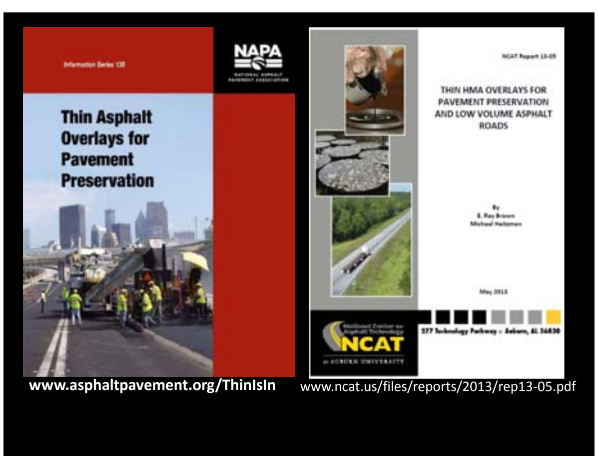
www.AsphaltPavement.org/EPD

Thinlays for Preservation: From Drawbacks to *Innovative* Solutions

- May have higher initial cost than other preservation strategies.
  - *Provide longer life*
  - *Thinner lifts*
  - *Use low-cost screenings and recycled materials (RAP, RAS, rubber)*
- Construction & application in cooler temperatures
  - *Warm Mix Asphalt*
- Durability versus permanent deformation
  - *Higher asphalt contents*
  - *Engineered binders (e.g. polymer, rubber, etc.)*


POSITION PAPER
NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION
5100 Forbes Boulevard, Lanham, MD USA 20706-4407
TF: 888.468.6499 PH: 301.731.4748 FX: 301.731.4621
www.asphaltpavement.org
Thinlays: The Pavement Preservation Tool of Choice
NAPA Position on Thin Asphalt Overlays for Pavement Preservation
Every day in 2011, more than 48 million tons of goods, worth some $46 billion, were
transported across
nation's highways
percent of vehicle
standard of "good
stringent "acceptab
vehicle operating c
Poor pavement ca
Given the value of
road condition on costs, time, and safety for the public, it is critical that our nation's highways
and roads be kept in proper condition.
Many agencies apply pavement preservation techniques to cost effectively maintain or
THINLAY
SAFE. SMOOTH. DURABLE.


Thin Overlays
THINLAY
SAFE. SMOOTH. DURABLE.
29


Information Series 138
NAPA
Thin Asphalt Overlays for Pavement Preservation
NCAT Report 13-05
THIN HMA OVERLAYS FOR PAVEMENT PRESERVATION AND LOW VOLUME ASPHALT ROADS
By
E. Ray Brown
Michael Heitzman
May 2013
NCAT
277 Technology Parkway • Auburn, AL 36830
www.asphaltpavement.org/ThinIsIn
www.ncat.us/files/reports/2013/rep13-05.pdf

OUTCOMES REVIEW

- The state-of-practice of the industry influencing WMA use
- The benefits of WMA
- Benchmarks, improvement efforts, & resources for WMA use
- Technologies for expanding use of WMA

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Warm Mix Asphalt Project

Questions? Please contact us

WMAPROJECT.20.44@gmail.com

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WARM MIX BRIEF 2-1
SUMMARY OF NCHRP 9-43: WMA MIX DESIGN PROCESS

Don Christensen
Advanced Asphalt Technologies, LLC
dwcaat@Hotmail.com

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OUTCOMES

By the end of this Warm Mix Brief 2-1, you will be able to:

- Know where to find the main AASHTO standard related to WMA mix design
- Identify the key features of the mix design process for WMA, including major differences from HMA mix design
- Recall why coating and compactability are evaluated during WMA design
- Describe how rutting resistance is evaluated in WMA design
- Discuss recent research and possible future changes in AASHTO R 35

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WMA BRIEF 2-1, PART 1: MIX DESIGN OVERVIEW

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WMA MIX DESIGN CATEGORIES

Additive added to the binder

Wet aggregate mixtures

Additive added to the mixture

Foamed asphalt mixtures

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CONCLUSION FROM NCHRP 9-43 MIX DESIGN PROCEDURES FOR WMA

- WMA can be designed with only minor changes to AASHTO R35, Standard Practice for Superpave Volumetric Design for Hot-Mix Asphalt (HMA)

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MAJOR ELEMENTS OF MIXTURE DESIGN

Materials Selection

Volumetric Design

Mixture Evaluation

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KEY DIFFERENCES: MATERIAL SELECTION

Item	HMA	WMA
WMA Process	NA	Producer Selected
Gradation	AASHTO M323	AASHTO M323
Aggregate	AASHTO M323	AASHTO M323
Binder Selection	PG Grade AASHTO M323	PG Grade AASHTO M323
RAP	AASHTO M323	Compaction Temp

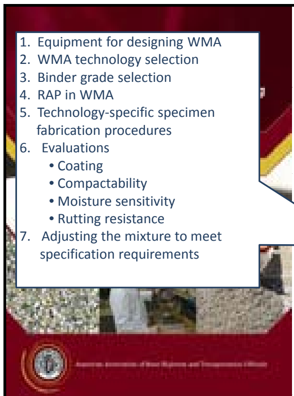
KEY DIFFERENCES: VOLUMETRIC DESIGN

Item	HMA	WMA
Mixing & Compaction Temperatures	Viscosity	Coating Compactability
Specimen Preparation	Standard	Process specific
Optimum Binder Content	AASHTO M323 Volumetrics	AASHTO M323 Volumetrics

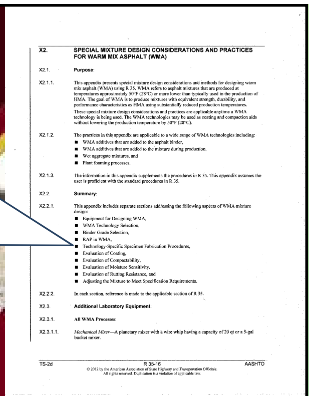
KEY DIFFERENCES: EVALUATION

Item	HMA	WMA
Coating	Viscosity	AASHTO T195
Compactability	Viscosity	Measured
Moisture Sensitivity	AASHTO T283	AASHTO T283
Rutting Resistance	None	Flow Number Test

WMA BRIEF 2-1, PART 2: APPENDIX TO AASHTO R 35



1. Equipment for designing WMA
2. WMA technology selection
3. Binder grade selection
4. RAP in WMA
5. Technology-specific specimen fabrication procedures
6. Evaluations
   - Coating
   - Compactability
   - Moisture sensitivity
   - Rutting resistance
7. Adjusting the mixture to meet specification requirements



X2. **SPECIAL MIXTURE DESIGN CONSIDERATIONS AND PRACTICES FOR WARM MIX ASPHALT (WMA)**

X2.1. **Purpose:**

X2.1.1. This appendix presents special mixture design considerations and methods for designing warm mix asphalt (WMA) using R 35. WMA refers to asphalt mixtures that are produced at temperatures approximately 50°F (28°C) or more lower than typically used in the production of HMA. The goal of WMA is to produce mixtures with equivalent strength, durability, and performance characteristics as HMA using substantially reduced production temperatures.
These special mixture design considerations and practices are applicable anytime a WMA technology is being used. The WMA technologies may be used as coating and compaction aids without lowering the production temperature by 50°F (28°C).

X2.1.2. The practices in this appendix are applicable to a wide range of WMA technologies including:
- WMA additives that are added to the asphalt binder,
- WMA additives that are added to the mixture during production,
- Wet aggregate mixtures, and
- Plant foaming processes.

X2.1.3. The information in this appendix supplements the procedures in R 35. This appendix assumes the user is proficient with the standard procedures in R 35.

X2.2. **Summary:**

X2.2.1. This appendix includes separate sections addressing the following aspects of WMA mixture design:
- Equipment for Designing WMA,
- WMA Technology Selection,
- Binder Grade Selection,
- RAP in WMA,
- Technology-Specific Specimen Fabrication Procedures,
- Evaluation of Coating,
- Evaluation of Compactability,
- Evaluation of Moisture Sensitivity,
- Evaluation of Rutting Resistance, and
- Adjusting the Mixture to Meet Specification Requirements.

X2.2.2. In each section, reference is made to the applicable section of R 35.

X2.3. **Additional Laboratory Equipment:**

X2.3.1. **All WMA Processes:**

X2.3.1.1. *Mechanical Mixer*—A planetary mixer with a wire whip having a capacity of 20 qt or a 5-gal bucket mixer.

TS-2d R 35-16 AASHTO

ADDITIONAL LABORATORY EQUIPMENT

Low shear mixer

Mechanical mixer

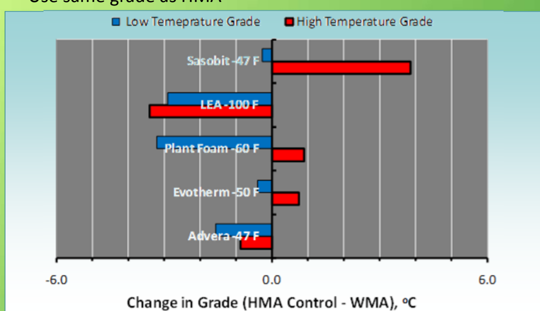
Laboratory foaming

WMA TECHNOLOGY SELECTION

- WMA mix design requires the producer to select
  - WMA product
  - Planned production temperature
  - Planned temperature to start compaction
- Laboratory specimen fabrication
- Producer should consider
  - Past performance and technical support
  - Cost
  - Useful temperature range
  - Production rates
  - Modifications

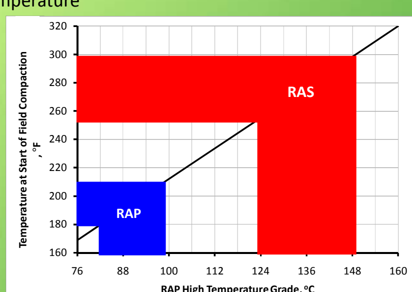
BINDER GRADE SELECTION

- Use same grade as HMA



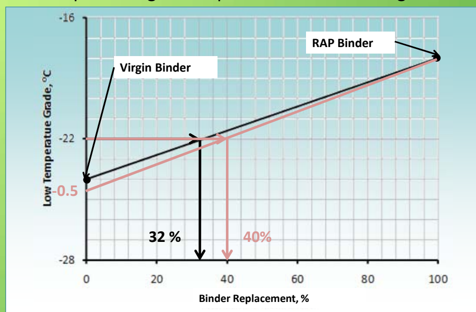
RAP IN WMA

- High temperature grade of RAP <= planned compaction temperature



RAP IN WMA

- Low temperature grade improvement for blending charts



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TECHNOLOGY-SPECIFIC SPECIMEN FABRICATION PROCEDURES

- Specimen fabrication procedures
  - Additive added to the binder
  - Additive added to the mixture
  - Wet aggregate mixtures
  - Foamed asphalt
- Address laboratory mixing
  - At planned production temperature
  - Mixing times are for planetary mixers
- Short-term conditioning
  - 2 hours at the planned temperature for starting field compaction

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COATING

- Prepare loose mix at optimum binder content per specimen fabrication procedures
  - Mixing times in appendix to AASHTO R35 are for planetary mixers
- Evaluate coating per AASHTO T195
  - Separate coarse aggregates
    - 9.5-mm sieve for NMAS 12.5 mm and larger
    - 4.75-mm sieve for NMAS 9.5 and smaller
    - Min. 200 particles
- $\% \text{ coated particles} = \left(\frac{\#\text{ fully coated particles}}{\text{total }\#\text{ of particles}}\right) \text{ x } 100\ \%$
- >= 95 percent

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COMPACTABILITY

- Prepare mix for four gyratory specimens and one maximum specific gravity specimen at the optimum binder content
- Compact two specimens to N_{design} at the planned temperature at the start of field compaction
  - Compute gyrations to 92% of G_{mm}
- Compact two specimens to N_{design} at 30 °C below the planned temperature at the start of field compaction
  - Compute gyrations to 92% of G_{mm}
- $Ratio = \frac{(N_{92})_{T-30}}{(N_{92})_T}$ <= 1.25

COMPUTE % G_{MM} FOR EACH GYRATION

$$\%G_{mm} = 100 \times \left(\frac{G_{mb} \times h_d}{G_{mm} \times h_N} \right)$$

G_{mm} = relative density at N gyrations
G_{mb} = bulk specific gravity for specimens compacted to N_{design}
G_{mm} = maximum specific gravity
h_d = specimen height for N_{design} gyrations
h_N = specimen height for N gyrations

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TYPICAL COMPACTABILITY RESULT

Gmm	2.674	2.674				
Gmb	2.561	2.573				
	Height, mm			Density, %Gmm		
Gyrations	Specimen 1	Specimen 2		Specimen1	Specimen 2	Average
0	139.0	138.3		78.3	78.5	78.4
1	134.9	134.1		80.7	80.9	80.8
2	131.7	130.8		82.6	83.0	82.8
⋮	Ratio = 24/20 = 1.20			< 1.25 Acceptable		⋮
18	119.9	119.1		90.7	91.1	90.9
19	119.6	118.7		91.0	91.4	91.2
20	119.3	118.5		91.2	91.6	91.4
21	119.1	118.3		91.4	91.7	91.6
22	118.9	118.1		91.5	91.9	91.7
23	118.6	117.8		91.7	92.1	91.9
24	118.4	117.6		91.9	92.3	92.1
25	118.3	117.4		92.0	92.5	92.2
26	118.0	117.2		92.2	92.6	92.4
⋮	⋮	⋮		⋮	⋮	⋮
75	113.6	112.8		95.8	96.2	96.0

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MOISTURE SENSITIVITY AND RUTTING RESISTANCE

- AASHTO T283
  - Tensile strength ratio >= 0.80 with no visual stripping
- Rutting resistance
  - Flow number, AASHTO T79

Traffic Level, Million ESALs	Minimum Flow Number
<3	NA
3 to < 10	30
10 to < 30	105
$\geq$ 30	415

FLOW NUMBER TESTING CONDITIONS

- NCHRP 9-33 Conditions
  - Air Voids = 7.0 +/- 0.5 percent
  - Temperature = 50% reliability high pavement temperature from LTPPBind 3.1
    - Depth of 20 mm for surface courses, top of layer for intermediate and base courses
    - No adjustments for traffic or speed
  - Unconfined
  - 600 kPa repeated deviator stress, 30 kPa contact deviator stress

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ADJUSTING THE MIXTURE TO MEET SPECIFICATIONS

- Coating
- Compactability
- Moisture sensitivity

} Consult WMA technology supplier

- Rutting resistance
  - Change binder grade
  - Add RAP
  - Increase filler content
  - Decrease VMA
  - Increase N_{design}

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WMA BRIEF 2-1: RECENT RESEARCH AND POSSIBLE FUTURE CHANGES IN R 35

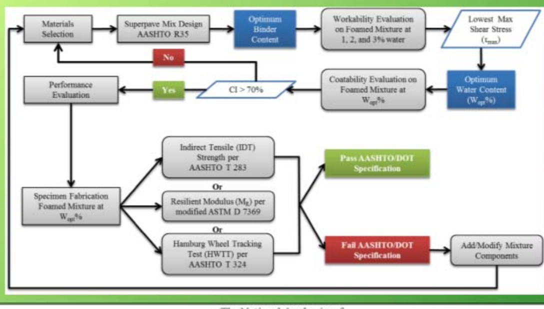
RECENT RESEARCH ON WMA AND POSSIBLE FUTURE CHANGES

- NCHRP 9-47A: Properties and Performance of Warm Mix Asphalt Technologies
  - Randy West and others
  - NCHRP Report 779
- NCHRP 9-53: Properties of Foamed Asphalt for Warm Mix Asphalt Applications
  - Dave Newcomb and others
  - NCHRP Report 807

NCHRP 9-47A RECOMMENDATIONS

- Drop-in approach confirmed—optimum binder content w/o using WMA technology
- Coating, compactibility and moisture resistance (TSR) determined using WMA technology
- Rut resistance testing only for design traffic > 30 MESALs
- TSR reduced to 75 %
- For Hamburg testing, increase conditioning to 4 hours or increase maximum rut depth

NCHRP 9-53: FOAMED ASPHALT MIX DESIGN METHOD



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OUTCOMES REVIEW

We are at the end of Warm Mix Brief 2-1, you should now be able to:

- Know where to find the main AASHTO standard related to WMA mix design
- Identify the key features of the mix design process for WMA, including major differences from HMA mix design
- Recall why coating and compactability are evaluated during WMA design
- Describe how rutting resistance is evaluated in WMA design
- Discuss recent research and possible future changes in AASHTO R 35

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ACKNOWLEDGMENTS

- The NCHRP
- NCHRP 20-44 (01) Panel
- Ray Bonaquist, NCHRP 9-43 Principal Investigator
- NCHRP 9-43 Panel
- Randy West, other NCHRP 9-47A team members and Panel
- Dave Newcomb, other NCHRP 9-53 team members and Panel
- Others that have contributed to NCHRP projects cited and these training materials

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NCHRP PROJECT 20-44(01)

Questions? Please contact us

WMAPROJECT.20.44@gmail.com

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Warm Mix Brief # 2-2 Properties of Foamed Asphalt for Warm Mix Asphalt Applications

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d-newcomb@tamu.edu

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OUTCOMES

By the end of this Warm Mix Brief 2-2, you will be able to:

- Discuss the properties of foamed asphalt that relate to mixture performance
- Describe the approach to designing asphalt mixtures using foam processes
- Discuss variables that affect the performance of foamed asphalt
- Describe tests for workability and coatability

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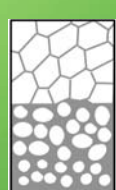
Binder Foaming

Types of foam

1. Polyhedral foam
   - volume of gas >> volume of the fluid
   - fluid → very thin films separating the gas
2. Spheroidal foam
   - volume of gas < volume of fluid
   - fluid → a relatively thick film separating the gas



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Field Foaming
A Few Available Devices
DOUBLE BARREL GREEN
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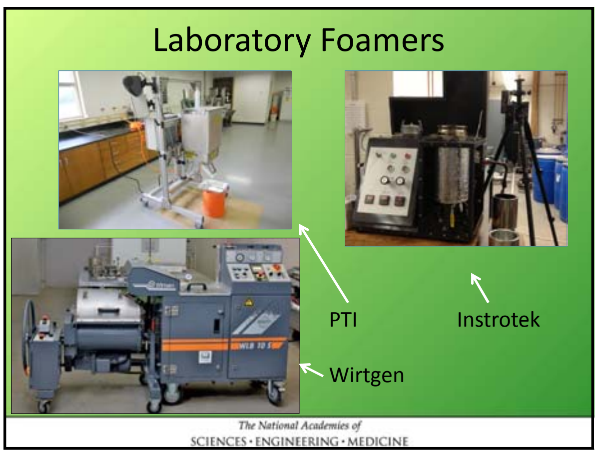
Laboratory Foamers
PTI
Instrotek
Wirtgen
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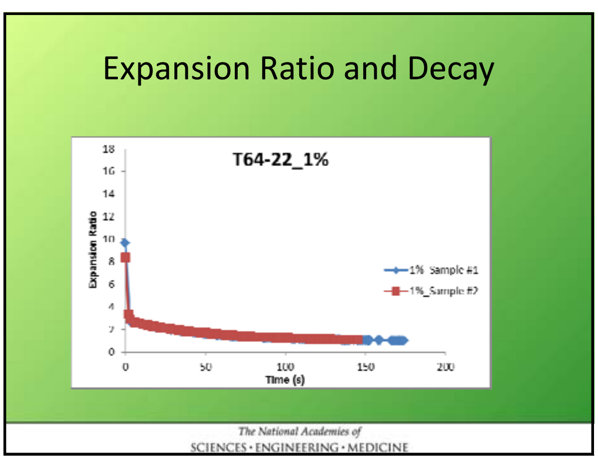
Expansion Ratio and Decay
T64-22_1%
Expansion Ratio
Time (s)
1% Sample #1
1%_Sample #2
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
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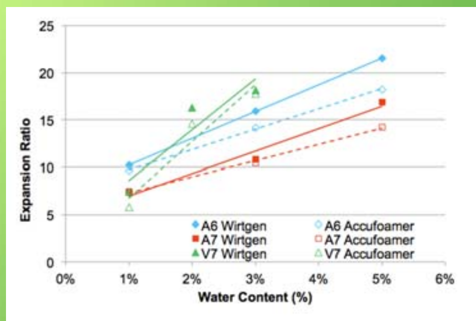
Moisture Content & Foamer Type



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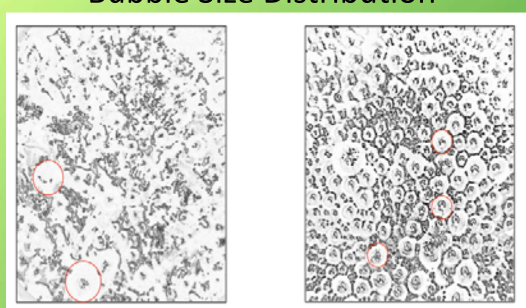
Bubble Size Distribution



3% Moisture

1% Moisture

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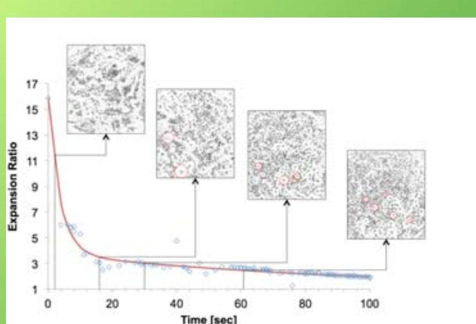
Bubble Size with Time



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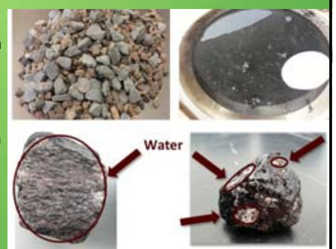
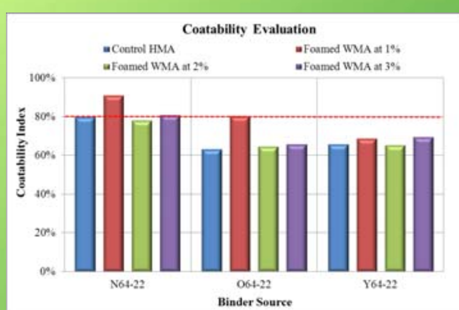
DEVELOP LABORATORY MIX METHODS

- Coatability
  - Coarse aggregate > 3/8 in
  - Mix at 275°F, 60s, STOA 2h at 240°F
  - Submerge mix and aggregates in water for 60 min
  - Measure water absorption
  - Calculate coatability Index (CI) = relative difference in mix/ aggregate water absorption
  - Higher CI = better coatability



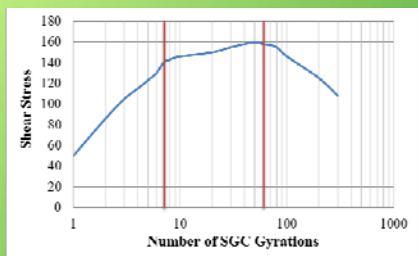
Coatability



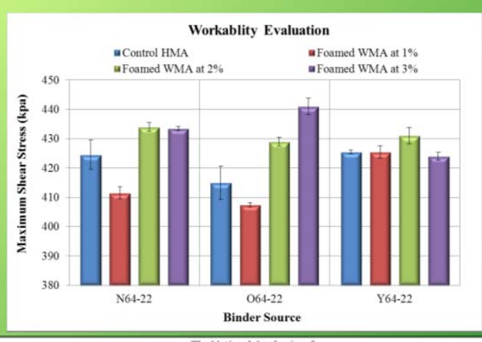
Workability

- Set foamer to desired water content
- Add foam to aggregate at design asphalt content
- Mix for 90 sec
- Condition for 2 hrs. at 275 (HMA) or 240 (WMA)
- Compact in SGC capable of monitoring shear stress
- Compact to maximum shear stress and record

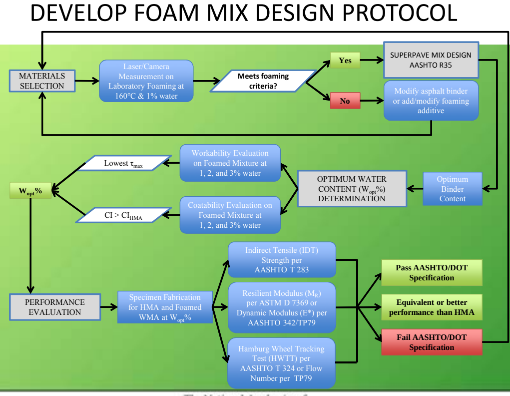
Workability



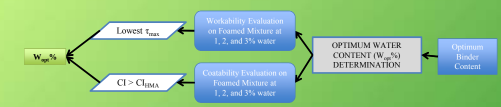
Workability

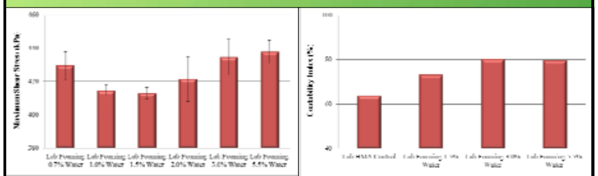


DEVELOP FOAM MIX DESIGN PROTOCOL



MIX DESIGN PROTOCOL VALIDATION





Min τ_{max} @ 1.5% water content

CI @ 1.5% water content > CI HMA

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Uses of Tests

- Evaluate foamability of binders
- Optimize moisture content
  - Lab
  - Field
- Mix design for performance testing
- Relate to coatability
- Relate to workability

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Foaming

- Will water affect strength and durability?
- How long will the effect of the foam last?
- How do different asphalts foam?
- Do foaming techniques produce the same quality and quantity of foam?
- How will polymer modified binders behave?
- How will other additives interact with foaming?
- Will mix design need to be modified?

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Outcomes

- Foaming characteristics vary according to:
  - Source
  - Date of production
  - Polymer modification
- Binder foaming may be improved with certain additives
- The three lab foamers produce different foaming characteristics
- Increasing moisture contents produced increasing expansion ratios in most binders tested.

Outcomes

- Increasing moisture contents did not improve workability and coatability
- The best workability generally occurred between one and two percent moisture
- Workability and coatability were better for neat asphalt for same mixing and molding temperature
- Workability improves with higher mixing temperatures for foamed asphalt
- The mix design procedure for optimum moisture content was validated through a field trial

Warm Mixed Asphalt Project

Questions? Please contact us

WMAPROJECT.20.44@gmail.com

Warm Mix Brief #2-3
Long-term Field Performance of Warm Mix Asphalt Pavements

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Louisiana State University
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Pennsylvania State University, Altoona
szs20@psu.edu

OUTCOMES

By the end of this Warm Mix Brief 2-3, you will be able to:

- Explain the approach that was used to evaluate the long-term field performance of WMA pavements
- Compare the long-term field performance of WMA pavement as compared to HMA pavement
  - Transverse cracking
  - Wheel-path longitudinal cracking
  - Rutting

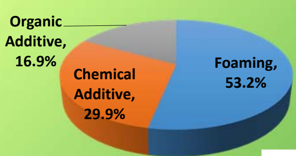
Outline

- **Introduction & Objectives**
- **Research Methodology and Project Information**
- **Results**
  - **Transverse Cracking**
  - **Wheel-path Longitudinal Cracking**
  - **Rutting & Moisture**
- **Findings**

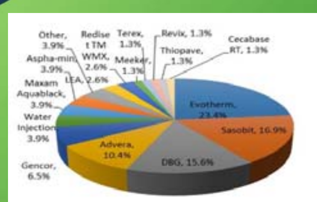
Introduction

- 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

Introduction



Long-term Performance



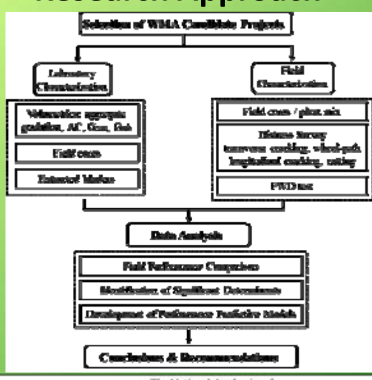
Research Objectives

- Investigate the long-term field performance of WMA: transverse cracking, wheel-path longitudinal cracking, and rutting
- Identify the material and engineering properties of WMA pavements that are significant determinants of their long-term field performance, and
- Recommend best practices for the use of WMA technologies.

Outline

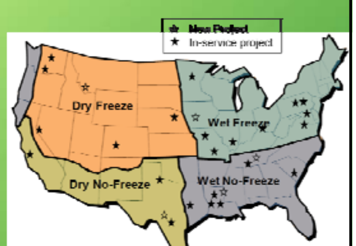
- Introduction & Objectives
- Research Methodology and Scope
- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture
- Findings

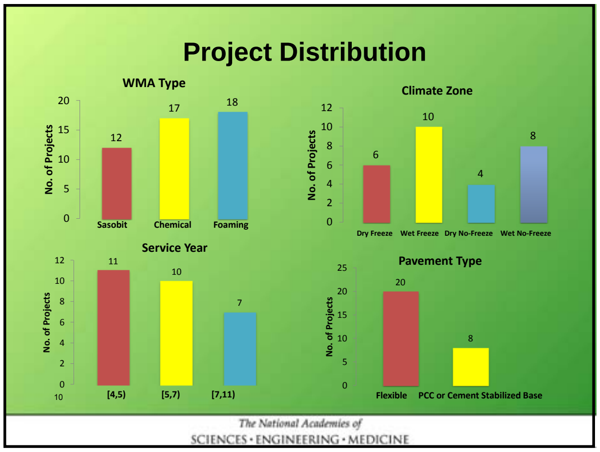
Research Approach



Project Scope

- 2011-2016, 5 years
- 23 in-serve projects (4-10 years), 40 HMA-WMA pairs
- 5 newly constructed in 2011-2012, 8 HMA-WMA pairs
- 2 rounds of field investigation
- Field coring and laboratory testing




Project Distribution
WMA Type
No. of Projects
20
15
10
5
0
12
17
18
Sasobit
Chemical
Foaming
Climate Zone
No. of Projects
12
10
8
6
4
2
0
6
10
4
8
Dry Freeze
Wet Freeze
Dry No-Freeze
Wet No-Freeze
Service Year
No. of Projects
12
10
8
6
4
2
0
11
10
7
[4,5)
[5,7)
[7,11)
Pavement Type
No. of Projects
25
20
15
10
5
0
20
8
Flexible
PCC or Cement Stabilized Base
10
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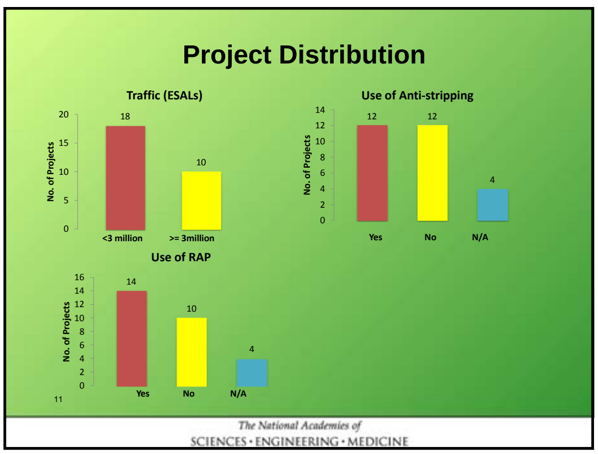
Project Distribution
Traffic (ESALs)
No. of Projects
20
15
10
5
0
18
10
<3 million
>= 3million
Use of Anti-stripping
No. of Projects
14
12
10
8
6
4
2
0
12
12
4
Yes
No
N/A
Use of RAP
No. of Projects
16
14
12
10
8
6
4
2
0
14
10
4
Yes
No
N/A
11
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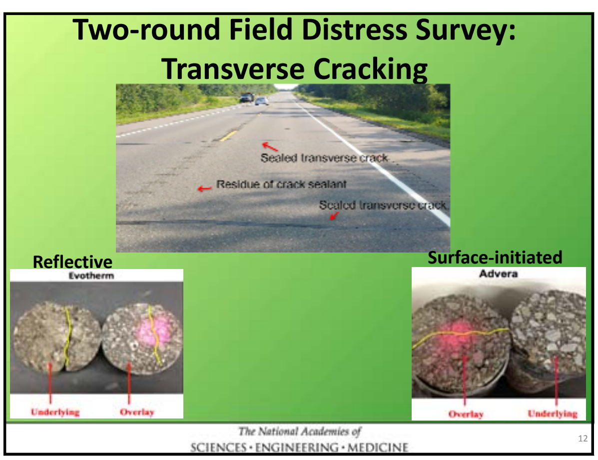
Two-round Field Distress Survey:
Transverse Cracking
Sealed transverse crack
Residue of crack sealant
Sealed transverse crack
Reflective
Evotherm
Underlying
Overlay
Surface-initiated
Advera
Overlay
Underlying
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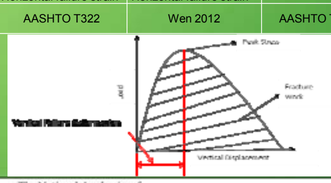
Two-round Field Distress Survey: Wheel-path Longitudinal Cracking

Two-round Field Distress Survey: Rut Depth

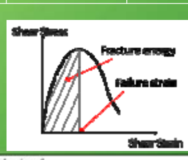
Material Characterization: Mix

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: 100 seconds	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); Cycles
References /Standards	Wen et al. 2002	AASHTO T322	Wen 2012	AASHTO T324



Material Characterization: Binder

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)	Stress: 0.1, 3.2kPa Temp.: 98% Reliability from LTPP Bind	Temp.: 68ºF Shear strain rate: 0.3 s^{-1}	Temp.: 41ºF 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/Standards	AASHTO MP1/T240/T313	AASHTO T350	Wen et al. 2010	Wen 2012



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Outline

- Introduction & Objectives
- Research Methodology and Scope
- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture
- Conclusions

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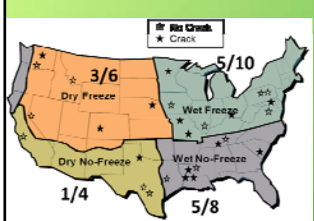
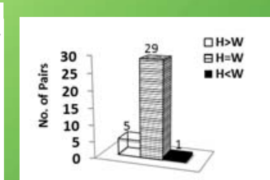
Transverse Cracking: 1st Round





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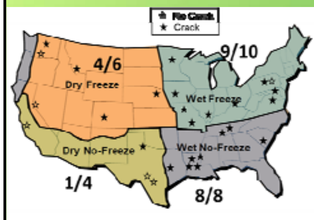
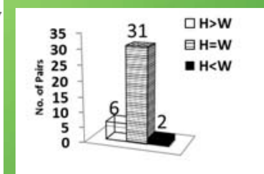
Transverse Cracking: 2nd Round





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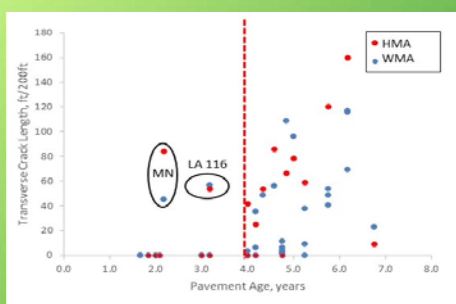
Transverse Cracking Performance for WMA and HMA



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Outline

- Introduction & Objectives
- Research Methodology and Projects
- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture
- Findings

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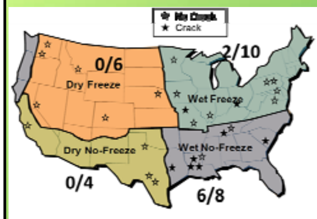
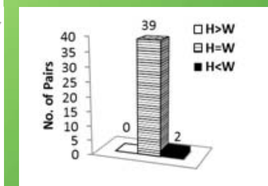
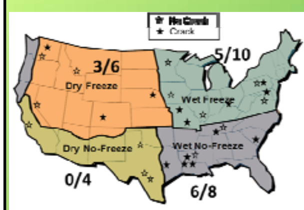
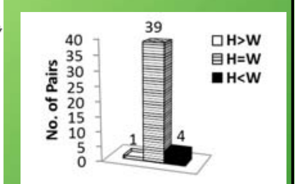
Wheel-path Longitudinal Cracking: 1st Round



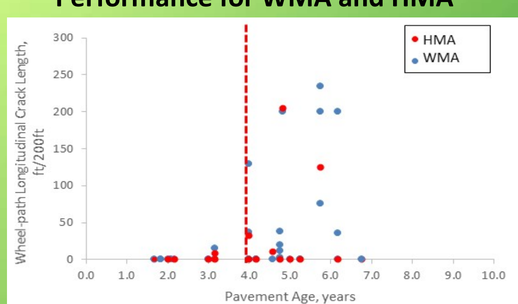


Wheel-path Longitudinal Cracking: 2nd Round





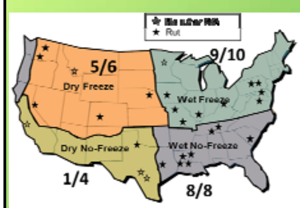
Wheel-Path Longitudinal Cracking Performance for WMA and HMA

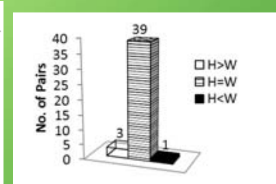


Outline

- Introduction & Objectives
- Research Methodology and Projects
- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture
- Conclusions

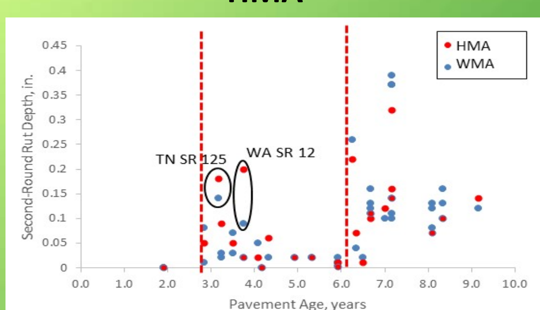
Rutting: 2nd Round





Note: Rut depth for the 1st survey is very minor.

Rutting Performance for WMA and HMA



Moisture Susceptibility - Field Performance

- No moisture damage was found in the field for both WMA and HMA pavements

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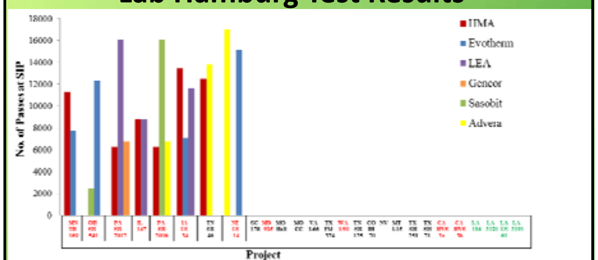
Moisture Susceptibility - Lab Hamburg Test Results



Note: The projects in red are those without anti-stripping, and projects in green are those the anti-stripping agent information are not available.

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Outline

- Introduction & Objectives
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- Results
  - Transverse Cracking
  - Wheel-path Longitudinal Cracking
  - Rutting & Moisture
- Findings

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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.
- Majority of HMA and WMA pavements showed comparable transverse cracking performance in the field.
- Field transverse cracking is mostly seen in pavements with four or more years of age.
  - Younger pavements show less transverse cracks.

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Findings: Wheel-path Longitudinal Cracking

- Wheel-path longitudinal cracks were found to initiate from surface of pavement
  - may be indicative of top-down fatigue cracking.
- Majority of HMA and WMA pavements exhibited comparable wheel-path longitudinal cracking.
- In general, field wheel-path longitudinal cracks start to develop at the age of 4 years;
  - more longitudinal crack is seen in HMA and WMA pavements with an age of 6 years or longer.

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Findings: Rutting & Moisture Susceptibility

- Majority of HMA and WMA pavements shows comparable rutting performance.
- Based on field investigation, no moisture-related distress was found for both HMA and WMA pavements.
  - WMA pavements performed similarly in moisture resistance as HMA pavements.
- Based on laboratory HWT test results, most of mixes without an anti-stripping agent exhibited SIPs
  - suggesting that use of anti-stripping agent may be beneficial overall for both HMA and WMA mixtures.

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OUTCOMES

By the end of this Warm Mix Brief 2-3, you will be able to:

- Explain the approach that was used to evaluate the long-term field performance of WMA pavements
- Compare the long-term field performance of WMA pavement as compared to HMA pavement
  - Transverse cracking
  - Wheel-path longitudinal cracking
  - Rutting

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Warm Mix Brief #2-3

Questions? Please contact us

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Warm Mix Brief #2-4
Contractor Perspective on WMA Placement

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Quality Control Manager, Blythe Construction
(704) 805-6410
berry.hall@blytheconstruction.com

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OUTCOMES

By the end of this Warm Mix Brief 2-4, you will be able to:

- Explain the economic and environmental reasons to construct flexible pavements with WMA
- Compare the post-construction densities for WMA and HMA over time for a project in North Carolina

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Perspective on Advantages for WMA

- Reduces emissions
- Reduces the tender zone effect
- Extends the paving season during the cooler temperatures of the early season & late fall
- Improves mix workability in high percentage RAP mixes, long hauls, & where excessive handwork is involved
- Improves density, depending on the temperature

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Environmental Reasons for WMA

- Oglala Sioux Proverb: “Treat the earth well…. We do not inherit it from our ancestors; we borrow it from our children.”
- 1997 Kyoto Protocol: UN Framework Convention on climate change to reduce 4 greenhouse gasses (carbon dioxide, methane, nitrous oxide, & hexafluoride)
- Don Brock: The rate of oxidation doubles for every 25° F increment increase above 275° F

Silo Observations: HMA vs. WMA

HMA
(no Aspha-min)

WMA
(with Aspha-min)

Stack Observations: HMA vs. WMA

HMA
(no Aspha-min)

WMA
(with Aspha-min)

Modified Stack Test Results: 2004

Test Sequence	O_2	CO_2	CO	SO_2	NO_x	THC
	%	%	ppm	ppm	ppm	ppm
Emissions before product was added	15.74	4.10	26.12	22.38	54.35	39.81
Emissions during product addition	15.93	4.00	27.28	17.29	50.47	24.25
Emissions after product was added	15.84	4.05	26.74	19.58	53.11	35.12
-	-	-	-	-	-	-
Average emissions before & after product addition	15.79	4.10	26.43	20.98	53.73	37.46
Difference between average normal operating period and product addition	-0.14	0.09	-0.85	3.69	3.26	13.22
Percent reduction in emissions	-0.90%	2.30%	-3.20%	17.60%	6.10%	35.30%

O2 :Oxygen CO2: Carbon Dioxide CO: Carbon Monoxide SO2: Sulfur Dioxide NOx: Nitrogen Oxide THC: Total Hydrocarbons

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North Carolina DOT (2012)

Approved WMA Technologies

Prior to any approval, the WMA technology manufacturer must submit documentation from a minimum of three (3) successfully constructed projects using the WMA technology that includes the following:

- Product Name & Supplier;
- Contact Name & Telephone Number;
- WMA Technology Material Safety Data Sheet (MSDS);
- Documentation from each successfully constructed project, including: project type, project owner, location, tonnage placed, mix design used, field density and performance data.

After the initial review process, the WMA technology can be given the following approval statuses based on the construction and performance of NCDOT-approved job mix formulas (JMFs) using the technology:

WMA Manufacturer	WMA Technology	Current Approval Status
Astec Industries	Double Barrel Green	Limited
Gencor Industries	Ultrafoam GX	Limited
MeadWestvaco	Evotherm 3G	Limited
Aqua Foam, LLC	Aqua Foam WMA	Trial
Maxam Equipment	AQUABlack WMA	Trial
PQ Corporation	Advera	Trial
Sasol Wax	Sasobit	Trial
Terex Roadbuilding	Terex WMA	Trial

1) Trial Approval – one or more NCDOT-let projects have been successfully constructed using the WMA technology and monitored through a minimum of one Winter season.

- WMA technologies with Trial status may be used on NC and Secondary Routes.

2) Limited Approval – a minimum of 75,000 tons of mix using the WMA technology have been successfully constructed on NCDOT-let projects.

- WMA technologies with Limited status may be used on US, NC, and Secondary Routes.

Contact **Todd Whittington** of the Materials & Tests Unit at (919) 329-4060 for any information and current approval status.

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WMA Project on Old Statesville Road

Placed on 9/2004

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WMA Project on Old Statesville Road

Placed on 9/2004

WMA Project on Old Statesville Road

Placed on 9/2004

WMA Project on Old Statesville Road

Reviewed on 1/2009

Warm Mix Asphalt Densities

	November 29, 2006				January 9, 2009		11/29/06-1/9/09
Cores	G_{mb}	G_{mm}	Density	Location	G_{mb}	Density	Difference
1	2.386	2.579	92.5	Bicycle path	2.474	95.9	3.4
2	2.448	2.579	94.9	Drift path	2.456	95.2	0.3
3	2.413	2.579	93.6	Bicycle path	2.416	93.7	0.1
4	2.451	2.579	95.0	Wheel path	2.480	96.2	1.1
5	2.404	2.579	93.2	In-between	2.437	94.5	1.3
6	2.471	2.579	95.8	Wheel path	2.487	96.4	0.6
7	2.456	2.579	95.2	Drift path	2.493	96.7	1.4
8	2.431	2.579	94.3	In-between	2.471	95.8	1.6
9	2.467	2.579	95.7	Wheel path	2.491	96.6	0.9
10	2.454	2.579	95.2	Wheel path	2.448	94.9	-0.2
11	2.455	2.579	95.2	Bicycle path	2.456	95.2	0.0
12	2.418	2.579	93.8	In-between	2.415	93.6	-0.1
13	2.461	2.579	95.4	Wheel path	2.462	95.5	0.0
14	2.417	2.579	93.7	Bicycle path	2.406	93.3	-0.4
15	2.41	2.579	93.4	Bicycle path	2.407	93.3	-0.1
16	2.478	2.579	96.1	In-between	2.486	96.4	0.3
17	2.478	2.579	96.1	Wheel path	2.490	96.5	0.5
18	2.450	2.579	95.0	Wheel path	2.457	95.3	0.3
19	2.470	2.579	95.8	In-between	2.471	95.8	0.0
20	2.481	2.579	96.2	Drift path	2.489	96.5	0.3
21	2.446	2.579	94.8	Drift path	2.476	96.0	1.2
22	2.395	2.579	92.9	Bicycle path	2.481	96.2	3.3
23	2.439	2.579	94.6	In-between	2.464	95.5	1.0
24	2.443	2.579	94.7	Wheel path	2.457	95.3	0.5
25	2.384	2.579	92.4	Bicycle path	2.384	92.4	0.0
26	2.454	2.579	95.2	Wheel path	2.465	95.6	0.4
27	2.472	2.579	95.9	Drift path	2.465	95.6	-0.3
28	2.395	2.579	92.9	In-between	2.495	96.7	3.9
29	2.374	2.579	92.1	Bicycle path	2.389	92.6	0.6
30	2.423	2.579	94.0	In-between	2.432	94.3	0.3

Average density of all cores:
2006: 94.55%
2009: 95.18%
Diff: 0.63%

Standard deviation of all cores:
2006: 1.22
2009: 1.15
Diff: 1.05

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Conventional Hot Mix Densities

	December 11, 2006				January 9, 2009		12/11/06-1/9/09
Cores	G_{mb}	G_{mm}	Density	Location	G_{mb}	Density	Difference
1	2.383	2.579	92.4	Bicycle path	2.402	93.1	0.7
2	2.373	2.579	92.0	Drift path	2.494	96.7	4.7
3	2.327	2.579	**90.2**	Bicycle path	2.460	95.4	5.2
4	2.435	2.579	94.4	Wheel path	2.446	94.8	0.4
5	2.421	2.579	93.9	In-between	2.430	94.2	0.3
6	2.439	2.579	94.6	Wheel path	2.467	95.7	1.1
7	2.432	2.579	94.3	Drift path	2.474	95.9	1.6
8	2.428	2.579	94.1	In-between	2.445	94.8	0.7
9	2.439	2.579	94.6	Wheel path	2.460	95.4	0.8
10	2.445	2.579	94.8	Wheel path	2.486	96.4	1.6
11	2.397	2.579	92.9	Bicycle path	2.415	93.6	0.7
12	2.398	2.579	93.0	In-between	2.418	93.8	0.8
13	2.461	2.579	95.4	Wheel path	2.476	96.0	0.6
14	2.358	2.579	**91.4**	Bicycle path	2.385	92.5	1.0
15	2.373	2.579	92.0	Bicycle path	2.386	92.5	0.5
16	2.433	2.579	94.3	In-between	2.442	94.7	0.3
17	2.404	2.579	93.2	Wheel path	2.426	94.1	0.9
18	2.468	2.579	95.7	Wheel path	2.484	96.3	0.6
19	2.432	2.579	94.3	In-between	2.422	93.9	-0.4
20	2.439	2.579	94.6	Drift path	2.462	95.5	0.9
21	2.477	2.579	96.0	Drift path	2.494	96.7	0.7
22	2.38	2.579	92.3	Bicycle path	2.395	92.9	0.6
23	2.455	2.579	95.2	In-between	2.462	95.5	0.3
24	2.463	2.579	95.5	Wheel path	2.475	96.0	0.5
25	2.359	2.579	**91.5**	Bicycle path	2.364	**91.7**	0.2
26	2.361	2.579	**91.5**	Wheel path	2.372	92.0	0.4
27	2.377	2.579	92.2	Drift path	2.400	93.1	0.9
28	2.438	2.579	94.5	In-between	2.444	94.8	0.2
29	2.388	2.579	92.6	Bicycle path	2.387	92.6	0.0
30	2.371	2.579	**91.9**	In-between	2.392	92.7	0.8

Average density of all cores:
2006: 93.53%
2009: 94.45%
Diff: 0.92%

Standard deviation of all cores:
2006: 1.50
2009: 1.51
Diff: 1.14

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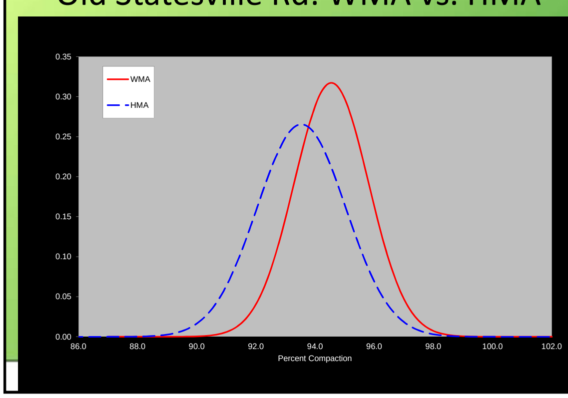
Old Statesville Rd: WMA vs. HMA



WMA Project: JW Clay

Placed on 6/2009

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WMA Project: JW Clay

Placed on 6/2009

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WMA Project: JW Clay

Placed on 6/2009

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WMA Project: CMP Kart Track

Placed on 7/2009

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Carolina Motorsports Park

Kershaw, SC

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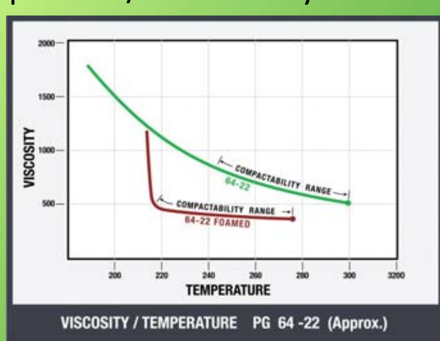
Compaction / Workability Curve

Source: Don Brock



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Economic Reasons for WMA

- Waste oil costs $1.65 a gallon & contains about 140,000 BTUs
- It takes 440 BTUs to raise 1 ton of aggregate 1° F
- Lowering temperature 25° F saves 11,000 BTUs (25 x 140)
- (11,000 / 140,000) x $1.65 = $0.13

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Why Isn't WMA Used All The Time?

Cost vs. Benefits

- No line item in bid contracts for WMA…no extra $ to compensate for extra cost of WMA
- No bonus for higher density
- Lower emissions don't reduce our environmental permit fees

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OUTCOMES REVIEW

- Explain the economic and environmental reasons to construct flexible pavements with WMA
- Compare the post-construction densities for WMA and HMA over time for a project in North Carolina

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Warm Mix Asphalt Project

Questions? Please contact us

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Warm Mix Brief #2-5

Florida DOT Experience: WMA Mixture Design and Performance

Howie Moseley
Florida Department of Transportation
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OUTCOMES

By the end of this Warm Mix Brief 2-5, you will be able to:

- Describe the mix design process and placement of WMA in Florida
- Show statistically the performance of WMA from various FDOT projects
- Describe the use of RAP in WMA in Florida, and
- Show the successes and concerns of WMA as seen by FL contractors.

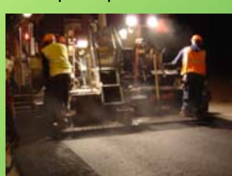
Florida DOT Experience: WMA Mixture Design and Performance

Outline

- Introduction
- Implementation
- Usage
- Mix Design Process / Specifications
- Performance
- Lessons Learned

Introduction

- WMA has been used in Florida since 2006.
- In Florida, WMA is asphalt with an approved warm mix additive or process produced and paved at lower temperatures than conventional hot mix asphalt.
- WMA asphalt is an option in the tool box that can be used by the asphalt producers and contractors as needed or desired.

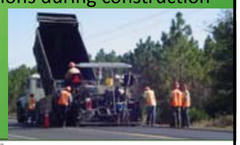


FDOT Mission Statement

The Department will provide a safe transportation system that ensures the mobility of people and goods, enhances economic prosperity and preserves the quality of our environment and communities.

WMA Implementation

- In Florida, there are three steps:
- Be acknowledged by another state agency as an acceptable warm mix technology or be listed on the following website: http://warmmixasphalt.com with a successful project(s) constructed nationally or internationally.
- Partner with a contractor and FDOT and construct a demonstration section on a FDOT project.
- Meet all FDOT construction specifications during construction of the demonstration section.



Approved WMA Technologies in Florida

Approved WMA Additives & Processes
AD-here LOF 65-00/Cecabase RT 945
Aqua Foam System
Aspha-min Zeolite
Double Barrel Green System
Eco Foam II
Evotherm DAT H-5
Evotherm M-1
Ultrafoam GX Process
Warm Mix Asphalt System
ZycoTherm

http://www.fdot.gov/materials/quality/programs/warmmixasphalt/index.shtm

FDOT Florida Department of TRANSPORTATION

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State Materials Office

Warm Mix Asphalt

Requirements

Requirements to be included on the approved products/process list:

1. Be acknowledged by another state agency as an acceptable warm mix technology or be listed on the following website: http://warmmixasphalt.com with a successful project(s) constructed nationally or internationally.
2. Partner with a contractor and FDOT District Office and construct a demonstration section on a FDOT project.
3. Meet all FDOT construction specifications during construction of the demonstration section.

Approved Additives/Processes

Product	Company	Web Address
AD-here LOF 65-00 with Cecabase RT 945	Road Science LLC	http://www.roadscience.net
Aqua Foam System	Meeker Equipment	[illegible]
Aspha-min	Aspha-min	http://www.aspha-min.com/
Double Barrel Green System	Astec Industries	http://www.astecindustries.com
Eco-Foam II	AESCO/Madsen	[illegible]
Evotherm DAT	MeadWestvaco Asphalt Innovations	http://www.evotherm.com
Evotherm M1	MeadWestvaco Asphalt Innovations	http://www.evotherm.com
Ultrafoam	Gencor Industries	[illegible]
Warm Mix Asphalt System	Terex Roadbuilding	[illegible]
Zycotherm	Zydex Industries	[illegible]

Statistics

The Florida Department of Transportation began using Warm Mix Asphalt (WMA) on a trial basis in 2006, with a slow, gradual increase in usage to date. The following link provides a summary of the quantities of WMA currently being used in the state's construction projects.

Warm Mix Usage Summary (PDF-156KB)

WMA Usage on FDOT Projects

Year	Tonnage		Percent WMA
	Total Asphalt	WMA	
2006	4,049,000	730	0.02
2007	4,514,000	9,856	0.22
2008	5,233,000	9,545	0.18
2009	5,015,000	187,236	3.73
2010	5,151,000	223,942	4.35
2011	4,418,000	252,402	5.71
2012	4,827,000	113,928	2.36
2013	4,548,000	230,729	5.07
2014	4,277,352	231,922	5.42
2015	4,780,423	64,584	1.35

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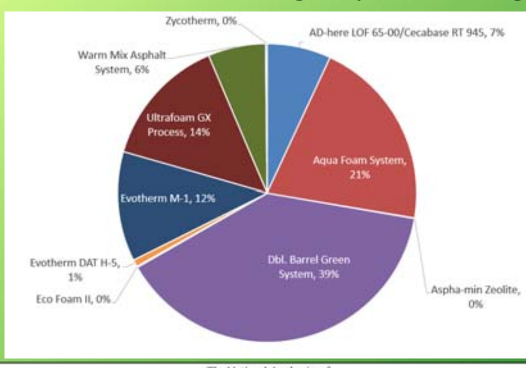
Percent WMA Tonnage by Technology



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FDOT WMA Mixture Design Process

- Similar to the hot mix asphalt mix design process. Contractors are responsible for designing their warm mixes according to FDOT specifications.
- Each mix design may only have one warm mix process. Switching processes requires a different mix design.
- The asphalt producer chooses the mixing and compaction temperatures.
- All mix designs are verified in the laboratory at the State Materials Office (central office) and field verified.
  - Verified in the lab at the WMA temperature with any additive.

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What is Different on the Warm Mix Design

Product Description	Product Code	Producer Name	Product Name
1. Crushed R.A.P.	334-CR	Better Roads Inc.	1-12
2. S1A Stone	C44	Martin Marietta Materials	#7 Stone
3. S1B Stone	C54	Martin Marietta Materials	#89 Stone
4. Screenings	F22	Martin Marietta Materials	Screenings
5. Warm Mix Process	334-WM	Astec	Double Barrel Green System
6.			
7. PG Binder	916-58		PG 58-22

SPW 13-12049A (TL-D)

(Plant)
Mixing Temperature 270 °F 132 °C
(Roadway)
Compaction Temperature 270 °F 132 °C

FDOT WMA Specifications

- Market driven. No incentives or disincentives.
- Any approved WMA process may be used. The process must be indicated on the mix design.
- For WMA, the first five loads of asphalt may be produced up to 330˚F to heat the equipment.
- When using a warm mix technology, mix may be placed at lower ambient temperatures (up to 5˚F lower by spec) than hot mix asphalt designs.

WMA Mixture Production and Control Requirements

- Similar to hot mix asphalt, no additional FDOT requirements.
- Some contractors reconfigured their plant for WMA production.
  - Retuned the burner.
  - Changed drum flighting, slope, and/or air flow to increase bag house temperature.
  - Sealed leaks in the bag house.



WMA Placement and Compaction Equipment Practices

- Same as HMA, must meet the same requirements for density, ride, and texture as hot mix asphalt.

WMA Testing and Acceptance Process

- Must meet the same requirements as hot mix asphalt.
  - Air voids
  - Density
  - AC content
  - Gradation

Table 334-5
Master Production Range

Characteristic	Tolerance [1]
Asphalt Binder Content (%)	Target ±0.55
Passing No. 200 Sieve (%)	Target ±1.50
Air Voids (%)	2.30 – 6.00
Density (minimum % G_{mm})[2]	89.50

(1) Tolerances for sample size of n = 1 from the verified mix design
(2) Based on an average of 5 randomly located cores

Table 334-8
Specification Limits

Quality Characteristic	Specification Limits
Passing No. 8 sieve (percent)	Target ± 3.1
Passing No. 200 sieve (percent)	Target ± 1.0
Asphalt Content (percent)	Target ± 0.40
Air Voids (percent)	4.00 ± 1.20
Density, vibratory mode (percent of G_{mm}):	93.00 + 2.00, - 1.20
Density, static mode (percent of G_{mm}):	92.00 + 3.00, - 1.50 [1]

(1): No vibratory mode in the vertical direction will be allowed. Other vibratory modes will be allowed, if approved by the Engineer.

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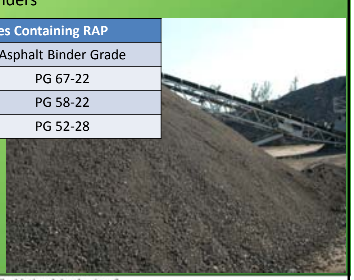
RAP and WMA

- Same requirements as HMA
  - Limited to 20% RAP with modified binders (polymer or GTR)
  - No RAP limit with neat binders

Asphalt Binder Grade for Mixes Containing RAP	
Percent RAP	Asphalt Binder Grade
0 – 15	PG 67-22
16 – 30	PG 58-22
>30	PG 52-28



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RAP and WMA

- RAP usage in all Florida asphalt mixtures (HMA & WMA).

RAP Usage in Mixtures without RAP Restrictions						
	FY 10/11	FY 11/12	FY 12/13	FY 13/14	FY 14/15	FY 15/16
Average	25%	26%	25%	29%	24%	29%
Maximum	40%	38%	39%	45%	50%	50%

- WMA usage during this timeframe.
  - 25% Average
  - 40% Maximum
- Some contractors have indicated using RAP with WMA helps with bag house condensation issues.

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HMA / WMA Density

- Average Density of HMA and WMA mixtures in Florida since 2009.
  - HMA = 92.45%
  - WMA = 92.38%
  - No significant difference

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Warm Mix Performance Data

- Initial WMA Performance Report published in 2009.
  - No performance issues documented at that time.
  - Three initial projects, two dense graded mixtures and one OGFC.
  - Control sections also placed on each project.

Road	SR 417		US 92		SR 11	
Mix Type	OGFC		Dense SP 12.5 mm		Dense SP 12.5 mm	
WMA process	Aspha-min Zeolite		Evotherm DAT H-5		Double Barrel Green System	
Date paved	May 2006		October 2007		December 2007	
Process	HMA	WMA	HMA	WMA	HMA	WMA
Mix Temperature (˚F)	320	270	325	250	310	270
Energy ratio	0.47	0.60	1.66	1.64	1.70	1.85
APA rut depth (mm)	-	-	2.8	2.8	4.1	2.7
Moisture Damage TSR	-	-	70	65	61	58

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SR 417 Performance Data

- SR 417, Warm Mix in OGFC (PG 76-22) only
  - WMA Process: Aspha-min Zeolite
  - Some rippling began to appear in both sections in 2014.

Performance Measurement	PCS Test Date and Mixture Type			
	May 2006		October 2016	
	HMA OGFC	WMA OGFC	HMA OGFC	WMA OGFC
Rutting (inches)	0.00	0.00	0.07	0.02
Crack rating (0-10)	10	10	10	10
Ride (Average IRI)	46	51	62	75

US 92 Performance Data

- US 92, Warm mix in dense graded structural course (PG 76-22) only. Overlaid with OGFC.
  - WMA Process: Evotherm DAT H-5.
  - A new project began through this corridor in 2015.

Performance Measurement	PCS Test Date and Mixture Type			
	November 2007		January 2014	
	HMA SP 12.5	WMA SP 12.5	HMA SP 12.5	WMA SP 12.5
Rutting (inches)	0.03	0.03	0.09	0.11
Crack rating (0-10)	10	10	10	10
Ride (Average IRI)	54	56	60	54

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SR 11 Performance Data

- SR 11, Warm mix in dense graded structural course only with 45% RAP.
  - Overlaid with 1.5" dense graded friction course.
  - WMA Process: Double Barrel Green System.

Performance Measurement	PCS Test Date and Mixture Type			
	June 2008		October 2016	
	HMA SP 12.5	WMA SP 12.5	HMA SP 12.5	WMA SP 12.5
Rutting (inches)	0.03	0.05	0.06	0.10
Crack rating (0-10)	10	10	10	7.0
Ride (Average IRI)	50	46	73	59

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I-10 WMA OGFC

- Structural Course in all four travel lanes paved with WMA SP 12.5 with PG 76-22 and 20% RAP.
- WMA process was Evotherm M-1 (280˚F).
- OGFC in the inside travel lanes is HMA with PG 76-22.
- OGFC in the outside travel lanes is WMA with PG 76-22.

Performance Measurement	PCS Test Date and Mixture Type							
	October 2013				October 2016			
	HMA OGFC		WMA OGFC		HMA OGFC		WMA OGFC	
Lane	Inside EB	Inside WB	Outside EB	Outside WB	Inside EB	Inside WB	Outside EB	Outside WB
Rutting (in.)	0.04	0.04	0.07	0.03	0.06	0.05	0.05	0.10
Ride (Avg. IRI)	38	39	37	34	46	49	40	37

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Contractor Anecdotal Successes

- Once they optimized the paving operation, some contractors have been able to reduce the number of rollers and still consistently meet the target density.
- Experienced up to a 23% fuel savings.
- WMA optimum AC contents can be 0.1 – 0.2% less than HMA mix designs.
- The paving crew likes it.
- Very little difference in the delivery, lay down, and placement. Good construction practice is the key.

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Contractor Anecdotal Concerns

- The fuel savings is small, and not worth the cost of the process.
- Plant must be set up / tuned for warm mix to maximize the benefits. Some local agencies don't allow WMA. Can't switch back and forth efficiently.
- From a cost standpoint, it is break even at best.
- See better results as a compaction aid in hot mix.
- Hand work can be more difficult at WMA temps.

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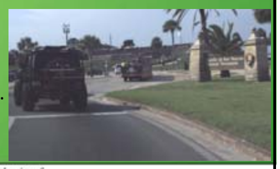
Other WMA Information

- In Florida, three approved warm mix processes are also approved liquid anti-stripping agents.
  - AD-here LOF 65-00 with Cecabase RT 945
  - Evotherm M1
  - ZycoTherm
- Anti-stripping agents are listed on the Approved Products list (APL), not the mix design. Any approved anti-strip can be used on a mix design.
- Many contractors choose to use these products with hot mix asphalt to maximize the benefits.
  - Fuel resistant mix in St. Augustine.



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OUTCOMES

By the end of this Warm Mix Brief 2-5, you will be able to:

- Describe the mix design process and placement of WMA in Florida
- Show statistically the performance of WMA from various FDOT projects
- Describe the use of RAP in WMA in Florida, and
- Show the successes and concerns of WMA as seen by FL contractors.

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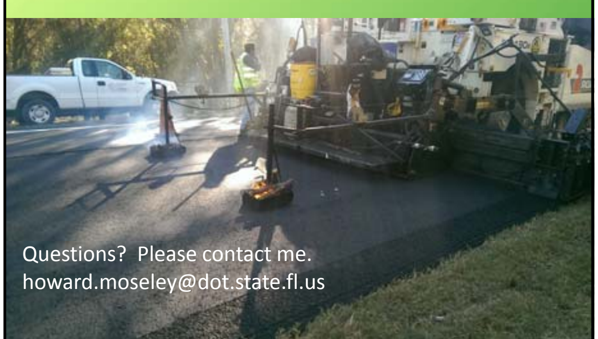
Thank You!



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Warm Mix Asphalt Project

Questions? Please contact us

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Warm Mix Brief #3-1
Short-Term Laboratory Aging of Asphalt Mixtures, NCHRP 9-52 & 9-52A

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OUTCOMES

By the end of this Warm Mix Brief 3-1, you will be able to:

- Explain the relationship between short-term lab and field aging of asphalt
- Understand the impact of WMA and aggregate absorption on the aging of asphalt
- Understand the relationship between climate and intermediate aging of asphalt
- Be able to identify the point at which WMA stiffness = HMA stiffness for cold and warm climates

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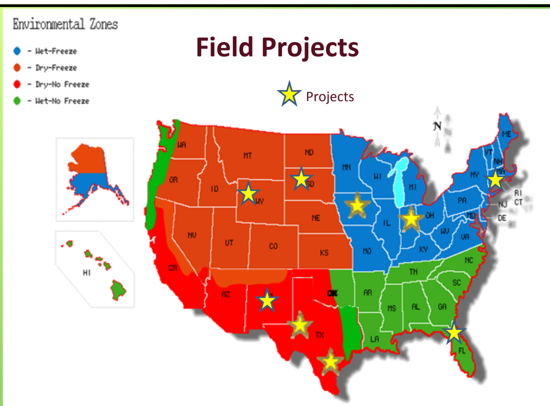
Field Projects



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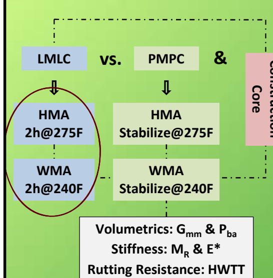
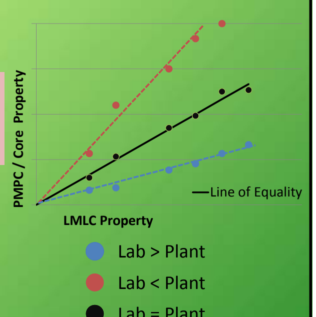
Field Projects

Field Project	WMA	Production Temperature	Plant Type	RAP/RAS	Aggregate Absorption	Binder Source
Texas I	√			√		
Connecticut	√					
Wyoming	√	√				
South Dakota	√					
New Mexico	√			√		
Iowa	√	√			√	
Florida	√				√	
Indiana	√		√			
Texas II			√			√

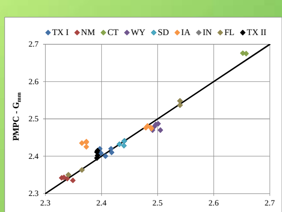
Validation of STOA Protocols



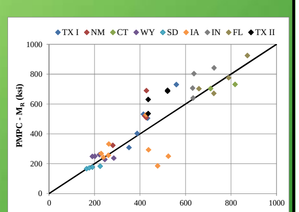


Validation of STOA Protocols

Mixture Volumetrics (G_{mm})

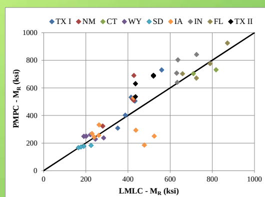


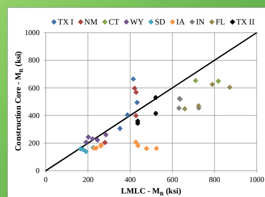
M_R Stiffness



M_R Stiffness at 25°C/10Hz

LMLC vs. PMPC | **LMLC vs. Core**





Equivalent M_R stiffness for LMLC vs. PMPC

Slightly lower M_R stiffness for construction cores vs. LMLC due to higher AV

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Summary – Validation of STOA Protocols

Validated laboratory STOA protocols of 2 hours at 275°F for HMA and 240°F for WMA to simulate plant aging

- Volumetrics: LMLC = PMPC
- E* stiffness: LMLC = PMPC
- M_R stiffness: LMLC = PMPC
- Rutting resistance: LMLC = PMPC

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Quantification of Field Aging

- Cumulative Degree Days (CDD)

$$CDD = \sum (T_{dmax} - 32)$$

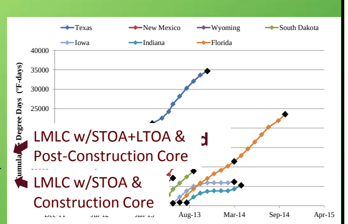
  - Geographic location
  - Construction date

- Property Ratio (PR)

$$M_R\ Ratio = \frac{Aged\ M_R}{Unaged\ M_R}$$

- PR vs. CDD

$$PR = 1 + \alpha * exp\left[-\left(\frac{\beta}{CDD}\right)^{\gamma}\right]$$



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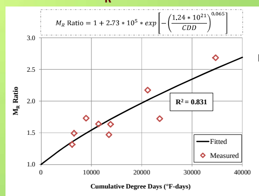
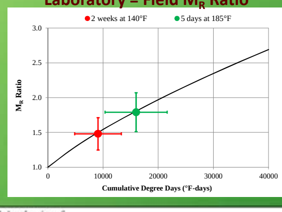
Field M_R Ratio vs. CDD



Laboratory M_R Ratio

LTOA Protocols	M_R Ratio	
	Avg	Stdev
2W@140°F	**1.478**	0.233
5D@185°F	**1.781**	0.279

Laboratory = Field M_R Ratio



Laboratory LTOA vs. Field CDD

LTOA Protocols	CDD
2W@140°F	**9,600**
5D@185°F	**17,500**

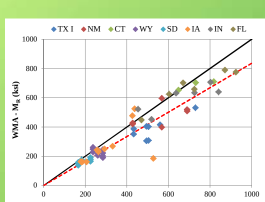
Summary – LTOA Protocols vs. Field Aging

- Proposed CDD to quantify field aging of asphalt pavements
- Proposed PR to evaluate mixture property evolution with field and laboratory aging
- Established LTOA protocols to simulate field

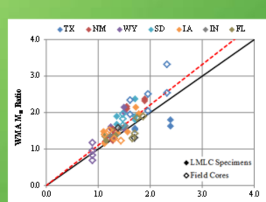
LTOA Protocols	CDD	In-Service Time	
		Warmer Climates	Colder Climates
2 weeks at 140°F	9,600	7 months	12 months
5 days at 185°F	17,500	12 months	23 months

Factor Analysis – WMA Technology

Short-Term: M_R Stiffness

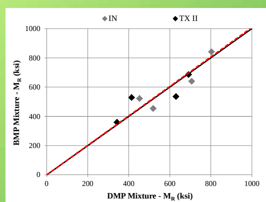


Long-Term: M_R Stiffness Ratio

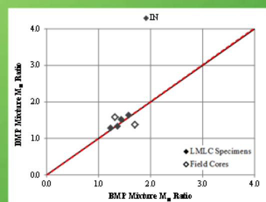


Factor Analysis – Plant Type

Short-Term: M_R Stiffness



Long-Term: M_R Stiffness Ratio



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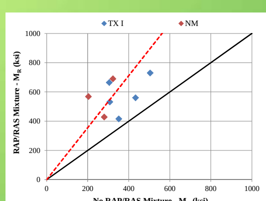
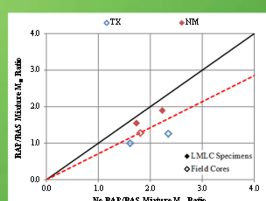
Factor Analysis – Recycled Materials

Short-Term: M_R Stiffness



Long-Term: M_R Stiffness Ratio



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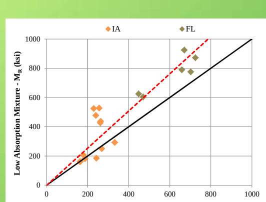
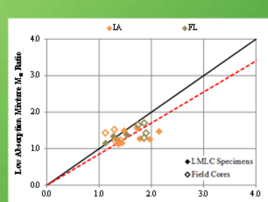
Factor Analysis – Aggregate Absorption

Short-Term: M_R Stiffness



Long-Term: M_R Stiffness Ratio



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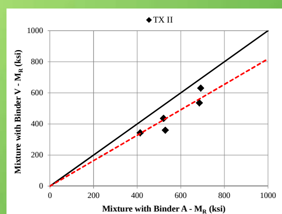
Factor Analysis – Binder Source

Short-Term: M_R
Stiffness



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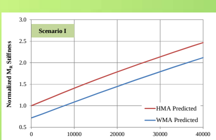
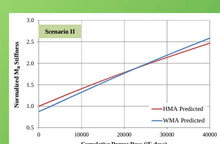
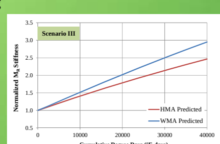
When does WMA = HMA?



Parallel Aging



Convergent Aging



Divergent Aging

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When does WMA = HMA?

- Three Scenarios
  - Parallel Paths
  - Convergent Paths
  - Divergent Paths
- Time for WMA = HMA0 ~ 2-3 months
- Time for WMA = HMA
  - 17 months in Warm Climate
  - 30 months in Cool Climate
- Time of year for construction is critical to LTA

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OUTCOMES

Summary

- STOA of 2 hrs @ 275F for HMA ad 240F for WMA = Plant Aging
- Variables Impacting Aging: Recycled Materials, WMA Technology, Aggregate Absorption, Asphalt Source
- LTOA of 5 Days at 185F Same as 12 mos. in Warm Climate and 23 mos. in Cold Climate
- WMA = HMA_0 in 2-3 mos.
- WMA = HMA
  - Warm Climate 17 mos.
  - Cold Climate 30 mos.

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Warm Mix Brief #4-1
Increasing RAP/RAS Contents with Recycling Agents

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OUTCOMES

By the end of this Warm Mix Brief 4-1, you will be able to:

- Identify objectives of NCHRP 9-58 & use of WMA in field projects
- Describe the approach used to evaluate the use of Recycling Agents to increase RAP and RAS contents in NCHRP 9-58
- List findings to date and next steps

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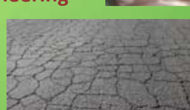
INTRODUCTION

Motivation – High Recycled Binder Ratio (RBR)
Mitigation – Recycling Agent (RA)

BENEFITS

- ✓ Economic
- ✓ Environmental
- ✓ Engineering

REMAINING ISSUES

? Engineering

- **Embrittlement**
- **Aging**
- **Blending**
- **Mixture Performance**

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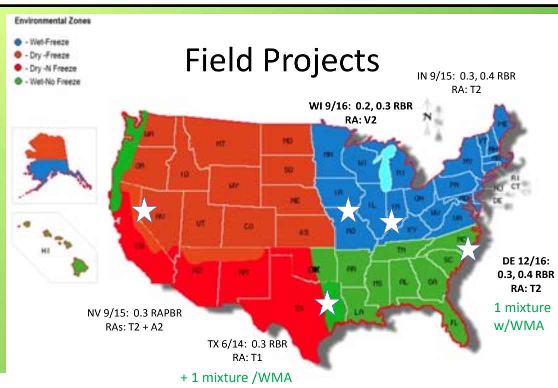
NCHRP 9-58 The Effects of Recycling Agents on Asphalt Mixtures with High RAP and RAS Binder Ratios – TTI, UNR, UNH ($1500k, 5/14-9/18)

- Assess effectiveness of RAs to
  - **partially restore binder rheology**
  - **improve mixture cracking performance** at optimum dosage rates
- Evaluate the **evolution of RA effectiveness**
- Recommend **evaluation tools**

Research Plan

PHASE I Identification of Gaps in Knowledge on RA Use with High RBRs	PHASE II Investigation of Effectiveness of RAs in Restoring Binder Rheology, Development of Blending Protocol, and Associated Mixture Performance	PHASE III Validation of RA Use in Mixtures with High RBRs
Task 1. Gather Information	Task 4. Conduct Laboratory Experiment	Task 6. Conduct Field Experiment
Task 2. Design Laboratory Experiment	Task 5. Design Field Experiment and Document Results in Second Interim Report	Task 7. Propose Revisions to AASHTO Specifications and Test Methods
Task 3. Document Results in First Interim Report		Task 8. Develop Training Materials and Best Practices and Deliver Workshop
		Task 9. Document Results in Final Report

Field Projects



BINDER & MORTAR Tests

- PG - BOTH


- Glover-Rowe

G-R@ 15 °C, 0.005 rad/sec

Rejuvenating Effectiveness in Black Spac

- Carbonyl Area Growth by FT-IR

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MIXTURE Tests


- Stiffness
  - M_R @ 25 °C
  - E*
- Embrittlement
  - UTSST Viscous-Glassy Transition
  - Mixture Black Space w/E*, ϕ & BBR Sliver
- Cracking Resistance
  - FI by SCB
  - N_f by S-VECD
  - RI by UTSST


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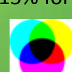
Findings to Date

- **RA Dosage Selection Method** for proportioning specific material combination developed through multiple trials & validated with mortar & mixture tests
- **Economics** support RA Dosages up to 10-15% for RAP-only mixtures
- **Blending Charts** can estimate RA Dosage



- **Binder Availability** important to consider
- Rheological **Incompatibility** Indicators promising
- Loss of **Rejuvenating Effectiveness w/aging** for high RBRs may be minimized by engineering binder blends

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Next Steps

- ❑ Complete **Aging Analysis** to explore oven vs PAV aging, chemical vs rheological properties & predict aging
- ❑ Complete **Mixture Characterization** to validate RA Dosage Selection & evaluate Rejuvenating Effectiveness
- ❑ Evaluate **Binder Availability**
- ❑ Evaluate **Phase III Field Projects** (NV, IN, WI, DE) to set thresholds for **Rejuvenating Effectiveness w/Aging, RAS Content**

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OUTCOMES REVIEW

- Identify objectives of NCHRP 9-58 & use of WMA in field projects
- Describe the approach used to evaluate the use of Recycling Agents to increase RAP and RAS contents in NCHRP 9-58
- List findings to date and next steps

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Warm Mix Brief 4-2
NAPA Perspective on Construction of Various WMA Technologies

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OUTCOMES

By the end of this Warm Mix Brief 4-2, you will be able to:

- List the inherent challenges of combining WMA and recycled materials
- Discuss the advantages seen with combining WMA with recycled materials
- Explain how recycled materials and WMA impact construction

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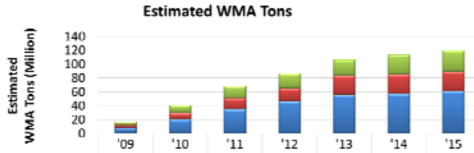
WARM MIX BRIEF 4-2



	'09	'10	'11	'12	'13	'14	'15
Commercia & Residential	4.6	11.3	17.8	21.4	22.8	28.5	30.4
Other Agency	3.6	9.8	16.3	18.9	27.9	28.4	28.5
DOT	8.6	20	34.6	46.4	55.7	56.9	60.9

DOT · Other Agency · Commercia & Residential

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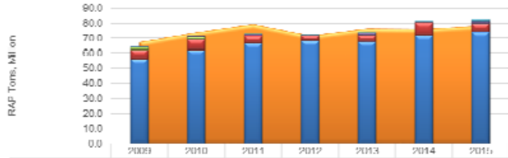
WARM MIX BRIEF 4-2



	2009	2010	2011	2012	2013	2014	2015
Accepted	67.2	73.5	79.1	71.3	76.1	75.8	78.0
Landfilled	0.1	0.0	0.3	0.2	0.1	0.2	1.0
Used in Other	0.7	0.8	0.7	0.2	1.5	0.6	1.6
Used in Cold Mix	1.5	1.6	0.2	0.2	0.2	0.2	0.2
Used in Aggregate	6.2	7.3	4.9	3.8	4.0	8.5	5.5
Used in HMA/WMA	56.0	62.1	66.7	68.3	67.8	71.9	74.2

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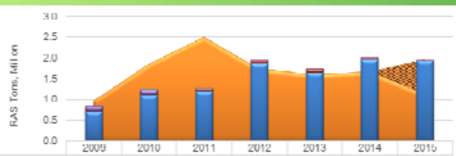
WARM MIX BRIEF 4-2



	2009	2010	2011	2012	2013	2014	2015
Processed Accepted	0	0	0	0	0	0	0.842
Unprocessed Accepted	0.957	1.851	2.500	1.724	1.599	1.664	1.129
Landfilled	0.000	0.007	0.000	0.000	0.000	0.000	0.000
Used in Other	0.123	0.125	0.000	0.012	0.005	0.008	0.000
Used in Cold Mix	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Used in Aggregate	0.006	0.003	0.074	0.073	0.082	0.043	0.009
Used in HMA/WMA	0.702	1.100	1.192	1.863	1.647	1.964	1.931

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WARM MIX BRIEF 4-2

- The industry supports the use of Warm Mix Asphalt
- The industry supports the use of recycled materials

Can recycled materials and WMA work together?

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WARM MIX BRIEF 4-2

- Why might there be some challenges?

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WARM MIX BRIEF 4-2

The Same, but Different

Schroer, 2009

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WARM MIX BRIEF 4-2

- How do you overcome this challenge?
  - Material management
    - Cover stockpiles
    - Keep moisture out of RAP/RAS/virgin materials

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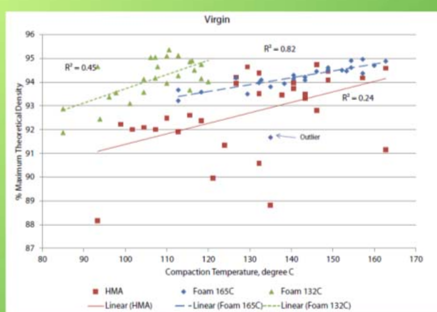
WARM MIX BRIEF 4-2

- Industry perspective
  - WMA is another tool in our tool box
  - Don't worry as much about temperature reduction during production/construction
  - See benefits of how it can impact work

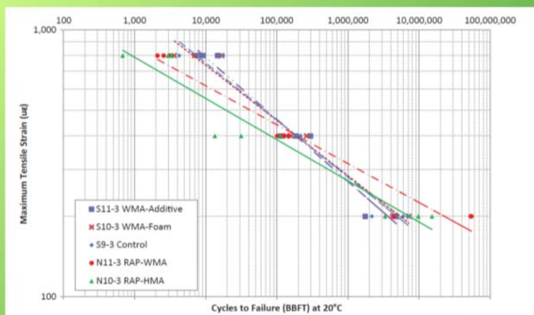
WARM MIX BRIEF 4-2



WARM MIX BRIEF 4-2

- Does WMA allow one to increase recycled content
  - Theory: Less oxidation of virgin binder allows increase of recycled materials
  - Some European trials were successful

Timm, West, and Taylor, 2016



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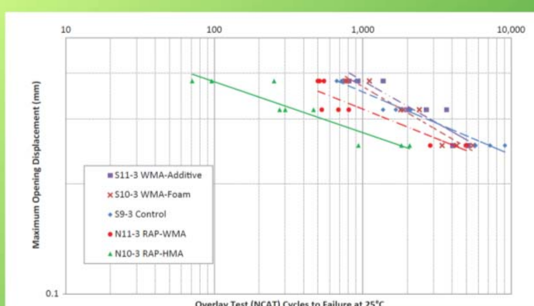
Timm, West, and Taylor, 2016



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Timm, West, and Taylor, 2016

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WARM MIX BRIEF 4-2

- Does WMA allow one to increase recycled content
  - Industry has not really seen this
  - Most of the initial work saying this would help was theoretical
  - In practice, use recycled materials best practices
    - No difference really between using WMA or HMA

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WARM MIX BRIEF 4-2

- Construction of WMA
  - Use common best practices
  - Contractors like using WMA
    - Eases laydown and compaction
    - Handwork in some urban areas difficult
    - Longer haul distances?

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Goh and You, 2012

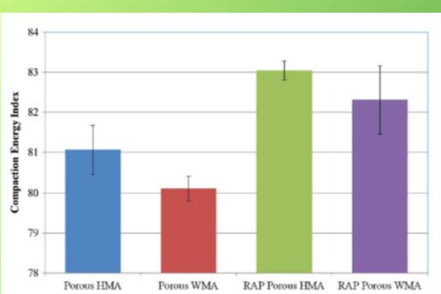

Fig. 4. Comparison of compaction energy for porous asphalt with and without RAP

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% Change in N92 Values

RAP%	HMA (%)	Evotherm (%)	Foamer (%)
0%	Control	-12	-6
20%	6	0	-6
40% with PG 64-22	35	12	-6
40% with PG 58-28	-6	18	6

(Kusam, Malladi, Tayebali, and Khosla, 2016)

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WARM MIX BRIEF 4-2

- What about rubber?
  - ODEQ Survey (Ghabchi et al., 2016)
    - 57% of states using GTR allow in WMA
  - Illinois Tollway – SMA with GTR (Vavrick et al., 2010)
    - Hot mix (335°F) v. Warm-Hot (330°F) v. Warm-Warm (270°F)
    - All field densities 93.5 to 94.3% Gmm
    - No construction issues

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OUTCOMES REVIEW

- The inherent challenges of combining WMA and recycled materials
- The advantages seen with combining WMA with recycled materials
- How recycled materials and WMA impact construction

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Warm Mix Brief #4-3

WMA in California: Use of WMA in Mixes Containing High Recycled Tire Rubber Content

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OUTCOMES

By the end of this Warm Mix Brief 4-3, you will be able to:

- Explain the differences between HMA and WMA used with recycled tire rubber content
- Describe whether the addition of additives to reduce the production and construction temperatures of asphalt concrete influences performance
- Identify the impact on pavement rutting performance of WMA mixtures with recycled tire rubber content, both experimentally (using accelerated pavement testing and in the lab) and in the field

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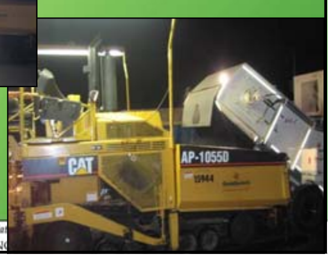
R-HMA vs. R-WMA In a Nutshell



Outline

- Introduction
- Objectives and workplan
- Test track construction
- APT and lab testing results
- Field tests
- Conclusions & implementation

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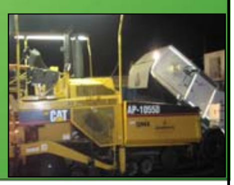
Introduction

- Rapid growth in the use of WMA
- Limited research on rubberized mixes
  - California rubber mandate
  - Fundamental properties of HMA change
    - Lower production and compaction temperatures
    - Less oxidation of the binder
    - Additives in the mix
  - Many projects, but limited long-term monitoring
- Better understanding required before full implementation



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Project Objectives

- Determine whether the addition of additives to reduce the production and construction temperatures of asphalt concrete influences performance
- Quantify benefits
  - Night paving, long hauls, environmental, worker safety and health, etc.
- Guide the implementation of WMA in California

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Workplan Summary

- Objectives met through:
  - Laboratory studies
  - Accelerated pavement testing
  - Field testing
- Phased approach followed
- Phase 3, R-WMA-G
  - 7 WMA technologies
  - 2 R-HMA controls
  - Produced at two different AC plants

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Outline

- Introduction
- Objectives and workplan
- Test track construction
- APT and lab testing results
- Field tests
- Conclusions & implementation

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Phase 3: Test Track Detail

- Test track 110m x 15m
- Nine cells (37m x 5m)
  - 2 hot mix controls
  - 2 water injection (foam)
  - 1 chemical foam
  - 1 wax
  - 3 surfactant
- Mix design
  - Standard Caltrans mix designs for R-HMA-G
  - Mix designs not changed for WMA technologies
  - PG64-16 binder base binder
  - No anti-strip added

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UCPRC – Lab and Test Tracks

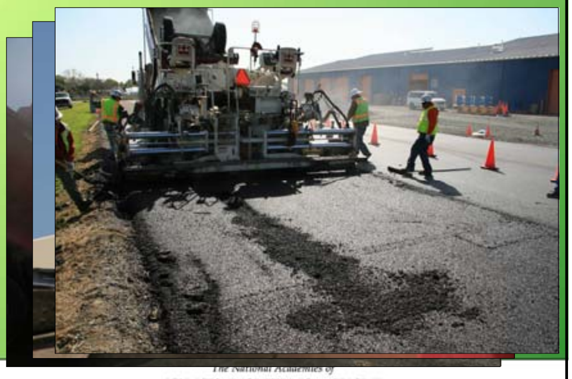
Phase 3: Construction - QC

Parameter	Control	Foam	Surfactant	Surfactant
Rubber content	18%			
Air temp °C	7 to 9			
Haul time	60 minutes			
Binder content*	7.7	7.9	7.7	7.7
Prod Temp °C	160	140	125	130
Pave Temp** °C	154	128	120	128
Air voids %	4.9	6.3	6.2	6.4
* Target 7.3% ** Behind screed *** Immediate, No curing				

Phase 3: Construction QC

Parameter	Control	Wax	Chem Foam	Foam	Surfact-ant
Rubber content	19%				
Air temp °C	7 - 9				
Haul Time	+ 120 minutes				
Binder content*	7.7	8.0	7.6	8.4	10.0
Prod Temp °C	166	149	145	145	140
Pave Temp** °C	137	137	130	125	126
Air voids %	11.6	8.5	10.7	9.1	8.4
* Target 8.3%	** Behind screed				

Phase 3: Control



Phase 3: Warm-mix

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Phase 3: HVS & Laboratory Testing

Standard rutting test: 40, 60, and 80kN half axle loads
Pavement temperature: 50°C at 50mm
Lab testing (specimens cored/cut from track): Rutting, fatigue, moisture sensitivity, emissions

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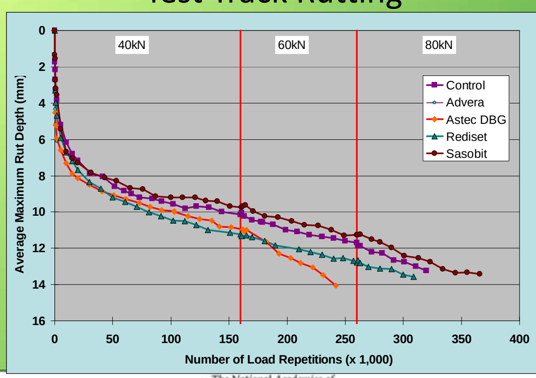
Test Track Rutting



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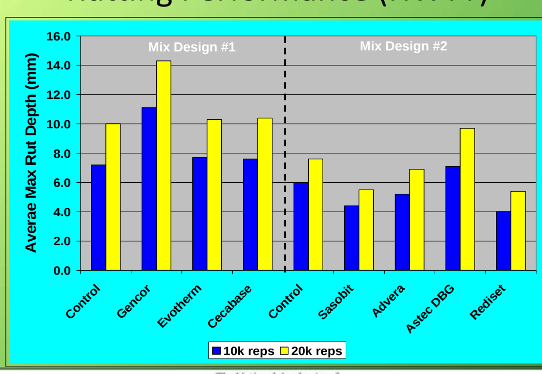
Rutting Performance (HWTT)



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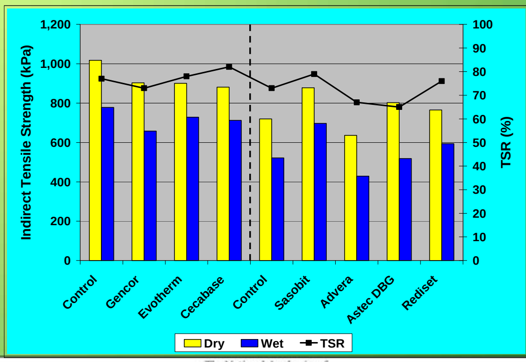
Tensile Strength Ratio



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Field Tests

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Point Arena: 2009 - 2015

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Outline

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Phase 3 Conclusions

- R-WMA mixes have significantly less smoke and odors than R-HMA
- R-WMA mixes are notably more workable than R-HMA mixes
- R-WMA generally had equal, but not better performance to R-HMA on test track, better performance in field
- Definite advantages:
  - Long hauls, early/late paving, night paving, thin lift construction, etc.

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General Conclusions on WMA

- Confirmed that equal performance can be obtained from WMA
  - Understand compaction temperatures
  - Beware initial tenderness/initial higher rutting
  - Beware moist aggregates
  - WMA does not replace good engineering practice

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Implementation in California

- Pilot projects and technology approval process 2007-2010
- Specifications and statewide workshops early in 2011
- Statewide implementation in 2011
  - > 1.1 million tons placed in 2011 paving season
  - Most rubber projects in northern California mandate use of WMA
  - 32% of all projects had rubber
  - About 4 million scrap tires used
- Full permissive spec in 2012
  - Approved technologies only (11 currently approved)
  - Contractor option plus mandated
- Since 2016
  - All surface courses on roads below 3,000 ft must now contain rubber

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OUTCOMES

Summary

- Explain the differences between HMA and WMA used with recycled tire rubber content
- Describe whether the addition of additives to reduce the production and construction temperatures of asphalt concrete influences performance
- Identify the impact on pavement rutting performance of WMA mixtures with recycled tire rubber content, both experimentally (using accelerated pavement testing and in the lab) and in the field

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Warm Mix Brief #5-1
Moisture Susceptibility of WMA

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OUTCOMES

By the end of this Warm Mix Brief 5-1, you will be able to:

- Describe the approach used to evaluate Moisture Susceptibility of WMA in NCHRP 9-49
- Identify evaluation guidelines developed in NCHRP 9-49
- Describe the approach used to verify evaluation thresholds in NCHRP 9-49B
- List contributions from NCHRP 9-49 and NCHRP 9-49B

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INTRODUCTION

- WMA with foaming or additives provide economic, environmental, & engineering benefits
- Concerns remain regarding moisture susceptibility

(http://www.ksasphalt.com/Warmix.html)

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NCHRP 9-49 **Performance of WMA Technologies**
Stage I – Moisture Susceptibility - TTI
($450k, 7/10-9/13), NCHRP Report 763

- Information Gathering – 2010 Web-Survey
  - 48% use anti-stripping additives, 76% MS in mix design, 91% no moisture damage
- 3 standard laboratory tests & field performance
- LMLC, PMLC, & Cores from 9 mixtures in 4 field projects
- Appropriate Aging Protocols
- Guideline Thresholds to identify and limit WMA moisture susceptibility

NCHRP 9-49
Laboratory Tests

- Indirect Tensile (IDT) Strength
  - Lottman Conditioning
  - Dry/Wet IDT Strength @25°C
  - Tensile Strength Ratio (TSR)
  - 61% survey respondents
- Resilient Modulus (M_R)
  - Lottman Conditioning
  - Dry/Wet M_R Stiffness @25°C
  - M_R-ratio

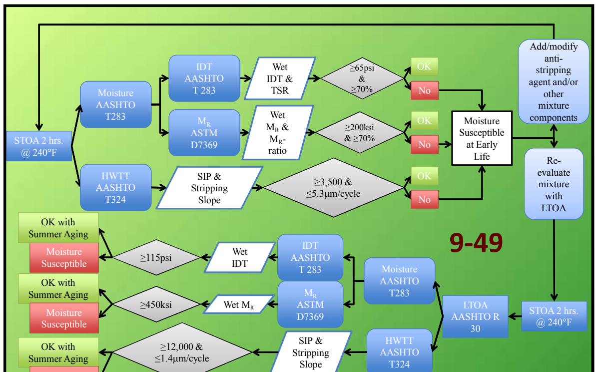
NCHRP 9-49
Laboratory Tests

- Hamburg Wheel Tracking Test
  - Stripping Inflection Point (SIP)
  - Stripping Slope
  - 17% survey respondents

NCHRP 9-49
Field Projects

NCHRP 9-49 **Performance Summary**

Field Project	Climate Traffic	Materials	WMA Field to 3/13	WMA Lab	
IA US 34 9/11	Wet, F/T Moderate	PG58-28 17% RAP Sasobit, Evotherm	✗ Raveling	= Field WMAs vulnerable early, some ok w/age; lab tests separate	Threshold Development
TX FM 973 1/12	Hot, Wet Heavy Trucks	PG70-22 Foaming, Evotherm	✓	"=" Field WMAs vulnerable early, ok w/age	Threshold Development
MT I-15 10/11	Cold, Multi-F/T Heavy	PG70-28 1.4% Lime Foaming, Sasobit, Evotherm	✓	= Field except wet IDT/TSR, on-site	Threshold Verification
NM I-25 10/12	Dry, Cold Winter, Hot Summer Heavy	PG64-28 35% RAP 1% Versabind Foaming, Evotherm	✓	= Field except wet IDT/TSR, LMLC; M_R-ratio, LMLC; Foaming, on-site	Threshold Verification



WMA Mix Design with LMLC
select single test method and use throughout

NCHRP 9-49B

Performance of WMA Technologies:

Stage I – Moisture Susceptibility Validation - TTI ($81.5k, 4/14-11/15), NCHRP Report 817

- Review of Recent Relevant Literature
- Follow-Up Web 2014 Web-Survey
- Collaboration with NCHRP 9-47A and 9-49A

- Validation of 9-49 Thresholds
- Laboratory Experiment to assess alternate moisture conditioning protocols & explore various specimen-drying methods with 1 mixture w/out lime

NCHRP 9-49B

Threshold Validation

- 64 WMA mixtures from 44 field projects identified from web-survey respondents & NCHRP 9-47A and 9-49A

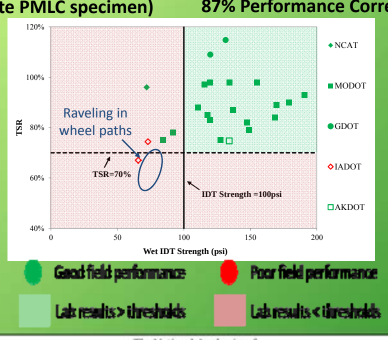
- Moisture susceptibility data
  - Mix design
  - QC/QA
  - Pavement performance

NCHRP 9-49B

Threshold Validation

TSR & Wet IDT Strength (off-site PMLC specimen)

87% Performance Correlation



NCHRP 9-49B

ROC ANALYSIS - TSR

TSR Threshold	LAB : FIELD	65%	70%	75%	80%
True Positive	FAIL : FAIL ✔	2	2	2	2
False Negative	PASS : FAIL ✘	0	0	0	0
False Positive	FAIL : PASS ✘	8	8	10	15
True Negative	PASS : PASS ✔	43	43	41	36
TPR	---	1.00	1.00	1.00	1.00
FPR		0.16	0.16	0.20	0.29
Accuracy		0.85	0.85	0.81	0.72

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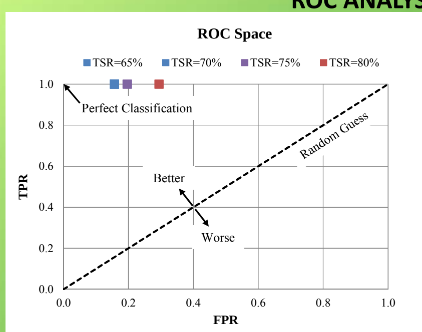
NCHRP 9-49B

ROC ANALYSIS - TSR



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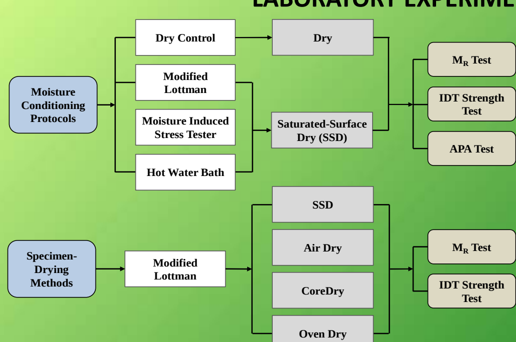
NCHRP 9-49B

LABORATORY EXPERIMENT



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NCHRP 9-49B

LABORATORY EXPERIMENT

Moisture Conditioning Protocols

- Modified Lottman (AASHTO T283)
  - Vacuum saturation + 1 freeze/thaw cycle
  - 3 Days
- Moisture Induced Stress Tester (MIST)
  - Temperature: 60°C
  - Pressure: 40 psi
  - 1,000 and 2,000 cycles
  - 0.5 Day
- Hot Water Bath (HWB)
  - Temperature: 60°C
  - 3 Days

NCHRP 9-49B

LABORATORY EXPERIMENT

Statistical Analysis Results

Moisture Conditioning Protocols	M_R Stiffness	IDT Strength	APA RRP
Dry Control	A	A	A
Modified Lottman	B	B	D
1,000-cycle MIST	B	B	B-C
2,000-cycle MIST	C	C	C-D
3-day HWB	B	B	B

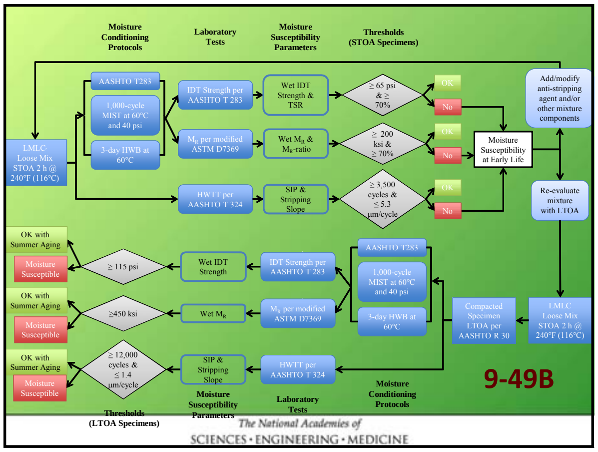
➡ 1,000 MIST & 3-day HWB proposed as alternatives to AASHTO T283

NCHRP 9-49B

LABORATORY EXPERIMENT

Specimen-Drying Methods after AASHTO T 283

- Saturated-surface dry (SSD) per AASHTO T 166 ✗
- 48-hour air dry at 25°C ✓
- 24-hour oven dry at 40°C ✓
- CoreDry per AASHTO PP 75 ✓ ✓



NCHRP 9-49 & 9-49B

CONTRIBUTIONS & IMPLEMENTATION

- Guideline Thresholds for Revising Appendix to AASHTO R 35 with Commentary
- Revised and Validated Guideline Thresholds with flexibility in Laboratory Tests & Moisture Conditioning Protocols
- WMA Aging Protocols utilized in NCHRP 9-52, 9-58

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OUTCOMES REVIEW

- Describe the approach used to evaluate Moisture Susceptibility of WMA in NCHRP 9-49
- Identify evaluation guidelines developed in NCHRP 9-49
- Describe the approach used to verify evaluation thresholds in NCHRP 9-49B
- List contributions from NCHRP 9-49 and NCHRP 9-49B

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Warm Mix Asphalt Project

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Warm Mix Brief #5-2
Ohio DOT Experience: Implementation and Field Performance of WMA

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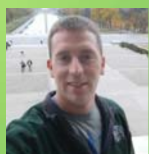

OUTCOMES

By the end of this Warm Mix Brief #5-2, you will be able to:

- Understand how Ohio DOT implemented WMA and why they chose water injection over other technologies.
- Understand what water injection foamed WMA is and what limitations there are.
- List pros and cons of water injection foamed WMA.

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Outline

- Ohio DOT's implementation of water-injection foamed WMA
  - Key Dates for Ohio
  - What is water injection foamed WMA?
  - Why did Ohio choose water injection over other technologies?
  - Experience and usage
  - Mix Designs
  - Tracking WMA versus HMA
- Field Performance of WMA versus HMA
- Pros and Cons of water injection WMA

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Key Dates for Ohio

- In August 2006, 1st WMA trial job using 3 chemical additive methods
  - Research project began with Ohio University (OU)
- In early 2008, ODOT's Director Beasley determines to use foaming method and be 100% WMA
  - Specifications written for use in 2009 for water injection foaming only.
  - 7 trial jobs in 2008 with control sections were done with water injection and some had stack testing.
    - Trial jobs showed about a 14% energy savings

Key Dates for Ohio

- In 2009, Projects being sold with WMA and mix plants rapidly started adding water injection equipment
  - Placement didn't being until mid-summer
  - The specification had language that "no grade change is required with RAP at 26 to 40% if WMA technology is used in a manner to maintain the mix temperature below 275 °F (135 °C)."
    - Based on the concept that less PG binder aging occurs at lower temperature
  - Student Study starts with Akron University on lab binder foaming equipment

Key Dates for Ohio

- Four total university studies between 2009 and 2014 were performed on water injection WMA, which include moisture susceptibility, binder aging, and low temperature cracking.
  - **Evaluation of low temperature cracking resistance of WMA**
  - **Influence of warm mix asphalt on aging of asphalt binders**
  - **Determining the limitations of warm mix asphalt by water injection in mix design, quality control and placement**
  - **Mechanical properties of warm mix asphalt prepared using foamed asphalt binders : final report**

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Key Dates for Ohio

- In 2015, Ohio DOT's specifications were revised and removed the "no grade change required if WMA is used."
  - Decision was after a research study done by Akron University and another done through NCHRP that said no differences between WMA and HMA after 2 years
  - Also had issues with plants staying below 275 °F
- Large usage of water injection foamed WMA from 2010 to present.

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What is water injection foamed asphalt?

- Water that is injected in-line with the virgin PG binder at a very small dosage (about 2% by weight of virgin PG binder)
  - The water causes the binder to quickly expand
  - In Ohio, we started out at 1.8% max, but bumped it to 2.2% after a research project was completed.
  - How much water is being added?
    - A 4.0% virgin binder mix would mean about 1.6 lbs (0.2 gal) of water/ton added
      - Most of this water flashes within seconds during foaming

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What is water injection foamed asphalt?

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Outline

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  - ***Why did Ohio choose water injection over other technologies?***
  - Experience and usage
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Why did Ohio choose water injection over other technologies?

- At the time of writing the specification, water injection seemed to be the least risk of all the technologies
  - The one concern was moisture susceptibility but Ohio, in general, does not have a stripping issue

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Outline

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Experience and Usage

Year	Total Ton*	WMA Tons**	% WMA
2006	4,173,618	0	0
2007	4,667,966	0	0
2008	5,130,600	10,430	0.2
2009	4,953,472	148,576	3.0
2010	6,104,867	1,948,162	32.0
2011	3,098,582	1,704,220	55.0
2012	4,900,000	2,891,000	59.0
2013	4,470,000	2,726,700	61.0
2014	4,737,330	3,167,862	66.9

* = Tons paid on projects and not tons sold
** = Water Injection Foamed

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Experience and Usage

- In 2016, we estimate 50-55% WMA
- We see less usage of WMA with small quantity asphalt, single plant contractors, and rural locations.
  - Low energy costs also low
- Are we seeing a cost savings with WMA? Not really

Outline

- Ohio DOT's implementation of water-injection foamed WMA
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  - Experience and usage
  - ***Mix Designs***
  - Tracking WMA versus HMA
- Field Performance of WMA versus HMA
- Pros and Cons of water injection WMA

Mix Designs

- In Ohio for water injection, we require contractors to perform mix design following HMA requirements and temperatures.
  - We have a minimum total virgin binder for all mixes and most HMA designs were already designed at the minimum
- After volumetrics are determined, contractor is given a HMA job mix formula (JMF) number and a WMA JMF number.
  - The WMA JMF number has mixing and compaction temperatures 30 °F lower than HMA.
  - This was done through the end of 2014

Outline

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Tracking WMA versus HMA

- Up to 2015, we entered both HMA and WMA JMF numbers and data into our construction database system (ODOT CMS & SiteManager)
  - HMA's start with B; WMA start with W
  - We do not keep track of injection system used at plant or percent of water used
- When mix is sampled for a project, our districts log the sample in our database system including the JMF number, sample date, plant, project number, etc.
  - Material is assigned to project line items on the material side in units of tons

Tracking WMA versus HMA

- On the construction side, ODOT project personnel enter placed quantity (what's paid) for the project and line item
  - Most projects this is in cubic yards
  - Design Builds have the entire pavement structure as a lump sum of 1 unit.
    - This makes it hard to quantify tons paid.
- To get WMA tonnage, a few queries are ran, combined, and massaged to get data but not 100% accurate. Even less accurate with more design builds or when ran to early.
  - Typically takes a few days

Outline

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- ***Field Performance of WMA versus HMA***
- Pros and Cons of water injection WMA

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Field Performance of WMA versus HMA

- No major performance issues to date
- Early on during hot summer days, pavement surfaces appeared shiny. Contractors advised to keep temperatures down and not to over roll.
- Noticeable visual difference with better binder coating with WMA

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Field Performance of WMA versus HMA

- ODOT 446 Mat Density from 2013 to 2014
  - Does not include joint cores
  - Ohio has min % density of 92.0% for intermediate and 93.0% for surface courses

	WMA	HMA
Total Cores	5774	3703
Average % Density	93.5	93.8
Standard Deviation	1.93%	1.98%
50^{th} Percentile	93.6	94.0

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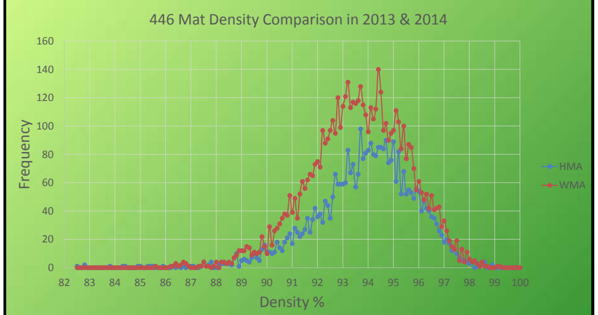
Field Performance of WMA versus HMA



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- ***Pros and Cons of water injection WMA***

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Pros and Cons of water injection WMA

Pros

- After initial investment and some maintenance costs, water is basically free
- Ability to turn on and off water injection if producing multiple mixes
- Improved aggregate coating
- Approximately 10-14% energy savings
- Some decrease in emissions

Cons

- No extended season for freeze states
- Limited on temperature drop compared to chemical additives
- Still have to add antistrips if you use them
- Potential increase in rutting

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Conclusion

- At Ohio DOT, we have not seen performance issues with WMA versus HMA and consider our implementation a success.
- Knowing what Ohio DOT knows now, we would probably have allowed more technologies from the beginning
- There are limitations with water injection foamed WMA compared to other technologies

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OUTCOMES

By the end of this Warm Mix Brief #5-2, you will be able to:

- Understand how Ohio DOT implemented WMA and why they chose water injection over other technologies.
- Understand what water injection foamed WMA is and what limitations there are.
- List pros and cons of water injection foamed WMA.

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Questions? Please contact us

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Warm Mix Brief #5-3
Industry Perspective: Contractors and Suppliers and the Possibilities with WMA

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OUTCOMES

By the end of this Warm Mix Brief 5-3, you will be able to:

- List the possibilities associated with the use of WMA for production and construction
- Relate the Industry perspective for successfully moving forward with WMA

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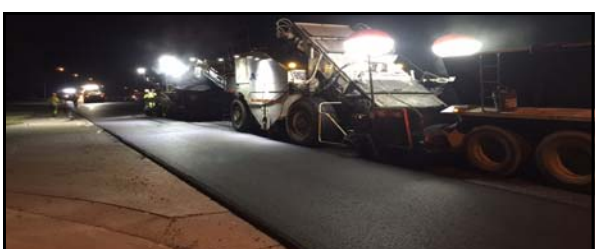

Industry Perspective – Contractors, Suppliers

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Possibilities with WMA

- *Extend the paving season (compact at lower ambient temperatures)*
- *Improve workability and quality (better and more efficient and consistent when achieving compaction)*
- *Reduce fuel consumption at the plant*
- *Reduce emissions at the plant*
- *Increase haul distance*
- *Reduce fumes and improve safety for on-site personnel*
- *Reduce aging of the binder (improve performance)*
  - *source CDOT, MAC Sept. '09*

The Benefits of Additives

No Fumes or smoke at the paver!

Current Use of Additives in Colorado

- CAPA Sent a questionnaire to our Producer members. We asked…
  - What is the current use of WMA technology within your company (or the companies you work with or supply to)?
    - Suppliers are utilizing WMA in many ways, from none to every ton being produced at a facility.

Current Use of Additives in Colorado

- What are you seeing as the benefits and reasons for using WMA technology?
  - This discussion occurs every time a subject of WMA is brought up.
    - The items to be included here are the same as what CDOT published in 2009
      - Placement at lower temperatures
      - Improved compaction
      - Ability to hold temperatures in longer hauls
      - Lower temperatures at the plant and the paver
      - Better working conditions for the crews
      - Better/more consistent coating of the aggregate

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What is the current usage?

- What are the reasons that you are not using warm mix asphalt technology on all mixes?
  - This ranges from producer to producer
    - Cost of the products
    - Not being approved for use
    - Many of the customers for producer do not understand the benefits of WMA

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Where have we seen Asphalt Paving Materials with additives

- I-70 MM 208 to the tunnels (2007)
- YMCA Camp of the Rockies, Hauled from Ft Collins 1.5 hours in flow boy trailers, dumped, reloaded into tandems and then placed (2008)
- Highway 9
- I-25 Co Springs North to Monument 2014
- City of Lakewood (entire overlay program) 2012
- Town of Castle Rock, marginal weather paving
- US 85 Bowles to Blakeland 2016
- Many other projects at local Agencies and CDOT

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What is WMA?

- Currently most people refer to WMA as "Warm Mix Asphalt". Using what is known today a better name for WMA should be Workability Mixture Additive.
- There are many different ideas of what WMA is…
  - Is it a reduced temperature mixture?
  - Is it an Asphalt Paving Mixture (APM) produced for workability and as a compaction aid?
  - Is it a process to lower temperature to keep the binders softer and help avoid early cracking of the APM?

Where Do We Go From Here?

- What are the reasons that you are not using warm mix asphalt technology on all mixes?
  - It is important that specifier and end users understand the benefits of WMA technologies and embrace them for what they are.
  - Time to stop restrictions of approved WMA products at any level within agencies.
  - No minimum production temperatures.
  - Let the contractors decide what is an appropriate process and utilize the other testing and inspection to determine the end result of the APM placed.

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Conclusions

- Re-evaluate the current specifications (end result)
- Encourage the use of additives based on the current approved product list (APL) for all projects
- Rebrand WMA technologies as a workability additive. This would help remove the issues associated with WMA as a title. It is just another tool to be used for efficient production of APM.
- Add information in mix design submittals which states an "an APL additive is present in this mixture"

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- Relate the Industry perspective for successfully moving forward with WMA

NCHRP Project 20-44(01)

Questions? Please contact us

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NCHRP 20-44(01) Webinar Closing: Moving Forward with WMA Implementation & the 2-Day Workshop

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Project Objectives

- Identify barriers encountered by state DOTs where WMA technologies remain to be implemented
- Assist those agencies who have yet to embrace WMA
- Identify continuing knowledge gaps
- Establish and update implementation performance indicators to provide a better picture of WMA implementation nationwide
- Develop a series of webinars to provide common ground for understanding and a two-day workshop to identify barriers and provide peer leadership for lagging states

Webinars

Provide a series of Topical Webinars to deliver NCHRP Study products to reach common background knowledge.

- Overview of WMA History, Development and Usage
- Mix Design Properties of WMA
- Laboratory Conditioning of WMA for Short and Long Term Ageing
- Inclusion of Recycled Materials and other Additives with WMA Technologies
- Successful Implementation and Field Performance of WMA

Workshop

Provide a two-day workshop for lead states, lagging states and industry partners

- Workshop will be structured to provide two or more breakout sessions each composed of 5-6 topic areas. Barriers and impediments will be identified
- Targeted to showcase successful implementation activities so barriers and risk can be lowered for those states using limited or no WMA
- Provide sufficient detail for modification of specifications and construction practices
- Identify Performance Measures/Indicators

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