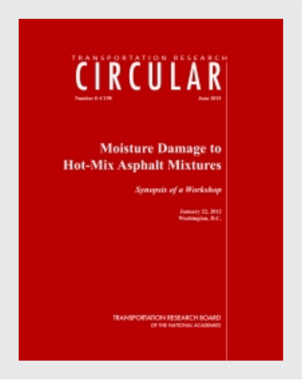
TRANSPORTATION RESEARCH
CIRCULAR

Moisture Damage to
Hot-Mix Asphalt Mixtures

Synopsis of a Workshop

Washington, D.C.

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Moisture Damage to Hot-Mix Asphalt Mixtures

DETAILS

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January 22, 2012
Washington, D.C.

Sponsored by the Standing Committees on
Flexible Pavement Construction and Rehabilitation
General Issues in Asphalt Technology
Characteristics of Nonasphalt Components of Asphalt Paving Mixtures
Flexible Pavement Design
Transportation Research Board

June 2015

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Preface

This Transportation Research E-Circular includes a synopsis of six presentations of the Moisture Damage to Hot-Mix Asphalt Mixtures Workshop conducted at the 91st Annual Meeting of the Transportation Research Board. The publication of this E-Circular is timely and will likely serve as an important reference for pavement researchers and professionals throughout the transportation community. Thanks go to the presenters for participating in this workshop. Special thanks also go to the members and friends of the sponsoring committees who were involved in the publication of this E-Circular.

The content of the presentations are those of the individual authors and do not necessarily represent the views of standing committees, TRB, or the National Research Council. The papers have not been subjected to the formal TRB peer-review process.

—Victor (Lee) Gallivan
Chair, Flexible Pavement Construction and Rehabilitation Committee

Contents

Workshop Introduction

ISAAC L. HOWARD
Mississippi State University

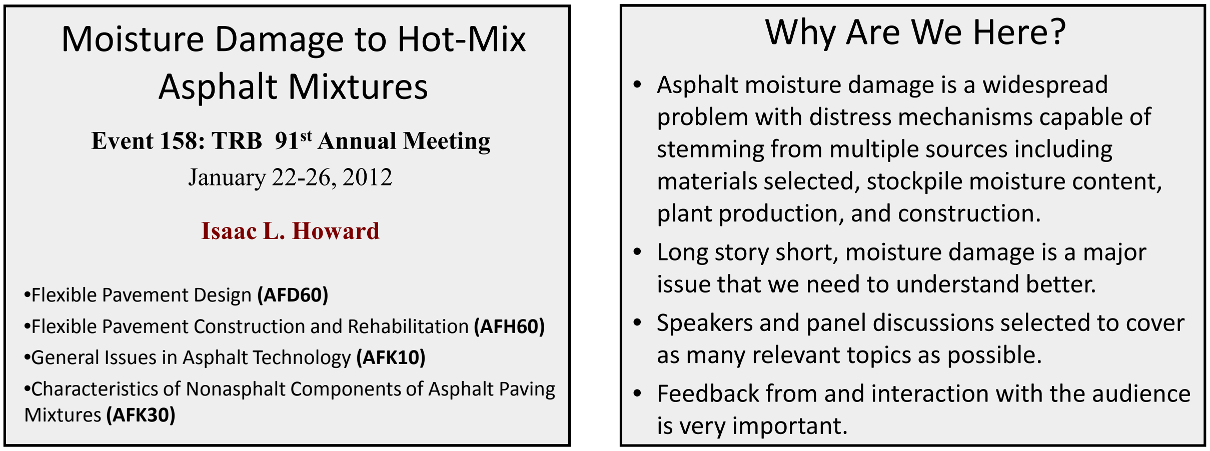
VICTOR (LEE) GALLIVAN
Gallivan Consulting, Inc.

GERRY HUBER
Heritage Research Group

Asphalt concrete moisture damage is a widespread problem with distress mechanisms capable of stemming from multiple sources including materials selected, stockpile moisture contents, plant production, construction, and sustained elevated moisture levels under heavy traffic. Rapid deterioration of pavements occurs due to moisture damage, yet many key aspects of the problem are not fully understood and some of the behaviors that are better understood are not always monitored or controlled. Moisture damage practices vary between the auspices of different agencies.

To provide a forum to improve resistance of asphalt concrete to moisture damage, a half-day workshop was held at the 91st Annual Meeting of the Transportation Research Board in 2012. The workshop was organized to provide a global assessment of moisture damage from materials and construction through service. Test methods and theoretical aspects of moisture in relation to asphalt concrete were also considered.

The workshop provided best practices, but also provided forums to discuss areas where improvement is needed. The workshop attracted a large and diverse audience. A goal of the workshop was to facilitate knowledge transfer to and from the audience. Figure 1 is a condensed version of the slides used by the presiding officer to introduce the workshop to the audience.



Moisture Damage to Hot-Mix Asphalt Mixtures

Event 158: TRB 91st Annual Meeting

January 22-26, 2012

Isaac L. Howard

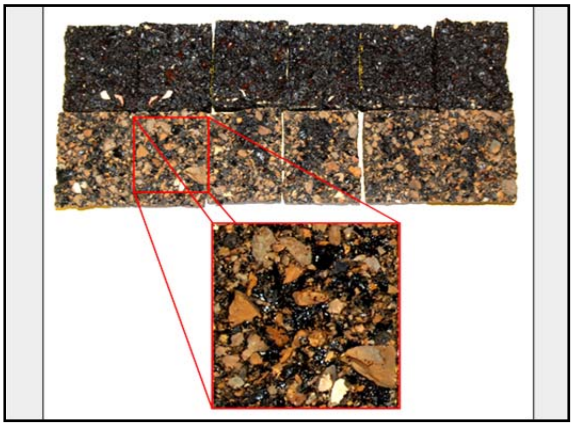
- Flexible Pavement Design **(AFD60)**
- Flexible Pavement Construction and Rehabilitation **(AFH60)**
- General Issues in Asphalt Technology **(AFK10)**
- Characteristics of Nonasphalt Components of Asphalt Paving Mixtures **(AFK30)**

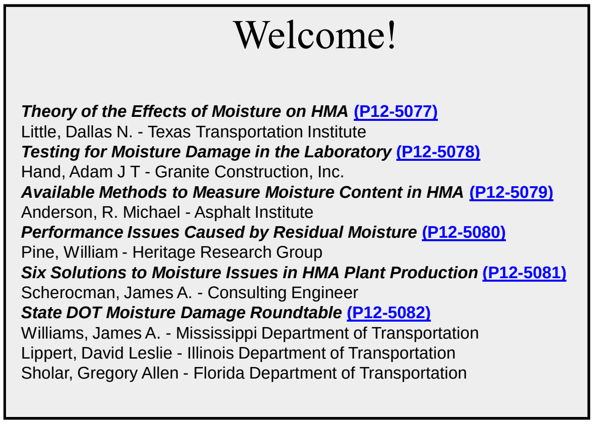
Why Are We Here?

- Asphalt moisture damage is a widespread problem with distress mechanisms capable of stemming from multiple sources including materials selected, stockpile moisture content, plant production, and construction.
- Long story short, moisture damage is a major issue that we need to understand better.
- Speakers and panel discussions selected to cover as many relevant topics as possible.
- Feedback from and interaction with the audience is very important.

FIGURE 1 Condensed version of workshop presiding officer's introductory slides.

(continued)





Welcome!

Theory of the Effects of Moisture on HMA (P12-5077)
Little, Dallas N. - Texas Transportation Institute
Testing for Moisture Damage in the Laboratory (P12-5078)
Hand, Adam J T - Granite Construction, Inc.
Available Methods to Measure Moisture Content in HMA (P12-5079)
Anderson, R. Michael - Asphalt Institute
Performance Issues Caused by Residual Moisture (P12-5080)
Pine, William - Heritage Research Group
Six Solutions to Moisture Issues in HMA Plant Production (P12-5081)
Scherocman, James A. - Consulting Engineer
State DOT Moisture Damage Roundtable (P12-5082)
Williams, James A. - Mississippi Department of Transportation
Lippert, David Leslie - Illinois Department of Transportation
Sholar, Gregory Allen - Florida Department of Transportation

FIGURE 1 (*continued*) Condensed version of workshop presiding officer's introductory slides.

The presentations given at the workshop are listed in Figure 1. All presenters were invited to contribute to this E-Circular, and the majority of the presenters chose to participate. The remainder of this E-Circular contains content provided by the invited speakers. Some of the presentations are condensed relative to that given at the workshop, with the intent of being concise, yet still preserving content and all key points. Some presentations are given with a summary preceding the presentation describing key points, while other presentations have annotated slides.

Testing for Moisture Damage in the Laboratory

ADAM J. T. HAND
Granite

Moisture damage of asphalt concrete pavements continues to be an item mix designers and specifying agencies must address. Every combination of aggregate, asphalt binder, and additives have a unique level of resistance to moisture damage. With the ever-changing supply of asphalt binder and introduction of new technologies [modifiers, polymers, anti-strip additives, and warm-mix asphalt (WMA) technologies] the need for effective laboratory test methods for evaluation of resistance to moisture damage of hot-mix asphalt (HMA) and WMA is as important today as it has ever been.

Moisture damage or stripping of asphalt pavements may manifest itself in several forms ranging from loss of mix integrity throughout one of more layers or at the bottom of a layer working its way to the top and can visually appear as several forms of distress ranging from rutting, fatigue cracking, potholes, and fatty spots in wheelpaths to raveling across an entire pavement surface. It typically occurs over time and is not apparent for several years unless it is catastrophic, for example in the case of when an amine (basic) anti-strip and polyphosphoric acid asphalt binder modifier are used together or when induced by a preventive maintenance treatment sealing moisture into a pavement. With the proliferation of the use of WMA fear that moisture damage would be a performance problem, especially with foaming technologies, has not been realized. In fact, with some WMA technologies moisture resistance of a mixture may be improved or liquid anti-strip additive may not be necessary.

Public agencies recognize the importance of mitigating moisture damage in the design and construction of asphalt pavements. A 2003 survey of state highway agencies revealed that over 80% of them required treatment using liquid anti-strip or lime and that the bulk of agencies were using tensile strength ratio (TSR) to evaluate compacted mixture. At the time some agencies were also using wheel tracking devices such as the Hamburg wheel tracking device (HWTD), which has grown in use since the 2003 survey.

The ideal situation would be to have a fast, economical, highly repeatable, and reproducible laboratory test which represented loading and environmental conditions in real pavement that could be used to determine moisture resistance of HMA–WMA, and for selection and optimization of anti-strip additives. Unfortunately, such a test does not exist today. There are many tests used to evaluation raw materials (asphalt binder, aggregates, anti-strip agents) and mixtures (both loose and compacted) relative to moisture resistance. Some of the tests provide qualitative results, while other provide quantitative results and many specifications are redundant in that they include both raw material and mixture requirements. Additionally, the tests fail to accurately account for differences in laboratory- and field-produced mixture, as well as the influence of changes in field conditions over time like mixture aging.

Commonly employed aggregate and HMA–WMA mixture tests are summarized in Slides 13 and 16, respectively. Aggregate tests are essentially used as screening tests or minimum aggregate source property tests which minimize the amount and activity of clays. The boil test is a quick loose mixture test used by some mix designers to narrow down the available combinations of asphalt binder and anti-strip additives prior to performing more complex and time-consuming compacted mixture tests. The most commonly specified compacted mixture test is the TSR. TSR is the ratio of unconditioned to conditioned tensile strengths of a mixture, expressed as a percentage. This test is sensitive several parameters such as air void and saturation levels and there are actually many different variations of the test being used today. Some are as significant as including versus not including a freeze–thaw conditioning cycle prior to TSR determination. This is likely part of the reason that a strong correlation between a minimum TSR value and field performance has never been established nationally. Some agencies have also recognized the need to include a minimum or maximum unconditioned tensile strength in addition to a minimum TSR, which may be a function of asphalt binder grade or virgin asphalt binder replacement with reclaimed asphalt pavement (RAP) or reclaimed asphalt shingles (RAS).

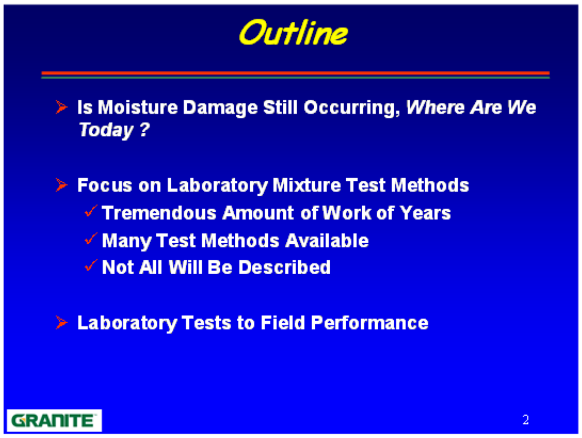
There is currently a significant amount of research underway to improve existing or develop new HMA–WMA moisture sensitivity tests. The HWTD is gaining popularity with public agencies and mix designers, while more fundamental tests like resilient or dynamic modulus under different loading, environmental, and conditioning cycles are being evaluated by the academic community. There is also fundamental research considering surface free energy and adhesive and cohesive bonding coupled with mechanical mixture tests being used to try to predict performance. One of the drivers being given consideration in all of this is the recognition that differences in laboratory and field produced mixture moisture resistance exists and that there are some relatively low-cost best practices (materials and selection and acceptance, as well as design and construction) that can be followed to minimize these differences as illustrated on Slides 31 and 32.

The risk to a public agency of placing a moisture sensitive mixture is very significant and the impact of increasing pavement life by as little as 1 to 2 years by using effective anti-strip agents has been illustrated to be very significant when considering an agency network over time. Thus the need for a fast, economical, highly repeatable, and reproducible laboratory test which can be used to predict the impact of moisture sensitivity on HMA–WMA pavement performance. Finally, the same test is needed to minimize contract risk as illustrated in Slide 33.

Testing for Moisture Damage in the Laboratory

Moisture Damage to HMA Mixtures Workshop
TRB 91st Annual Meeting
Adam J.T. Hand, PhD, PE
January 22, 2012

1



Outline

- Is Moisture Damage Still Occurring, *Where Are We Today ?*
- Focus on Laboratory Mixture Test Methods
  - ✓ Tremendous Amount of Work of Years
  - ✓ Many Test Methods Available
  - ✓ Not All Will Be Described
- Laboratory Tests to Field Performance

2

Field Observations

- Is Moisture Damage Still Occurring?

3

Field Observations

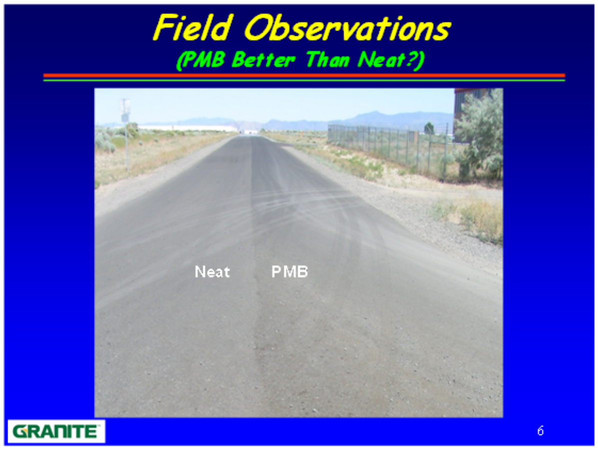
(Moisture Damage)

4

Field Observations

(Exacerbated Raveling)

5



Field Observations

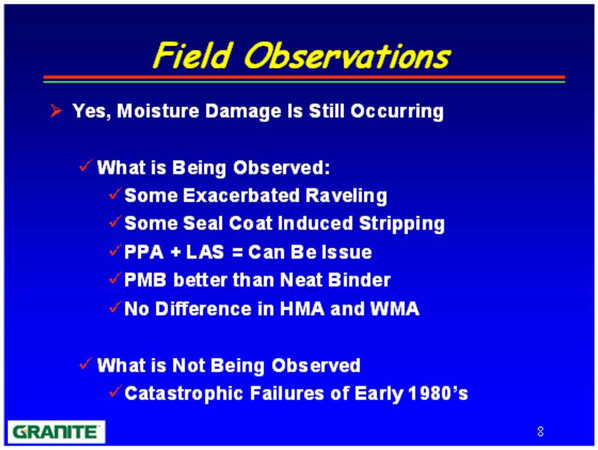
(PMB Better Than Neat?)

6

Field Observations

(Seal Coat Induced Stripping)

7



Field Observations

- Yes, Moisture Damage Is Still Occurring
  - ✓ What is Being Observed:
    - ✓ Some Exacerbated Raveling
    - ✓ Some Seal Coat Induced Stripping
    - ✓ PPA + LAS = Can Be Issue
    - ✓ PMB better than Neat Binder
    - ✓ No Difference in HMA and WMA
  - ✓ What is Not Being Observed
    - ✓ Catastrophic Failures of Early 1980's

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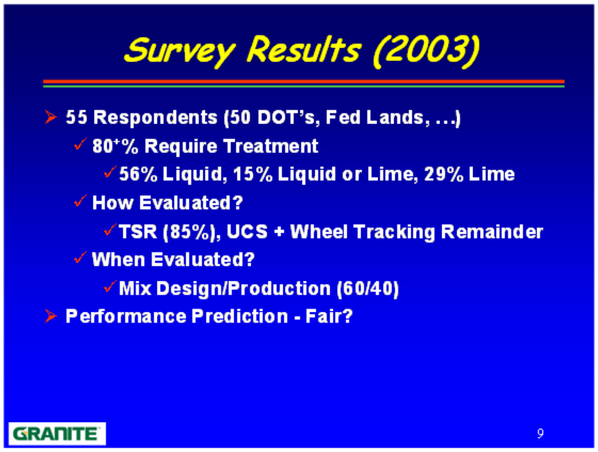

Survey Results (2003)

- 55 Respondents (50 DOT's, Fed Lands, …)
  - ✓ 80⁺% Require Treatment
    - ✓ 56% Liquid, 15% Liquid or Lime, 29% Lime
  - ✓ How Evaluated?
    - ✓ TSR (85%), UCS + Wheel Tracking Remainder
  - ✓ When Evaluated?
    - ✓ Mix Design/Production (60/40)
- Performance Prediction - Fair?

9

What Do We Want From a Laboratory Test Method?

- Represent Mechanisms that Cause Moisture Damage
  - ✓ Environmental Conditions
    - ✓ Moisture, Temperature, F/T, …
  - ✓ Loading Conditions
    - ✓ Traffic, Pore Pressure
- Antistrip Effectiveness and Optimization
- Correlate with Field Performance
- Repeatable and Reproducible
- Fast, Practical, Economical

10

What Can We Test in the Lab?

- Asphalt Binder
- Antistrip Additives
- Aggregates
- HMA or WMA Mixture
  - ✓ Loose Mix
  - ✓ Compacted Mix
    - ✓ Lab or Field Compacted?
  - ✓ Array of Conditioning
- Asphalt Binder and Antistrips Only Tested for Specification Compliance
- Must Test HMA Mix to Determine Effectiveness of Unique Combo's

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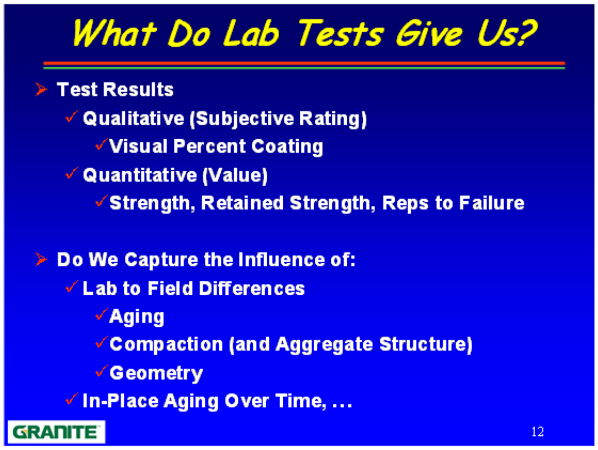

What Do Lab Tests Give Us?

- Test Results
  - ✓ Qualitative (Subjective Rating)
    - ✓ Visual Percent Coating
  - ✓ Quantitative (Value)
    - ✓ Strength, Retained Strength, Reps to Failure
- Do We Capture the Influence of:
  - ✓ Lab to Field Differences
    - ✓ Aging
    - ✓ Compaction (and Aggregate Structure)
    - ✓ Geometry
  - ✓ In-Place Aging Over Time, …

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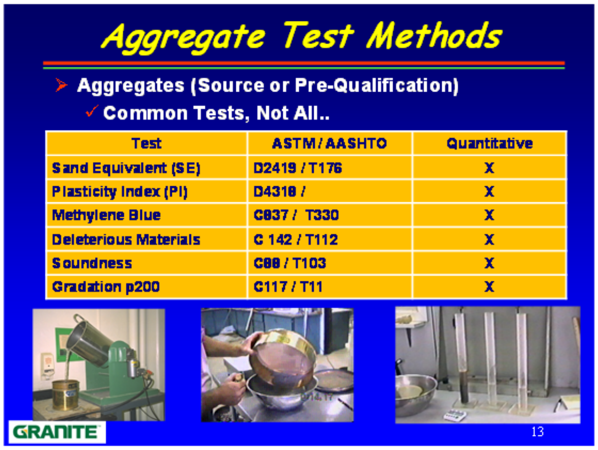

Aggregate Test Methods

- Aggregates (Source or Pre-Qualification)
  - ✓ Common Tests, Not All..

Test	ASTM / AASHTO	Quantitative
Sand Equivalent (SE)	D2419 / T176	X
Plasticity Index (PI)	D4318 /	X
Methylene Blue	C837 / T330	X
Deleterious Materials	C 142 / T112	X
Soundness	C88 / T103	X
Gradation p200	C117 / T11	X

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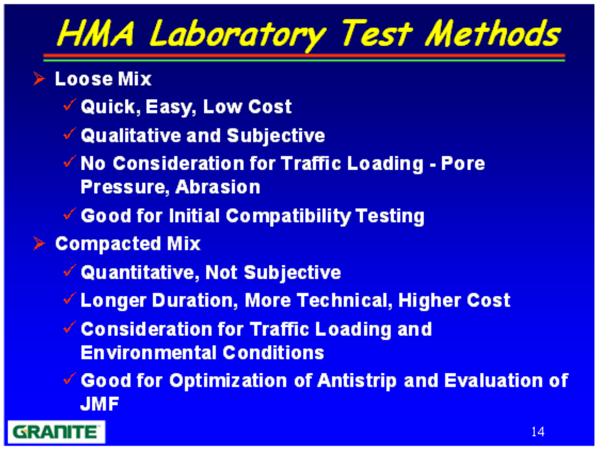

HMA Laboratory Test Methods

- Loose Mix
  - ✓ Quick, Easy, Low Cost
  - ✓ Qualitative and Subjective
  - ✓ No Consideration for Traffic Loading - Pore Pressure, Abrasion
  - ✓ Good for Initial Compatibility Testing
- Compacted Mix
  - ✓ Quantitative, Not Subjective
  - ✓ Longer Duration, More Technical, Higher Cost
  - ✓ Consideration for Traffic Loading and Environmental Conditions
  - ✓ Good for Optimization of Antistrip and Evaluation of JMF

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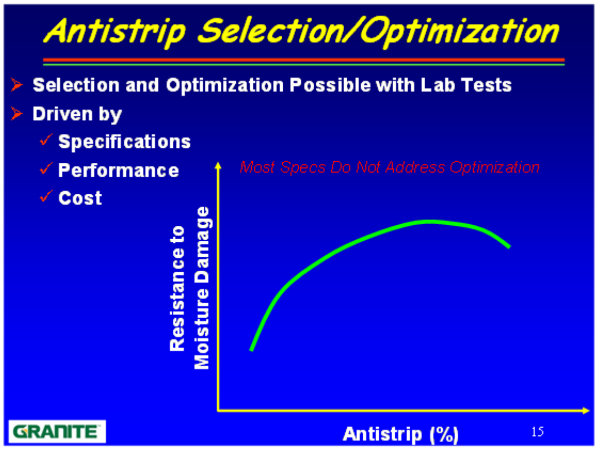

Antistrip Selection/Optimization

- Selection and Optimization Possible with Lab Tests
- Driven by
  - ✓ Specifications
  - ✓ Performance
  - ✓ Cost

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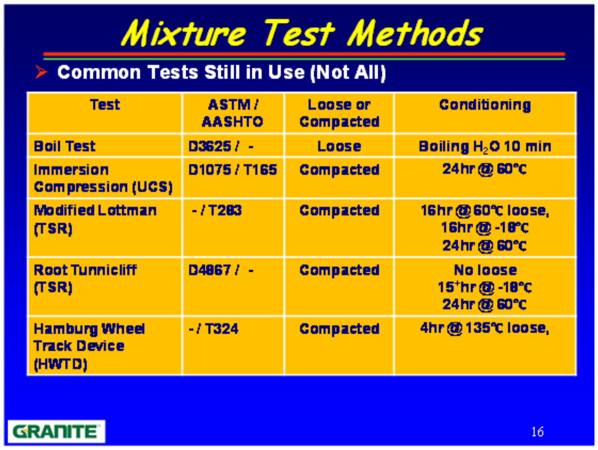

Mixture Test Methods

- Common Tests Still in Use (Not All)

Test	ASTM / AASHTO	Loose or Compacted	Conditioning
Boil Test	D3625 / -	Loose	Boiling H_2O 10 min
Immersion Compression (UCS)	D1075 / T165	Compacted	24hr @ 60°C
Modified Lottman (TSR)	- / T283	Compacted	16hr @ 60°C loose, 16hr @ -18°C 24hr @ 60°C
Root Tunnicliff (TSR)	D4867 / -	Compacted	No loose 15^+hr @ -18°C 24hr @ 60°C
Hamburg Wheel Track Device (HWTD)	- / T324	Compacted	4hr @ 135°C loose,

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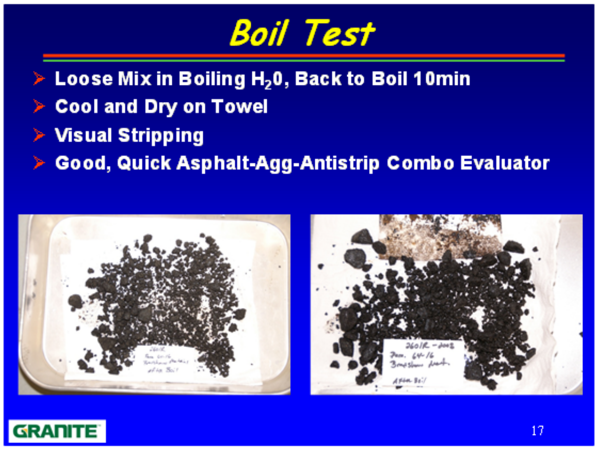

Boil Test

- Loose Mix in Boiling H_20, Back to Boil 10min
- Cool and Dry on Towel
- Visual Stripping
- Good, Quick Asphalt-Agg-Antistrip Combo Evaluator

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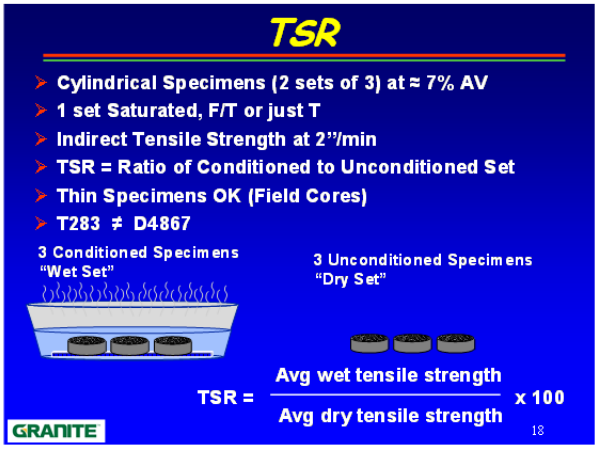

TSR

- Cylindrical Specimens (2 sets of 3) at ≈ 7% AV
- 1 set Saturated, F/T or just T
- Indirect Tensile Strength at 2"/min
- TSR = Ratio of Conditioned to Unconditioned Set
- Thin Specimens OK (Field Cores)
- T283 ≠ D4867

$$\text{TSR} = \frac{\text{Avg wet tensile strength}}{\text{Avg dry tensile strength}} \times 100$$

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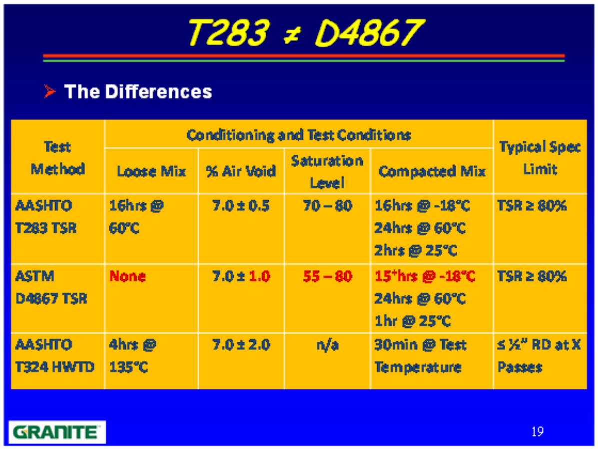

T283 ≠ D4867

- The Differences

Test Method	Conditioning and Test Conditions				Typical Spec Limit
	Loose Mix	% Air Void	Saturation Level	Compacted Mix	
AASHTO T283 TSR	16hrs @ 60°C	7.0 ± 0.5	70 – 80	16hrs @ -18°C 24hrs @ 60°C 2hrs @ 25°C	TSR ≥ 80%
ASTM D4867 TSR	None	7.0 ± 1.0	55 – 80	15^+hrs @ -18°C 24hrs @ 60°C 1hr @ 25°C	TSR ≥ 80%
AASHTO T324 HWTD	4hrs @ 135°C	7.0 ± 2.0	n/a	30min @ Test Temperature	≤ ½" RD at X Passes

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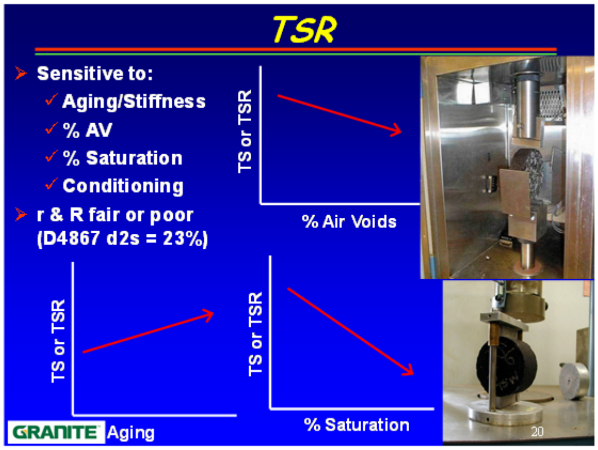

TSR

- Sensitive to:
  - ✓ Aging/Stiffness
  - ✓ % AV
  - ✓ % Saturation
  - ✓ Conditioning
- r & R fair or poor (D4867 d2s = 23%)

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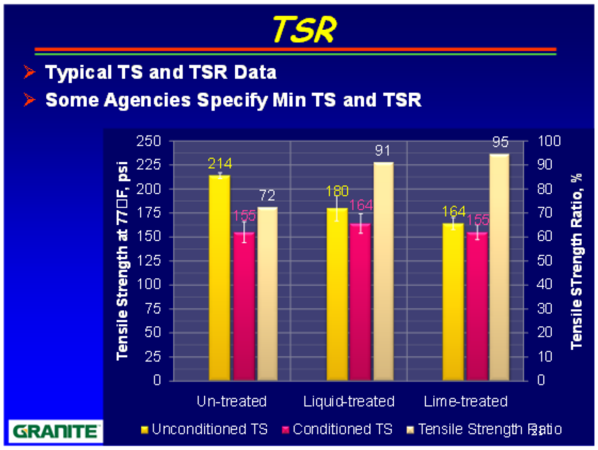

TSR

- Typical TS and TSR Data
- Some Agencies Specify Min TS and TSR

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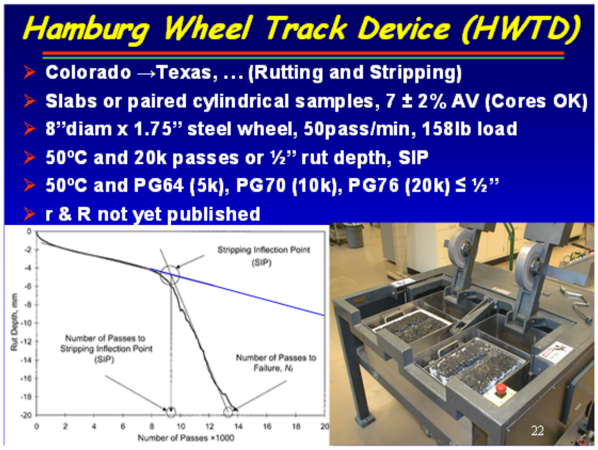

Hamburg Wheel Track Device (HWTD)

- Colorado →Texas, … (Rutting and Stripping)
- Slabs or paired cylindrical samples, 7 ± 2% AV (Cores OK)
- 8"diam x 1.75" steel wheel, 50pass/min, 158lb load
- 50°C and 20k passes or ½" rut depth, SIP
- 50°C and PG64 (5k), PG70 (10k), PG76 (20k) ≤ ½"
- r & R not yet published

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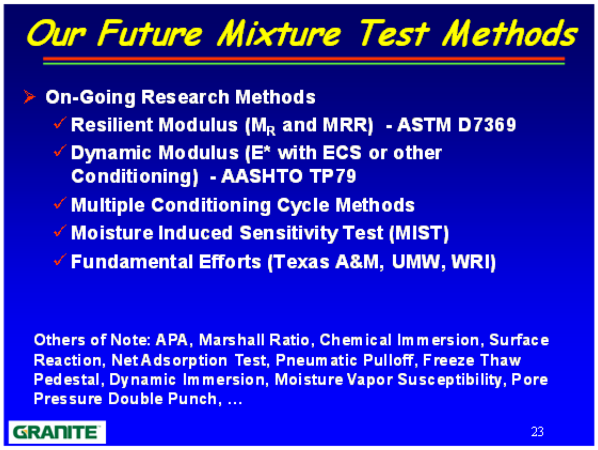

Our Future Mixture Test Methods

- On-Going Research Methods
  - ✓ Resilient Modulus (M_R and MRR) - ASTM D7369
  - ✓ Dynamic Modulus (E* with ECS or other Conditioning) - AASHTO TP79
  - ✓ Multiple Conditioning Cycle Methods
  - ✓ Moisture Induced Sensitivity Test (MIST)
  - ✓ Fundamental Efforts (Texas A&M, UMW, WRI)

Others of Note: APA, Marshall Ratio, Chemical Immersion, Surface Reaction, Net Adsorption Test, Pneumatic Pulloff, Freeze Thaw Pedestal, Dynamic Immersion, Moisture Vapor Susceptibility, Pore Pressure Double Punch, …

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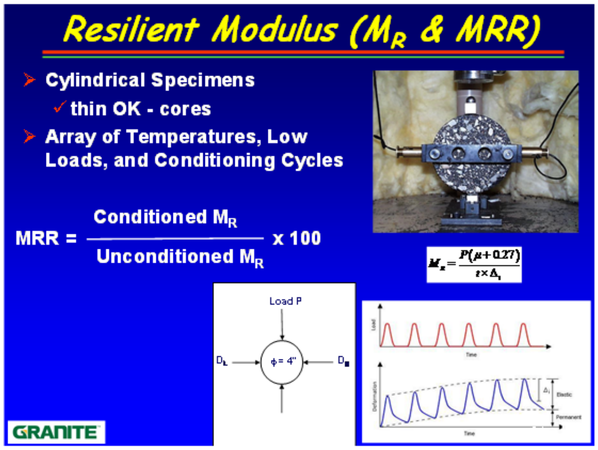

Resilient Modulus (M_R & MRR)

- Cylindrical Specimens
  - ✓ thin OK - cores
- Array of Temperatures, Low Loads, and Conditioning Cycles

$$\text{MRR} = \frac{\text{Conditioned } M_R}{\text{Unconditioned } M_R} \times 100$$

$$M_R = \frac{P(\mu + 0.27)}{t \times \Delta_t}$$

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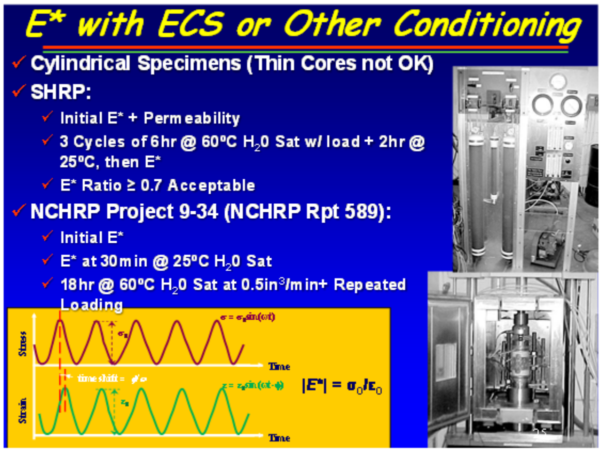

E* with ECS or Other Conditioning

- ✓ Cylindrical Specimens (Thin Cores not OK)
- ✓ SHRP:
  - ✓ Initial E* + Permeability
  - ✓ 3 Cycles of 6hr @ 60°C $H_2$0 Sat w/ load + 2hr @ 25°C, then E*
  - ✓ E* Ratio ≥ 0.7 Acceptable
- ✓ NCHRP Project 9-34 (NCHRP Rpt 589):
  - ✓ Initial E*
  - ✓ E* at 30min @ 25°C $H_2$0 Sat
  - ✓ 18hr @ 60°C $H_2$0 Sat at 0.5in^3/min+ Repeated Loading

$$|E^*| = \sigma_0/\varepsilon_0$$

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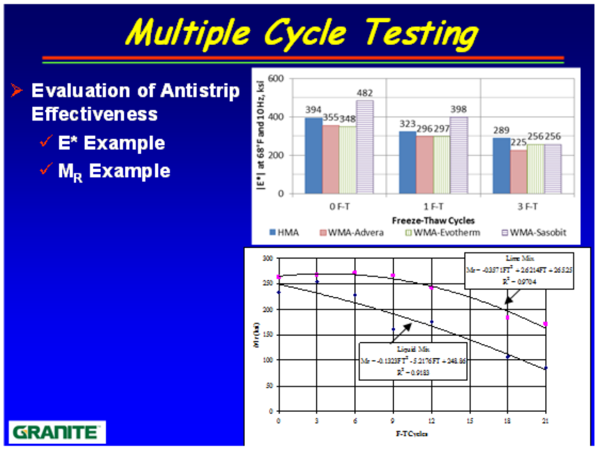

Multiple Cycle Testing

- Evaluation of Antistrip Effectiveness
  - ✓ E* Example
  - ✓ M_R Example

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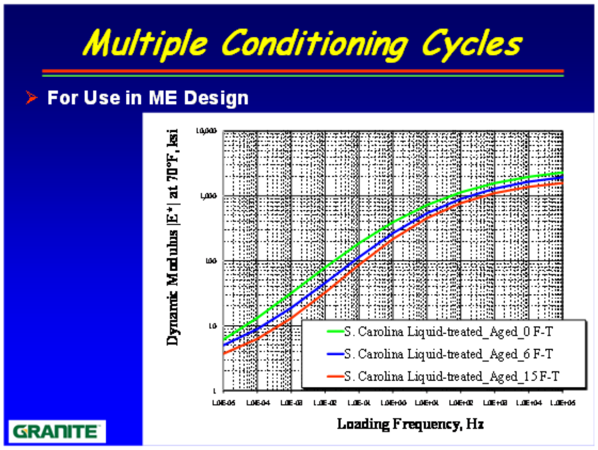

Multiple Conditioning Cycles

- For Use in ME Design

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Moisture Induced Stress Tester (MIST)

- Cylindrical Specimens
- Pore Pressure/Scour
- 0 - 40psi Cycling
- 60°C H_2O
- ½ Day Duration

- Density Change
- M TSR

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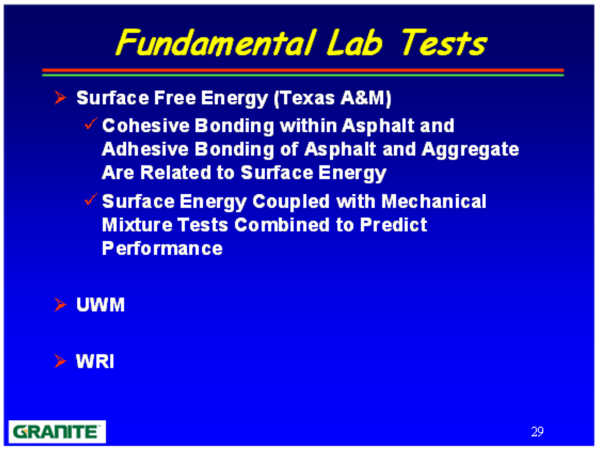

Fundamental Lab Tests

- Surface Free Energy (Texas A&M)
  - ✓ Cohesive Bonding within Asphalt and Adhesive Bonding of Asphalt and Aggregate Are Related to Surface Energy
  - ✓ Surface Energy Coupled with Mechanical Mixture Tests Combined to Predict Performance

- UWM

- WRI

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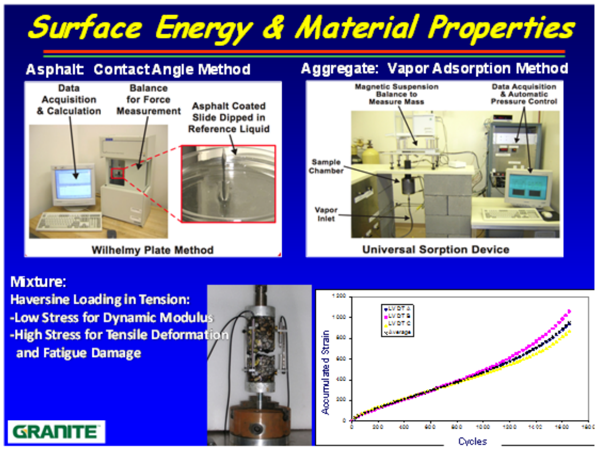

Surface Energy & Material Properties

Asphalt: Contact Angle Method

Aggregate: Vapor Adsorption Method

Mixture:
Haversine Loading in Tension:
-Low Stress for Dynamic Modulus
-High Stress for Tensile Deformation and Fatigue Damage

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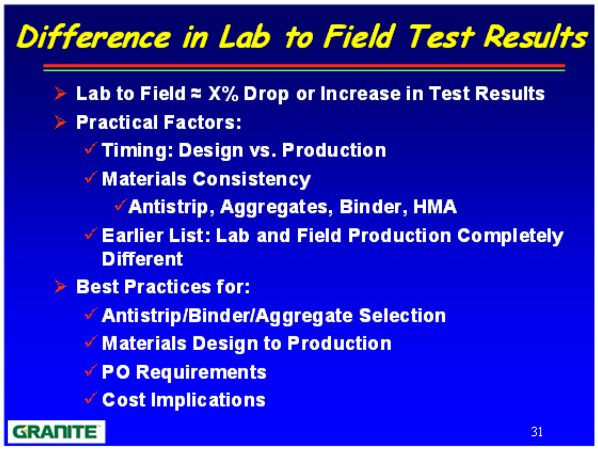

Difference in Lab to Field Test Results

- Lab to Field ≈ X% Drop or Increase in Test Results
- Practical Factors:
  - ✓ Timing: Design vs. Production
  - ✓ Materials Consistency
    - ✓ Antistrip, Aggregates, Binder, HMA
  - ✓ Earlier List: Lab and Field Production Completely Different
- Best Practices for:
  - ✓ Antistrip/Binder/Aggregate Selection
  - ✓ Materials Design to Production
  - ✓ PO Requirements
  - ✓ Cost Implications

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Minimizing Δ Lab to Field

- Design Practices Matter
  - ✓ Drainage
  - ✓ No M/F Bathtubs
  - ✓ Adequate t/NMAS

- Construction Practices/Conditions Matter
  - ✓ Antistrip Application
  - ✓ Mix Temperature
  - ✓ Weather
  - ✓ Mat Density
  - ✓ Joint Density
  - ✓ Segregation

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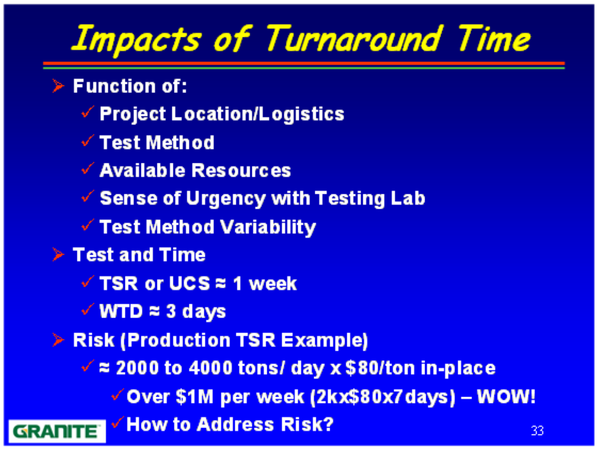
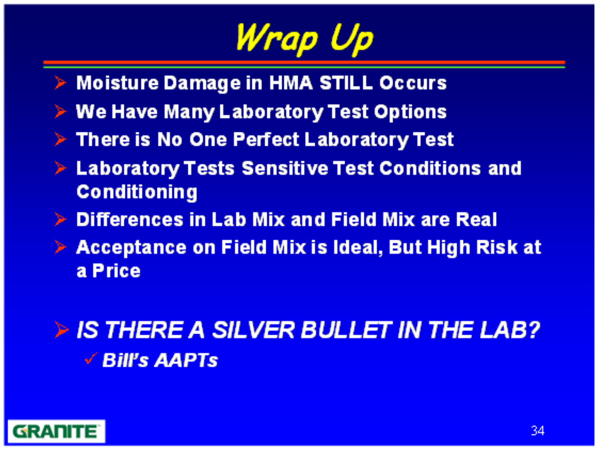


Impacts of Turnaround Time

- Function of:
  - ✓ Project Location/Logistics
  - ✓ Test Method
  - ✓ Available Resources
  - ✓ Sense of Urgency with Testing Lab
  - ✓ Test Method Variability
- Test and Time
  - ✓ TSR or UCS ≈ 1 week
  - ✓ WTD ≈ 3 days
- Risk (Production TSR Example)
  - ✓ ≈ 2000 to 4000 tons/ day x $80/ton in-place
    - ✓ Over $1M per week (2kx$80x7days) – WOW!
    - ✓ How to Address Risk?



Wrap Up

- Moisture Damage in HMA STILL Occurs
- We Have Many Laboratory Test Options
- There is No One Perfect Laboratory Test
- Laboratory Tests Sensitive Test Conditions and Conditioning
- Differences in Lab Mix and Field Mix are Real
- Acceptance on Field Mix is Ideal, But High Risk at a Price

- *IS THERE A SILVER BULLET IN THE LAB?*
  - ✓ *Bill's AAPTs*

Available Methods to Measure Moisture Content in Hot-Mix Asphalt

R. MICHAEL ANDERSON
Asphalt Institute

The presentation made by R. Michael Anderson was derived from research conducted approximately 10 years earlier. More details can be found in the paper of the same name published in *Transportation Research Record: Journal of the Transportation Research Board, No. 1813*.

As user agencies began specifying Superpave® mixes in the late 1990s, they occasionally experienced tender mix behavior, particularly with coarse-graded mixes. Tender mix behavior is exhibited by the inability to compact the asphalt mixture during construction. When subjected to normal compaction operations, the asphalt mixture deforms instead of becoming denser. Classic tender mix behavior is usually associated with insufficient stiffness directly behind the paver, often caused by an excess of rounded fine aggregate in the mix. The solution to classic tender mix behavior is to allow the mix to cool before breakdown rolling begins.

The mix behavior experienced by users with some Superpave coarse-graded mixtures have been similar, but not quite the same, as classic tender mix behavior. Initially these mixes appeared to have sufficient stiffness to support breakdown rolling and compaction, but once the mixture reached a temperature range of approximately 85°C to 120°C, it was found that the mix would shove under the drum of the roller making further densification very difficult. The one solution that appeared to work for these mixes was to delay compaction until the temperature was outside of this “tender zone.” While this solution was found to work in most cases, it resulted in an inefficient compaction process for the contractor.

To develop a better solution to the problem, it was necessary to understand the reason for the tender mix behavior in the Superpave mixes. The usual suspect—excess rounded fine aggregate—could not be at the root cause since Superpave aggregate criteria limited the amount of rounded sands that could be used in a mixture. As such a hypothesis was developed that the tender mix behavior was related to the presence of entrapped moisture in the mix. The rationale for this hypothesis was that coarse-graded Superpave mixes are often harder to dry in the drum of the plant because the increased percentage of coarse aggregate means that there is a corresponding smaller percentage of fine aggregate available to create a “veil” needed to efficiently trap the heat and dry the aggregates. Heat is lost through the stack instead of being used to dry the aggregates. As a result, the higher percentage of coarse aggregate results in a greater opportunity to have entrapped moisture remaining in the aggregate pores during the mixing process.

While mixes become stiffer and more difficult to compact as the temperature decreases, asphalt mixtures with entrapped moisture may experience a tender zone period where the mixture temporarily loses stiffness. The entrapped moisture may not weaken the mixture until it escapes as steam, temporarily breaking the asphalt–aggregate bond and appearing as excess fluids in the mix. Once the internal steam has escaped from the aggregate, the asphalt–aggregate bond redevelops and the tender mix behavior dissipates.

Field experience with some mixtures that exhibit tender zone behavior has shown that the problem may be weather dependent. Wet stockpiles seem to be a common denominator with

Superpave tender mix behavior. Often, as the aggregate stockpiles dry the tender zone behavior dissipates. Increasing the dwell time in a dryer or mixing drum (i.e., slowing the production rate) may help eliminate some tender mix behavior. Increasing the fan capacity on the mixing plant may have the same effect.

Complicating the problem of testing the hypothesis is the fact that the accurate measurement of moisture in asphalt mixtures has often been considered to be very difficult with typical reported values under 0.1%.

The overall objectives of the study were to: (*a*) develop a test method to accurately measure the moisture in a mixture and (*b*) determine if the Superpave tender zone phenomenon is related to entrapped moisture in the asphalt mixture.

To accomplish these objectives, the first step was to develop a laboratory procedure to trap moisture in an asphalt mixture. A 12.5-mm coarse-graded Superpave mixture with a combined aggregate absorption of 2.9% was used for this evaluation. Four methods were evaluated:

1. Vacuum saturation of coarse aggregate;
2. Use of a pressure cooker (Sonderegger, 1961);
3. Vacuum saturation with a pressure cooker; and
4. Use of a bucket mixer with a propane torch.

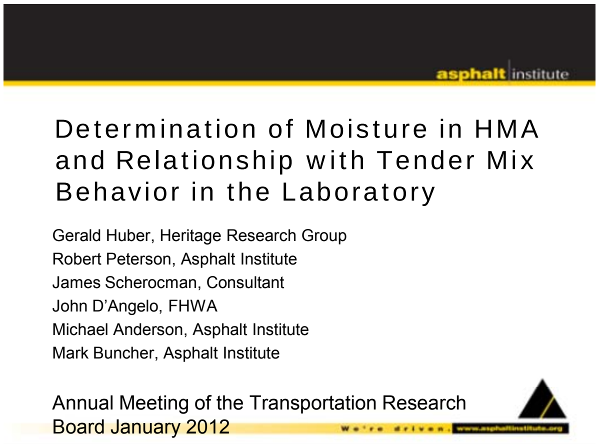
Of the four methods evaluated, the bucket mixer with propane torch was the most efficient at trapping moisture in the mix with measured moisture content of 0.8% to 1.8%.

Once the mix preparation procedure was selected, two other mixes were added to the testing program to evaluate the methods for measuring the moisture content of the mix. Of the procedures evaluated, the selected procedure was to dry the sample to a constant mass in a forced-draft oven operating at 110°C. The standard distillation procedure using xylene (ASTM D1461) produced similar results but was considered too cumbersome for this study.

Another factor that was considered to potentially affect moisture content of asphalt mixtures was the storage of samples before testing. To evaluate this factor, three storage containers (aluminum paint can, oven cooking bag, and paper grocery bag) were selected. After preparation using the bucket mixer, the samples were quartered. One quarter of each sample was placed in the three storage containers with the fourth quarter placed in a pan for immediate determination of moisture content. The stored samples were then held for a period of time (1, 4, 24, or 72 h) before placing the container in the oven and drying to constant mass. From this work it was seen that only the aluminum paint can retained all of the moisture from the original state; that is, the moisture content of the mix did not decrease as a function of time when stored in a sealed aluminum paint can. Finally, the study attempted to simulate and quantify tender mix behavior in the laboratory by producing asphalt mixtures that were dry (normal lab procedures) and wet (with some trapped moisture using the bucket mixer with propane torch) and evaluating their compaction characteristics in the Superpave gyratory compactor. Four compaction temperatures were selected from 79°C to 138°C with the intent of bracketing the temperatures normally observed with the tender mix zone. To evaluate compaction characteristics, the gyratory load-cell plate assembly was used. This device, developed by Guler and Bahia, measures the load placed on the mix sample during compaction. It was expected that tender mix behavior during compaction would be indicated by a reduction in load.

Although the wet subset of mixtures generally exhibited lower peak load than the dry subset, as expected, the research team was unable to effectively simulate the expected Superpave tender zone behavior during lab compaction. Two possible explanations for this inability to simulate the tender mix behavior were: (*a*) the average moisture content of the wet subset of mixtures was low (0.2%) compared to earlier experiments and (*b*) the mix may not actually exhibit Superpave tender zone behavior in field. Selecting a mixture with known problems with Superpave tender zone behavior would have been better for this study.

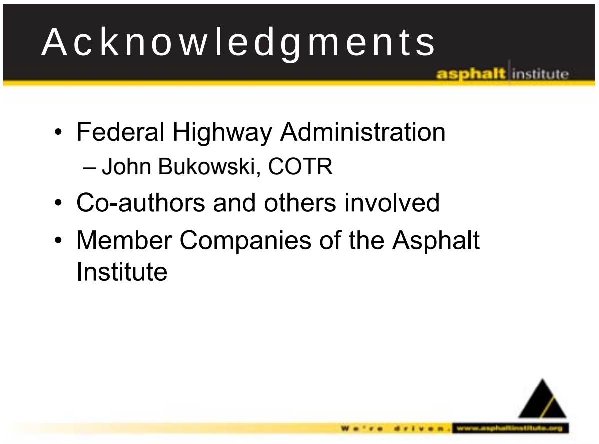
As user agencies have gained experience with Superpave mixtures, there have been less instances of the Superpave tender zone behavior reported. It is possible that the problem still occurs, but users have learned how to compact such mixtures in the field. Another, more likely reason for the reduced reports of tender mix behavior is that users have transitioned away from the type of coarse-graded mixtures that were susceptible to the effects of trapped moisture. The transition to finer, more dense-graded mixtures to reduce permeability may have alleviated many of the problems seen in the late 1990s and early 2000s.



Determination of Moisture in HMA and Relationship with Tender Mix Behavior in the Laboratory

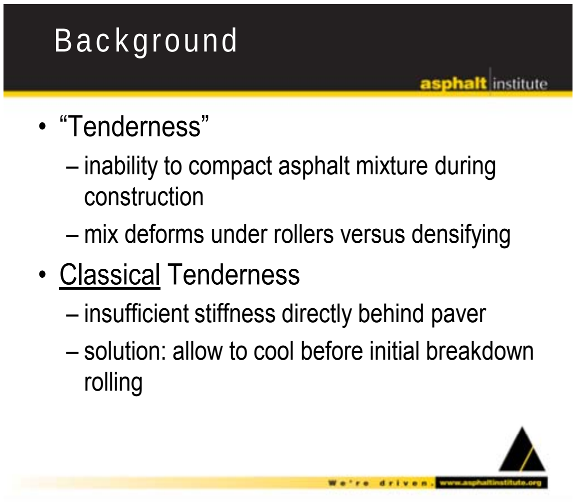
Gerald Huber, Heritage Research Group
Robert Peterson, Asphalt Institute
James Scherocman, Consultant
John D'Angelo, FHWA
Michael Anderson, Asphalt Institute
Mark Buncher, Asphalt Institute

Annual Meeting of the Transportation Research Board January 2012



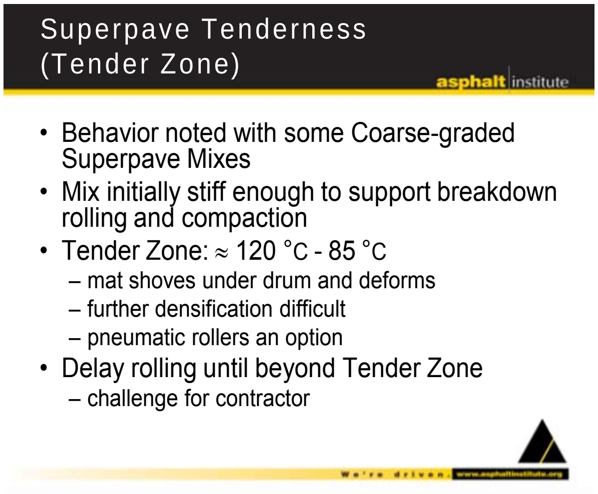
Acknowledgments

- Federal Highway Administration
  - John Bukowski, COTR
- Co-authors and others involved
- Member Companies of the Asphalt Institute



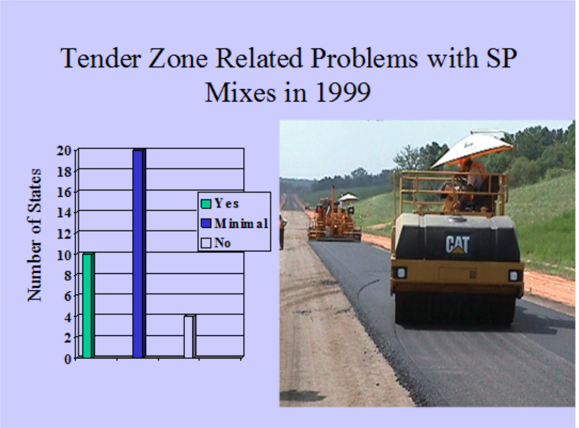
Background

- "Tenderness"
  - inability to compact asphalt mixture during construction
  - mix deforms under rollers versus densifying
- Classical Tenderness
  - insufficient stiffness directly behind paver
  - solution: allow to cool before initial breakdown rolling

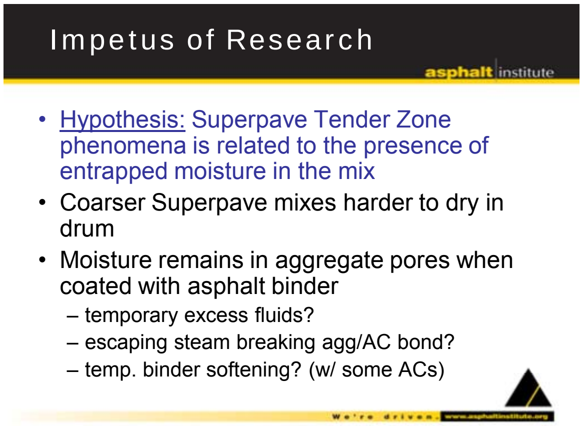


Superpave Tenderness (Tender Zone)

- Behavior noted with some Coarse-graded Superpave Mixes
- Mix initially stiff enough to support breakdown rolling and compaction
- Tender Zone: ≈ 120 °C - 85 °C
  - mat shoves under drum and deforms
  - further densification difficult
  - pneumatic rollers an option
- Delay rolling until beyond Tender Zone
  - challenge for contractor



Tender Zone Related Problems with SP Mixes in 1999



Impetus of Research

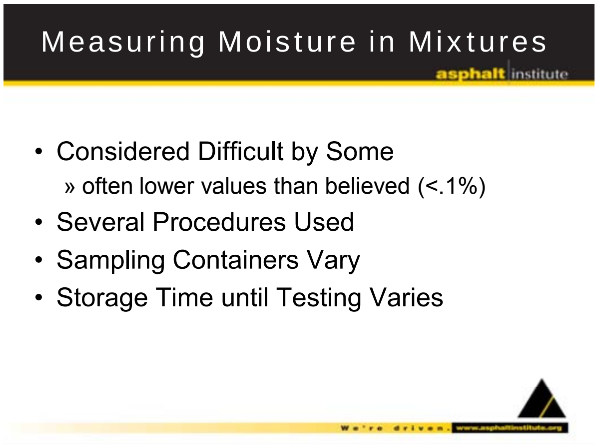
- Hypothesis: Superpave Tender Zone phenomena is related to the presence of entrapped moisture in the mix
- Coarser Superpave mixes harder to dry in drum
- Moisture remains in aggregate pores when coated with asphalt binder
  - temporary excess fluids?
  - escaping steam breaking agg/AC bond?
  - temp. binder softening? (w/ some ACs)

Wet Stockpiles...

...Common for Mixes w/ a Tender Zone

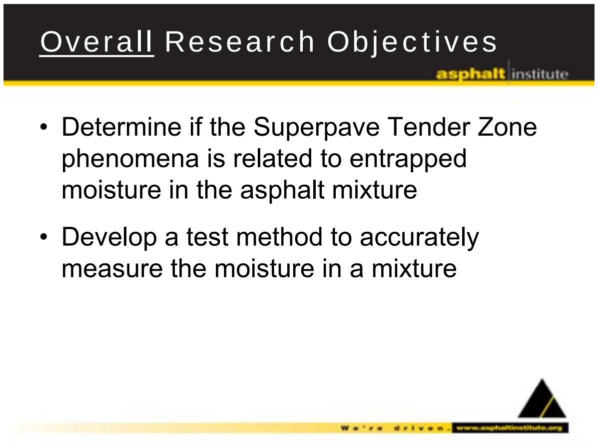
Steam at the Plant

Steam from the Trucks



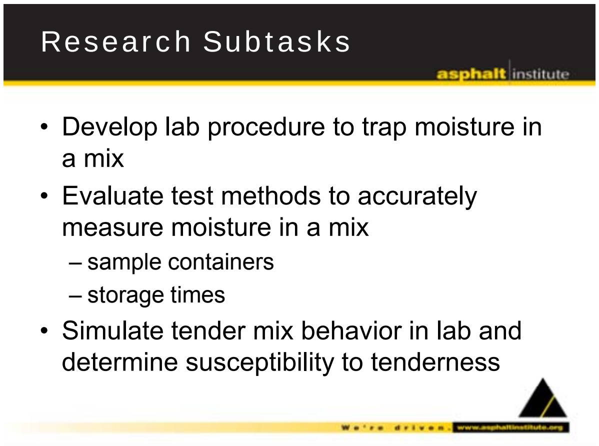
Measuring Moisture in Mixtures

- Considered Difficult by Some
  - » often lower values than believed (<.1%)
- Several Procedures Used
- Sampling Containers Vary
- Storage Time until Testing Varies



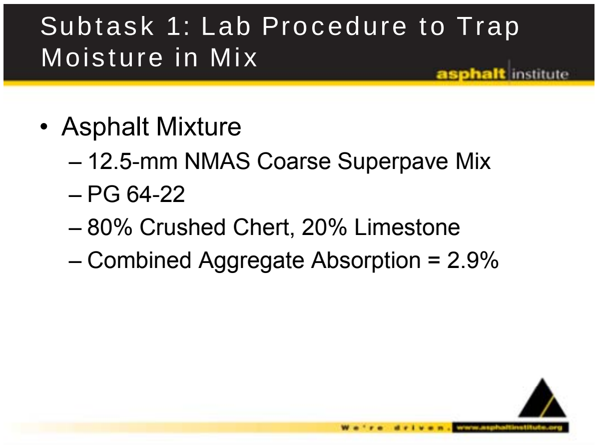
Overall Research Objectives

- Determine if the Superpave Tender Zone phenomena is related to entrapped moisture in the asphalt mixture
- Develop a test method to accurately measure the moisture in a mixture



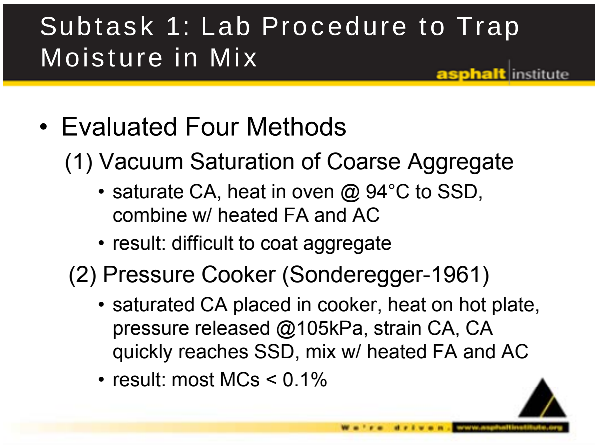
Research Subtasks

- Develop lab procedure to trap moisture in a mix
- Evaluate test methods to accurately measure moisture in a mix
  - – sample containers
  - – storage times
- Simulate tender mix behavior in lab and determine susceptibility to tenderness



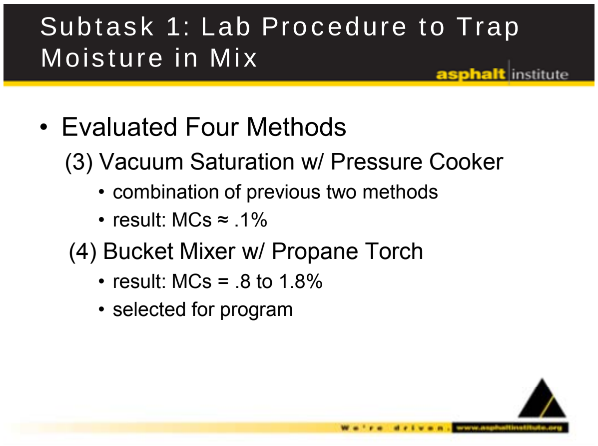
Subtask 1: Lab Procedure to Trap Moisture in Mix

- Asphalt Mixture
  - – 12.5-mm NMAS Coarse Superpave Mix
  - – PG 64-22
  - – 80% Crushed Chert, 20% Limestone
  - – Combined Aggregate Absorption = 2.9%



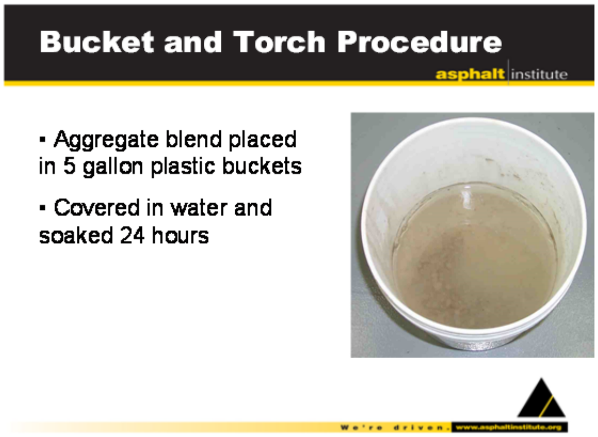
Subtask 1: Lab Procedure to Trap Moisture in Mix

- Evaluated Four Methods
  - (1) Vacuum Saturation of Coarse Aggregate
    - saturate CA, heat in oven @ 94°C to SSD, combine w/ heated FA and AC
    - result: difficult to coat aggregate
  - (2) Pressure Cooker (Sonderegger-1961)
    - saturated CA placed in cooker, heat on hot plate, pressure released @105kPa, strain CA, CA quickly reaches SSD, mix w/ heated FA and AC
    - result: most MCs < 0.1%



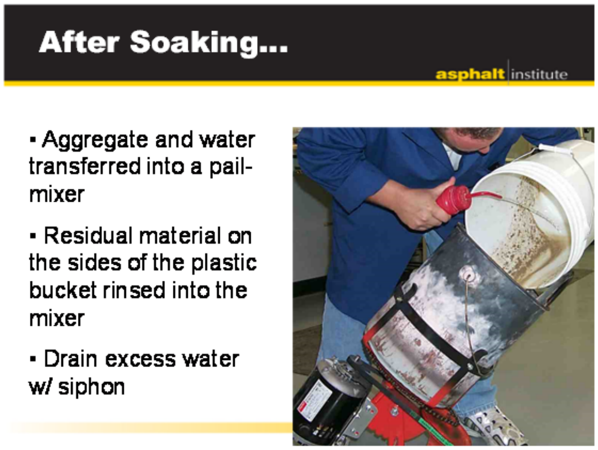
Subtask 1: Lab Procedure to Trap Moisture in Mix

- Evaluated Four Methods
  - (3) Vacuum Saturation w/ Pressure Cooker
    - combination of previous two methods
    - result: MCs ≈ .1%
  - (4) Bucket Mixer w/ Propane Torch
    - result: MCs = .8 to 1.8%
    - selected for program



Bucket and Torch Procedure

- Aggregate blend placed in 5 gallon plastic buckets
- Covered in water and soaked 24 hours

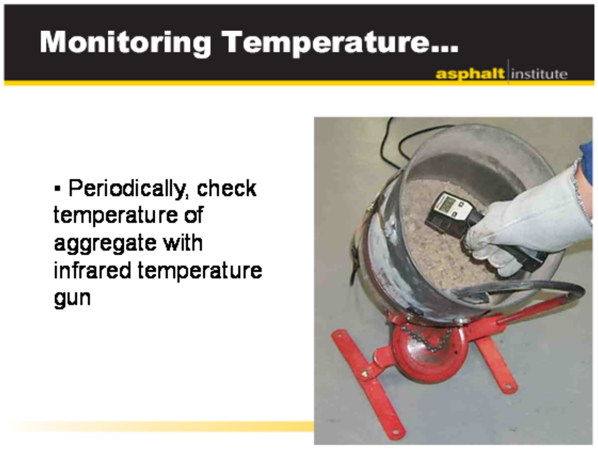


After Soaking…

- Aggregate and water transferred into a pail-mixer
- Residual material on the sides of the plastic bucket rinsed into the mixer
- Drain excess water w/ siphon

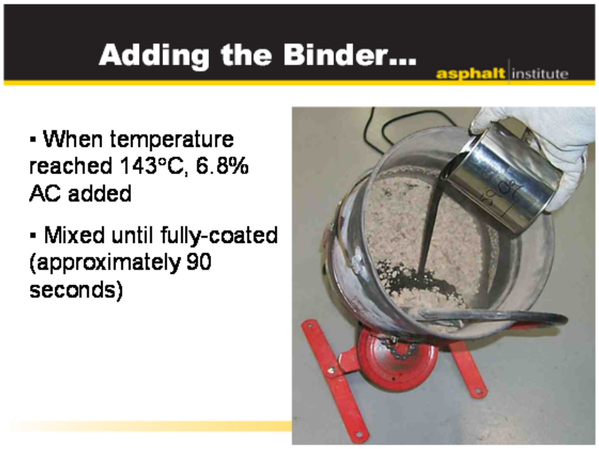
Mixing Begins…

- Pail-mixer activated to continually mix wet aggregate while rapidly heating it with large propane torch



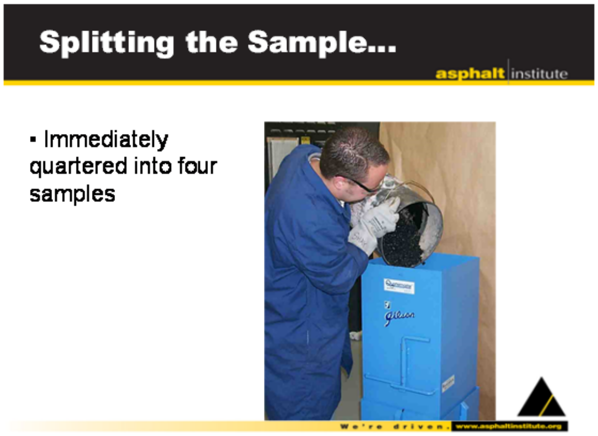
Monitoring Temperature…

- Periodically, check temperature of aggregate with infrared temperature gun



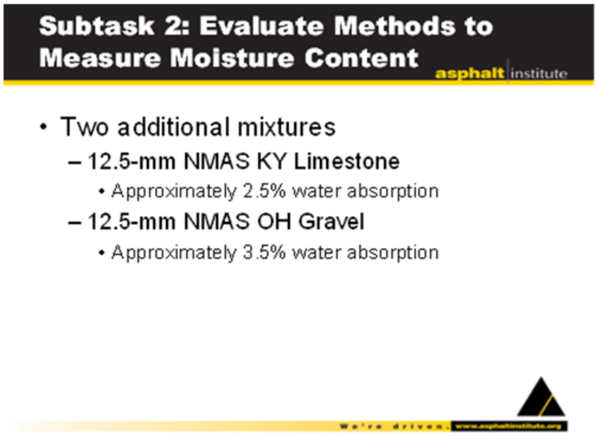
Adding the Binder…

- When temperature reached 143°C, 6.8% AC added
- Mixed until fully-coated (approximately 90 seconds)



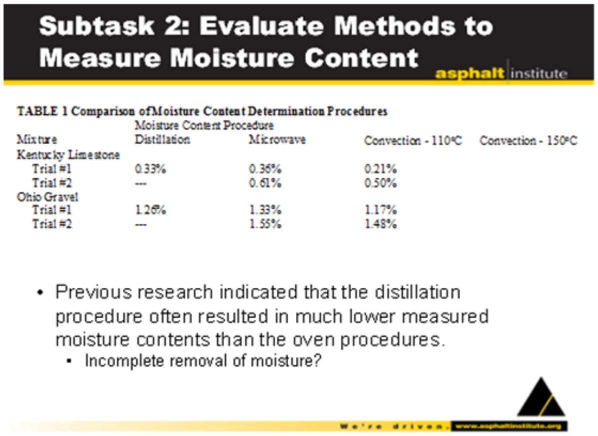
Splitting the Sample…

- Immediately quartered into four samples



Subtask 2: Evaluate Methods to Measure Moisture Content

- Two additional mixtures
  - 12.5-mm NMAS KY Limestone
    - Approximately 2.5% water absorption
  - 12.5-mm NMAS OH Gravel
    - Approximately 3.5% water absorption

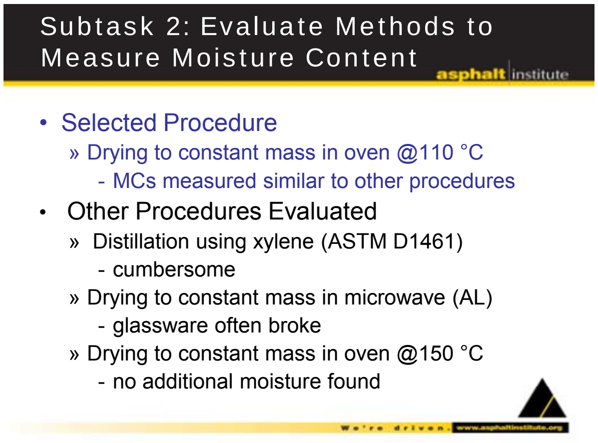


Subtask 2: Evaluate Methods to Measure Moisture Content

TABLE 1 Comparison of Moisture Content Determination Procedures

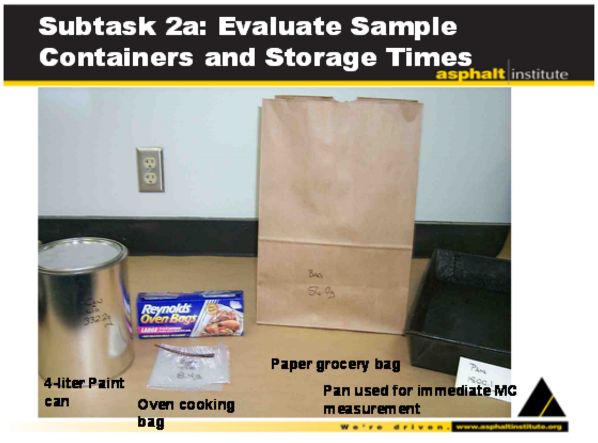
	Moisture Content Procedure			
Mixture	Distillation	Microwave	Convection - 110°C	Convection - 150°C
Kentucky Limestone				
Trial #1	0.33%	0.36%	0.21%	
Trial #2	---	0.61%	0.50%	
Ohio Gravel				
Trial #1	1.26%	1.33%	1.17%	
Trial #2	---	1.55%	1.48%	

- Previous research indicated that the distillation procedure often resulted in much lower measured moisture contents than the oven procedures.
  - Incomplete removal of moisture?

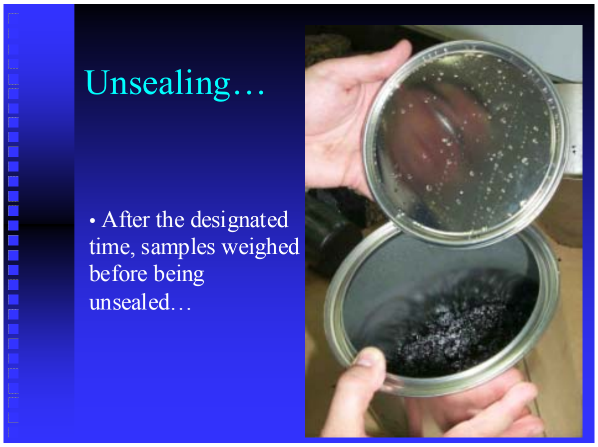


Subtask 2: Evaluate Methods to Measure Moisture Content

- Selected Procedure
  - » Drying to constant mass in oven @110 °C
    - \- MCs measured similar to other procedures
- Other Procedures Evaluated
  - » Distillation using xylene (ASTM D1461)
    - \- cumbersome
  - » Drying to constant mass in microwave (AL)
    - \- glassware often broke
  - » Drying to constant mass in oven @150 °C
    - \- no additional moisture found

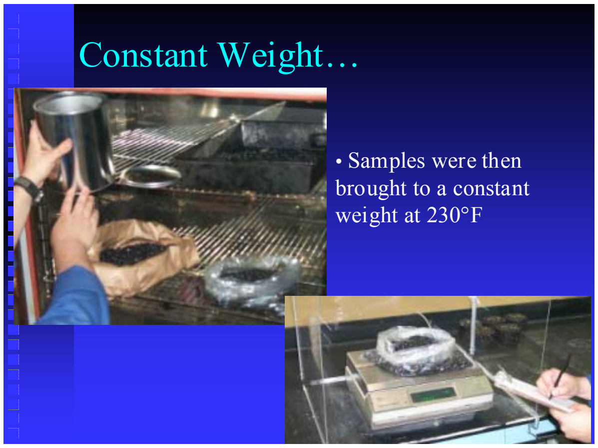


Subtask 2a: Evaluate Sample Containers and Storage Times



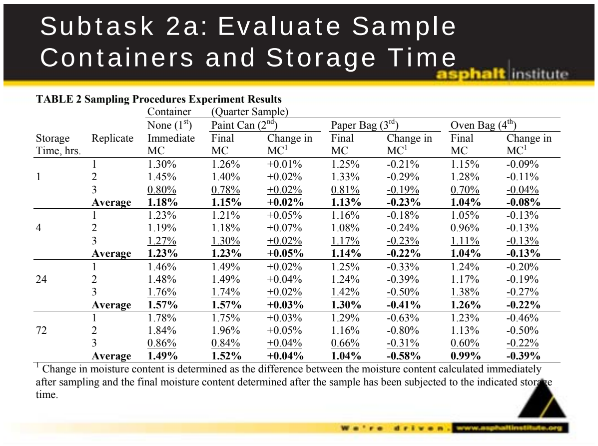
Unsealing…

- After the designated time, samples weighed before being unsealed…



Constant Weight…

- Samples were then brought to a constant weight at 230°F

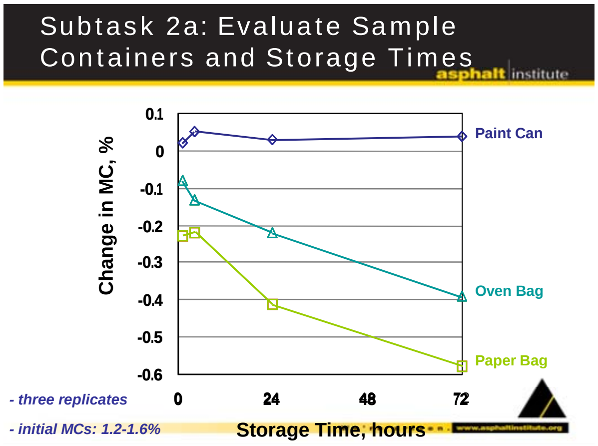


Subtask 2a: Evaluate Sample Containers and Storage Time

TABLE 2 Sampling Procedures Experiment Results

		Container	(Quarter Sample)					
		None (1st)	Paint Can (2nd)		Paper Bag (3rd)		Oven Bag (4th)	
Storage Time, hrs.	Replicate	Immediate MC	Final MC	Change in MC[1]	Final MC	Change in MC[1]	Final MC	Change in MC[1]
	1	1.30%	1.26%	+0.01%	1.25%	-0.21%	1.15%	-0.09%
1	2	1.45%	1.40%	+0.02%	1.33%	-0.29%	1.28%	-0.11%
	3	0.80%	0.78%	+0.02%	0.81%	-0.19%	0.70%	-0.04%
	Average	**1.18%**	**1.15%**	**+0.02%**	**1.13%**	**-0.23%**	**1.04%**	**-0.08%**
	1	1.23%	1.21%	+0.05%	1.16%	-0.18%	1.05%	-0.13%
4	2	1.19%	1.18%	+0.07%	1.08%	-0.24%	0.96%	-0.13%
	3	1.27%	1.30%	+0.02%	1.17%	-0.23%	1.11%	-0.13%
	Average	**1.23%**	**1.23%**	**+0.05%**	**1.14%**	**-0.22%**	**1.04%**	**-0.13%**
	1	1.46%	1.49%	+0.02%	1.25%	-0.33%	1.24%	-0.20%
24	2	1.48%	1.49%	+0.04%	1.24%	-0.39%	1.17%	-0.19%
	3	1.76%	1.74%	+0.02%	1.42%	-0.50%	1.38%	-0.27%
	Average	**1.57%**	**1.57%**	**+0.03%**	**1.30%**	**-0.41%**	**1.26%**	**-0.22%**
	1	1.78%	1.75%	+0.03%	1.29%	-0.63%	1.23%	-0.46%
72	2	1.84%	1.96%	+0.05%	1.16%	-0.80%	1.13%	-0.50%
	3	0.86%	0.84%	+0.04%	0.66%	-0.31%	0.60%	-0.22%
	Average	**1.49%**	**1.52%**	**+0.04%**	**1.04%**	**-0.58%**	**0.99%**	**-0.39%**

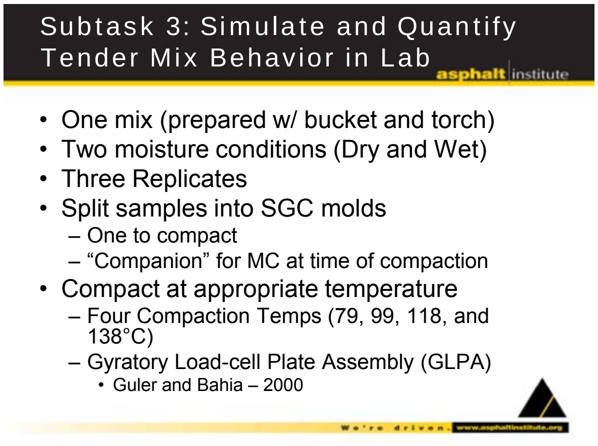
[1] Change in moisture content is determined as the difference between the moisture content calculated immediately after sampling and the final moisture content determined after the sample has been subjected to the indicated storage time.



Subtask 2a: Evaluate Sample Containers and Storage Times

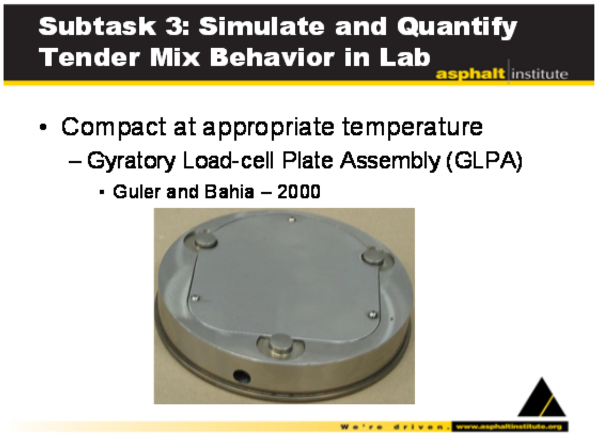
- three replicates

- initial MCs: 1.2-1.6%



Subtask 3: Simulate and Quantify Tender Mix Behavior in Lab

- One mix (prepared w/ bucket and torch)
- Two moisture conditions (Dry and Wet)
- Three Replicates
- Split samples into SGC molds
  - One to compact
  - "Companion" for MC at time of compaction
- Compact at appropriate temperature
  - Four Compaction Temps (79, 99, 118, and 138°C)
  - Gyratory Load-cell Plate Assembly (GLPA)
    - Guler and Bahia – 2000



Subtask 3: Simulate and Quantify Tender Mix Behavior in Lab

- Compact at appropriate temperature
  - Gyratory Load-cell Plate Assembly (GLPA)
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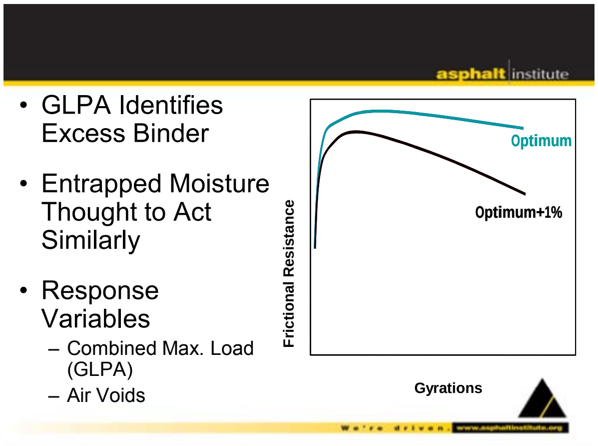
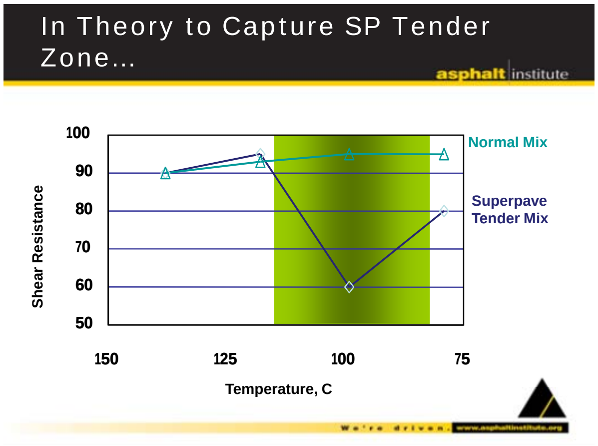
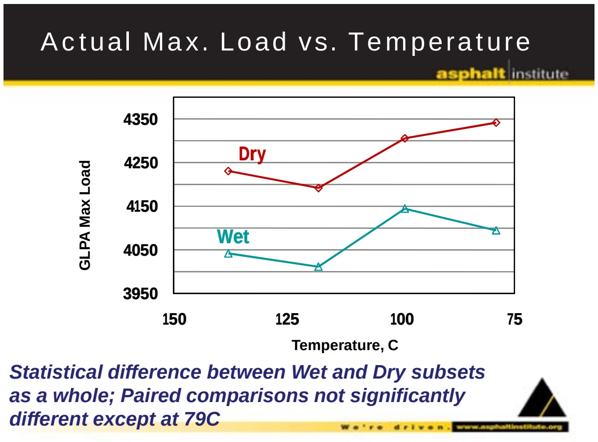


- GLPA Identifies Excess Binder
- Entrapped Moisture Thought to Act Similarly
- Response Variables
  - Combined Max. Load (GLPA)
  - Air Voids

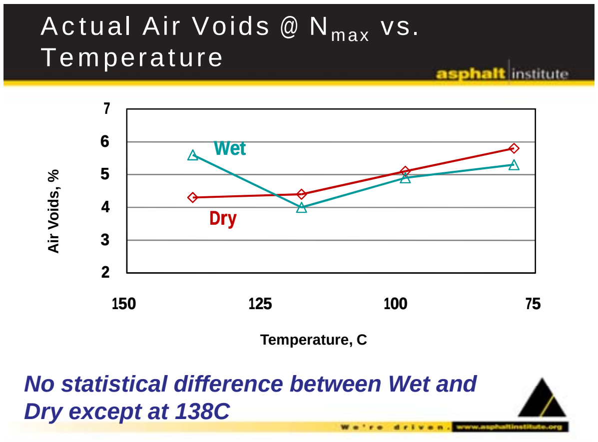


In Theory to Capture SP Tender Zone…



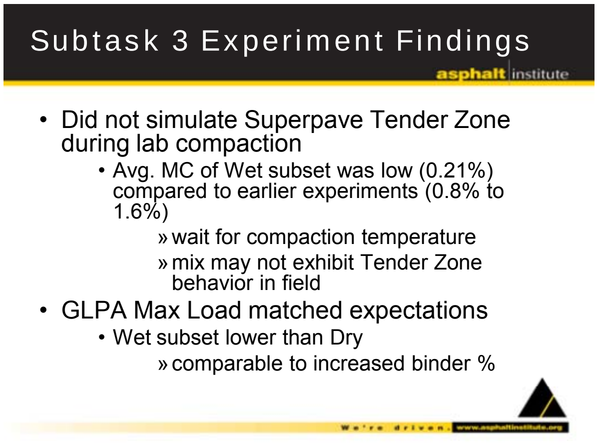
Actual Max. Load vs. Temperature

Statistical difference between Wet and Dry subsets as a whole; Paired comparisons not significantly different except at 79C



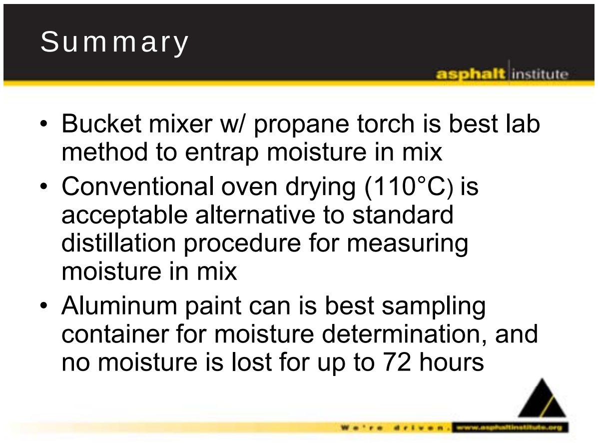
Actual Air Voids @ N_{max} vs. Temperature

No statistical difference between Wet and Dry except at 138C



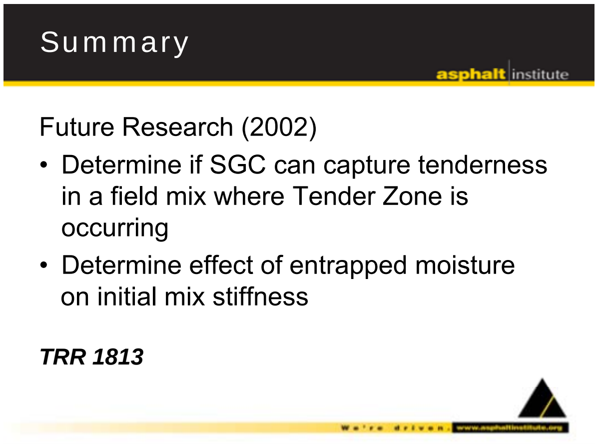
Subtask 3 Experiment Findings

- Did not simulate Superpave Tender Zone during lab compaction
  - Avg. MC of Wet subset was low (0.21%) compared to earlier experiments (0.8% to 1.6%)
    - » wait for compaction temperature
    - » mix may not exhibit Tender Zone behavior in field
- GLPA Max Load matched expectations
  - Wet subset lower than Dry
    - » comparable to increased binder %



Summary

- Bucket mixer w/ propane torch is best lab method to entrap moisture in mix
- Conventional oven drying (110°C) is acceptable alternative to standard distillation procedure for measuring moisture in mix
- Aluminum paint can is best sampling container for moisture determination, and no moisture is lost for up to 72 hours

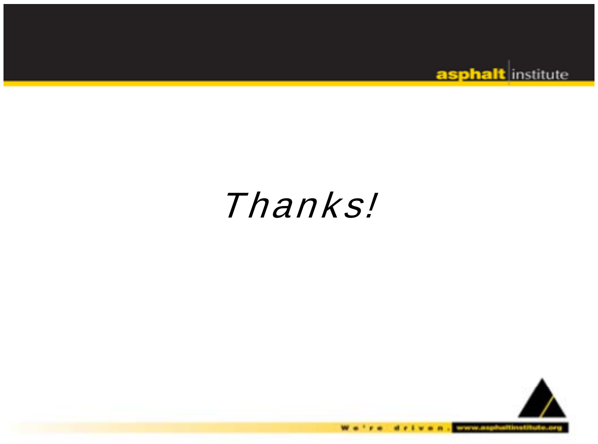


Summary

Future Research (2002)

- Determine if SGC can capture tenderness in a field mix where Tender Zone is occurring
- Determine effect of entrapped moisture on initial mix stiffness

TRR 1813



Thanks!

Performance Issues Caused by Residual Moisture

William J. Pine
Heritage Construction and Materials

This presentation has been annotated below each slide in a manner that a presentation summary is redundant. Slides are numbered with corresponding annotations below.

Performance Issues Caused by Residual Moisture

TRB AFH60 Workshop:

Moisture Damage in Hot Mix Asphalt Mixtures

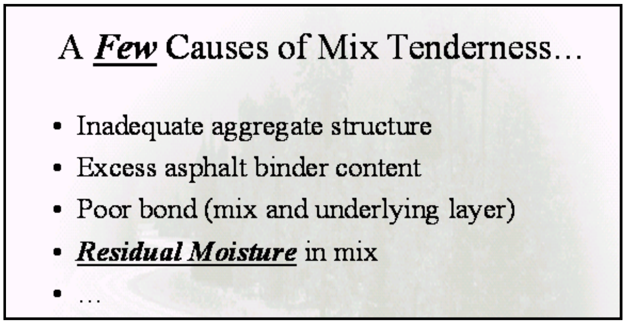
January 22, 2012
Gerald Huber and William Pine
Heritage Research Group

SLIDE 1

First, I would like to thank Gerry Huber for his help in developing this presentation.

Heritage Research Group is the research arm of the Heritage Group (HG) companies. Part of my role is supporting the HG companies, and their customers, in problem resolution with material selection, mix design, production, placement, and forensic analysis.

One of the most difficult problems I'm asked to help solve is mix tenderness during time of construction. A tender mix is generally difficult to compact, easy to crack with the edge of a roller drum, and difficult to roll in a manner that achieves a smooth ride.



A ***Few*** Causes of Mix Tenderness…

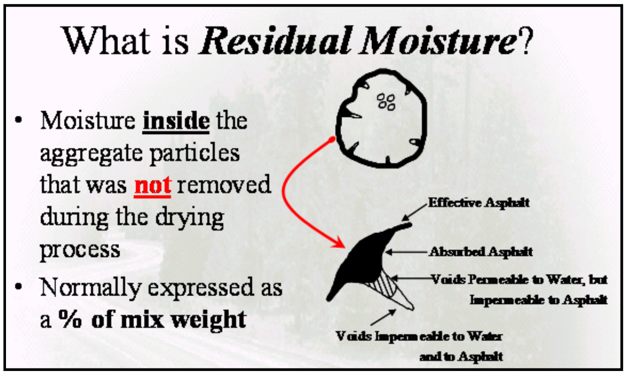
- Inadequate aggregate structure
- Excess asphalt binder content
- Poor bond (mix and underlying layer)
- ***Residual Moisture*** in mix
- …

SLIDE 2

There are many things that can cause tenderness in a mix such as tenderness that occurs during field compaction with steel-wheeled rollers. Seldom is there one thing that is causing tenderness with a mix.

A few of the primary causes of mix tenderness are

- An inadequate aggregate structure as it pertains to gradation, shape, strength, and texture of the aggregate particles, especially in regards to the portion of the aggregate structure that is in control of the overall aggregate blend (i.e., C-G and F-G mixes).
- ***Excess*** asphalt binder content (some would say total fluids content)—one that results in too many voids within the aggregate structure being completely filled with asphalt binder—can make a mix tender because we can't compress a fluid, so when we attempt to, it moves the aggregate structure around.
- A poor bond between the mix being placed and the underlying layer can allow the mix to slip and slide during field compaction. My experience has been tender mixes seldom are a problem when they are being placed on a milled surface.
- When it comes to analyzing tender mixes, my field experience has taught me to always look first for residual moisture.
- Although there are several other things that can cause or at least contribute to mix tenderness in the field, this presentation is going to focus on residual moisture.



What is ***Residual Moisture***?

- Moisture **inside** the aggregate particles that was **not** removed during the drying process
- Normally expressed as a **% of mix weight**

SLIDE 3

Residual moisture is moisture that is left inside the aggregate particles when they are not dried completely during the mix production process.

Realistically, we seldom get all of the aggregate particles completely dry during asphalt mix production and we can normally see that in the typical moisture tests that are performed during quality control (QC) production samples. However, those moisture content results may not always be entirely accurate as to the amount.

The amount of residual moisture in the mix is normally expressed as a percent of the total mix weight.

Water, due to its lower viscosity as compared to asphalt binder, should always penetrate a void in an aggregate particle to a greater depth.

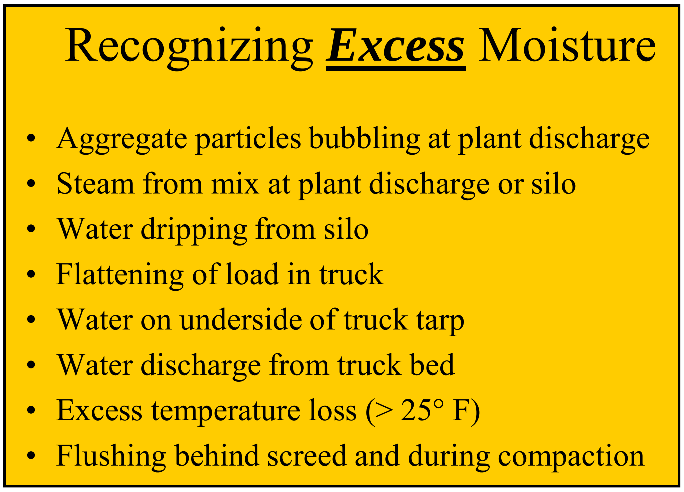
Some aggregate particles, depending upon things such as their size, shape, moisture content and porosity, are more difficult to dry completely than others.

It Starts With ***Wet*** Stockpiles…

SLIDE 4 FI in Rt. 26, 2000.

The problem with residual moisture virtually always starts with **wet** stockpiles, especially in the spring of the year!

The type of underlying base material and the slope each play a significant role in how easily water drains from an aggregate stockpile.



Recognizing ***Excess*** Moisture

- Aggregate particles bubbling at plant discharge
- Steam from mix at plant discharge or silo
- Water dripping from silo
- Flattening of load in truck
- Water on underside of truck tarp
- Water discharge from truck bed
- Excess temperature loss (> 25° F)
- Flushing behind screed and during compaction

SLIDE 5

These are some rules of thumb to use when you're trying to recognize excess residual moisture in an asphalt mix:

- The asphalt film on the larger aggregate particles bubbles. This is generally most noticeable when the sample is taken at the point of plant discharge.
- Steam coming off the mix at the plant discharge, from the top of the silo or surge bin, or from the truck after it has been loaded.
- Water dripping from the gates underneath a storage silo. Have you ever heard the phrase "It's raining under the silo"? Would the truck drivers be the first to notice this issue?
- Flattening of a load of mix. Having a truck driver apply his breaks hard as he moves across the plant yard, can cause a mix containing excess moisture to flatten out, as does normal movement of the mix in the truck during transport to the project.
- If tarps are being used to cover the load, especially good tarps that don't have holes in them and they fold over the sides and ends of the truck, can trap moisture on the underside of them during mix transport. Visually inspect the bottom of tarp as they role it back on the project before they dump the mix.
- Water discharge from the truck bed, just before the load breaks loose and goes into the paver hopper or material transfer device hopper. Make sure you know whether or not release agent was applied to the bed before the mix was loaded.
- As excess moisture escapes from a mix, it takes temperature with it. A loss of 25°F or more from the plant discharge to the mat directly behind the screed is fairly significant.
- Excess moisture can cause flushing in the mix behind the screed, normally in the area of the paver flight chains. If you can stir the surface of the mix with a lute before roller compaction, it can decrease the visual effects that remain after compaction. Rollers can cause flushing as well during compaction of the mix.

SLIDE 6 FI in Rt. 26, 2000.

This was a small parallel flow plant with a 60-ton surge bin.

Notice the steam coming off the surge bin and the tarp that is covering it to help hold heat it. The tarp works well to keep rain out but it also works well for holding moisture in the mix.

SLIDE 7 Milestone Contractors, LP, (MCLP) Whitestown.

Steam coming from the mix as it is discharged from a drum plant into a slat conveyor.

SLIDE 8

Slide 8 is a photo of the most residual moisture I’ve seen in hot mix. Notice the brown color of the larger particles. The moisture coming out of the aggregate through the asphalt film was emulsifying the asphalt. You could watch the color turn back to black in a short period of time, just like emulsion shot for tack coat breaks on the road.

SLIDE 9 FI in Rt. 26, 2000.

The next time you're at an asphalt plant, look to see if there is moisture around the gate beneath the silos—but do it safely.

SLIDE 10 FI in Rt. 26, 2000

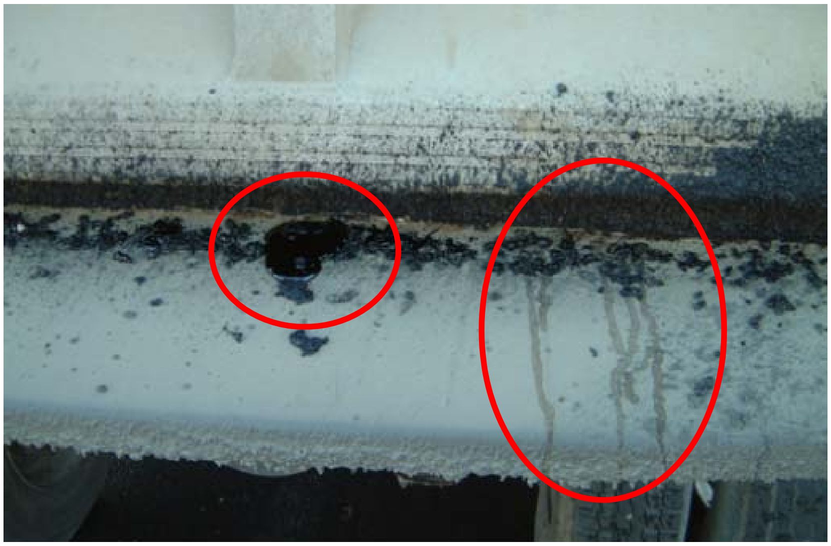
You can see the steam coming off the mix. This truck had just been loaded with a 25-mm nominal maximum aggregate size mix from that parallel flow plant with a small surge bin in Slide 6. There were brown particles still in the mix at this point. The load is standing up, at least for now.

SLIDE 11 FI in Rt. 26, 2000.

That’s steam, not smoke, coming off the mix as this truck is transporting mix to a job site.

SLIDE 12 FI in Rt. 26, 2000.

This is what one of those loads of 25-mm mix looked like when it got to the job after being produced at that parallel flow plant. You can clearly see the asphalt binder that has flushed to the top of the load. Also notice how flat the load is, as compared to Slide 10, just after it had been loaded with mix that was releasing steam.



SLIDE 13 FI in Rt. 26, 2000.

The right red oval is showing moisture that is coming out of the truck bed of that flat load. And the truck bed hasn't even been raised yet.

What is really unusual about this photo is the left red oval pointing out liquid asphalt binder that has oozed out onto the tailgate lip of the truck. I don't have a photo, but moisture should have been clearly evident on the bottom of the truck tarp as well.

SLIDE 14 FI in Rt. 26, 2000.

This photo doesn't do this issue justice, but mixes that contain excess residual moisture are prone to flushing. It often appears just a short distance behind the screed, often before the breakdown roller has rolled over it, and normally in the area behind the flight chains. If you stir these areas with a lute before the first roller pass is completed and if the flushing is strictly moisture related, it can reduce the visible effects on the macrotexture of the mix. But flushing can also occur as the rollers compact or compress the mix and force asphalt binder to the surface.

SLIDE 15 FI in Rt. 26, 2000.

The contractors' solution to the problem project from the parallel flow plant with a small surge bin was to run the mix through a shuttle buggy.

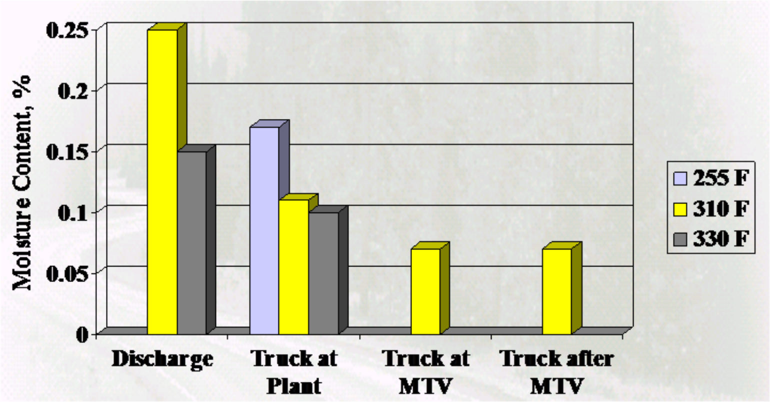
Notice the tool shed in the background. The pavement structure was not sufficient to allow the material transfer vehicle (MTV) to operate in front of the paver. So the contractor set up an MTV in a lot and used that location as a transfer point.

SLIDE 16 FI in Rt. 26, 2000.

They dumped one truck into the MTV and discharged the mix into a waiting truck that then transported the mix to the paver. The difference between the mix transported directly to the paver versus the mix after they started using the MTV was significant. The mix run through the MTV was much more stable during field compaction. The MTV did a nice job of remixing the flushed material and it will generally help release moisture during the agitation period, but our results on this project did not indicate that was the case.

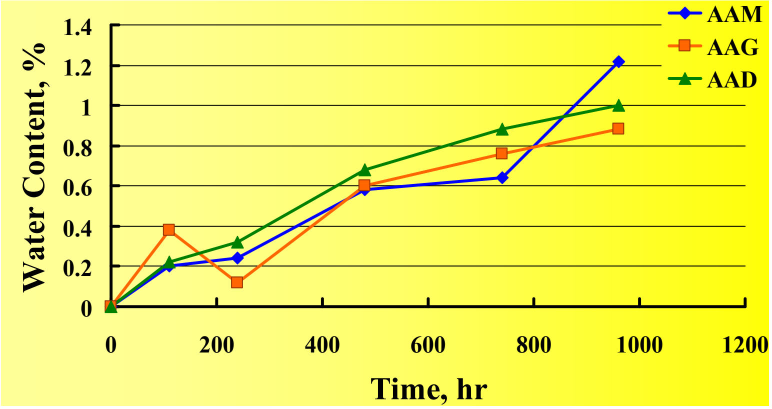
SLIDE 17 FI in Rt. 26, 2000.

Those results were from moisture content tests performed on various samples taken during this project. We used a metal can with a friction lid. Each can was weighed, lid included, before the sample was obtained. Just remember, if there is significant residual moisture in the mix, to get the lid on as soon as possible after the mix is placed in the container and then seek a scale quickly before the lid blows off!



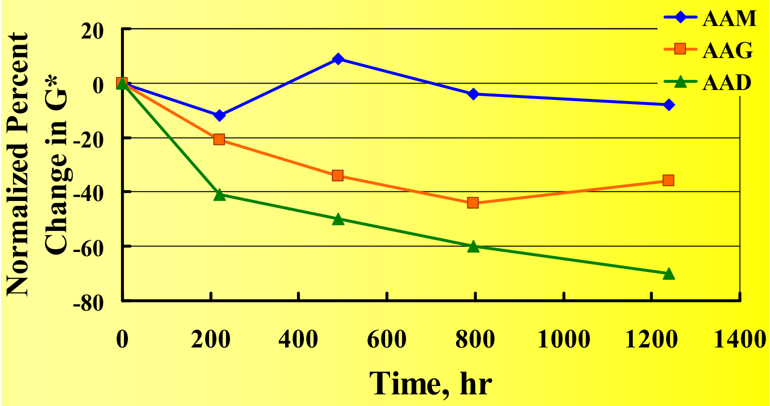
SLIDE 18 FI in Rt. 26, 2000.

These are our average moisture contents for a number of tests taken at multiple occasions and at different mix production temperatures that were used to see their effect on moisture content. Notice the maximum value is the far left yellow bar, 0.25% by weight of the total mix, from a sample taken at the plant discharge, of mix produced at 310°F as measured at that point. Some specs allow up to 0.5% moisture. None of these values were nearly that high, yet we had significant problems with the mix on that project, prior to running it through the MTV. Perhaps a maximum value of 0.5% is more related to preventing excess total fluids in the mix (asphalt concrete and moisture combined by weight) in order to not overfill the voids in the aggregate structure and consequently have a mix that is tender. However, we have found much smaller amounts of residual moisture serve to significantly reduce the stiffness of the asphalt binder in some mixes, thereby reducing mix stiffness.



SLIDE 19 FI in Rt. 26, 2000.

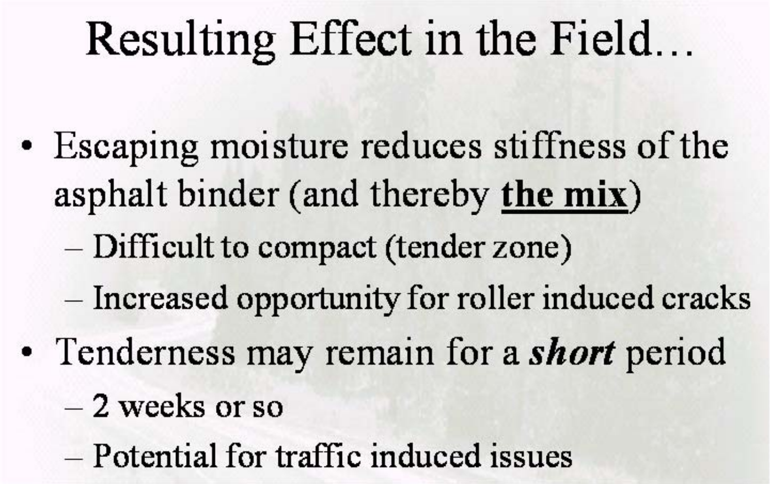
Western Research Institute (WRI) did some work back in 2001 where they took samples of asphalt binder from different sources and soaked them in water for different periods of time. The results clearly show that water was absorbed by the three asphalt binders. The amount of water absorption increased with soak time, pretty uniformly in these particular samples.



SLIDE 20

WRI also looked at the effect of water absorption on binder stiffness for those same samples and found the effect to be source dependent. The stiffness of the AAM (blue) source is mostly unaffected. The stiffness of the AAD (green) source shows a significant reduction with an increase in soak time.

All of the sources absorbed about the same amount of water relative to soak time. The effect of the water absorbed on asphalt binder stiffness is clearly different between sources.



Resulting Effect in the Field…

- Escaping moisture reduces stiffness of the asphalt binder (and thereby **<u>the mix</u>**)
  - Difficult to compact (tender zone)
  - Increased opportunity for roller induced cracks
- Tenderness may remain for a ***short*** period
  - 2 weeks or so
  - Potential for traffic induced issues

SLIDE 21

The resulting effect in the field due to excess residual moisture is a reduction in mix stiffness. As residual moisture escapes, it reduces stiffness of the asphalt binder film and consequently the stiffness of the mix. The reduction in mix stiffness makes compaction difficult. It increases the opportunity for roller induced cracking at the edge of the drums and makes it easier to create a bump at the end of the rolling pattern, which will generally reduce the resulting mix smoothness. Some mixes remain softer than normal for a couple weeks or so. That can lead to additional negative performance issues!

SLIDE 22 2005 SR-67 Indy.

When a mix is shoved by the drum of a roller, a shear plane is created at each edge of the drum, which often causes longitudinal cracks.

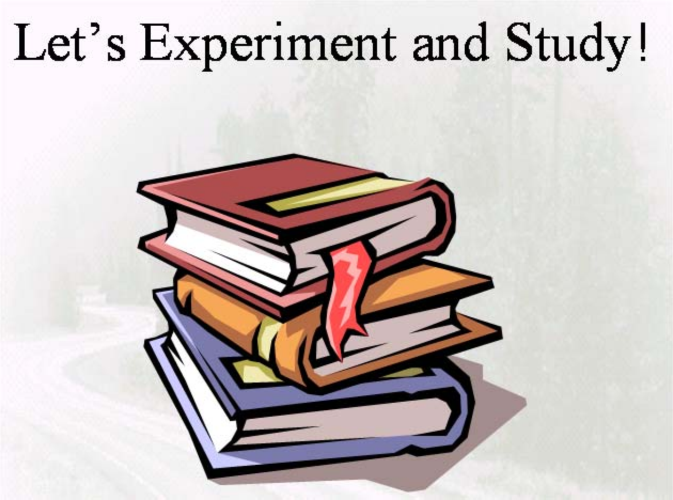
SLIDE 23 MCLP 2007 Cville SR-47.

This is another example of a longitudinal crack caused by the edge of a steel-wheel roller at the end of a rolling pattern.

Notice the angle of the crack that resulted from the roller turning.

SLIDE 24 MCLP 2007 Cville SR-47.

Tender mixes can also shear when a roller is driving straight down the mat.



Let's Experiment and Study!

SLIDE 25

Some time back, we decided to do some experimenting within the Heritage Group to see what we could learn by intentionally trying to produce asphalt mix with residual moisture contents above "normal." We wanted to see if the moisture content of the mix related to sample location and the way we handled the sample. And we also wanted to see the resulting effect on stiffness of the mix.

SLIDE 26 MCLP Whitestown.

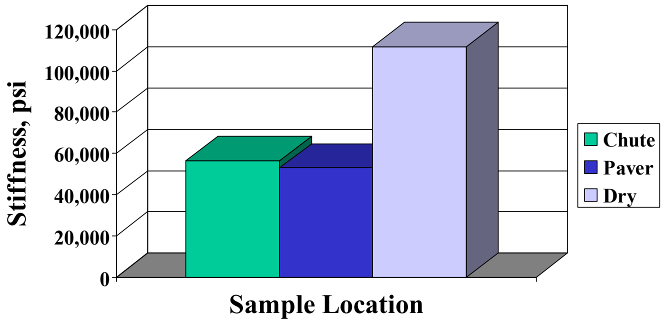
We picked a day with high humidity.

SLIDE 27 MCLP Whitestown.

The stockpiles were slightly wetter than normal.

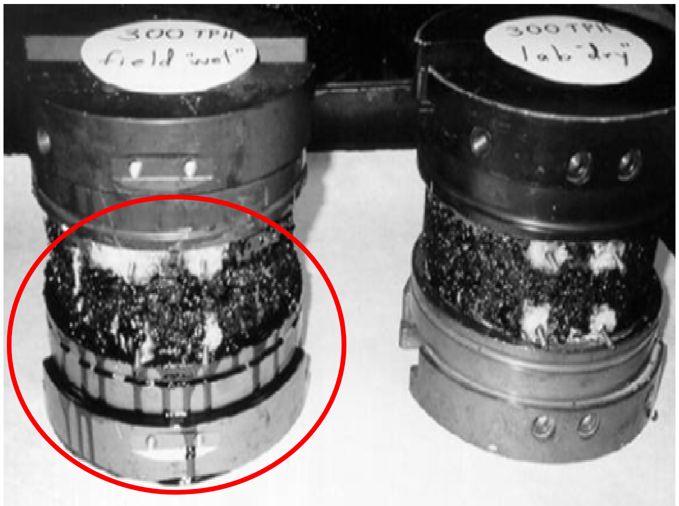
SLIDE 28 MCLP Whitestown.

Another close-up photo of one of the aggregate sources used.



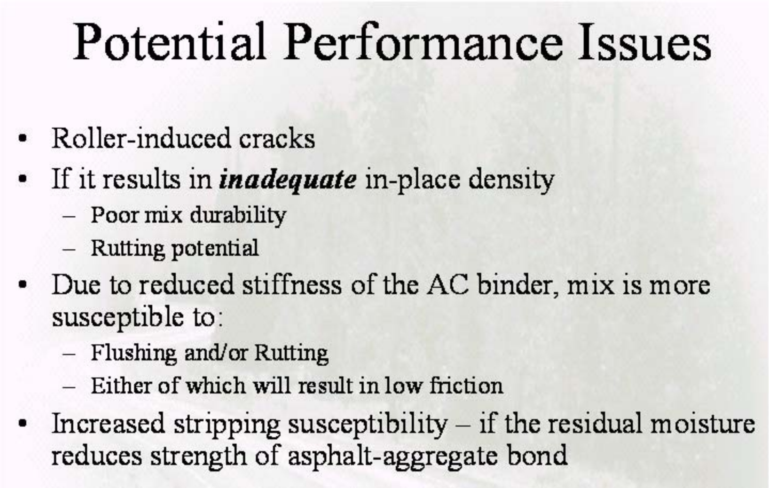
SLIDE 29 MCLP Whitestown.

We sampled mix at the plant discharge chute. We had a gyratory compactor in the back of a truck and compacted the sample right there at the discharge chute location to minimize moisture loss. We also obtained samples from the mat behind the paver. A portion of the mat sample was compacted immediately as well, while part of the mix was taken to our lab, dried back to a constant weight in a 120°F vacuum oven to ensure we did NOT age the asphalt nor did the process significantly increase asphalt absorption. The samples were checked for moisture content, which was found to be lower than expected (≈0.1% or less) for both the discharge chute and paver locations. All three sets of samples were compacted to ≈7 ± 1% voids and tested in our shear tester at 10 Hz and 40°C to determine the dynamic shear modulus (G*) of the mix. For this particular mix, the results clearly show a decrease in mix stiffness for the samples with some residual moisture, compared to the sample that was dried back. This experiment opened our eyes as to the potential effect of "normal" residual moisture contents.



SLIDE 30 MCLP 96th St. CTAA.

On a similar experimental project, we produced shear test samples. Note the label on top of the specimens as being field "wet" and lab "dry." After the samples were evaluated in the shear tester, they were placed back in the oven for heating and cleanup. With the "wet" samples there was a bubbling effect and free asphalt flowed out of the shear test specimen due to being pushed out by the water vapor from the pores within the mixture. This was not observed on any of the lab "dry" mixtures. This experiment also had what we would consider "normal" moisture contents (i.e., 0.1% or less).



Potential Performance Issues

- Roller-induced cracks
- If it results in ***inadequate*** in-place density
  - Poor mix durability
  - Rutting potential
- Due to reduced stiffness of the AC binder, mix is more susceptible to:
  - Flushing and/or Rutting
  - Either of which will result in low friction
- Increased stripping susceptibility – if the residual moisture reduces strength of asphalt-aggregate bond

SLIDE 31

If a mix suffers negative effects from residual moisture:

- It can be susceptible to roller-induced cracks that occur at the edge of the roller drums if the sliding mix shears. Bumps typically occur in these situations as well, especially when there is an underlying surface condition that tends to grab the mix and force the roller to roll over the top of the bow wave that exists in front of the drum.
- If a tender mix results in low in-place density, it will lead to less than desired mix durability and create the potential for rutting.
- If the stiffness of the mix is lowered due to residual moisture, how long will reduced stiffness last? The answer to that question has to be influenced by the amount of residual moisture and the weather conditions. The severity of the issue will also be related to the level of traffic the mix will be subjected to during that time period. The reduction in mix stiffness makes that mix susceptible to flushing and or rutting, either of which will result in low friction values.
- If the mix is already susceptible to stripping due to the asphalt–aggregate combination, will it be more susceptible to stripping due to the residual moisture as long as it exists in the mix?

SLIDE 32 IL-133 west of arc, 2012.

The next three photos (Slides 32 through 34) show cracks that have been sealed in an asphalt surface. This mix was tender when it was placed and I visited the project to try and help solve the problem. Notice the cracks that are at an angle.

That's the end of a vibratory breakdown roller pattern as the roller turned.

SLIDE 33 IL-133 west of arc, 2012.

The second of three photos showing cracks that are at an angle, which coincide with the end of a vibratory breakdown roller pattern as the roller turned. There are other longitudinal cracks on this project that have been sealed and they too may be related to shearing that occurred at the edge of the roller drums.

SLIDE 34 IL-133 west of arc 2012.

The third of three photos showing cracks that are at an angle, which coincide with the end of a vibratory breakdown roller pattern as the roller turned. This is clearly a performance issue from the owners' standpoint.

SLIDE 35 Gerry MCLP.

The next three photos (Slides 35 through 37) are from a project that flushed that we believe may have been related to residual moisture in the mix. The majority of this project was a mill and fill for the surface mix only.

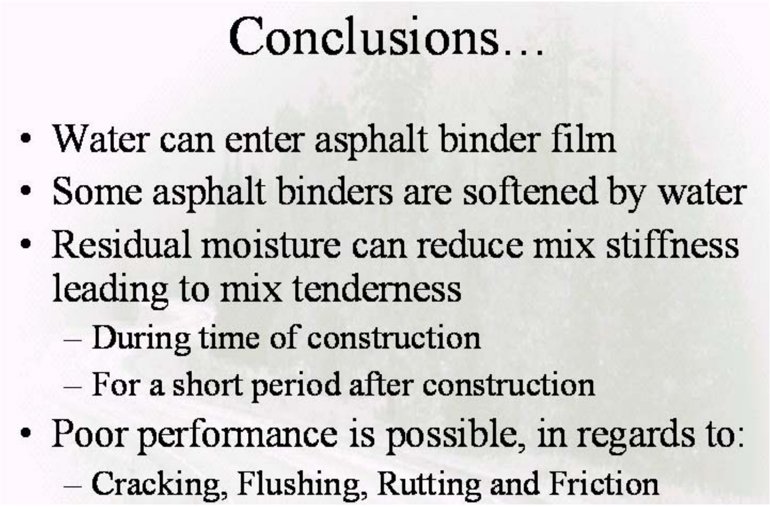
It experienced flushing, but little to no rutting.

SLIDE 36

Gerry from Milestone Contractors, LP, (MCLP): It was interesting that flushing under the overhead bridges was much less, which we feel is attributable to the pavement temperature being lower, maintaining a higher stiffness in the asphalt binder and consequently the mix.

SLIDE 37

Gerry, MCLP: There were a couple bridge approach areas that required a thicker mix removal and replacement. At these locations, the surface mix not only flushed, but also rutted. This led us to believe the new underlying mix was less stiff than what was left in place on the remaining portion of the project. We feel that new underlying mix may have had a residual moisture problem as well.



Conclusions…

- Water can enter asphalt binder film
- Some asphalt binders are softened by water
- Residual moisture can reduce mix stiffness leading to mix tenderness
  - During time of construction
  - For a short period after construction
- Poor performance is possible, in regards to:
  - Cracking, Flushing, Rutting and Friction

SLIDE 38

WRI's data clearly show that asphalt binder absorbs water, so water is able to enter the asphalt binder film. Their data also shows a difference in the reduction in stiffness due to water absorption, which may help explain why some mixtures seem to be more sensitive to residual moisture than others. Mixes that experience a reduction in stiffness due to residual moisture can be tender during the time of construction and also for a short period of time after construction, which suggests the amount and type of trafficking that occurs during that period of time will govern the extent of the resulting damage to the mix. The bottom line is poor performance is possible with mixes that experience a reduction in stiffness due to residual moisture in regards to cracking, flushing, rutting, and friction.

Moisture Issues in Asphalt Concrete Plant Production

James A. Scherocman
Consulting Engineer

The production of an asphalt concrete mixture in an asphalt plant depends on a number of factors. Among those factors are the properties of the aggregates incorporated into the mix, the properties of the asphalt binder, as well as the type of asphalt concrete plant used to manufacture the asphalt concrete mixture. The asphalt plant operation is essentially the same whether HMA is being produced or if WMA is being produced.

There are basically three types of asphalt plants currently employed to manufacture an asphalt concrete mixture, whether HMA or WMA. Those three types are batch plants, parallel flow drum mix plants, and counterflow drum mix plants. Figures 1 through 3 provide an illustration of each of these types of asphalt production plants. Additional information regarding proper operation of asphalt concrete production facilities can be found in resources such as *The Asphalt Handbook*, 7th edition, MS-4, of the Asphalt Institute, or the *Hot-Mix Asphalt Paving Handbook 2000*.

One of the primary factors that affect the properties of the HMA or the WMA asphalt concrete mixtures is the amount of moisture in the aggregate when it is coated with asphalt binder during the mixing process. The amount of moisture retained in the aggregate is dependent both on the amount of moisture in the combined coarse and fine aggregate when it is introduced into the plant and the production rate of the plant in terms of tons per hour of mix manufactured.

FIGURE 1 Batch plant illustration.

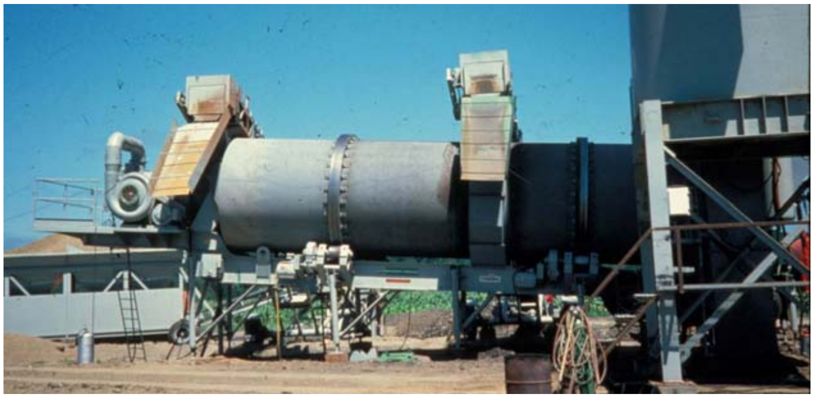


FIGURE 2 Parallel flow drum plant illustration.

FIGURE 3 Counterflow drum plant illustration.

The discussion below is provided to indicate some of the factors that directly affect the properties and moisture content of the asphalt concrete mix when it exits the discharge end of the asphalt plant. It is noted that different plants will be operated differently, but the analysis below can be used to gain an appreciation that the way that the asphalt plant is operated can have a direct effect on the properties and characteristics of the mix when it is placed on the roadway by the paver and compacted by the rollers.

TENDER ASPHALT CONCRETE MIXTURES

Many HMA mixtures are very stable during the laydown and compaction process. The composition and gradation of the coarse and fine aggregates incorporated into the mix provides an interlocking structure to support the applied traffic loads. For these mixes, the asphalt binder content provides a proper coating of the surface of the aggregate particles, allowing for the amount of asphalt binder that may be “lost” into the aggregate due to the amount of absorption of the aggregate. The mixing and discharge temperatures of the mix are high enough to allow for the properties of the asphalt binder and for the environmental conditions at the time of mix placement. When compacted by the rollers, these HMA mixtures are "stiff" and do not move transversely or longitudinally under the applied compactive effort.

Those same HMA mixtures, however, can sometimes become very tender, moving under the compactive effort of the rollers if all the moisture is not removed from the aggregate. Shoving of the mix can occur during compaction with the creation of a "bow wave" in front of the drum of a steel-wheel roller, vibratory or static, as illustrated in Figure 4. The movement of the mixture typically results in what is commonly termed in the industry as "checking." This phenomenon is illustrated in Figure 5.

Checking can be due to a number of different causes. Among those causes are the combined gradation of the coarse and fine aggregates, the fine aggregate angularity value, the voids in mineral aggregate (VMA) value, the voids filled with asphalt (VFA) value, as well as amount and type of asphalt binder incorporated into the mixture. When one of more of the above factors are the cause or the causes of the tender mix, however, the checking problem is typically a continuing problem. The checking normally happens whenever that particular combination of materials is used to produce the asphalt concrete mixture. The solution to the checking problem that occurs on a daily basis is most likely related to the properties of the materials included in the mixture.

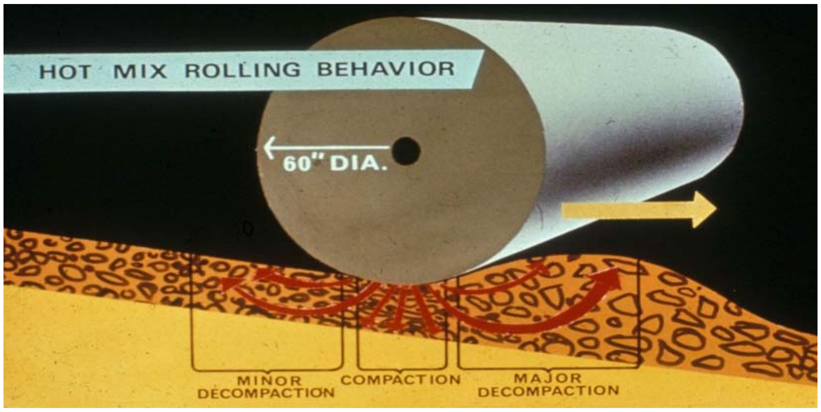


FIGURE 4 Bow wave in front of roller.

FIGURE 5 Checking of an HMA mix.

Checking sometimes occurs, however, on a periodic basis. It does not occur all day, every day. Checking sometimes occurs a day or two after a rain event. It can occur because the operation of the asphalt plant—batch plant, parallel flow drum plant, or counterflow drum plant—is not adjusted for the change in the total moisture content of the incoming coarse and fine aggregate materials being fed into the plant.

SIX ISSUES TO BE CONSIDERED DURING MIX PRODUCTION

There are six primary issues that should be analyzed in order to determine the possible causes of a tender mix, particularly if the problem occurs primarily within a day or two after a rain event. Those six issues include the following:

1. Aggregate stockpiles,
2. Incoming aggregate moisture content,
3. Type of asphalt plant,
4. Mix production rate,
5. Amount of RAP in the mix, and
6. Mix discharge temperature.

Aggregate Stockpiles

It is important that the aggregates stored at the asphalt plant site be placed on a stable foundation. It is also important that the aggregate stockpiles be sloped at the bottom of the piles to allow for rain which falls on the piles to drain away from the piles and not be collected at the bottom of the piles. After a rain event, it is imperative that the front-end loader operator work the aggregate piles in order to expose more aggregate to sun and wind in order to at least partially dry the aggregate before that material is delivered into the asphalt plant. Further, it is important that the front-end loader operator, who is moving the aggregate from the stockpile to the cold feed bins at the plant, take material from a short distance above the bottom of the pile, where the moisture content of the aggregate material should be somewhat less than at the bottom of the pile.

After a rain event, when the moisture content of the aggregates in the stockpiles is higher than normal, it is imperative to do two things before the aggregates are fed into the asphalt plant. First, the moisture content should be reduced as much as possible by moving the aggregates in each stockpile around and exposing the material to the atmosphere to allow for some drying to occur. Second, the moisture content of the aggregates should be equalized, as much as possible, by blending the aggregates together in each individual stockpile to provide as consistent moisture content as feasible when the aggregate is fed into the asphalt plant.

Incoming Moisture Content

The primary purpose of this paper is to recognize the very significant effect of the amount of moisture in the incoming coarse and fine aggregates when they are delivered into an asphalt plant. If the purpose of the plant is to produce dry aggregate before the asphalt binder is added to the material (assuming the production of HMA, not WMA), then the moisture content of the combined incoming coarse and fine aggregate will affect the rate at which the asphalt concrete mixture can be manufactured in the plant and deliver a HMA mix at the discharge end of the plant which is free of moisture. The effect of the moisture content of the incoming combined coarse and fine aggregate on the production rate of the asphalt plant is discussed in detail below.

Type of Asphalt Plant

The type of asphalt plant can have an effect on the amount of moisture removed from the incoming coarse and fine aggregates during the drying process. The dryer on a typical asphalt batch plant is operated as a counter-flow system, with the burner on the lower end of the dryer and the aggregates moving from the high (moist) end to the low (dry) end of the equipment—in the opposite direction to the flow of the burner exhaust gases. Because no asphalt binder is injected into the dryer, it is expected that the aggregate discharged from the batch plant dryer will be free of moisture. Reclaimed asphalt pavement (RAP) is not introduced into the drying drum.

For a parallel flow drum mix plant, the burner on the drum is on the upper end of the drum and the aggregates move in the same direction as the exhaust gases. RAP material, if used, is added to the drum upstream of the burner. The RAP, which usually contains some moisture, is mixed with the new aggregates and dried before the new asphalt binder is introduced into the mixing drum. If the amount of RAP incorporated into the asphalt concrete mix is increased, the amount of drying of the RAP material may be reduced depending on the amount of moisture in the RAP and the production rate of the plant.

For a counter-flow drum mix plant, the burner is again on the lower end of the drum and the aggregates move from the upper end of the drum toward the burner. RAP is added to be heated and dried new aggregate through an entry chute behind the burner. Asphalt binder is added to the combination of the new aggregate and RAP material after those two materials are blended together, with the heat in the new aggregate used to dry the RAP material.

For any of the three types of asphalt plants, the purpose is to dry the new aggregate or the combination of the new aggregate and the RAP material (in a parallel flow or a counter-flow type plant) before the asphalt binder is added to the aggregate materials.

Mix Production Rate

The discussion of the effect of the moisture content on the incoming coarse and fine aggregate is primary purpose for this summary. Basically, as discussed in detail below, as the moisture content of the aggregate being delivered into the asphalt plant increases, the production rate of the plant, in terms of tons per hour of mix manufactured, should decrease if the purpose of the plant operation is to completely dry the aggregate before the asphalt binder is added to produce the asphalt concrete mix.

Amount of RAP

As the amount of RAP introduced into the new HMA mix is increased, the amount of new coarse and fine aggregate is necessarily reduced. In order to provide enough heat to increase the temperature of the RAP, which is at ambient temperature when it is introduced into the plant, it is required to increase the temperature to which the new aggregate is heated prior to mixing the new aggregate with the RAP inside the drum. But, because the amount of new aggregate delivered into the drum is reduced, there is an effect on the completeness of the veil of the new aggregate in the drum as it rotates. This change in the veil affects the ability of the exhaust gases from the burner to interact with the new aggregates and completely remove the moisture from the new aggregate.

As the amount of RAP used in the mix is increased, it is necessary to increase the temperature to which the new aggregate is heated in order to completely dry that material and to have enough heat in the new aggregate to transfer to the RAP material. The additional heat in the new aggregate is necessary to be able to complete the temperature exchange between the new aggregate and the RAP prior to the addition of the new asphalt binder to the combined RAP and new aggregate material.

In general, the moisture content of the RAP is less than the moisture content of the combined new coarse and fine aggregate. This is due, in part, to the asphalt binder covering of the RAP material. It is noted, however, that the moisture content of the fine portion of RAP which has been fractionated may be quite high. Thus, it is important to consider both the amount of RAP being introduced into the HMA mix and also the moisture content of that material. In the calculations provided below, the effect of RAP and the moisture content of the RAP are not considered.

Mix Discharge Temperature

The higher the HMA mix temperature when it is discharged from the drum, the greater the effect of the moisture content on the incoming new aggregate and of the moisture content of the RAP. A mix discharge temperature of 280°F will not require as much drying of the combined new aggregate and RAP as would a mix discharge temperature of 310°F.

For WMA asphalt mixtures, the mix discharge temperature may be significantly reduced compared to a HMA mixture. The reduction in the mix discharge temperature is a function of the process used to produce the WMA material. Chemical additives, organic additives, and water foaming methods have been used successfully.

It is important to note, however, that the reduced mix discharge temperature for the WMA material may result in some residual moisture left inside the new aggregate when the new asphalt binder is added to the aggregate. This phenomenon is typically the reason why the tensile strength ratio, and particularly the wet tensile strength, of a WMA mix is lower when the mix is discharged from the mixing drum—there may be some moisture still in the aggregate due to the reduced mixing temperature.

PLANT PRODUCTION RATES

Normal Rated Capacity

The production capacity of an asphalt plant is usually rated based on the removal of 5% moisture from the combined incoming new coarse and fine aggregate. This is normally true for all three types of asphalt plants: batch plants, parallel flow drum mix plants, and counter-flow drum mix plants.

The production rate of the plant depends on the size or diameter of the drying drum. In addition, it also depends on the length of the drying portion of the drum. A drum with a larger diameter will normally be able to produce more dry HMA mix per hour compared to a drum with a smaller diameter.

Incoming Aggregate Moisture Content

The moisture content of the new fine aggregate is normally higher than the moisture content of the new coarse aggregate. Thus the assumed moisture content of an average of 5% for the combined new aggregate material is just that, an average. If, for example, the new HMA mix will contain 50% coarse aggregate, with an incoming moisture content of 4%, and 50% fine aggregate, with an incoming moisture content of 6%, the moisture content of the combined new coarse and fine aggregate would be 5%.

It is important to know the average moisture content of the new aggregate being delivered into the drum. This value is normally determined by measurement of the combined aggregate moisture content by taking samples from the gathering conveyor at the plant. The samples of the combined aggregate should be taken at least daily in dry weather conditions. The samples should be taken much more frequently after a rain event when the moisture content of the aggregate can be significantly higher.

Production Rate Chart

Most asphalt plant manufacturers provide a production rate chart with each asphalt plant when the plant is purchased by the contractor. That chart is specific to the particular plant—to the type of plant, to the diameter of the drum, to the length of the drying portion of the drum, and to the mix discharge temperature from the plant.

It is important to review the information contained in that chart when determining the proper production rates for a particular plant. The data on the chart, when compared to the current production rate of the plant, could provide some indication as to why the HMA mix being produced by the plant might be tender at some times and not tender at other times.

PRODUCTION RATE EXAMPLES

Production Rate Variables

In the examples provided in Table 1, there are two primary variables that are considered when estimating the production rate of an asphalt plant when it is required to completely dry the incoming new aggregates before the asphalt binder is added to that material. Those two variables are the diameter of the drying portion of the drum and the average moisture content of the incoming coarse and fine aggregates.

In these examples, the inclusion of RAP is not taken into account. Further, the reduced mix discharge temperature for the production of WMA is not taken into account.

The incoming moisture contents in the examples are three amounts: 3%, 5%, and 7%. This moisture content is the average moisture content of the combined new coarse aggregate and new fine aggregate. Again, it is noted that the capacity of an asphalt plant is usually calculated using an average moisture content of the combined incoming aggregate of 5%.

TABLE 1 Typical HMA Mix Production Rates

Drum Diameter (feet)	Average Incoming Aggregate Moisture Content (percent)	Production Rate (tons per hour)
6	3	220
6	5	158
6	7	121
8	2	430
8	5	305
8	7	236
10	3	430
10	5	541
10	7	761

Also for these examples, three different diameters of the drying portion of the drum are used. Those diameters are 6, 8, and 10 ft. These diameters do not take into account the increased diameter of the drum which may be present in the mixing portion of the drum.

IMPORTANT POINTS TO CONSIDER

Change in Incoming Aggregate Moisture Content

When the moisture content of the incoming new aggregate increases for an asphalt plant with a given diameter of the drying portion of the drum, the production rate of the plant would need to be decreased if it was desired to produce a HMA mixture that was completely dry.

Using a drum diameter of 8 ft, as shown above, an asphalt plant would have a rated capacity of 305 tons per hour when the incoming new aggregate average moisture content was 5%. This is the production capacity that the plant would be assumed would be the normal production rate for the plant.

If, however, it rained on the stockpiles, and the incoming new aggregate moisture content was 7% instead of 5%, the production rate for the same 8 ft diameter plant would have to be reduced to 236 tons per hour in order to completely remove the moisture from the aggregate and produce a dry HMA mixture.

Further, if the contractor kept the aggregate stockpiles relatively dry, the production rate of the plant could be increased significantly due to the reduction of the incoming new aggregate moisture content. In the example for the drum which is 8 ft in diameter, a reduced incoming moisture content of only 3% would result in a HMA mix production rate of 430 tons per hour and still allow a completely dry new aggregate to be mixed with the asphalt binder.

Burner Fuel Usage

It is also important to understand that the amount of fuel that would be needed to completely dry the combined new coarse and fine aggregate would be exactly the same for the removal of 7%, 5%, or 3% moisture when normal burner fuel is used for the burner. A rule of thumb often used in the industry is that it takes about 0.2 gal of No. 2 fuel oil to remove 1% moisture from the new aggregate. Thus the production rate for the HMA mix could be increased, without an increase in fuel usage, if the incoming aggregate has lower average moisture content. Thus, it might be economically advantageous for contractors to cover their aggregate stockpiles, particularly their fine aggregate materials (and their RAP material) in order to reduce the incoming moisture content and increase the production rate of the HMA mixture. It is noted that covering the aggregate stockpiles does not mean with a tarp over the top of the pile. It means using a roof over the aggregate stockpiles to keep the rain off of the aggregate.

CAUSES OF TENDER MIXES

There are many possible causes for an asphalt concrete mix to move under the applied compactive effort of the rollers during the compaction process. That movement, as discussed above, often results in “checking” of the asphalt concrete mix. The checking reduces the ability of the compaction equipment to achieve the desired density in the asphalt concrete mix.

If the checking in the mix is much more prevalent when the HMA mix is produced and placed a couple of days after a rain event, it is possible that the moisture content of the mix may be having a direct effect on the tender mix problem. The relationship between the moisture content of the incoming coarse and fine aggregate and the production rate for the HMA mix at the asphalt plant should be reviewed.

State Department of Transportation Moisture Damage Roundtable

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ROUNDTABLE DISCUSSION SUMMARY

A roundtable-style discussion was held with the audience and representatives of three state departments of transportation (DOTs). Some of the DOT representatives used presentation slides to begin discussion, while others summarized their state's practices without any slides. The audience actively participated in the discussion, which lasted for several minutes. Each DOT representative has summarized pertinent information from the roundtable workshop below, and in many cases the summary includes content used within their presentation slides.

ILLINOIS DOT MOISTURE TESTING AND MOISTURE DAMAGE SUMMARY

A series of slides titled "Stripping in HMA: Illinois Perspective" were presented during the workshop. Initially, some focus was given to aggregates used and their role in Illinois DOT's approaches to moisture damage. Prior to 1989, stripping was stated to be a nonfactor since carbonate aggregates were used. Illinois DOT's reaction to aggregates with stripping potential was to adopt a version of AASHTO T283 (Hot Water Only). Initially, anti-strip materials were required if the TSR was below 0.75 for 100 mm diameter Marshall hammer-compacted specimens.

Early on, almost all projects used liquid anti-strip when TSR improvement was needed. When the Marshall hammer was replaced with the Superpave gyratory compactor (SGC), 150 mm diameter gyratory specimens were required to achieve a TSR of 0.85. Illinois DOT has relied on the TSR for the past 20 or more years, but have never been fully satisfied with the ratio. For example, some liquid anti-strip materials greatly reduce tensile strength, but improve TSR. It was noted that many studies have looked into hydrated lime, which "seems to work well." Within Illinois DOT, hydrated lime has been used off and on over the years by requirement, but rarely used otherwise.

More recently, use of higher RAP contents has been observed within Illinois DOT to deter moisture damage in several applications. Some discussion was also given to technologies such as WMA, as well as to reclaimed asphalt shingles (RAS). Several questions were posed for WMA such as how it will perform, is a binder grade change needed, how will RAP and RAS behave with WMA, and should liquid anti-strip or hydrated lime be used for these types of mixes? Within the context of items such as WMA, RAP, and RAS, mixture proportions were discussed from the perspective of not having a mix that is too stiff (crack prone) or too soft (rut prone) but that a reasonable balance was needed between the two. Figure 1 shows example photographs used during the presentation demonstrating undesirable behaviors that needed to be considered alongside moisture damage. There was repeated emphasis that a balance between rutting, cracking, moisture damage, and other distress was needed.

Issues exampled in the previous paragraph were used to transition into discussing use of Hamburg Loaded Wheel Tracking (referred to hereafter as Hamburg). Figure 2 is a photograph of Illinois DOT's Hamburg testing equipment, and Figure 3 and Figure 4 shows specimen preparation. Some background was provided on the AASHTO T 324 Hamburg test; described as a torture test that identifies mixes susceptible to moisture damage. Hamburg rut depths were noted not to necessarily indicate the amount of rutting that might occur in the field.

FIGURE 1 Examples of issues with too hard or too soft mixes.

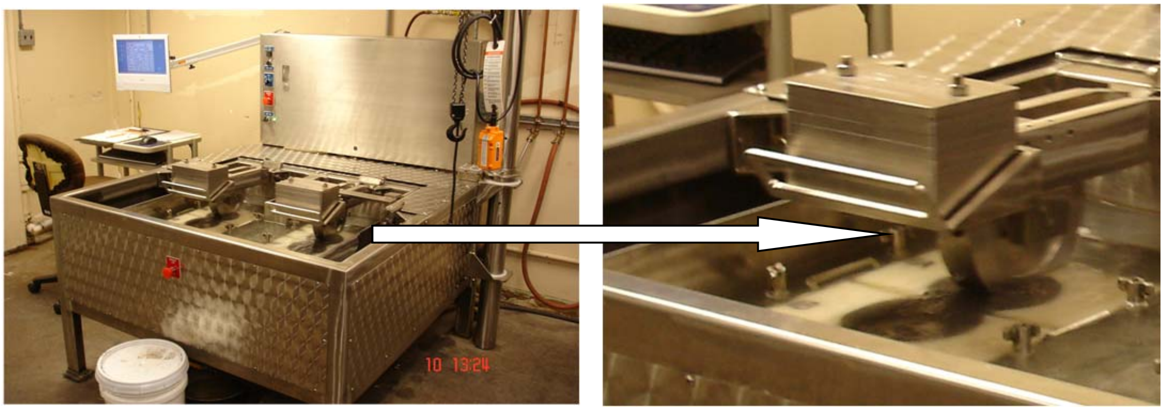

FIGURE 2 Illinois DOT Hamburg loaded wheel tester.

FIGURE 3 Hamburg specimen preparation.

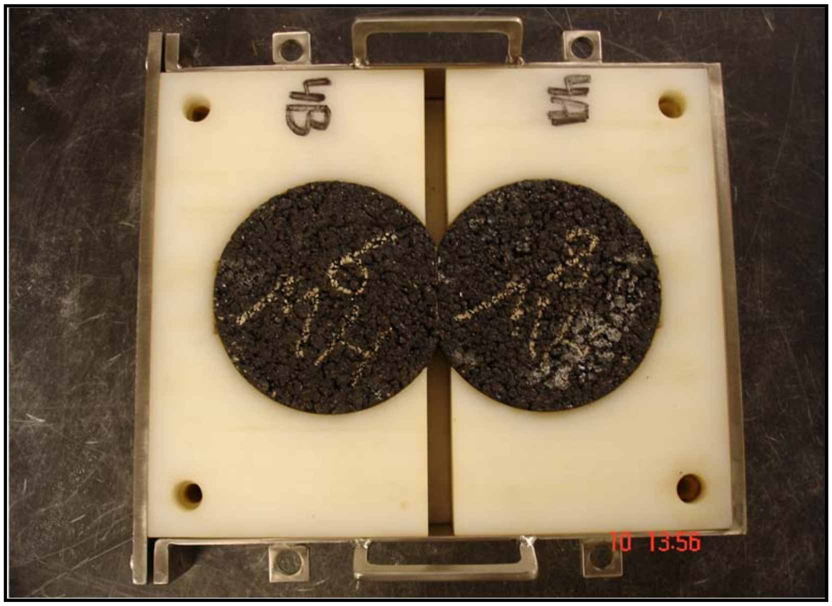

FIGURE 4 Hamburg specimen preparation.

There was discussion that Hamburg (or similar) criteria are gaining momentum because there are "too many cooks in the pot." These "cooks" were materials such as RAP or RAS (especially elevated levels of either), technologies such as WMA, downward grade bumping to soften mix to prevent cracking, or especially combinations of recycled materials and WMA. Hamburg criteria are candidates for end result specifications. Grade bumping was noted as a solution when over 20% binder replacement occurred with RAP or RAS (e.g., reduce from PG 64-22 to PG 58-28).

Hamburg specifications were discussed in the context of relating mixes to field performance by eliminating mixes that would fail in the field, but not eliminate those that have proven to perform well in the field. Hamburg criteria were reported to be 12.5 mm maximum rut depth at a 50°C test temperature. The number of passes where the rut depth cannot be exceeded was a function of the binder grade: 10,000, 10,000, 15,000, and 20,000 passes for PG 58, PG 64, PG 70, and PG 76, respectively. It was noted that the PG 58 requirement may need to be revisited. Figure 5 provides example photographs of specimens that passed and failed Illinois DOT Hamburg testing.

Other moisture damage criteria were reported to be a maximum split tensile value of 1,378 kPa (200 psi), and WMA minimum tensile strength values of 413 to 551 kPa (60 to 80 psi). The presentation concluded with some general discussions related to Illinois mixes currently in service. A primary item of discussion was to test core strengths fairly quickly or results could change and that cores should remain wrapped until tested. Some data was presented showing tensile strengths increasing over a few days period as they dried.

FLORIDA DOT MOISTURE TESTING AND MOISTURE DAMAGE SUMMARY

Background and Requirements

Florida DOT started testing asphalt mixtures for moisture damage when Superpave was adopted in 1996. Florida DOT uses AASHTO T 283 and specifies 100 mm diameter specimens compacted to 7.0 ± 0.5% air voids. Some conditioning parameters are: 70% to 80% vacuum saturation, a freeze–thaw cycle, and a hot water soak. Florida DOT requires that the unconditioned samples have a tensile strength of 100 psi and requires the TSR ≥ 0.80.

Florida DOT maintains a qualified products list (QPL) for liquid anti-stripping agents. For projects with a design traffic volume of <3 million equivalent single axle loads (ESALs), the contractor will select an anti-stripping agent from the QPL and no mixture testing is required. For design traffic volumes ≥3 million ESALs, the contractor must also use a liquid anti-stripping agent from the QPL and must also meet the requirements of AASHTO T 283 discussed above.

To qualify for inclusion on the QPL, Florida DOT uses a procedure similar to AASTHO T 283 and uses a 100% granite mixture known to have poor resistance to moisture damage for testing. The Florida DOT test requires that the TSR increase by 20% with the inclusion of the liquid anti-stripping agent.

Fail **Pass**

FIGURE 5 Example Hamburg loaded wheel tester results.

Hydrated lime is allowed for use in dense-graded mixtures but is not used by contractors due to the lower cost of using liquid anti-stripping agents.

Moisture damage testing is not performed for open-graded friction course (OGFC) mixtures. For OGFC mixtures containing Florida limestone, a liquid anti-stripping agent is added at a dosage rate of 0.5%. For OGFC mixtures containing a majority of granite, hydrated lime is added at a dosage rate of 1.0% by weight of total dry aggregate.

Moisture damage testing for dense-graded mixtures is only performed at mix design. During production, binder delivery tickets must identify the name of the liquid anti-stripping agent, its QPL number, and the dosage rate. All of this information must match the information listed on the approved mix design.

Field Performance

Prior to the implementation of Superpave, there were occasions where existing OGFC mixtures were overlaid instead of being milled. There was one instance on an interstate highway where the overlaid OGFC held moisture and stripped. The practice of overlaying OGFC was halted after this failure.

Additionally, it is believed that the short lifespan of Florida DOT's older generation OGFC mixtures was partially related to stripping due to low asphalt binder film thicknesses.

Other materials and construction related practices that were halted to improve the resistance to moisture damage include raising the in-place density values for coarse-graded and fine-graded dense mixtures, and eliminating the use of river gravel as an aggregate source.

Since the implementation of Superpave, there were moisture damage-related issues on the first three Superpave projects constructed. The reasons for this are (*a*) the mixtures were all coarse graded; (*b*) had low in-place density levels; (*c*) were highly permeable; and (*d*) consisted of granite from Georgia, which has the potential to strip more than Florida limestone aggregates. The three projects were resurfaced after 12 years but received minor patching repairs a few years earlier. Another project constructed with granite from Nova Scotia showed some stripping several inches below the surface at a layer interface. However, the road has not prematurely failed and is currently 10 years old.

As Superpave was implemented and refined, the in-place density levels were raised and fine-graded mixtures are now used exclusively for all dense-graded mixtures. Both of these actions result in nearly impermeable pavement, thereby reducing the impact of moisture on the mixtures' performance.

For OGFC mixtures, in order to increase the optimum binder content without experiencing "drain down" during construction, fiber-stabilizing additives (either mineral or cellulose) were added to the mixture to increase the binder content and help reduce raveling.

In general, Florida DOT does not have any substantial problem with moisture-related damage to asphalt mixtures.

MISSISSIPPI DOT MOISTURE TESTING AND MOISTURE DAMAGE SUMMARY

A considerable portion of the Mississippi DOT discussion related to moisture susceptibility were the high water absorption crushed gravel aggregates used on a widespread basis in Mississippi. If not properly handled, these materials can be prone to moisture damage (stripping in particular).

Mississippi DOT's primary specification manual is titled *Mississippi Standard Specifications for Road and Bridge Construction* (also known as the Red Book), and Section 401.02.3.1 states "hydrated lime shall be used in all HMA at the rate of one percent (1%) by weight of the total dry aggregate including aggregate in RAP, if used." An item of discussion for Mississippi DOT was this across the board requirement for 1% hydrated lime for asphalt mixtures.

Mississippi DOT's hydrated lime requirement has been in place statewide since the 1993 time frame. It took around a decade from initial discussions (mid-1980s) to statewide use. After a couple of years for lime silos to be installed statewide, the 1989 to 1993 time frame saw use on select Mississippi DOT projects. Hydrated lime was first included in the 1990 edition of the Red Book, but was not required in all Mississippi DOT mixes until the spring of 1993. Hydrated lime was required a few years before Mississippi DOT adopted Superpave (1996 to 1997 time frame).

Within Mississippi DOT specifications, terms such as anti-stripping additive or anti-stripping agent refer to liquid or dry powder materials in excess of 1% hydrated lime. If testing requirements can be met with only 1% hydrated lime, nothing else is required for moisture damage resistance. Moisture damage requirements are based on boiling water and TSR testing; Mississippi DOT test methods MT-59 and MT-63, respectively.

MT-59: Determination of Loss of Coating of HMA (Boiling Water Test) is performed on each day of production. A minimum particle coating of 95% is required based on visual examination. If a mixture fails the boil test, immediate action is required (Section 401.02.5.3).

MT-63: Resistance of Bituminous Paving Mixtures to Stripping (Vacuum Saturation Method) is performed at the beginning of production and at least once every 2 weeks thereafter. The required TSR (wet strength divided by dry strength) is 0.85 with a minimum interface coating of 95%. If a mixture fails the TSR test, immediate action is required (Section 401.02.5.3).

Specimens for MT-63 are compacted in the SGC to dimensions of 150 mm diameter by 95 mm tall and air void levels of 7 ± 1% according to AASHTO T166. Four specimens are compacted; two are tested absent conditioning for dry strength and two are wet conditioned and then tested for wet strength. Conditioned specimens are 55% to 80% vacuum saturated, submerged for 24 h in 60°C water, brought to room temperature, and then tested in indirect tension at a load rate of 50.8 mm/min.

Prior to or during production, mixes require addition of an anti-stripping agent (e.g., liquid anti-strip) if the TSR is below 0.85 or boil test is below 95%. Anti-stripping agents must produce TSR of 0.85 while also showing an increase in water conditioned indirect tensile strength (versus specimens with only 1% hydrated lime). Testing is performed with and without the anti-stripping additive (1% hydrated lime is used in both cases).

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