Asphalt Expert Task Group Update, AASHTO, and Emerging Topics

Matthew Corrigan, P.E.

U.S. DOT | Federal Highway Administration
Asset Management, Pavement, and Construction

May 10-11, 2016

U.S. Department of Transportation
Federal Highway Administration

Asphalt Expert Task Groups

- Forum for Government, Industry, and Academia
- Discussion of ongoing asphalt binder and mixture technology
- Provide technical input for current and future research, development, and specifications.

Asphalt Expert Task Groups

- Asphalt Mixture & Construction ETG
  - Last meeting in Salt Lake City on April 25-27, 2016
  - POC – John Bukowski
- Asphalt Binder ETG
  - Last meeting in Salt Lake City on April 27-28, 2016
  - POC – Matthew Corrigan
- Sustainable Pavements TWG
  - POC – Gina Ahlstrom

Open Meetings
All are Welcome!

www.AsphaltETGs.org

Upcoming ETG Meetings

To Be Announced (Next meeting plan - week of Sept 12, 2016)

Past ETG Meetings

September 2015 — Asphalt Mix ETG, Oklahoma City, OK
September 2015 — Binder ETG, Oklahoma City, OK
April 2015 — Asphalt Mix ETG, Fall River, MA
April 2015 — Binder ETG, Fall River, MA
September 2014 — Asphalt Mix ETG, Baton Rouge, LA
September 2014 — Binder ETG, Baton Rouge, LA

Current Asphalt ETG - Activities

- Asphalt Mixture Performance Tester (AMPT)
- Performance Tests for Cracking/Fatigue
- RAP & RAS Asphalt Binder Replacement
- MSCR Binder Grading
- Ground Tire Rubber
- Re-refined Engine Oil Bottoms (REOB)
- Provide technical input to AASHTO Subcommittee on Materials (SOM) & assist the revision and update standards

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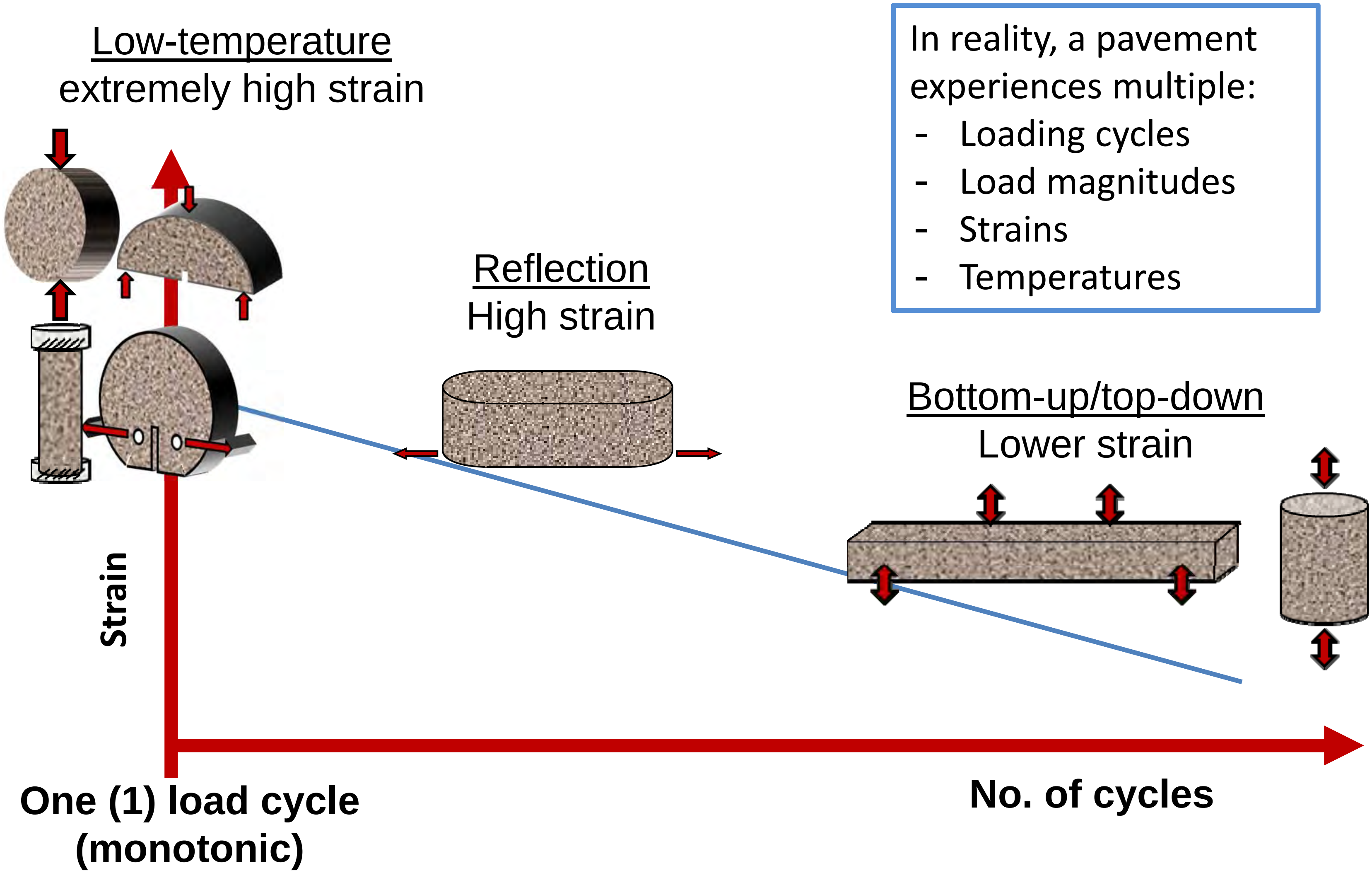
Cracking Modes versus Tests



In reality, a pavement experiences multiple:

- Loading cycles
- Load magnitudes
- Strains
- Temperatures

Cracking Laboratory Tests

Ten (10) protocols - highlighted as part of NCHRP Proj. 09-57

Low Temperature	Reflection	Bottom-Up	Top-Down
DCT (ASTM D7313-13)	Texas OT (TxDOT-Tex 248-F)	Beam fatigue (AASHTO T321)	IDT (Univ. of Florida)
SCB (AASHTO TP105)	DCT (ASTM D7313-13)	AMPT Cyclic Fatigue (AASHTO TP107)	AMPT Cyclic Fatigue (AASHTO TP107)
IDT (AASHTO T322)	SCB (Louisiana State Univ. - LTRC)	RDT (Texas A&M Univ.)	RDT (Texas A&M Univ.)
TSRST/UTSST (Univ. of Nevada, Reno)		SCB (LTRC and Univ. of Illinois)	SCB (LTRC and Univ. of Illinois)
		Texas OT (TxDOT-Tex 248-F)	

Asphalt Mix Performance Tester (AMPT)

www.fhwa.dot.gov/pavement/asphalt/tester.cfm

- Results used for PavementME Design inputs
- AASHTO Standards:
  - PP 60 for preparation of AMPT test specimens
  - TP 79 for Dynamic Modulus |E*| & Flow Number (F_n)
  - PP 61 for developing |E*| master curves
  - TP 107 for Cyclic Fatigue protocols

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Already invested in AMPT equipment for Pavement ME … the AMPT can do much more than just |E*| testing!!

Pv AASHTOWare Pavement AASHTO

Why AMPT Cyclic Fatigue Test?

1. Heritage and “pedigree” of the theory – aerospace industry application for solid rocket propellant
2. Vetting and peer review; “winning” candidate in NCHRP Project 09-19 (Tasks F&G)
3. Wanted a performance test that could be defensible, <u>not</u> empirical correlations
4. AASHTO TP 107-14 *Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests*

1.1 Description of the Problem

[redacted] are the prime component of [redacted] and the performance of such [redacted] influenced largely by the mechanical properties of [redacted] grains. The structural integrity of [redacted] is determined by performing stress analysis for loading and environmental conditions under which the [redacted] is likely to operate. Consequently, the accuracy of the representation of the [redacted] mechanical behavior is essential for the usefulness of stress analysis results of [redacted]

All modern [redacted] use an elastomeric binder which is filled with quite high levels of solid particles. The mechanical behavior of [redacted] is mainly determined by the polymeric nature of the binder and the binder-filler interaction. The application of a load causes irreversible microstructural changes referred to as damage. They mainly consist of broken molecular chains and interfacial debonding, also called dewetting, that result in the formation of microvoids at or near the interface of the particles and surrounding matrix. Under these influences [redacted] exhibit very complicated behavior including features associated with time and rate effects, temperature and superimposed pressure dependence, large deformations and large strains, stress softening during cyclic loading, called Mullins' effect, and transition from incompressible to compressible behavior…

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…sounds a lot like asphalt?…

1.1 Description of the Problem

Solid propellants are the prime component of solid rocket motors and the performance of such motors is influenced largely by the mechanical properties of propellant grains. The structural integrity of a rocket motor is determined by performing stress analysis for loading and environmental conditions under which the motor is likely to operate. Consequently, the accuracy of the representation of the solid propellant mechanical behavior is essential for the usefulness of stress analysis results of solid rocket motors.

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CONSTITUTIVE EQUATIONS FOR SOLID PROPELLANTS
Sebnem Ozupek - PhD Dissertation UT-Austin 1997

Some more on solid rocket propellant

Castable composite solid rocket motors were invented by John Whiteside "Jack" Parsons at Caltech in ***1942*** when he replaced double base propellant with ***roofing asphalt and potassium perchlorate***. […] Charles Bartley, employed at JPL (Caltech), ***substituted curable synthetic rubber for the gooey asphalt***, creating a flexible but geometrically stable load-bearing propellant grain that bonded securely to the motor casing. This made possible much larger solid rocket motors. Atlantic Research Corporation significantly boosted composite propellant in 1954 by increasing the amount of ***powdered aluminum in the propellant to as much as 20%.***

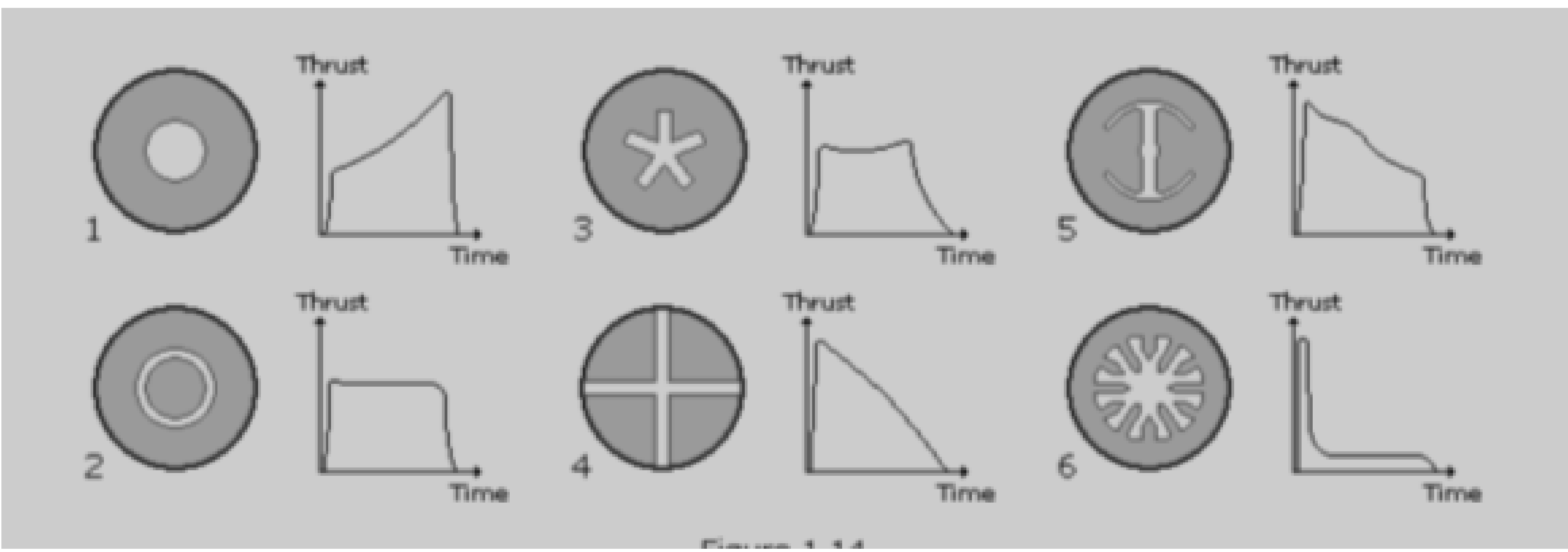
https://en.wikipedia.org/wiki/Solid-fuel_rocket

http://www.wired.com/2011/12/to-build-a-diy-spacecraft-is-a-daunting-task/

http://www.nasa.gov/mission_pages/shuttle/behindscenes/srb_inspection-gallery.html

Some more on solid rocket propellant

Common modes of failure in solid rocket motors include ***fracture of the grain***, failure of case bonding, and air pockets in the grain. All of these produce an instantaneous increase in burn surface area and a corresponding increase in exhaust gas and pressure, which may rupture the casing.



http://www.braeunig.us/space/propuls.htm

https://en.wikipedia.org/wiki/Solid-fuel_rocket https://youtu.be/lnyDnruVpTw

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The Rocket: Solid and Liquid Propellant Motors

Application of Schapery's Theory of Viscoelastic Fracture to Solid Propellant

S. R. Swanson*
University of Utah, Salt Lake City, Utah

The analysis of time-dependent crack propagation in viscoelastic materials in general, and solid propellants in particular, has been hampered by the difficulty of the mathematical analysis of a cracked viscoelastic material. The viscoelastic solution to the singular line crack has not provided a realistic fracture criterion, whereas various approximations to this problem have compared more favorably with experiments. However, it is difficult to assess the generality of the approximations involved. Recently, Schapery has generalized the Barenblatt model to the viscoelastic case and thus developed a model that appears to be consistent with both theory and experiment. The objective of the present work was to obtain a detailed comparison of this model with laboratory results available in the literature on a PBAN solid propellant. The results of the comparison are extremely good over a wide range of variables. A time-dependent fracture energy is found to result which can be incorporated readily into the theory.

Introduction

It is well known that cracks in viscoelastic solid-propellant rocket motor grains may initiate and propagate under various environmental loadings. The consequences of crack propagation during firing of the propellant grain depend critically on the time required for crack propagation compared with the burning rate, as burning can modify the geometry of the crack or flaw. Slowly propagating or stationary cracks thus may be removed essentially by burning, whereas more rapidly propagating cracks may become more severe as the crack deepens, and pressure may build up in the crack.

Viscoelastic crack propagation has been studied by a number of investigators,[1-10] and the results have been developed concerning the time dependence of the initiation of crack propagation and the subsequent velocity of crack propagation. Although the work cited has been a generalization of the classic elastic crack instability analysis, certain physically or mathematically based approximations necessarily have been made because of the complexity of the viscoelastic stress analysis of the crack geometry.

The exact solution to the problem of a line crack in a linearly viscoelastic material has been presented recently by Graham[11] and subsequently corroborated by Nuismer[12] using the usual thermodynamic power balance for fracture. The result of this solution is that the fracture criterion is given by

$$\sigma_{cr}(t_f) = (2\gamma_c / \pi D_g a_0)^{1/2} \qquad (1)$$

which is Eq. (11) by Nuismer.[12] It is seen that this is identical to the classic Griffith solution except that the elastic modulus is replaced by the reciprocal of the glassy creep compliance. A second feature of the preceding solution is that no information is given about crack propagation velocities; the criterion applies only to the initiation of cracking.

As pointed out by Nuismer, the foregoing result is physically unappealing in that it appears to be only an upper bound on the fracture stress. No information is available from this result about time-dependent fracture at lower stress levels or crack velocities. Thus the exact solution to the singular viscoelastic line crack problem does not give a realistic fracture criterion, and as discussed by Nuismer, raises question about the validity of the results obtained by the various approximate theories.

Knauss[13,14] has pointed out, however, that a length parameter not present in the singular line crack problem is necessary to introduce time or velocity effects into the viscoelastic fracture analysis. Thus an approximate solution that incorporates a failure zone length, as developed by Knauss,[5,8] may capture more of the physical features of the real case than does the singular line crack, even though an approximate stress analysis was employed.

A way out of this dilemma has been developed recently by Schapery.[15,16] Schapery has generalized the Barenblatt model[17] for elastic fracture to the linear viscoelastic case. In Schapery's model (as in the Barenblatt model), a small "cohesive" zone is assumed to exist at the tip of the crack which exerts tractions on the crack faces. The singularity in stress at the crack tip due to these cohesive forces is equated to the negative of the singularity in stress at the crack tip due to the external applied loads, so that the resulting stress is everywhere finite. Schapery calculates the work done on the cohesive zone by the surrounding linear viscoelastic material and equates this to the fracture energy. Schapery develops the equation for crack velocity as

$$C_v(\tilde{t}_\alpha) = 8\Gamma / K_I^2 \qquad (2)$$

where C_v is related to the creep compliance, Γ is surface energy, and K_I is the opening mode stress intensity factor. The term $\tilde{t}_\alpha$ can be viewed as the time required for the crack to traverse the cohesive zone at the crack tip. For a one- or two-term power law representation of C_v, this equation can be solved explicitly for the crack velocity as

$$\dot{a} = \left[\frac{C_2 \lambda_n \Gamma^{\gamma}}{\ldots} \right]^{1/m} K_I^{\ldots} \qquad (3)$$

where C_v has been taken as $C_v = C_2 t^m$. C_v is related approximately to the creep compliance $D(t)$ by $C_v(t) = 4(1-\nu^2)D(t)$. The terms in brackets are constants or material parameters developed by Schapery. If the fracture energy Γ is a constant, the propagation law is of the form

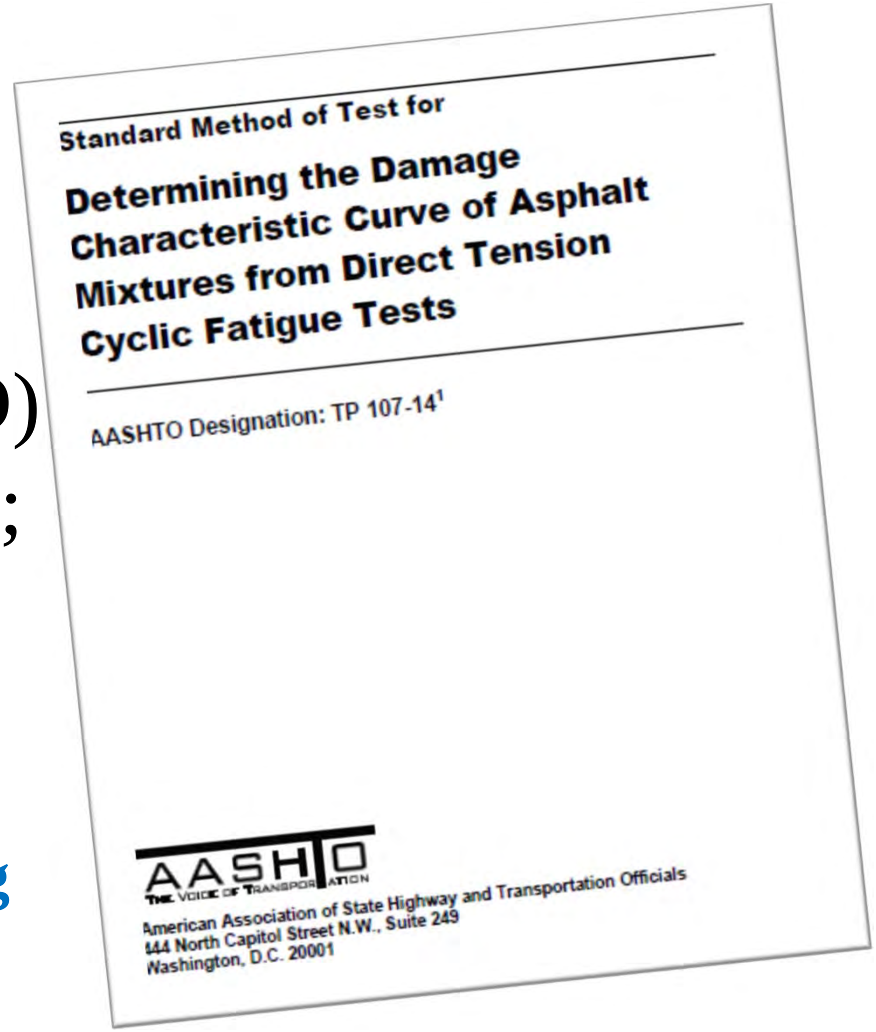
$$\dot{a} = A K_I^{\ldots} = A K_I^{q} \qquad (4)$$

Received Aug. 22, 1975; revision received Jan. 5, 1976. This work was supported in part by Hercules Incorporated. Discussions with J. J. Anderson, S. C. Beckwith, and R. A. Schapery were very helpful.
Index category: Solid and Hybrid Rocket Engines.
*Research Associate Professor, Department of Mechanical Engineering; also Consultant, Hercules Incorporated.

S. R. SWANSON. "*Application of Schapery's Theory of Viscoelastic Fracture to Solid Propellant*" Journal of Spacecraft and Rockets, Vol. 13, No. 9 (*1976*), pp. 528-533.

Richard Schapery's theories provided the foundation for asphalt viscoelastic continuum damage (VECD) using AMPT cyclic fatigue; all beginning with:

Kim, Y.R., Little, D.N.: One-dimensional constitutive modeling of asphalt concrete. ASCE J. Eng. Mech. 116(4), 751–772 (1990)



Standard Method of Test for

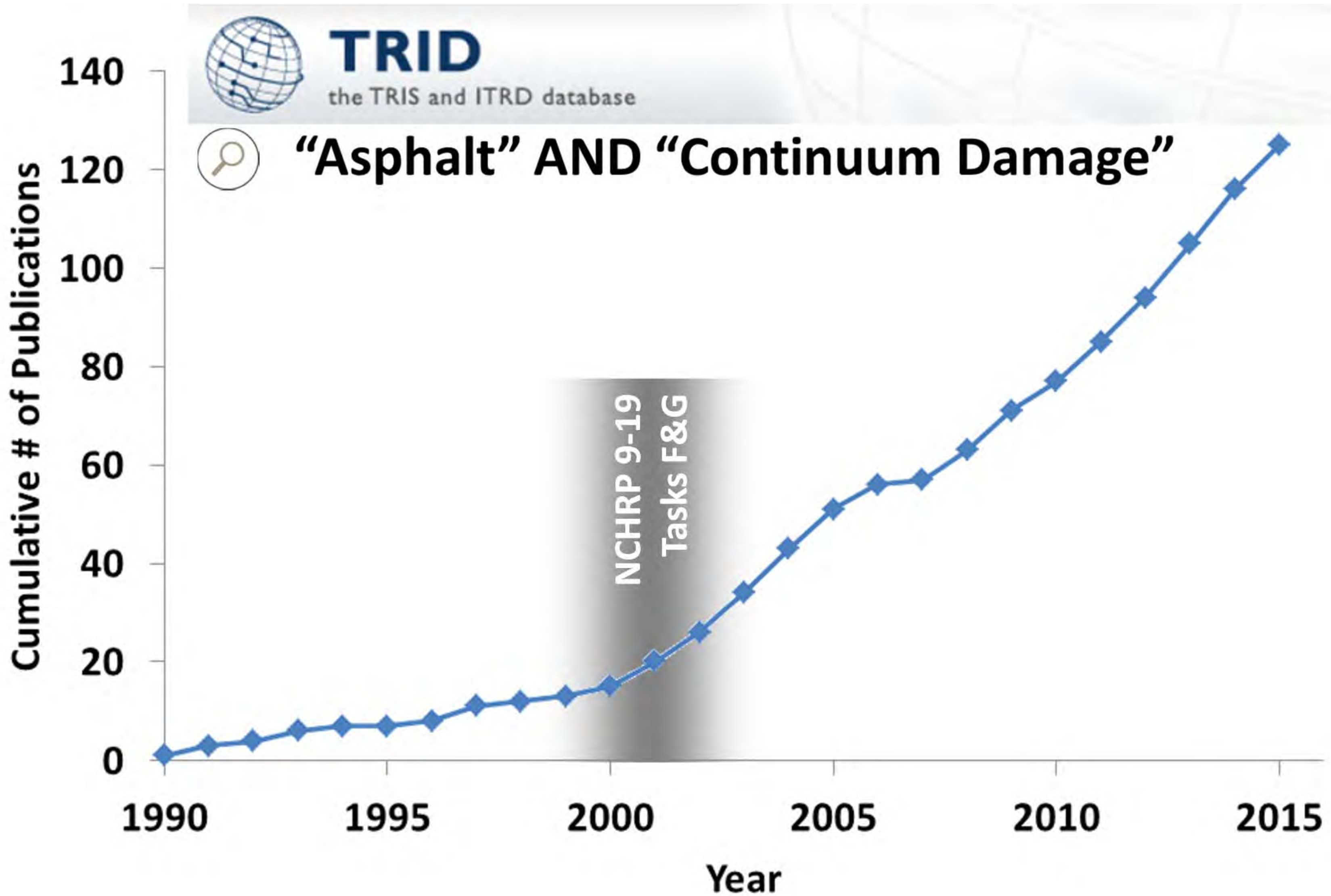
Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests

AASHTO Designation: TP 107-14[1]

AASHTO
THE VOICE OF TRANSPORTATION

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

This is not a “Johnny-come-lately” methodology!



Why AMPT Cyclic Fatigue Test?

4. Unified/common AMPT equipment & spec
   - Custom MTS or UTM machines which can differ greatly from institution to institution (laboratory to laboratory)
5. Unified/common compaction control with SGC
   - Density uncertainty with slab compactors
   - Other compactors vary greatly by design
     - -- slab, vibratory, plate-kneading, tamping, and shear box
   - Less material, less waste, easier handling
   - Less Testing!

Why AMPT Cyclic Fatigue Test?

6. <u>Extended time-temperature superposition !!!!!</u>
   – Discovered during NCHRP 9-19 Tasks F&G
   – Shift factors for |E*| vs. Temperature are the same for explaining fatigue damage vs. Temperature
7. Certainty in the stress–strain state within the test specimen
   – Uniaxial stress state is uniform not like a bending/flexural stress which is different everywhere
   – Strains are measured on the specimen rather than a beam deflection, avoiding end effects and other artifacts

Why AMPT Cyclic Fatigue Test?

8. <u>The test tells you a lot about your mix!!!</u>
   – Response under multiple strains: STRUCTURE/TRAFFIC
   – Response under multiple load rates: TRAFFIC
   – Response under multiple temperatures: SEASONAL
   – More information gained from this test protocol and analysis than from other single tests at a single rate/temperature
9. Connect mix design and construction by means of distress and performance prediction
   - not just a pass/fail test

Recent ETG efforts - AMPT Draft AASHTO Specifications

- Draft Documents
  - MP XX Equipment Specification
  - Equipment Spec Commentary
  - TP 79 Dynamic Modulus
  - TP XX Flow Number
- Distribute for Review & Comment
- Address Comments & Revise Drafts
- Submit to SOM Tech Section 2d

Specification Updates

- Equipment Spec based on NCHRP 9-29
- Revisions to address:
  - TP 107 Direct Tension Cyclic Fatigue
  - TP 116 iRLPD
- Tension Loading
- TP 79 split into E* and FN standards
- Calibration moved to Equipment Spec
- Computations moved to test standards

Specification Updates

Comments were received …

Next Steps: Address Comments & Revise Draft Documents to forward to AASHTO

Contacts:

- Ray Bonaquist (aatt@erols.net)
- Jeff Withee (jeff.withee@dot.gov)

Recycled/Reclaimed Asphalt Pavement (RAP) Recycled/Reclaimed Asphalt Shingles (RAS)

New RAP/RAS Task Force within ETG

- Current main issue to be addressed:
  - How much of the RAS binder becomes effective asphalt binder? "Quantity"
  - How to address the stiffness/brittleness of the RAS binder? "Quality"
  - Binder grade adjustment guidelines

Recycled/Reclaimed Asphalt Shingles (RAS)

Existing Guidance

- **M 323:** ***Superpave Volumetric Mix Design***
  - Modifications; Binder replacement revisions for RAS (RAS needs inclusion)

- **PP 78-14:** ***Standard Practice for Design Considerations When Using RAS in Asphalt Mixtures***

- **MP 23-14:** ***RAS for Use in Asphalt Mixtures***
  - Modifications regarding RAS

Recycled/Reclaimed Asphalt Shingles (RAS)

Existing Approach (AASHTO PP 78)

- Binder Quantity
  - uses RAS binder availability factor 0.70-0.85
- Binder Quality
  - uses binder grade adjustment guidelines

Recommended Virgin Asphalt Binder Grade	RAS or RAS + RAP Binder Percentage
No change	<15
One grade softer	15 to 25
Use blending charts	>25

ETG TF Recommendations - Quantity

- Raise minimum VMA by 0.1% for every 1% RAS (by weight of total aggregate).
  - Based on assumption of 70% binder availability
  - Will increase effective binder in the mix to offset for the <u>potential</u> for non-effective binder on the RAS
- Simple way of addressing binder availability
  - More binder → Improved durability
  - Angular aggregate and stiffer binder in RAS → Minimal risk of rutting

ETG TF Recommendations - Quality

- Focus on the critical low temperature difference of the binder ΔT_c using BBR:

  ΔT_c = BBR Stiffness critical temp (S) – the BBR Relaxation critical temp (m-value)

  $= T_{c(S)} - T_{c(m\text{-value})}$
- Criteria: ΔT_c for the blended binder should be greater than (warmer) or equal to -5.0°C
  - Binder is PAV aged for 40 hours

Binder Selection

The grading system is based on climate via a project specific location's in-service pavement temperatures

PG Asphalt Binder Designation

PG XX - YY

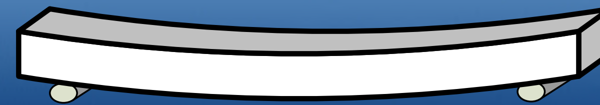
Performance Grade

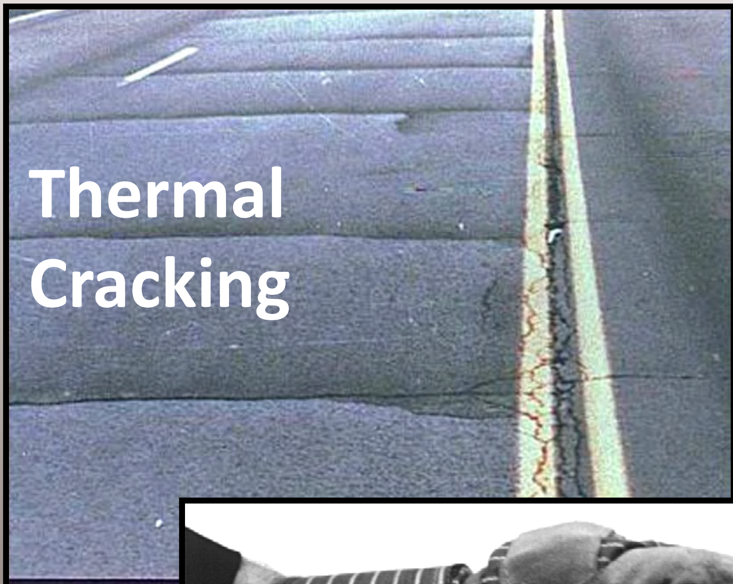
Damage weighted high pavement temperature

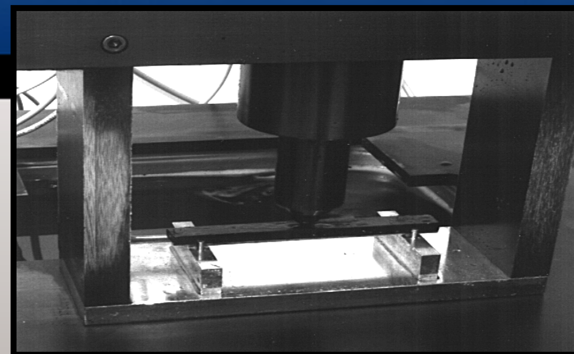
Min pavement temperature

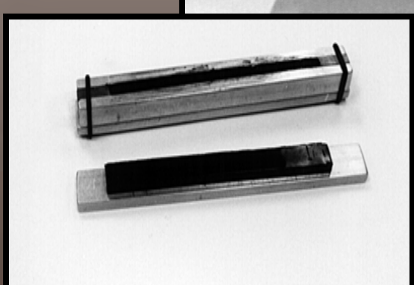
Pressure Ageing Vessel

Bending Beam Rheometer



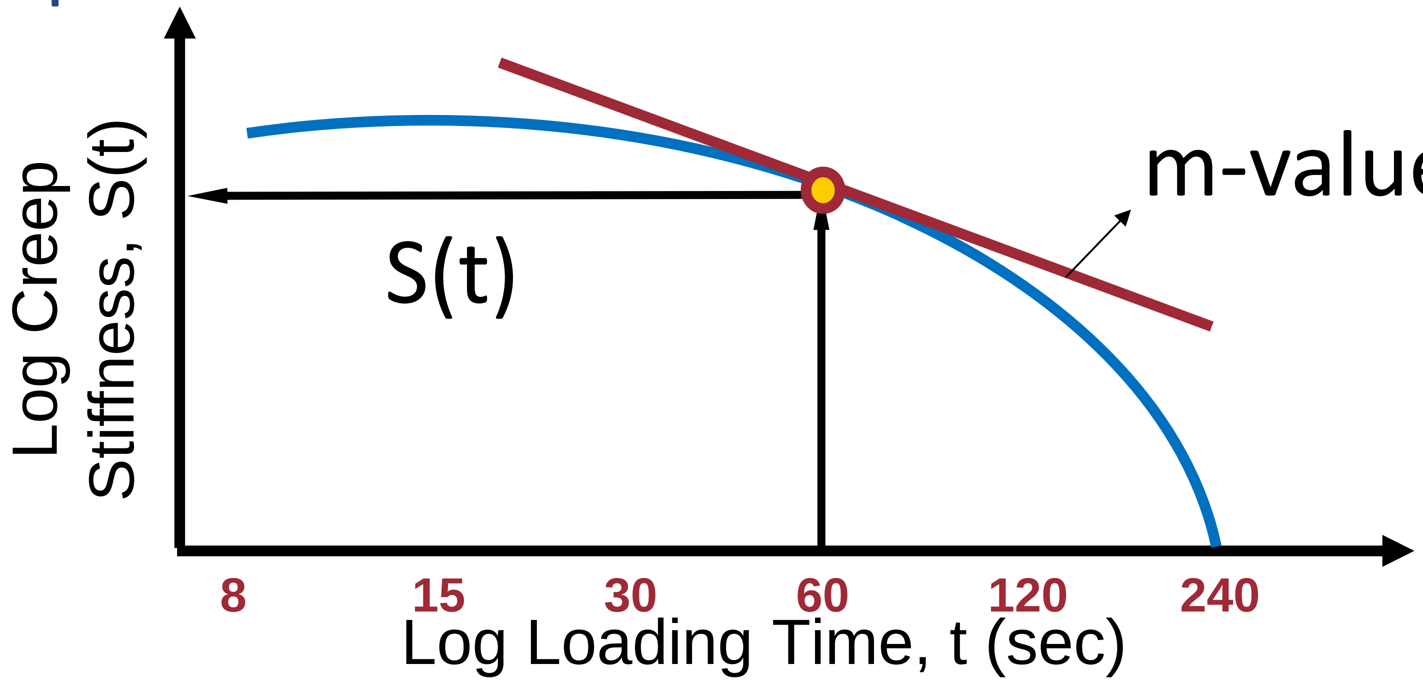






Bending Beam Rheometer

Determines low temperature specification parameters standardize in AASHTO M320



Creep Stiffness (S)

Creep slope (m-value)

Example 1

Test	Temperature	Result	Criteria
RTFO and PAV Residue – Aged Binder			
Dynamic Shear Rheometer G*sin(δ)	19ºC	NR	≤ 5000 kPa
	25ºC	4100 kPa	
	28ºC	NR	
Bending Beam Rheometer, Stiffness, S	-24ºC	NR	≤ 300 MPa
	-18ºC	368 MPa	
	-12ºC	187 MPa	
Bending Beam Rheometer, m-value	-24ºC	NR	≥ 0.3
	-18ºC	0.270	
	-12ºC	0.330	

$$\Delta T_c = -25.7 - (-25.0) = -0.7°C$$

Example 2

Test	Temperature	Result	Criteria
RTFO and PAV Residue – Aged Binder			
Dynamic Shear Rheometer G*sin(δ)	19°C	NR	≤ 5000 kPa
	25°C	NR	
	28°C	1870 kPa	
Bending Beam Rheometer, Stiffness, S	**-24°C**	313 MPa	≤ 300 MPa
	-18°C	110 MPa	
	-12°C	60 MPa	
Bending Beam Rheometer, m-value	-24°C	NR	≥ 0.3
	-18°C	0.266	
	-12°C	0.309	

$$\Delta T_c = -33.6 - (-23.3) = -10.3°C$$

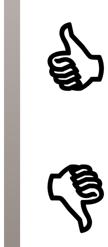
Critical Temperature Difference (ΔT_c)

ΔT_c = BBR Stiffness critical temp (S) – the BBR Relaxation critical temp (m-value)

$$= T_{c(S)} - T_{c(m\text{-value})}$$

$$= -25.7°C - (-25.0°C) = -0.7°C > -5°C$$

$$= -33.6°C - (-23.3°C) = -10.3°C < -5°C$$

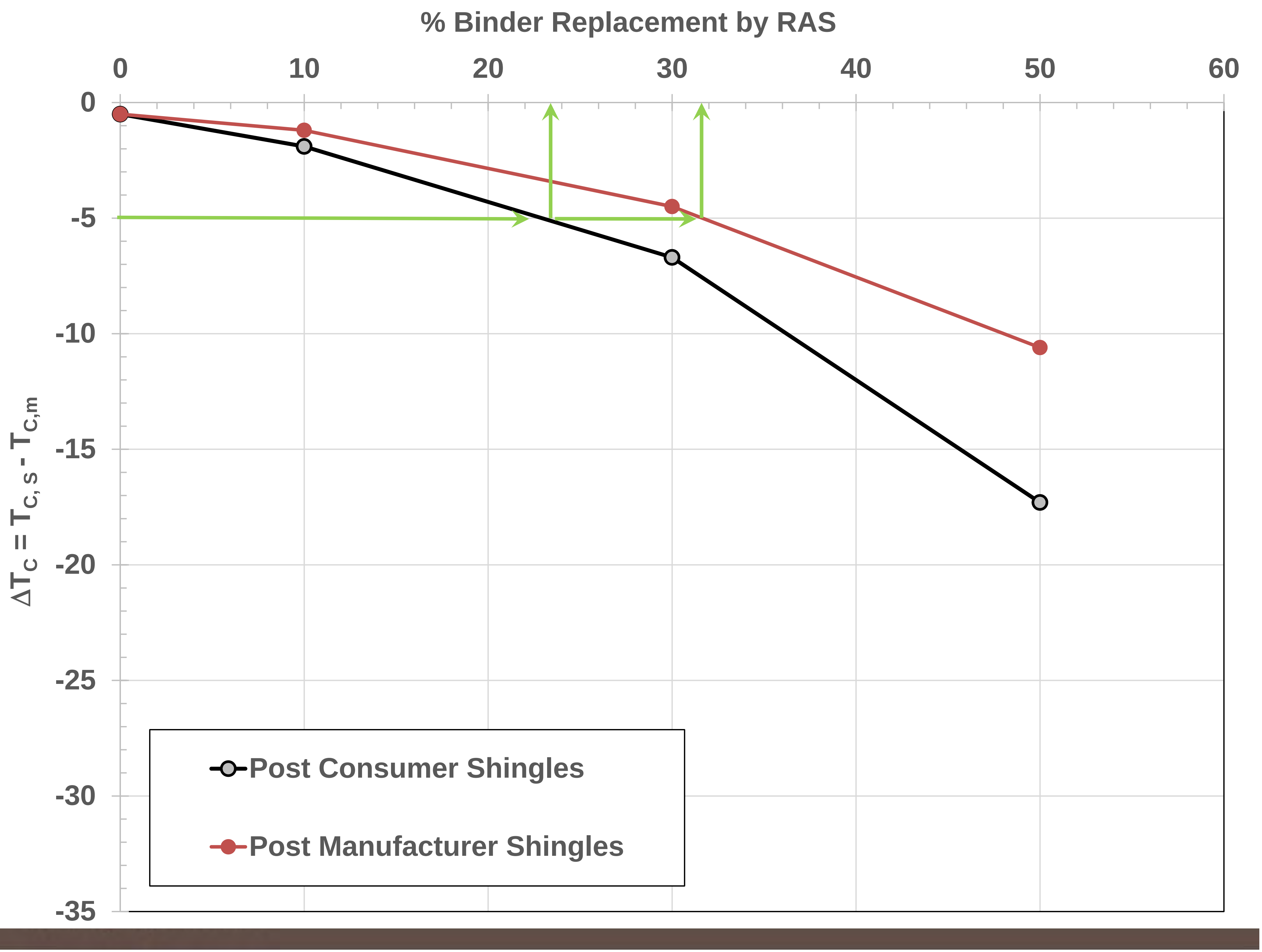


critical temperature (T_c)

also know as "continuous grade"

Two Approaches
1. Binder Blending Procedure

- Agency sets allowable RAS tiers;
- Extract, recover, blend typical materials (RAS, RAP, base binder, etc.) at varying percentages
- RASBR = 0.00, 0.15, 0.30
- PAV age the blended binder for 40 hours
- Test the blended binders to determine ΔT_c
- Set the allowable tiers based on the criteria that ΔT_c must be greater than or equal to -5.0°C, and the appropriate PG grade is met.



% Binder Replacement by RAS
0
10
20
30
40
50
60
0
-5
-10
-15
-20
-25
-30
-35
ΔTC = TC,S - TC,m
Post Consumer Shingles
Post Manufacturer Shingles

Two Approaches
2. Mixture Extraction Procedure

- Individual mixes are fabricated, extracted, the binder recovered and then PAV aged for 40 hours
- The recovered binder is tested to determine ΔT_c
- ΔT_c must be greater than or equal to -5.0°C, and the appropriate PG grade is met

Alternate Use of Performance Tests

- A mixture performance test for cracking implemented by the State may be acceptable in lieu of the binder testing for ΔT_c
  - Cracking test development and deployment in its infancy
- Default value option – a maximum RASBR can be used in lieu of testing
  - for example RASBR ≤ 0.10

Alternate Loose Mix Aging Procedure

- Mixture Extraction Procedure
  - Individual mixes are fabricated
  - Loose mix is conditioned at 135°C for 24 hours
    - Uncovered pan at a depth of 25 to 50 mm placed in a forced-draft oven with no stirring
  - Mix is then extracted, the binder recovered
  - The recovered binder is tested to determine ΔT_c
  - ΔT_c must be greater than or equal to -5.0°C, and the appropriate PG grade must be met

Assumptions

- Assumes "worse case" scenario (from a binder perspective)
  - If blending is less than complete, the impact of the aged binder on stiffening and relaxation is less than the laboratory would predict
  - If blending is completely homogeneous, the impact on stiffening and relaxation would be accounted for.

Advantages and Drawbacks

Advantages

- Simple approach … easy for states to make an informed decision on setting RAS limits based on available virgin binders and existing RAS materials.
- Quantified relationship to actual field cracking performance

Drawbacks

- Doesn't address all mixture or binder design issues if the RAS binder does not become fully blended
  - Binder volume would be less than calculated
  - Could have a mix with better <u>quality</u> binder but not enough of it
- Standard PAV conditioning not effective to identify poor ageing characteristics

Summary

- Revised Draft PP 78 *Standard Practice for Design Considerations When Using RAS in Asphalt Mixtures*
- Increased minimum VMA to address issue of binder quantity to help prevent low asphalt content and durability issues
- Used ΔT_c to address binder quality
  - Recovered binder is PAV aged for 40 hours
  - Criteria: $\Delta T_c \geq -5.0°C$
- Added loose mix aging (135°C for 24 hours) as an alternate in the appendix
  - Criteria: $\Delta T_c \geq -5.0°C$

Multiple Stress Creep Recovery (MSCR)

FHWA is working with the Asphalt Institute to assist States to effectively understand and implement MSCR.

- Technical Brief FHWA-HIF-11-038
  - www.fhwa.dot.gov/pavement/asphalt/index.cfm
- Resources posted on AI's website
  - www.asphaltinstitute.org/public/engineering/mscr-information.dot

Multi Stress Creep & Recovery (MSCR)

- Targeted interaction by FHWA and Institute engineers to gather information and document issues identified as hurdles to MSCR understanding, use, and implementation nationwide.
- Understand issues and provide solutions.
- Need your feedback!!

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MSCR – Note on Negative Recovery

"In some cases when the J_{nr} value is close to 4.5 a negative percent recovery may occur. With some rheometers when the load is cut off at the end of the creep cycle inertia of the movable plate causes it to continue to rotate and load the specimen. When the binder is Newtonian and has little to no recovery this can appear as a negative percent recovery. In these cases the strain at the end of the 1 second creep load shall be used to calculate the J_{nr} compliance value. The percent recovery shall be recorded as zero."

MSCR – $J_{nr\ diff}$ for “E” traffic

Remove the J_{nrdiff} max 75% for Extremely Heavy Traffic “E” grades with $J_{nr3.2} \leq 0.5$ kPa^{-1} due to very low non-recoverable creep compliance values for both $J_{nr3.2}$ and $J_{nr0.1}$ when “E” binders are evaluated at the specified environmental PG temperature (i.e. not the grade bumped temperature).

MSCR – Draft Stand Alone Recovery Standard Practice

- FHWA Binder ETG developed draft *"Practice for Evaluating the Elastic Behavior of Asphalt Binders Using the MSCR Test"*
- MSCR Recovery Practice submitted to AASHTO Subcommittee on Materials
- Technical Section 2b Task Force reviewing draft standard for action.

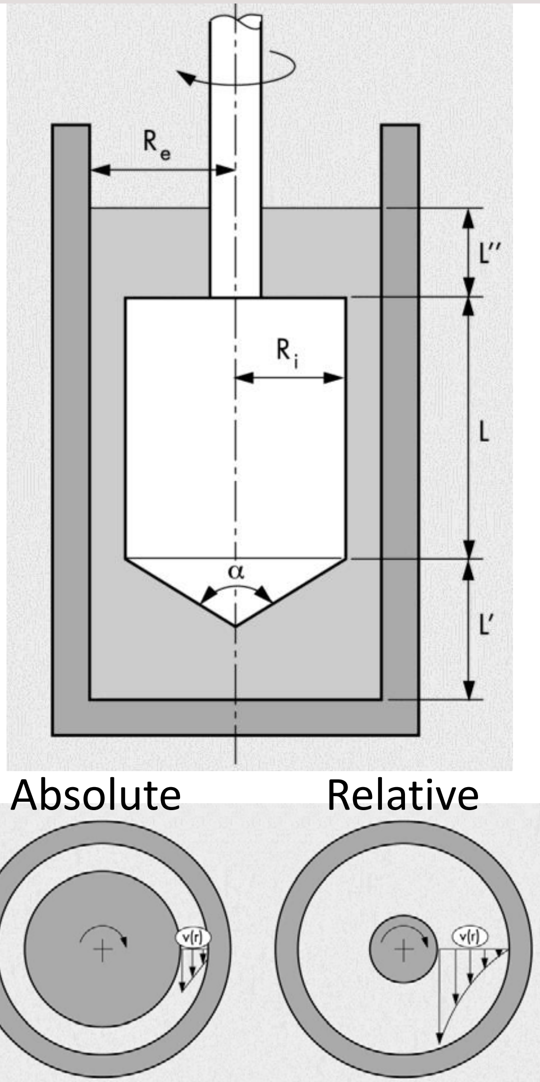
Ground Tire Rubber

Performance Grading

- Extensive development work conducted by Anton Paar on GTR modified binder with CC geometry
  - Reveal the practical and rheological challenges
  - Suggestion of a suitable measuring geometry for PG measurements of GTR modified Asphalt Binder
  - Finalized tool dimensions and requirements
- DSR Concentric Cylinder (CC) geometry … also known as Cup & Bob geometry
  - "required to enable good rheology!" … "Gap size matters!"

Small cylinder inside a big cylinder enables the use of large gaps

Courtesy of Anton Paar



CC17SP
Gap ≈ 6.2 mm
Suitable for neat and RTFO asphalt binder
(high PG temperatures)

CC10SP
Gap ≈ 9.5 mm
Suitable for PAV asphalt binder (intermediate PG temperatures)

Advantages and Drawbacks

Advantages

- Large gaps possible!
- Sample cannot flow off the shear gap
- No sagging / leak of binder issues
- No specimen trimming/sample geometry issues
- Representative sample volume
- No edge effects
- Disposable cups can be used

Drawbacks

- Increased sample volume

-Slower heating and cooling rates

-Higher temperature equilibrium time required

- Relative measuring geometry

-Calibration with Cannon N2700000 viscosity standard

Ground Tire Rubber

Ongoing work:

- Need to address RTFO and PAV conditioning challenges with increasing GTR %.
- Need to address BBR and DTT specimen fabrication and testing challenges with increasing GTR %

Ground Tire Rubber

Ongoing work:

- increasing emphasis on use of hybrid asphalt rubber systems
  - use of smaller/finer GTR grind size
  - use of lower percentage of GTR in combination with lower percentage of traditional polymers
- Triple Bottom Line Approach to Hybrid Binders and Dense Graded Asphalt Mixtures
  - three Ps: profit, people, and planet

Re-refined Engine Oil Bottoms (REOB)

New REOB Task Force within ETG

Discussions:

- Which rheological parameter
  - critical temperature change (ΔT_c)
  - Glover-Rowe (GR)
  - rheological index (R value)
  - cross over frequency (ω_c)

All of these parameters can be interrelated from understanding the relationship between loading time (or frequency) and temperature.

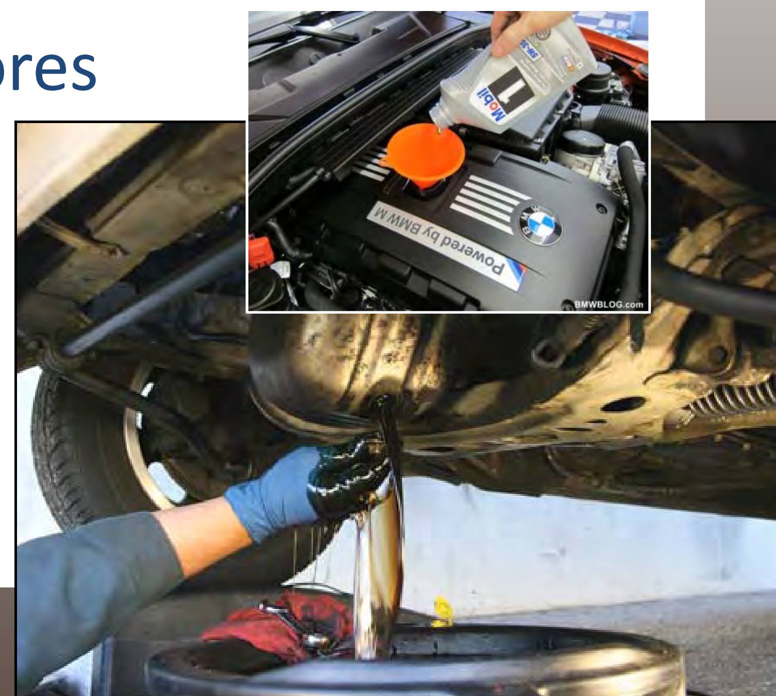
What is REOB?

- The re-refined residual distillation product from a vacuum tower in a re-refinery dedicated to processing recovered waste drain lubricating oil

Both “re-refined” and “vacuum tower” are important features for this product

Recovered Waste Drain Oil

- Example: used engine drain oil from
  - automobile and truck dealerships
  - instant oil change establishments
  - automotive parts stores
  - local and regional oil recycling centers



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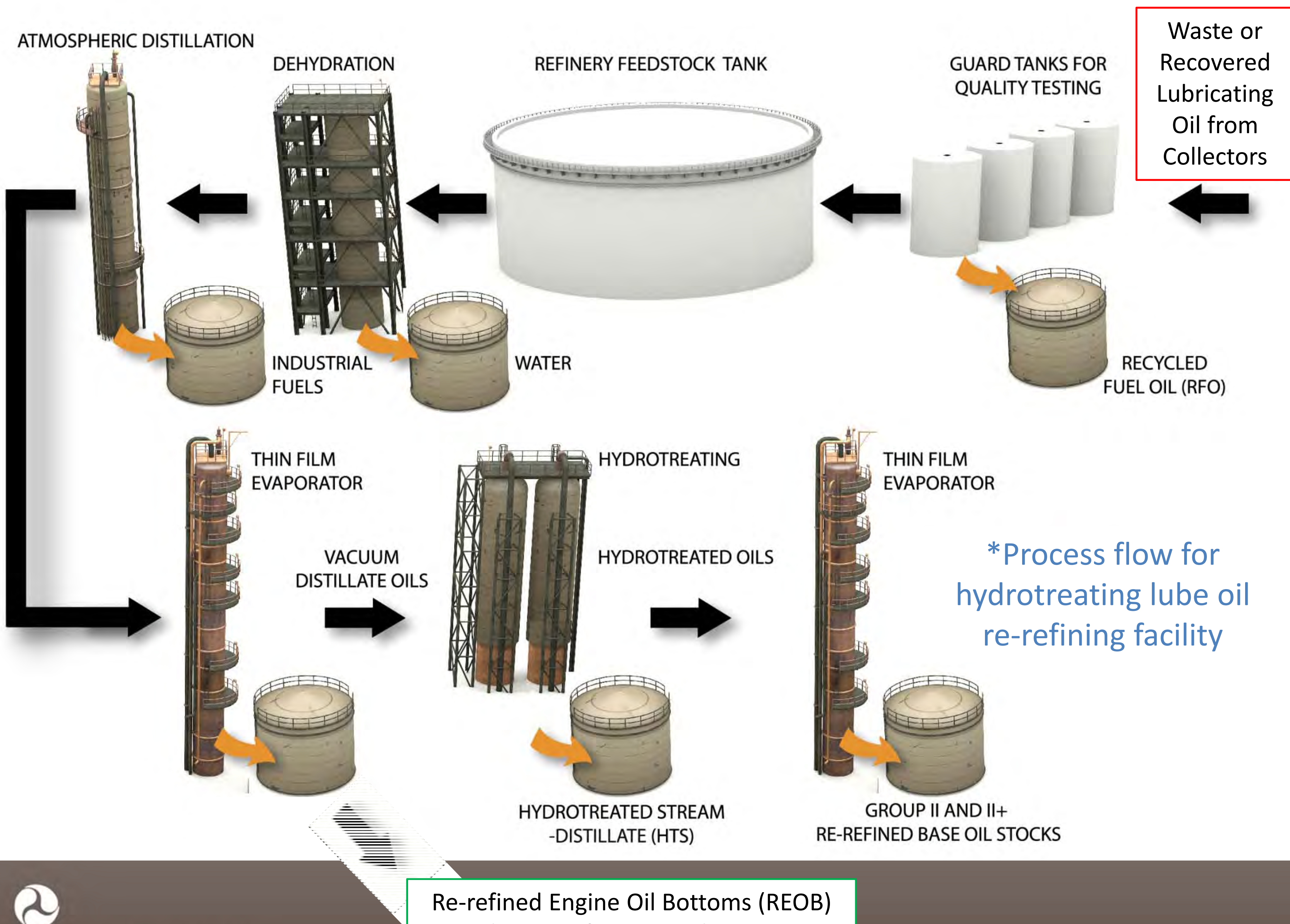
Recovered Waste Oil Collection

- the used oil is picked up by collection companies (collectors) and shipped to the waste oil refinery and re-refined into lubricant base oil for use again in automobiles and trucks



*Process flow for hydrotreating lube oil re-refining facility

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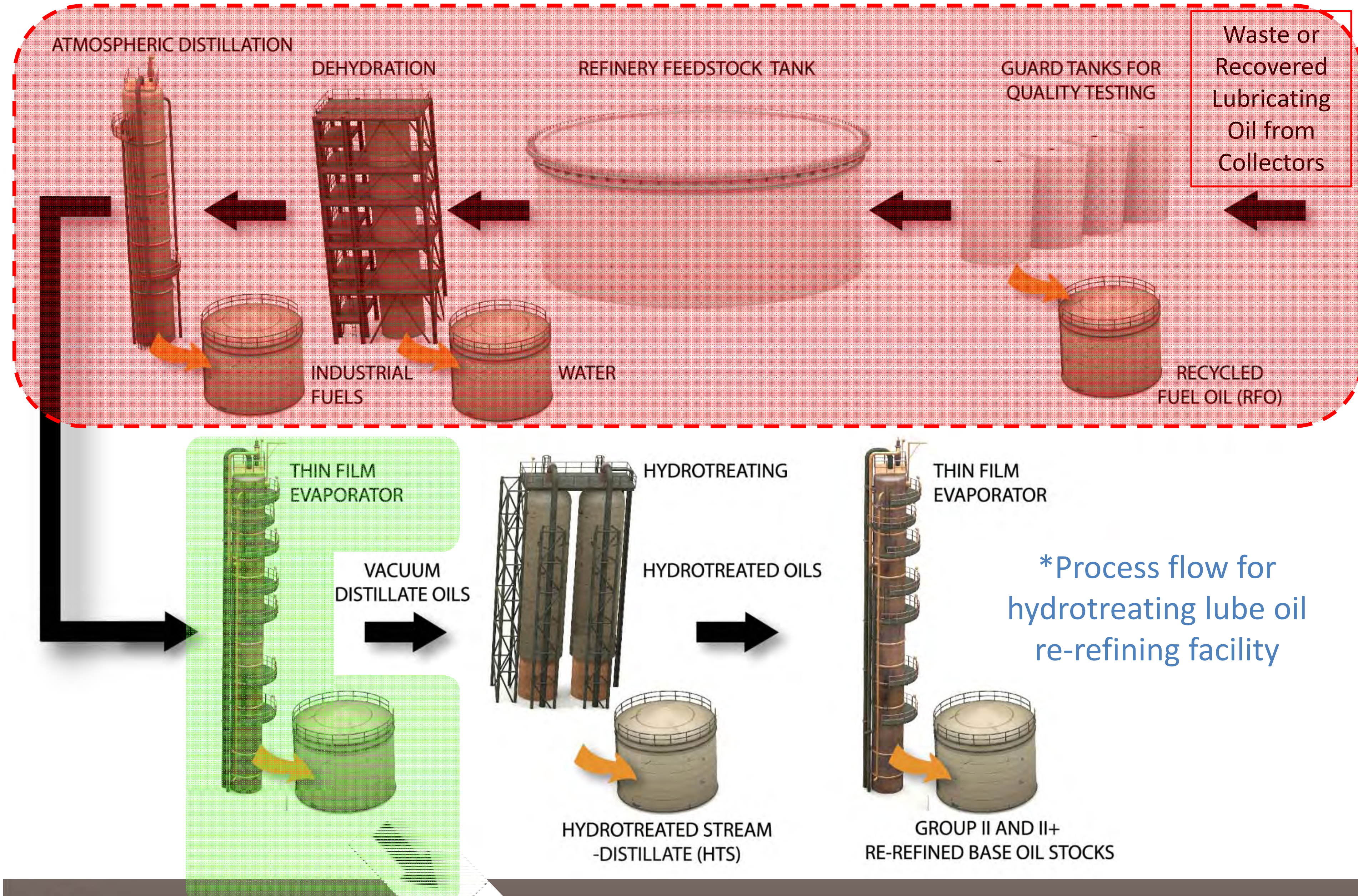
Federal Highway Administration

Basis credit:
Asphalt Institute, and
Kleen Performance Products

What is not REOB?

- NOT: residual from a crude oil refinery vacuum tower – it is NOT asphalt
- NOT: from only atmospheric distillation
- NOT: recovered *waste* oil
- NOT: cleaned/de-watered *waste* oil
- NOT: recycled *waste* oil
- NOT: recycled *fuel* oil

Both "re-refined" and "vacuum tower" are important features for this product



*Process flow for hydrotreating lube oil re-refining facility

Re-refined Engine Oil Bottoms (REOB)
aka: Re-refiners use the term
Vacuum Tower Asphalt Extender (VTAE)

U.S. Department of Transportation
Federal Highway Administration

Base Credit:
Asphalt Institute, and
Kleen Performance Products

What is REOB?

- The re-refined residual distillation product from a vacuum tower in a re-refinery dedicated to processing recovered waste drain lubricating oil
- It is not a "manufactured" product – i.e. REOB's properties are variable depending on the lube oil source(s) and the process(es) used to re-refine and control it's production

Why REOB?

- Used to soften base binder PG grade
- Increased use of RAP/RAS has led to a need for softer grades, which has led to increased demand for REOB or other "soft" fluxes
- Limited crude sources and refineries to produce "softer" grades w/o back blending
- Economic and market share pressures
- Recycling and "Green" initiatives

"Used since mid 1980's" … as reported by REOB re-refiners/suppliers

The Bitumen Industry – A Global Perspective

Production, chemistry, use, specification and occupational exposure

[Second Edition 2011]

"If used, re-refined engine oil bottoms are typically present at 5% to 10% by weight of the binder. ... In the past the main use for waste lubricating oils was as an industrial fuel. However, more recently economic incentives to re-refine waste drain oil to produce base oils have led to an increase in the volumes being re-refined. As a result there have been increased incentives to utilise these materials in bitumen. Little systematic research into the performance of pavements produced with REOB containing binders has been conducted."

The Bitumen Industry – A Global Perspective

Production, chemistry, use, specification and occupational exposure

[Third Edition 2015]

"These materials have been added to BITUMEN to change the low temperature properties and to enhance the oxidation of some bitumen roofing products. Numerous other terms have been employed by the producers and users of this type of additive. When used in paving the materials is added up to 10% to soften the BITUMEN for use with RAP or RAS or meet cold weather requirements. When used in OXIDISED ASPHALT it is added up to 6% as a paraffinic oil to increase penetration."

"see OIL (PETROLEUM) VACUUM DISTILLATION BOTTOMS, USED "

ETG meeting presentations

1. Asphalt Binder Modification with Re-refined Heavy Vacuum Distillate Oil - D'Angelo
2. Safety-Kleen Eco Addz (VDB's) – D'Angelo
3. REOB Background/Issues - M. Anderson
4. REOB FHWA Research on Mixture Effects - Gibson
5. REOB and other Additives Impact on Binder Aging and Mixture Low and Intermediate Properties – Reinke

ETG meeting presentations

6. REOB: RAS/RAP & Recycling Agent Considerations - Mohammad
7. REOB: AASHTO Task Force - Ahearn
8. REOB: Asphalt Institute Task Force - Buncher
9. REOB: Update on Olmsted County, MN comparative test sections & pavement distress survey - Reinke
10. REOB: University of Massachusetts Dartmouth - Mogawer

ETG meeting presentations

11. REOB: TFHRC Research - Gibson
12. REOB: Rutgers University - Bennert
13. REOB: Blended REOB Binder Advanced Chemical &Physical Characterization – Planche
14. REOB: AI's Task Force Update - Buncher
15. REOB: Evaluation and Performance - Reinke
16. REOB: TFHRC Research Update - Gibson

ETG meeting presentations

17. Asphalt Binder ΔT_c and S Value – Youtcheff
18. RAP/RAS Task Force Summary & ΔT_c recommendations - Musselman
19. REOB: Effect of REOB on the Performance of Asphalt Mixtures Containing RAS – Mohammad
20. Binder ETG - REOB Task Force – Rowe
21. Update Binder ETG – REOB Task Force – Rowe
22. Evolution and Use of the ΔT_c Parameter - Rowe

How do I know if its REOB?

- There is not an asphalt test that can definitively differentiate re-refined versus non re-refined products
- Supplier or producer certification of vacuum tower distillation may be the best way to ensure the material is vacuum tower derived

REOB CAS# 129893-17-0 from MSDS

- Typically encountered to designate REOB with description: *Lubricating oils, used, residues*.
- REOB is only one of many products that may fall under this CAS# designation.
- Re-refined vacuum tower distillation products are also typically designated with this same CAS#

REOB CAS# 129893-17-0 from MSDS

- Other products which are not re-refined using vacuum tower distillation may be designated with this same CAS#
- The CAS# designation does not assure the product is re-refined using vacuum tower distillation processes.
- Supplier or producer certification may be the best way to ensure the product is re-refined using vacuum tower distillation.

REOB Detection using XRF

- Detection of trace elements by X-Ray Flourescence (XRF) Spectroscopy
  - Phosphorous
  - Sulfur
  - Calcium
  - Iron
  - Copper
  - Zinc
  - Molybdenum

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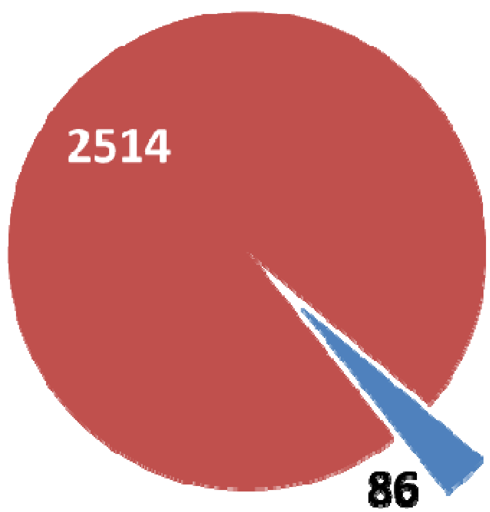
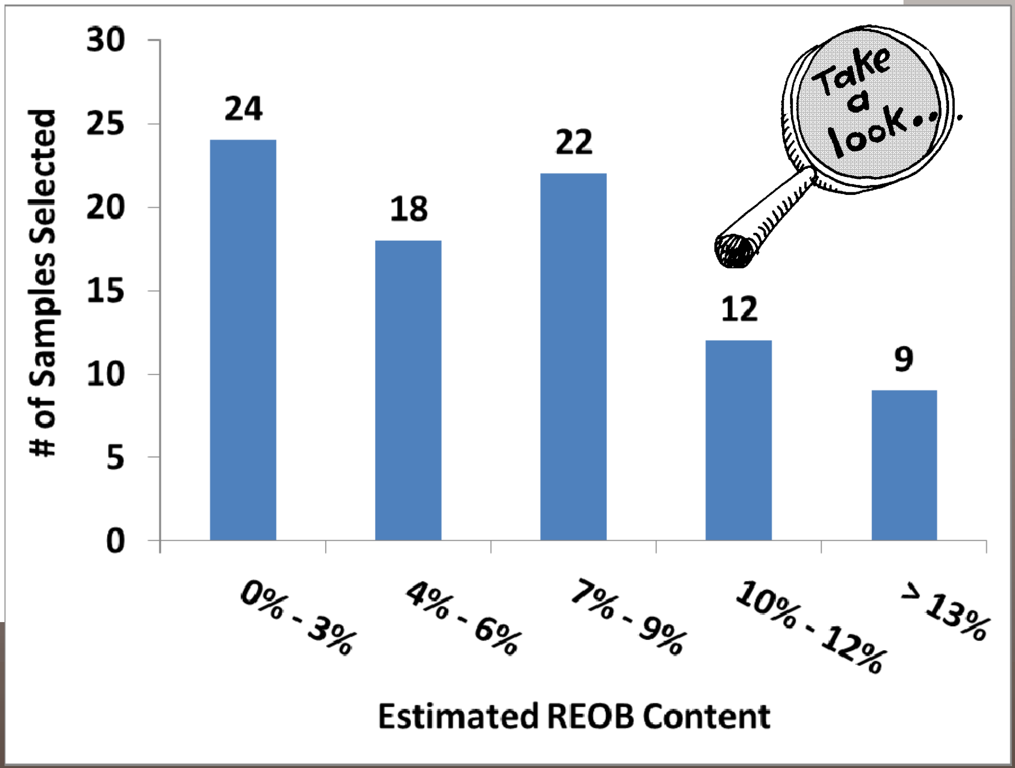
no standard guidance on how to perform these tests to quantify REOB

REOB Detection using XRF

- FHWA has tested 2,600 XRF samples
  - Select ~3% of the data set for further study…





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REOB Detection – other approaches

- Proton Nuclear Magnetic Resonance (^1H NMR) spectroscopy
  - REOB/VTAE contains much less aromatic protons and is mostly saturate alkanes (aliphatics); some of which are very different from those found in asphalt.
- Inductively Coupled Plasma (ICP) techniques

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Federal Highway Administration

no standard guidance on how to perform these tests to quantify REOB

Impact?

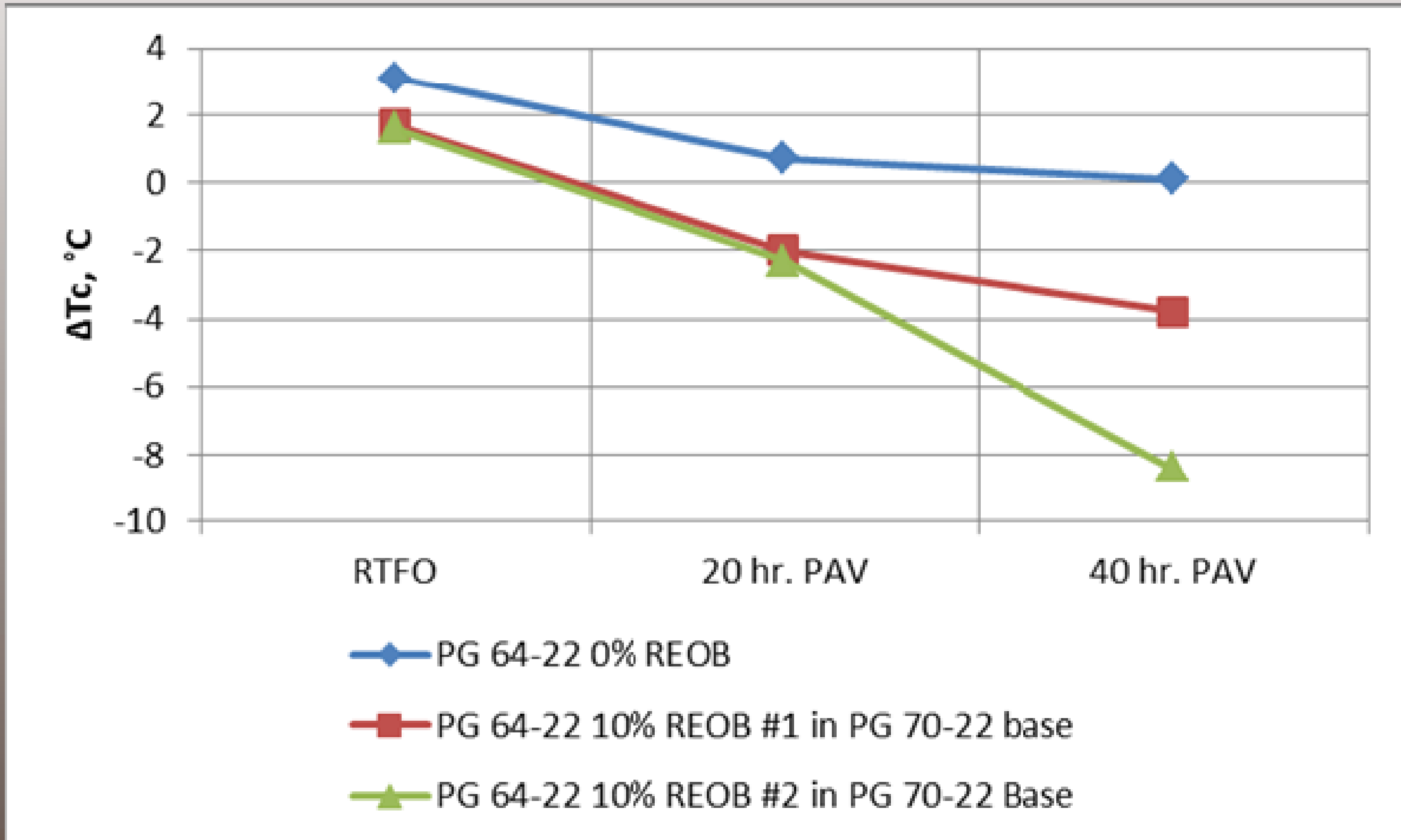
- Various REOB products may behave differently
  – properties can vary
- Impact on final properties is dependent on *both* the REOB and the base binder
  – interaction with base asphalt binder
- Irresponsible use and increasingly higher dosage rates have detrimental impact
- Limited field project data linked to accelerated pavement ageing and cracking distress

ETG REOB Task Force

ETG Consensus Items

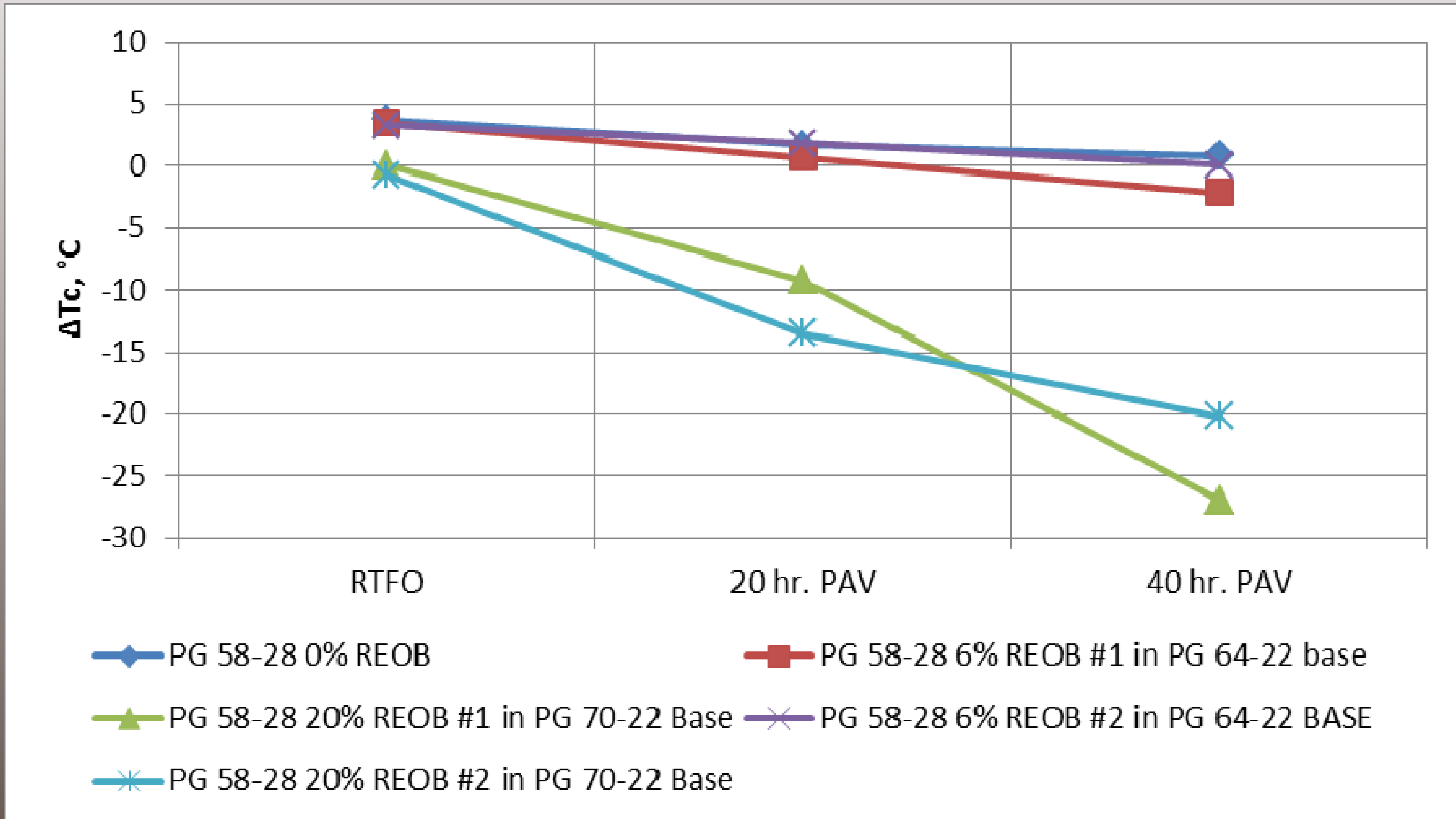
- Concerns exists from the agency/DOT perspective on the durability of asphalt pavements
- ΔT_c could be used to track performance and is readily available in the existing data
- The amount of REOB generally affects the ΔT_c but not all materials are created equal
- High RAS and RAP/RAS binder replacement can result in more negative values of ΔT_c
- PAV conditioning requirements

Critical Temperature Difference (ΔT_c)



Credit: Tom Bennert, Rutgers University

Critical Temperature Difference (ΔT_c)



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Credit: Tom Bennert, Rutgers University

Field Studies

- FHWA/Asphalt Research Consortium/WRI Validation Sites
  - Rochester, MN - Olmsted County 112
- MnROAD Test Track Low Volume Road Test Section Sites

FHWA/Asphalt Research Consortium/WRI Validation Sites

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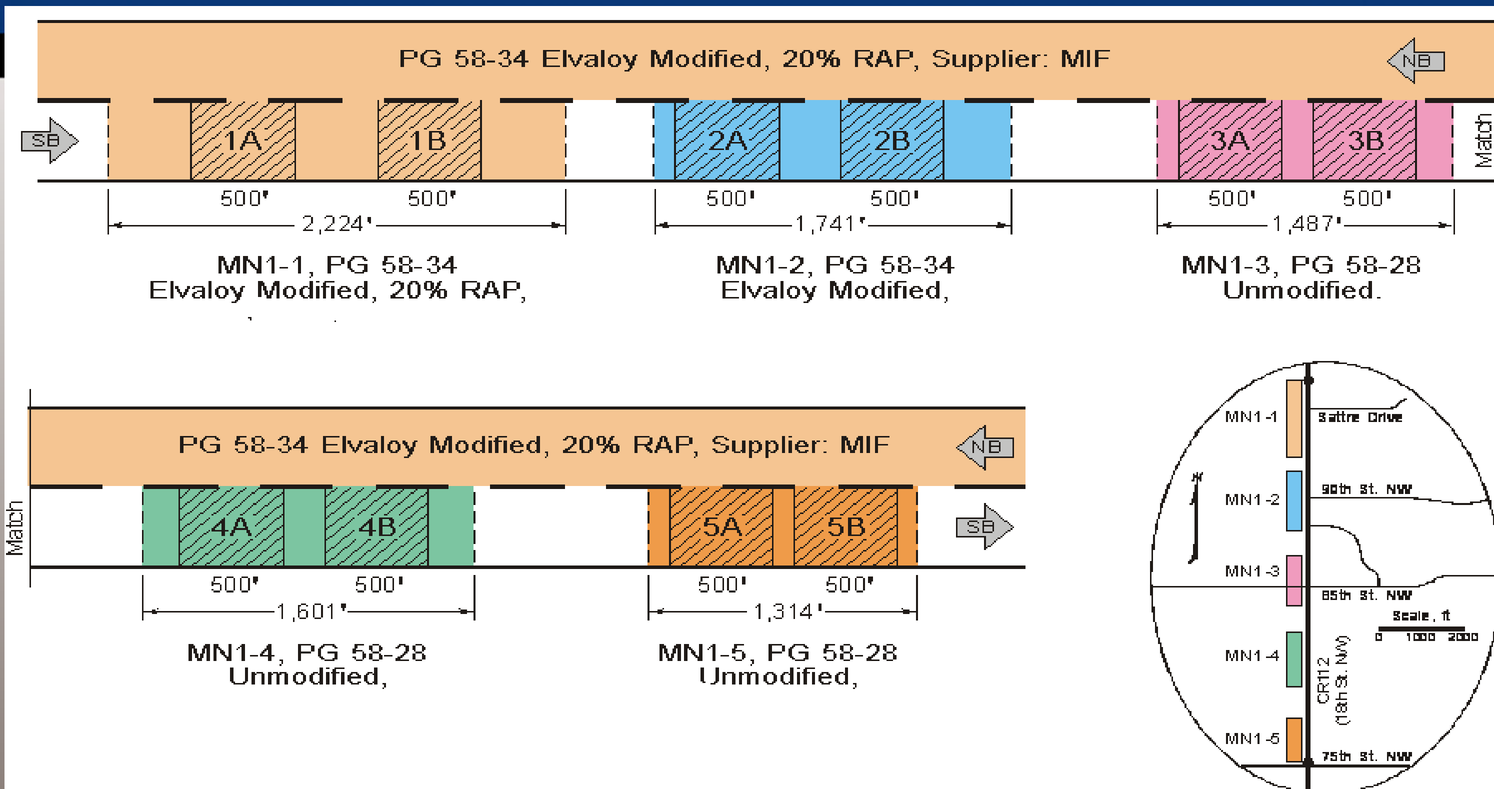
Credit: Western Research Institute (WRI) via Asphalt Research Consortium

Rochester, MN test site – Olmsted County

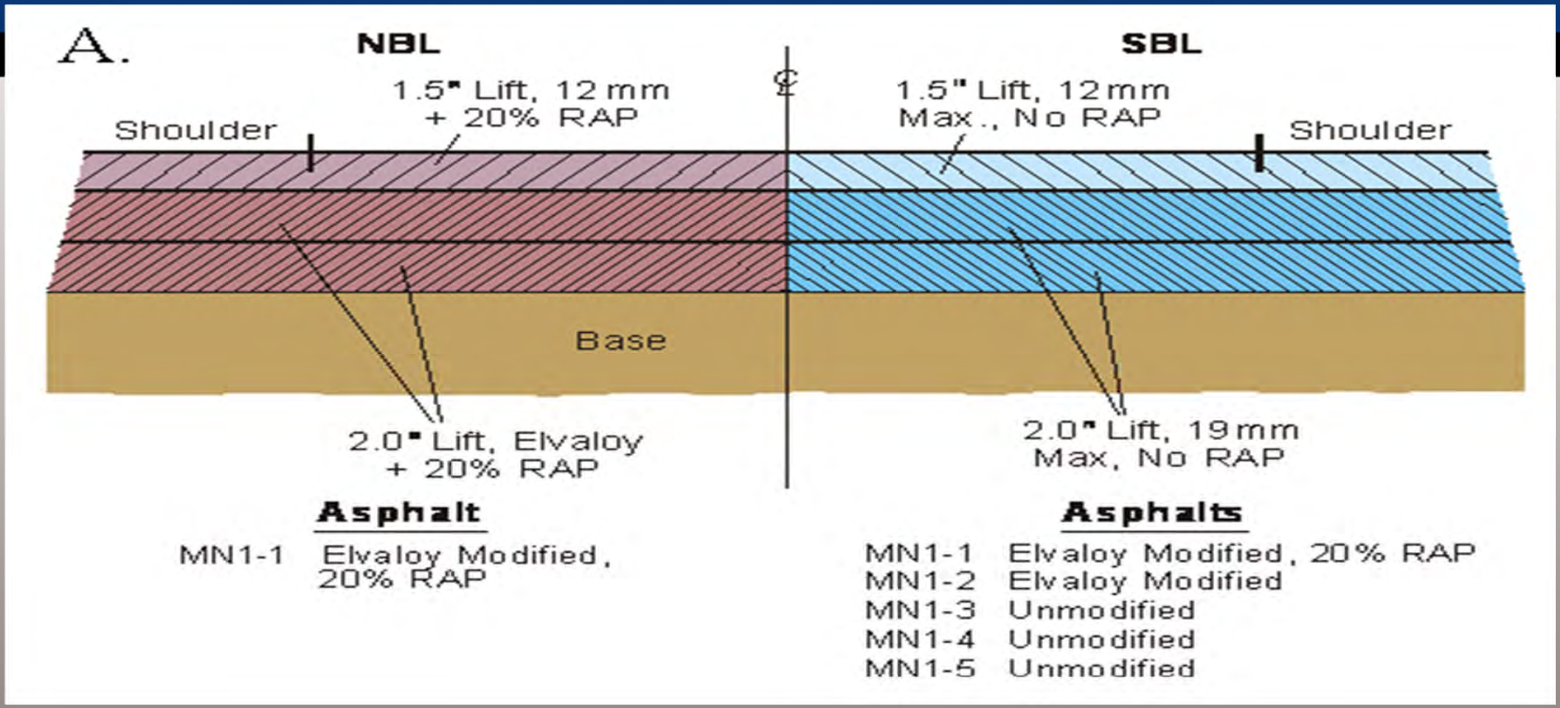


Built 2006

Sample Designation	Performance Grade Project specifications	Source Description
MN1-2	PG 58-34	Canadian blend, Elvaloy modified
MN1-3	PG 58-28	Canadian blend
MN1-4	PG 58-28	Middle East Blend
MN1-5	PG 58-28	Venezuelan blend

Credit: Western Research Institute (WRI) via Asphalt Research Consortium

Rochester, MN test site – Olmsted County

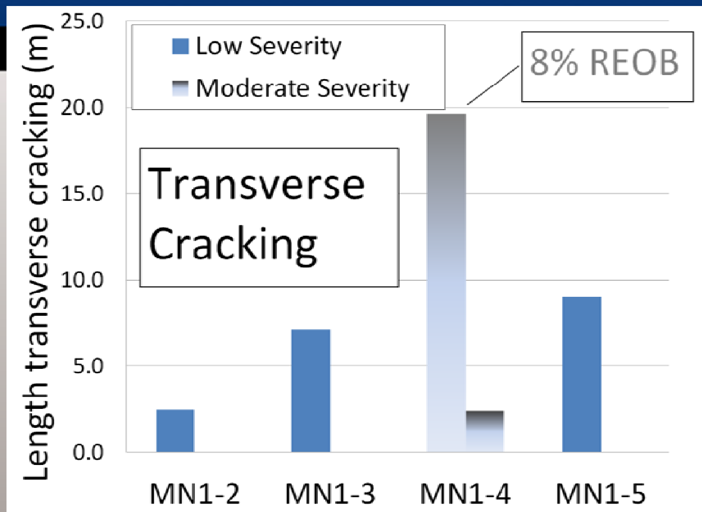


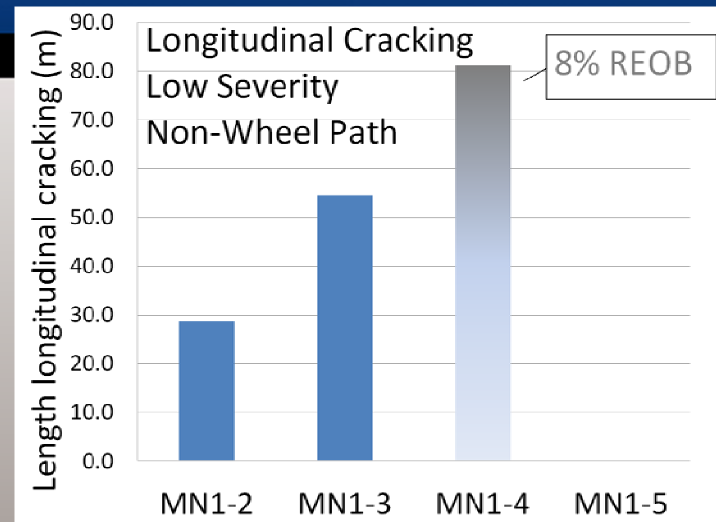
- **XRF analysis & REOB estimate**
  - **MN1-4 tank asphalt binder metal content (ppm)**
    - Ca 618.1, Cu 36.6, Fe 88, Zn 359.4, Mo 50.5 (V 350, Ni 72)
  - **MN1-1, 1-2, 1-3, 1-5 average metal content (ppm)**
    - Ca 0, Cu 0, Fe 27, Zn 6.6, Mo 2 (V 390, Ni 83)

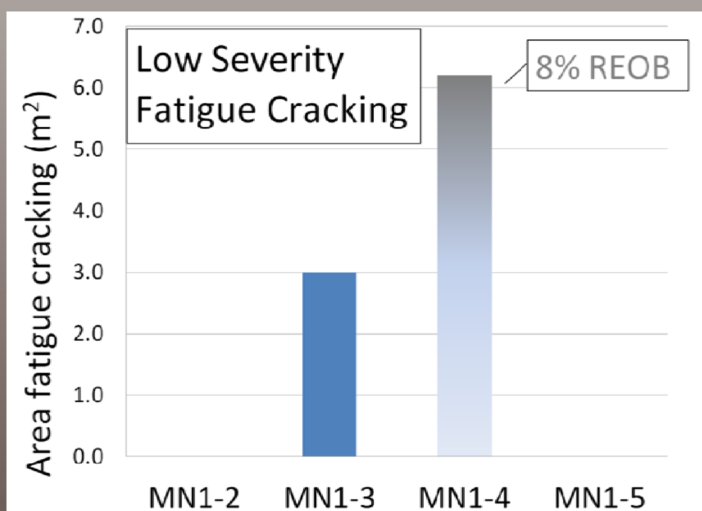
➢ **REOB found in MN1-4 … estimated at about 8% content**

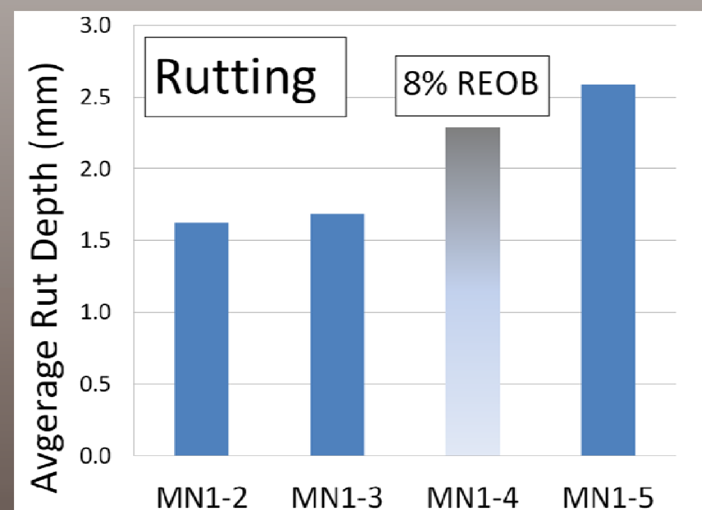
Credit: Western Research Institute (WRI) via Asphalt Research Consortium

Rochester, MN – 2012 Distress Data



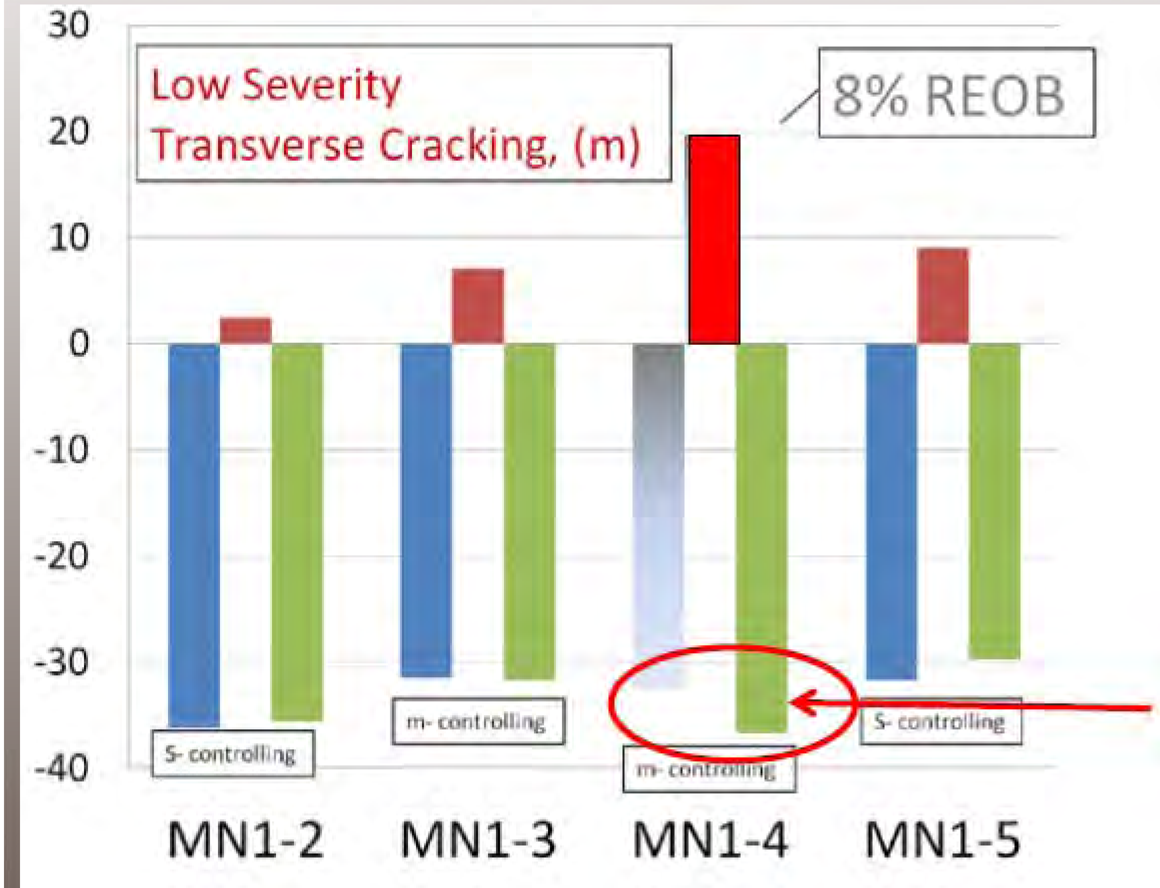






Credit: Western Research Institute (WRI) via Asphalt Research Consortium

Rochester, MN – BBR vs cracking



Credit: Western Research Institute (WRI) via Asphalt Research Consortium

- BBR limited T grading did not predict the cracking issue on the MN1-4 section
- But the BBR T_c is significantly m-value controlled $\Delta T_c < -5°C$
- Agreement with others

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Rochester, MN test site – Olmsted County

- Field performance – limited data
  - Potential cracking issue in cold climate (MN), both thermal and fatigue, in comparison with other similar PG asphalt w/o REOB
  - Could be captured through binder evaluation after appropriate aging
- REOB identification techniques:
  - XRF are promising possibilities

Follow-up work on Olmsted County

- New distress survey conducted in October 2014
- Samples of original project binders were laboratory conditioned for both 20 hour and 40 hour pressure ageing vessel (PAV) to simulate long term field ageing

Follow-up work on Olmsted County

- Retained original project construction mixtures from WRI were oven conditioned loose for both 12 and 24 hours
- Binders were recovered from aged mix and tested

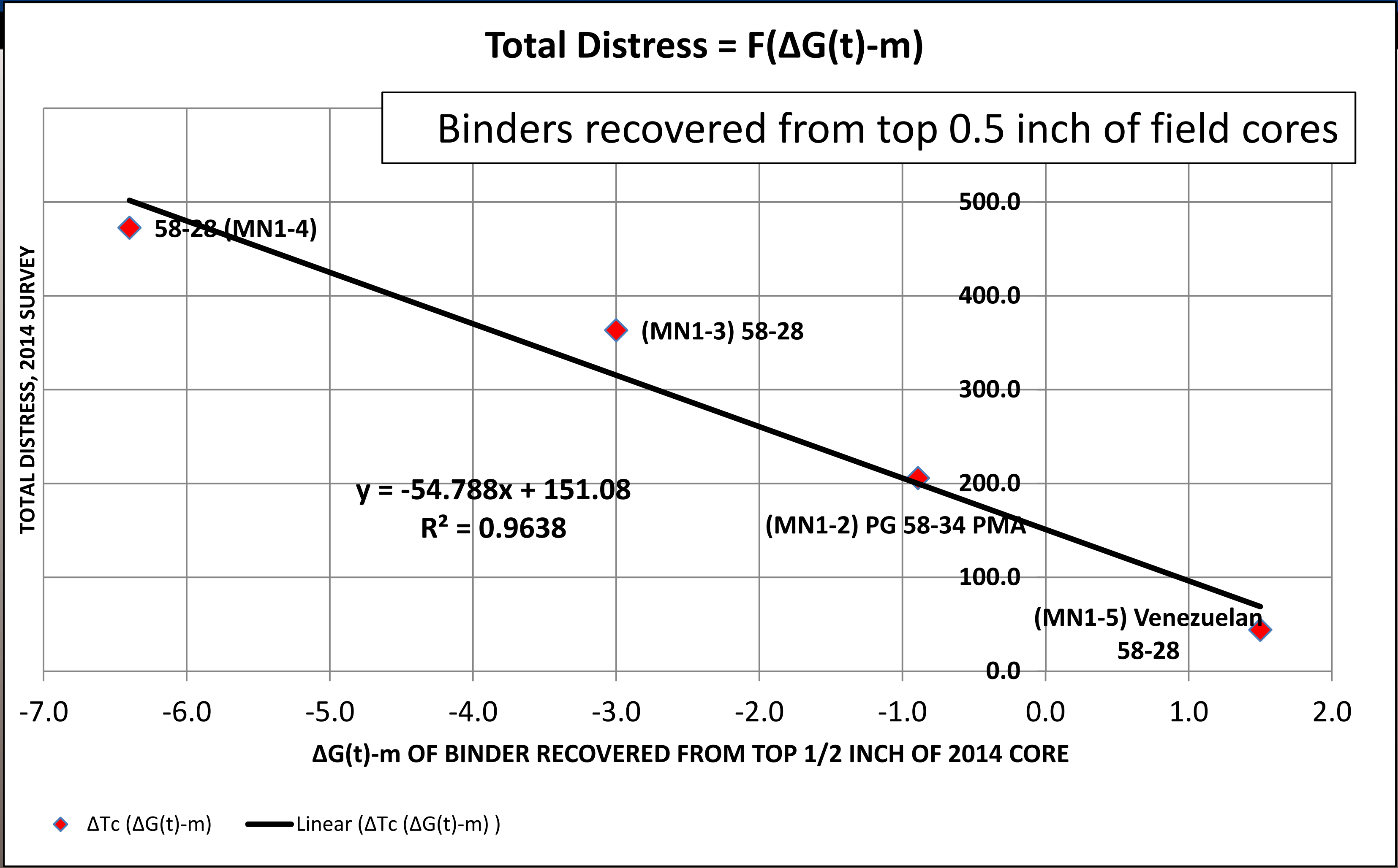
Olmsted Co. updated distress data - 2014

Olmsted Co. 112	Transverse (m)	Fatigue (m^2)	Longitudinal (m)	Centerline (m)	total_distress
MN 1-2 PMA 58-34	13.5	0	113.6	78.8	205.9
MN 1-3 Canadian blend 58-28	19.5	18.8	251.8	73.3	363.4
MN 1-4 Kirkuk blend w/ REOB 58-28	51.2	39.2	300.0	82.2	472.6
MN 1-5 Venezuelan 58-28	19.5	0	12.3	12.3	44.1

Recall the (MN1-4) Kirkuk PG 58-28 is the one that contain the REOB additive

The (MN1-2) 58-34 PMA binder was produced using Elvaloy and PPA from a PG 52-34 which came from a blend of Canadian crudes, similar to the (MN1-3) PG 58-28

Olmsted Co. updated distress data – 2014
Total distress is correlated to ΔT_c



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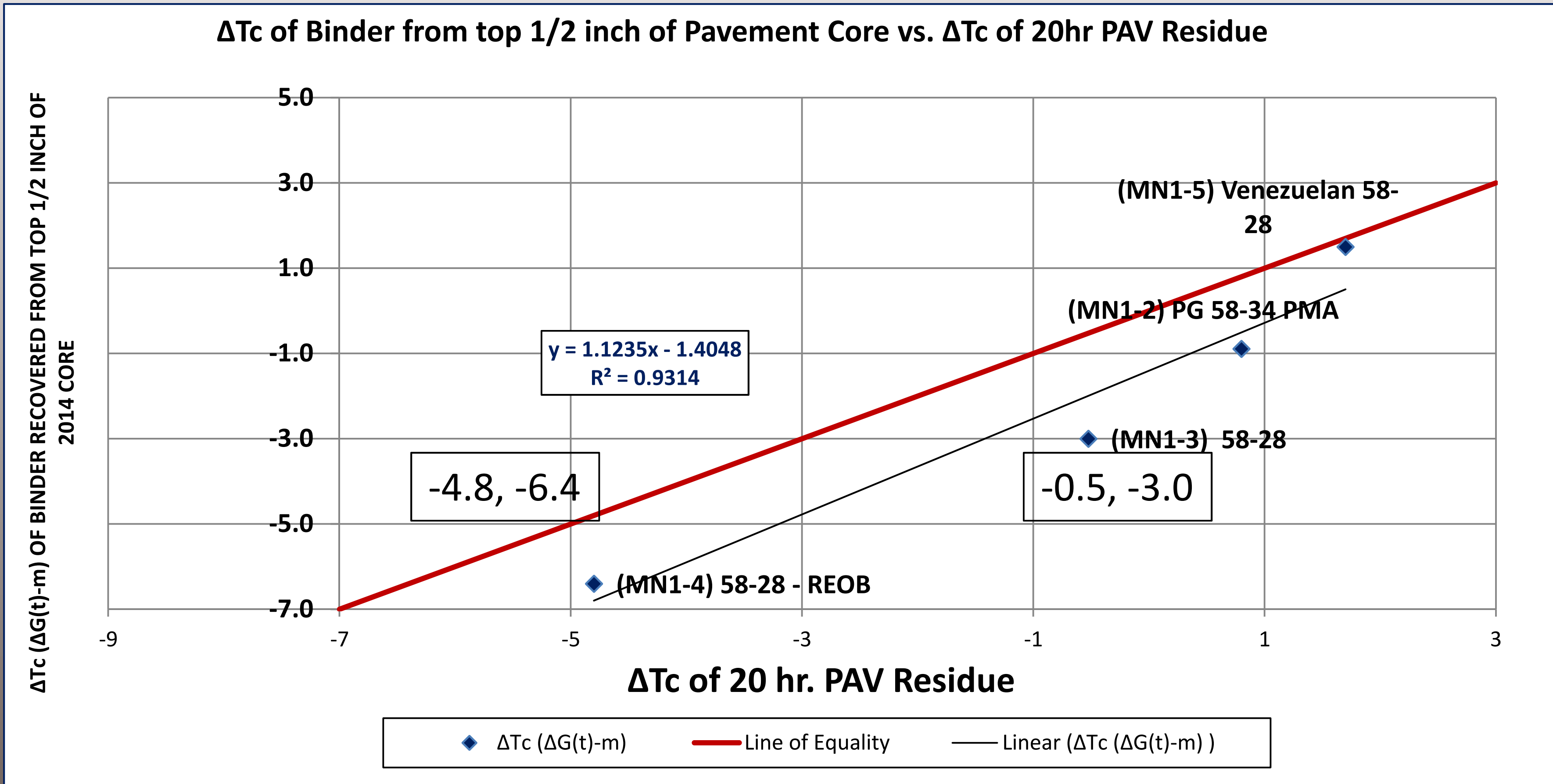
MTE
Mathy Technology & Engineering

ΔT_c of the 20 hr PAV residue under predicts the field binder recovered from cores



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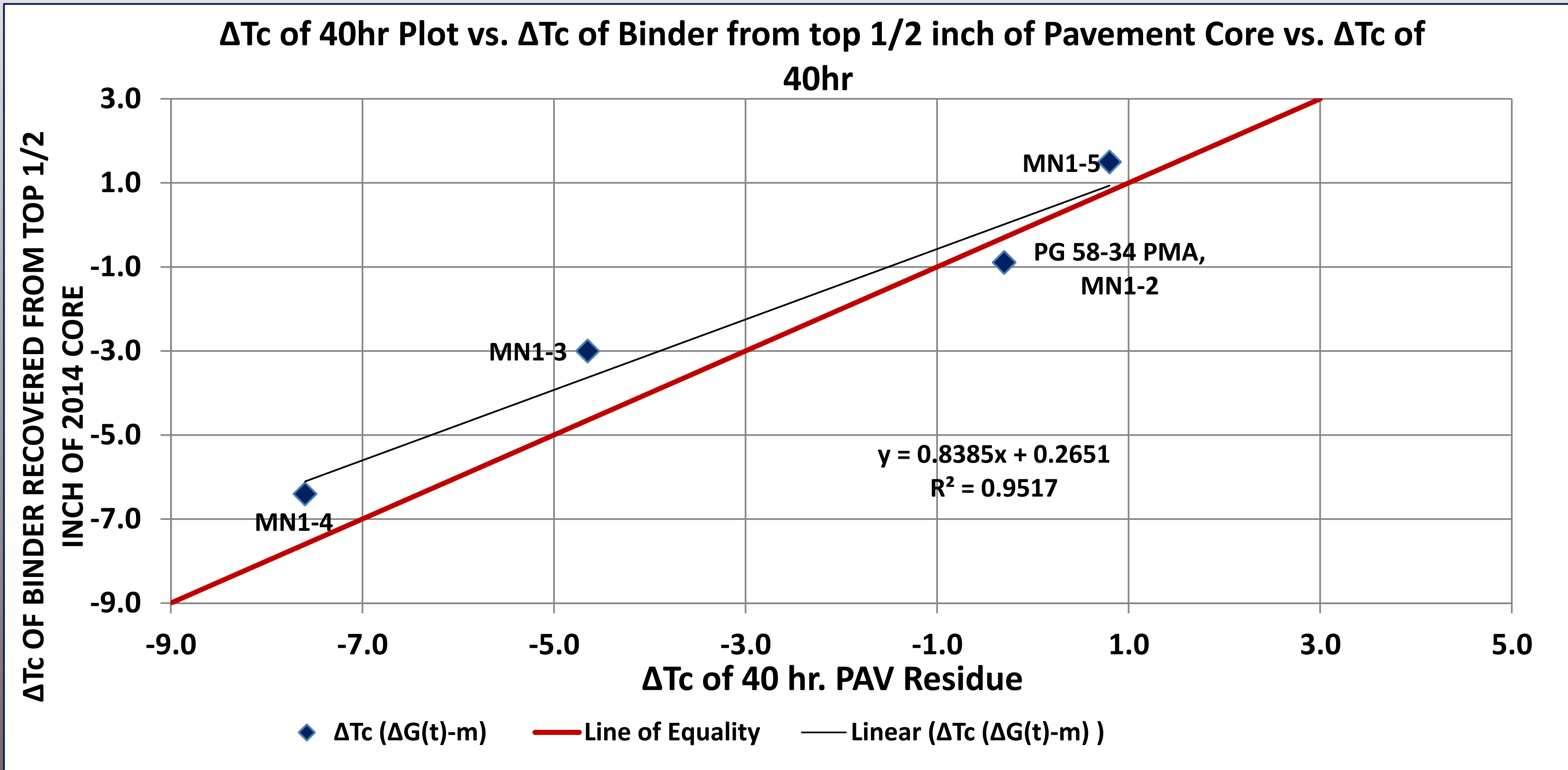
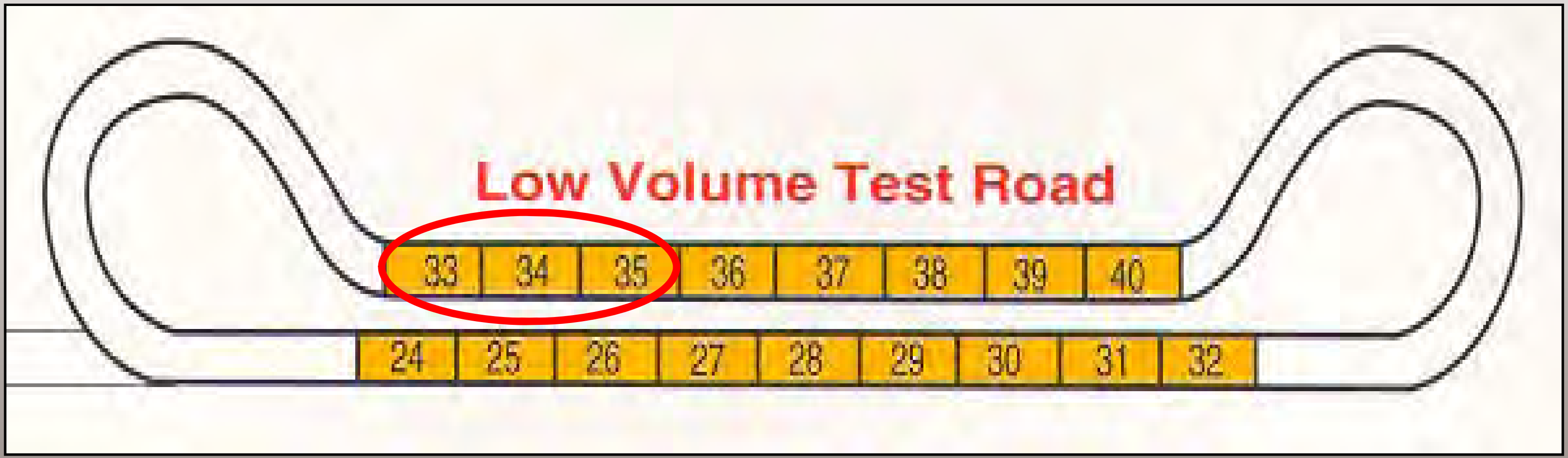
MTE
Mathy Technology & Engineering

ΔT_c of the 40 hr PAV residue more closely predicts the binder recovered from cores




MnROAD
Office of Materials and Road Research

MnROAD Low Volume Road



1999 SuperPave Cells

Cell 33 – PG 58-28

Cell 34 – PG 58-34

Cell 35 – PG 58-40

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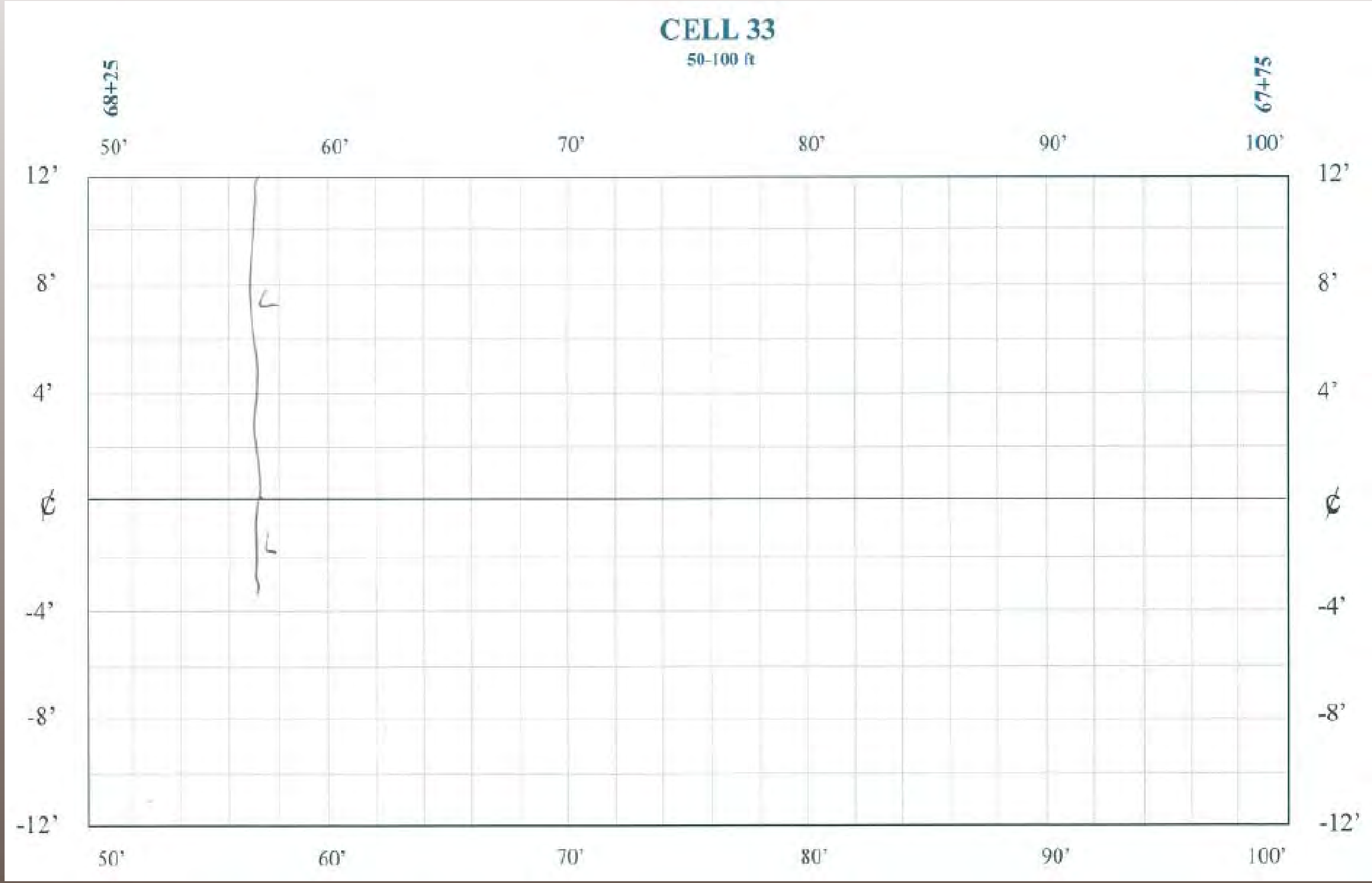
MnROAD Test Track Sections

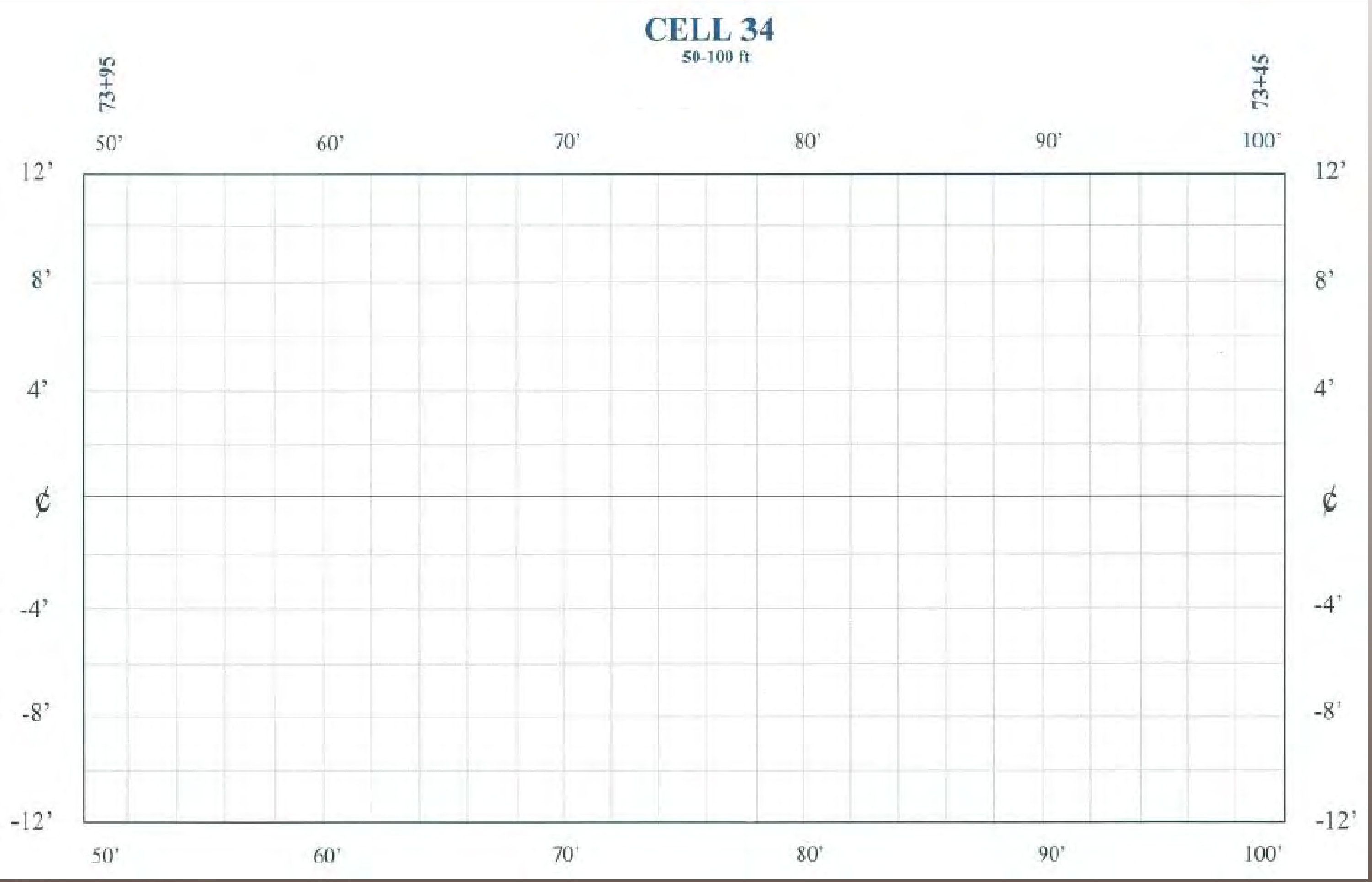
- Constructed in Sept 1999
- same mixtures with three (3) different binders
  - PG 58-28
  - PG 58-34
  - PG 58-40 (created with REOB) [Cell 35]
- Traffic until April 2007
- Annual distress surveys conducted

Cell 33 Crack Maps [.pdf]

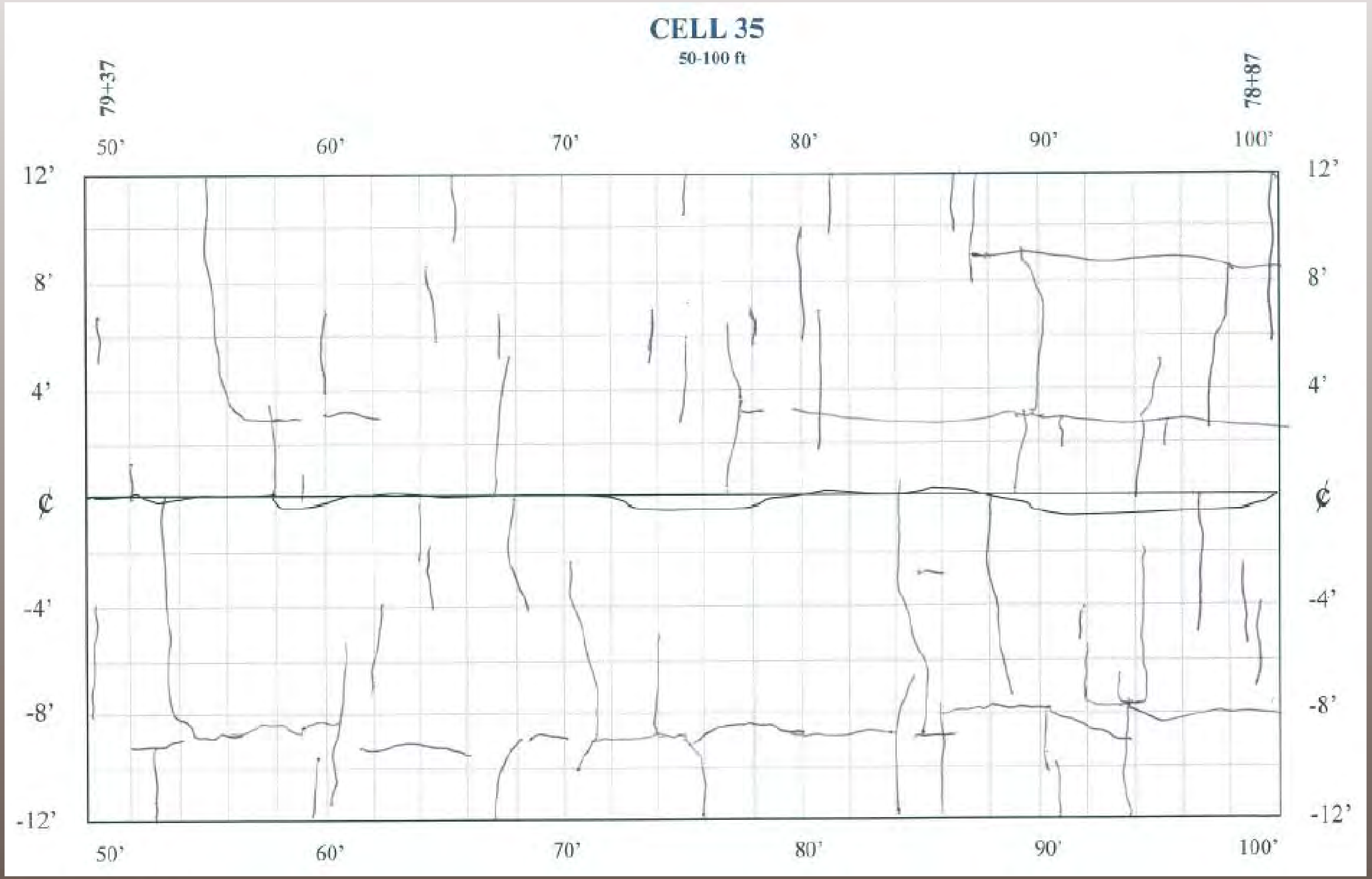


Credit: MnROAD

Cell 34 Crack Maps [.pdf]



Cell 35 Crack Maps [.pdf]

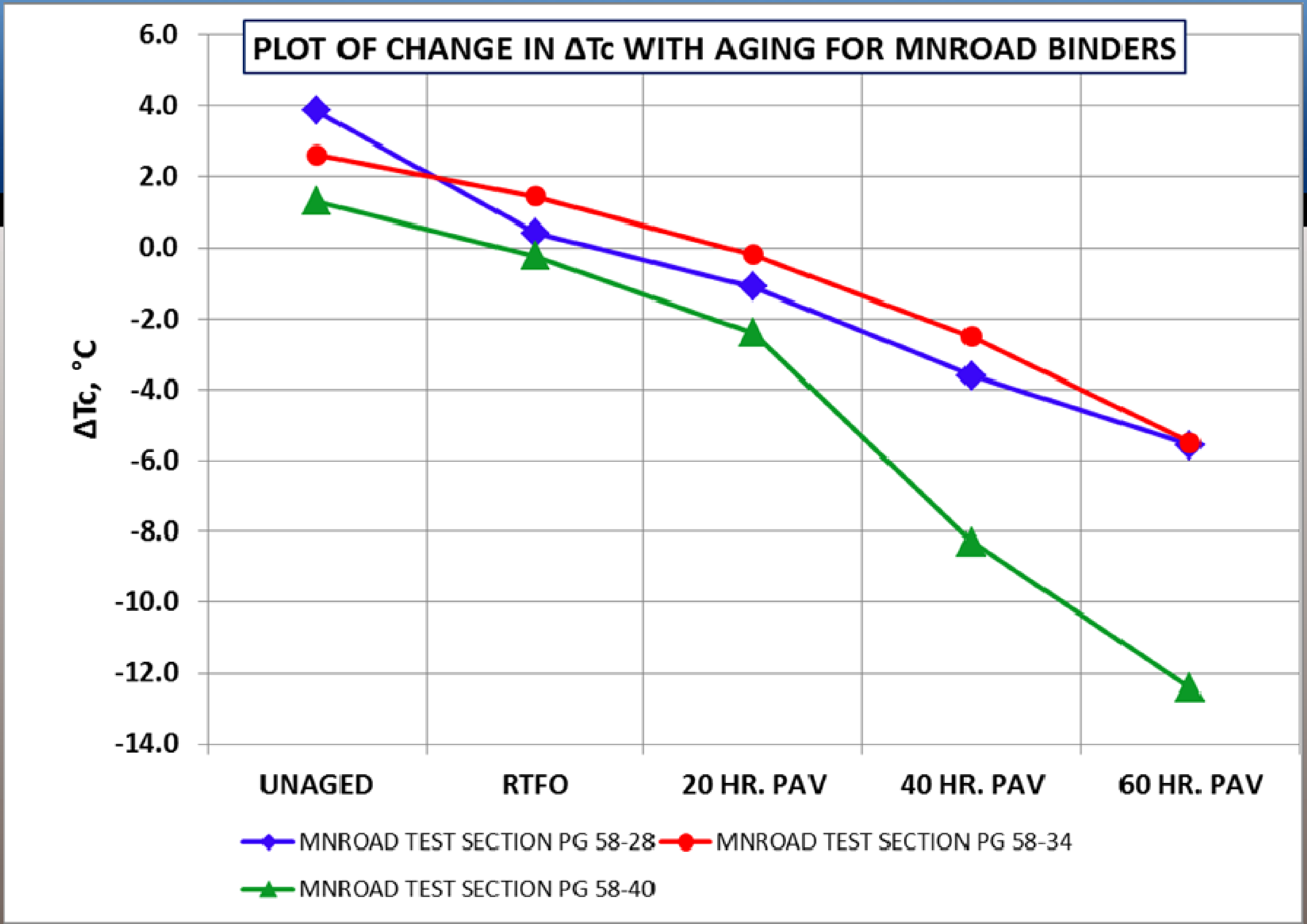


Credit: MnROAD

Binder grade	Data from 20 hr. PAV tests performed in 2000			20 hr. PAV	20 hr. PAV	20 hr. PAV
	S critical from BBR	m critical from BBR	ΔTc (S grade - m grade)	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔTc (S grade - m grade)
58-28	-30.9	-30.3	-0.6	-31.3	-30.5	-0.8
58-34	-34.8	-35.98	1.2	-35.6	-35.4	-0.2
58-40	-44.3	-42.9	-1.4	-44.4	-42.0	-2.4

Binder grade	40 hr. PAV	40 hr. PAV	40 hr. PAV	60 hr. PAV	60 hr. PAV	60 hr. PAV
	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔTc (S grade - m grade)	S_critical from 4 mm DSR	m_critical_temp from 4 mm DSR	ΔTc (S grade - m grade)
58-28	-29.5	-26.7	-2.8	-28.5	-22.7	-5.8
58-34	-34.9	-32.4	-2.5	-33.1	-27.6	-5.5
58-40	-42.9	-34.6	-8.3	-42.9	-30.5	-12.4

Binder grade	sulfur, %	phosphorus, %	molybdenum, ppm	zinc, ppm
58-28	4.896	0.001	9	19
58-34	4.374	0.001	8	10
58-40	3.969	0.059	18	925



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MTE Mathy Technology & Engineering

Asphalt Institute REOB Task Group

- Included AI Staff, Member's, and FHWA
- Most current State of REOB Knowledge thru end of December 2015
- Will become AI's official guidance and position on REOB
- Publishing Goal: May/June 2016
  - Electronic Format with free download
  - ~ 100 pages & literature review

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REOB State of the Knowledge Document

1. Introduction
2. Production of REOB/VTAE
3. Literature Review of REOB Performance
4. H.S. & E. Considerations
5. Discussion of Alternative Tests, Parameters and Aging Protocols and Their Applicability to Performance
6. Frequently Asked Questions (FAQ)

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Takeaways

- low dosage rates may be innocuous
  - up to approximately 3%
- high dosage rates appear detrimental
  - approximately 10% and greater
- middle dosage rates ???
  - dependent on REOB and base binder
  - need to evaluate properties
  - need to evaluate with longer laboratory conditioning (ageing) and <u>use 40 hour PAV</u>

Takeaways

- Asphalts w/ similar performance grades from different crude sources are impacted differently by a given amount & source of REOB
- When compared to neat asphalt binders of equivalent PG grade, asphalt binders modified w/ REOB typically exhibit higher rates of ageing, w/ small changes observed after RTFO & larger changes observed after 40 hours of PAV ageing.

Takeaways

- Test data correlated to field performance is based on long term aged (5+ years) field mixtures
- The binder recovered from field mixtures was better correlated to 40 hour PAV residue properties
- The rate of decrease in the value of ΔT_c as the binders are aged from 20 to 40 hours is informative
- A higher rate of decreasing ΔT_c values between 20 to 40 hours PAV ageing indicates potentially problematic materials

Takeaways

- Pavements built with binder ΔT_c values approaching -5°C & less (colder) have shown to exhibit increased pavement cracking distress in the field
- The m-value control & ΔT_c progress with ageing should be investigated to observe the REOB impact on binder properties and determine its susceptibility to accelerated ageing

Additional Resources

- www.AsphaltETGs.org
- www.asphaltinstitute.org/re-refined-engine-oil-bottom/
- NCHRP Projects 09-59 and 09-60
  - www.trb.org/NCHRP/NCHRPProjects.aspx

Hamburg Wheel Track Test – AASHTO T 324

- NCHRP Project 20-07/Task 361 *Hamburg Wheel-Track Test Equipment Requirements & Improvements to T 324*
  - Wheel position waveform, frequency, & maximum speed;
  - Impression measurement system;
  - Temperature measurement and control system;
  - Wheel dimensions and loads;
  - Specimen and track length;
  - Free Circulating Water on Mounting System; and
  - Data collection and reporting.

Hamburg Wheel Track Test – AASHTO T 324

NCHRP Project 20-07 Task 361

- Report available as NCHRP Web Only Document 219
- http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w219.pdf

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP

Web-Only Document 219:

Hamburg Wheel-Track Test Equipment Requirements and Improvements to AASHTO T 324

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Baton Rouge, LA

Contractor's Final Report for NCHRP Project 20-07/Task 361
Submitted September 2015

TRB TRANSPORTATION RESEARCH BOARD
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Hamburg Wheel Track Test – AASHTO T 324 NCHRP Project's Proposed Modifications

- **Section 5.1**: Define a tolerance for wheel dimensions
- **Section 5.1**: Define a tolerance for "*wheel be required to reciprocate over the specimen such that its position varies sinusoidally over time*"
- **Section 5.1**: Define a tolerance for maximum speed
- **Section 5.2:** AASHTO T 324 specifies the use of a water bath capable of controlling the temperature within ±1.0°C over a range of 25 to 70°C. Results of temperature experiment revealed shortcomings in this part of the spec

Hamburg Wheel Track Test – AASHTO T 324 NCHRP Project's Proposed Modifications

- **Section 5.3**: AASHTO T 324 does not currently specify the locations of the deformation readings or number of deformation readings
  - Recommend deformation readings at 11 locations along the length of the track.
  - -114, -91, -69, -46, -23, 0, +23, +46, +69, +91, +114 mm with zero being the midpoint of the track.
  - Midpoint of the track should be marked by the different manufacturers to assist the user. (cont.)

Hamburg Wheel Track Test – AASHTO T 324 NCHRP Project's Proposed Modifications

- **Section 9.2**: Report average rut depth based on five middle deformation sensors
  - Recommend sensors located at -46, -23, 0, + 23, and + 46 mm
- **Section 9.3:** Recommended method to calculate the stripping inflection point (SIP) and other reporting parameters not clearly defined in the current specification

Hamburg Wheel Track Test – AASHTO T 324 NCHRP Project's Proposed Modifications

- Report recommendations are currently being reviewed for action by AASHTO Subcommittee on Materials, Hamburg Task Force within the Tech Section 2c.
- Other T 324 improvements made by Hamburg Task Force will be published 2016
- Additional T 324 improvements forthcoming based on NCHRP report findings.

LTTPBind Improvements

- Alpha Release: January 10, 2016 at TRB
- Beta Release: April 2016
- Go-Live: July 2016 with the release of LTPP Standard Data Release 30

MERRA Data

MERRA: MODERN-ERA RETROSPECTIVE ANALYSIS FOR RESEARCH AND APPLICATIONS

- MERRA is a NASA **reanalysis** for the satellite era using a major new version of the Goddard Earth Observing System Data Assimilation System.
- **Reanalysis** is a scientific method for developing a comprehensive record of how weather and climate are changing over time.

MERRA Data

- Long-term (1979-present) synthesis of climate data from a suite of research satellite observations
- Continually updated with 4.2 million global observations every 6 hours (with 2 week delay)
- A native 1/2˚ latitude by 2/3˚ longitude data grid
- Conducted at the NASA Center for Climate Simulations (NCCS)

Software Testing

- Alpha and Beta testers are needed!!

Please contact Larry Wiser at larry.wiser@dot.gov for information on alpha and beta testing.

- Feedback and Comments.

Larry Wiser: larry.wiser@dot.gov and
Riaz Ahmad: rahmad@iengineering.com

Enhanced Durability through Increased In-Place Pavement Density

- Assumption – Pavement density can be increased with a minimum of additional cost.
- Long-Term Objective – States will increase their in-place asphalt pavement density requirements resulting in increased pavement life.

Enhanced Durability through Increased In-Place Pavement Density

- A 1% increase in field density (1% less air voids) is claimed to increase asphalt pavement service-life 10+%! (conservatively)
- Today's compaction target is typically 92% of maximum (G_{mm}) (8% air voids), with varying requirements for the area near the longitudinal joint

Increased Density Pavements target a 1-2% increase across the entire pavement!

– Just 1% more… makes a huge difference!

Thank You!!

Discussion / Comments / Questions

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