Outline

- Cracking Types
- Laboratory Test Loading Types
- Overview of 10 Tests (NCHRP 9-57)
- Recycled Materials
- Focus on AMPT Cyclic Fatigue
  - Rehabilitation Scenario
  - Performance Based Mix Design
Cracking Types (Modes)

- Four (4) basic cracking modes
  - Low Temperature  
  - Reflection / Reflective  
  - Bottom-Up  
  - Top-Down

Does mode matter? Are cracks simply cracks from an evaluation and prevention point of view?
Loading Types (Modes)

- Two (2) basic materials test loading modes
  - Monotonic load - gradually applying a load until reaching the test load magnitude (one cycle)
    - Tension
    - Compression
  - Cyclic load - multiple cycles of incremental loading and unloading
    - Oscillating
      - Tension
      - Compression
      - Combination of compression and tension
In reality, a pavement experiences multiple:
- Loading cycles
- Load magnitudes
- Strains
- Temperatures
Cracking Laboratory Tests

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

- Indirect Tensile (IDT)
  - for low temperature cracking
- Indirect Tensile (IDT)
  - for top-down cracking
- Semicircular Bend (SCB)
  - at low temperature
- Semicircular Bend (SCB)
  - at intermediate temp.
- Disk Shaped Compact Tension (DCT)
- Thermal Stress Restrained Specimen Test / Uniaxial Thermal Stress and Strain Test (TSRST/UTSST)
- Texas Overlay Test (TxOT or OT)
- Repeated Direct Tension (RDT)
- Bending Beam Fatigue
- AMPT Cyclic Fatigue (S-VECD)
## Cracking Laboratory Tests

Ten (10) protocols - cracking mode(s)

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

- Top-down - University of Florida
  - $M_r$ test (optional), $D_t$ test, and tensile strength test (cyclic and monotonic tests)
  - Energy Ratio

www.youtube.com/watch?v=xyevHX0XoyA
Semicircular Bend (SCB)

- Intermediate Temperature – LTRC and University of Illinois Testing Protocols, critical energy release rate

www.youtube.com/watch?v=YW5E69iKAPA
Disk Shaped Compact Tension

- ASTM D7313-13 Determining Fracture Energy of Asphalt-Aggregate Mixture Using the Disk-Shaped Compact Tension Geometry

www.youtube.com/watch?v=Ynsbs_M8gbk
Cracking Resistance

**TSRST / UTSST**

- Low Temperature - Fracture temperature (coefficient of thermal contraction from UTSST)

- AASHTO TP10-93 Thermal Stress Restrainted Specimen Tensile Strength (withdrawn)

- UTSST is also known as the Modified TSRST
  - University of Nevada, Reno

www.youtube.com/watch?v=gDdHMhAhnTU
Texas Overlay Test (TxDOT Test Standard Tex-248-F (cyclic test))

- Reflection cracking & bottom-up fatigue cracking – TxDOT Test Standard Tex-248-F (cyclic test)

www.youtube.com/watch?v=5Np6IgSPfLA
Repeated Direct Tension (RDT)

- Bottom-up and top-down - Texas A&M University
- Paris’ law parameters, endurance limit, healing properties, and average crack size

www.youtube.com/watch?v=_1Avh5nMV-g
Bending Beam Fatigue

- Bottom-up cracking - AASHTO T 321-14
  Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending

www.youtube.com/watch?v=3V0SW0vQ8mY
AMPT Cyclic Fatigue

- Bottom-up and top-down cracking
- AASHTO TP 107-14 Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests
- S-VECD used with more advanced models to simulate pavement performance and predict distresses
- validated with FHWA’s ALF test lanes
- used in FHWA’s Mobile Asphalt Testing Trailer

www.youtube.com/watch?v=9sGb2lkYb8I
Which test to use?

- Empirical vs. Mechanistic
  - simplified monotonic load single temperature
  - more robust regime of traffic loading and climate conditions

Actual pavement damage typically accumulates over multiple events
- NOT a single event
- Pavement remains intact while it loses a lot of modulus and then a crack occurs
Which test to use?

- Mixture ageing (conditioning)
  - short term vs. long term oven conditioning
  - a need for longer oven conditioning to simulate actual field conditions!

Field cracking behavior worsens with time due to field ageing, therefore … laboratory oven conditioning (ageing) must be considered.
Which test to use?

- National standard test method and equipment requirements?
- Ruggedness?
- Precision and Bias?
  - requires ruggedness evaluation first!
    - otherwise not valid
  - Repeatability/Reproducibility
  - use of test for acceptance/payment
Which test to use?

- Sensitivity Analysis?
  - various materials and combinations
- Acceptance Criteria?
- Correlation from lab to actual field pavement performance?
- Integration with Structural Design?
  - Climate
  - Pavement Structure
  - Traffic
FHWA Emphasis on AMPT Cyclic Fatigue

- Wanted a performance test that could be **defensible, not empirical correlations**
  - Circa 1999 - vetting and peer review; “winning” candidate in NCHRP 9-19 Tasks F&G
  - Heritage and “pedigree” of the theory – based in aerospace industry application for solid rocket propellant
  - **Performance Prediction** not single value index
    - AASHTO 1993 Layer Coefficient
    - Marshal Stability and Flow

- Extended Time-Temp Superposition = **Less Testing**

- FHWA promoting the **investment in AMPTs** for the PavementME design (formerly MEPDG) & the AMPT can do much more than just dynamic modulus $|E^*|$ testing
  - Unified/common AMPT equipment specification criteria
  - Unified/common compaction control with SGC
TP 107 & LVECD Handles Structure

Rehab “What-if?” Scenarios
George Washington Memorial Parkway
77,000 AADT

- Control
  - PG70-22
  - PG64-22
- A.R. chip seal SAMI
- SBS PG76-22
- Ultrathin Bonded Wearing Course
- Gap-Graded Wet Process Crumb Rubber
- Kraton HiMA®
  - PG76-28 E
- Fiber reinforced
Calibrated, Predicted Cracking

Field Sites Include:
NCAT, ALF$_{2002}$, Manitoba WMA, Manitoba RAP, Brazil, Korea, China, New York, Louisiana, & counting…

\[ y = 0.77x + 0.51 \]
\[ R^2 = 0.81 \]
AMPT Cyclic Fatigue Test (AASHTO TP-107) Instructional Videos

Contact Nelson Gibson or Matthew Corrigan if you would like to know more …

https://www.youtube.com/playlist?list=PLYlyLypK-v8I-KjQq-Z6Imad4v2o_LcR3b

Provides guidance for increased lab efficiency, reduced testing/replicates, and consistent test data
AMPT Cyclic Fatigue Test (AASHTO TP-107) Instructional Videos

- Part 1. Reheating and Compacting
- Part 2. Coring and Cutting
- Part 3. Cleaning and Gluing LVDT Tabs
- Part 4. Platen Cleaning and Gluing
- Part 5. Running $|E^*| -$ See also NHI Training Course
- Part 6. Choosing the Strain Level
- Part 7. Attaching Specimen and Running Test
- Part 8. Post Processing (alpha-Fatigue)
- Part 9. Post Processing LVECD Structural Analysis
Specimen Prep – Compaction Height

- Best Results for middle failure, experience-based
- Both $E^*$ and Cyclic Fatigue minimum 180mm SGC
- Cut more material away for Cyclic Fatigue
- Do not make a shorter SGC for Cyclic Fatigue
AMPT Cyclic Fatigue Test (AASHTO TP-107)
AMPT Cyclic Fatigue Test (AASHTO TP-107)

Guidance on Choosing Test Strain Levels*

- we went through the trial and error so you don’t need to (do as much)
- based on testing of 64 different mixes
  - additional mixes and materials being added
- identified a failure pattern

*courtesy of Dr. Nelson Gibson, FHWA
| If the $|E^*| > 11,000$ MPa, select 300 microstrain as the first specimen's strain | If $11,000 > |E^*| > 5,500$ MPa, select 500 microstrain as the first specimen's strain | If $|E^*| < 5,500$ MPa, select 800 microstrain as the first specimen's strain |
|---|---|---|
| 200 | 62,514 | 129,033 | 258,702 | 503,812 |
| 250 | 4,220 | 10,969 | 27,219 | 64,485 |
| 300 | 467 | 1,464 | 4,324 | 12,022 |
| 350 | 72 | 267 | 913 | 2,905 |
| 400 | - | - | 237 | 849 |
| 450 | - | - | 287 | 1,039 |
| 500 | - | - | - | 428 |
| 550 | - | - | - | 734 |
| 600 | - | - | - | 1,365 |
| 650 | - | - | - | 777 |
| 700 | - | - | - | 1,630 |
| 750 | - | - | - | 1,043 |
| 800 | - | - | - | 687 |
| 850 | - | - | - | 1,592 |
| 900 | - | - | - | 1,131 |
| 950 | - | - | - | 818 |
| 1,000 | - | - | - | 1,919 |
| 1,050 | - | - | - | 1,463 |
| 1,100 | - | - | - | 1,129 |
| 1,150 | - | - | - | 881 |
| 1,200 | - | - | - | 2,022 |
| 1,250 | - | - | - | 1,633 |
| 1,300 | - | - | - | 1,330 |
| 1,350 | - | - | - | 1,092 |
| 1,400 | - | - | - | 903 |
| 1,450 | - | - | - | 752 |
| 1,500 | - | - | - | 1,640 |
| 1,550 | - | - | - | 1,393 |
| 1,600 | - | - | - | 1,190 |
| 1,650 | - | - | - | 1,021 |
| 1,700 | - | - | - | 880 |
| 1,750 | - | - | - | 762 |
| 1,800 | - | - | - | 1,483 |
| 1,850 | - | - | - | 1,301 |
| 1,900 | - | - | - | 1,145 |
| 1,950 | - | - | - | 1,011 |
| 2,000 | - | - | - | 896 |
Cycles to Failure

Fatigue Strain

Improving Performance

Decreasing Performance
TP107-14 Section 11.2 requires three tests need to be completed at three strain levels.

Ideally failure cycles should be different by orders of magnitude between 1,000 - 64,000

*ETG 2012 Meeting Minutes
To get the right failure result **here**, how do I figure out what to put in **here**???
This is a representation of an infinite number of curves. A mix will land on one curve. If you have at least one data point from one trial – you can estimate your next strain level with some confidence.
Ultrathin Bonded Wearing Course = Thin Hot Mix Asphalt Overlay = "Novachip"
GAP GRADED
PG70-28
0% RAP
210°C (TP107; 18C)
Tested in AMPT
Oklahoma I-40 Mixes
PG76-28E & PG76-28 "Kraton"
21°C  (TP107; 21C)
Tested in AMPT

Cycles to Peak Phase Angle
Arizona and Colorado CFLHD Park Service mixes
PG58-28 & PG58-34
21oC (TP107; 12C & 9C)
Tested in AMPT
PennDOT Fiber study
PG64-22 & PG76-22
18°C  (TP107; 18°C & 24°C)
Tested in AMPT

"Programmed Actuator" Strain Level [microstrain]
REOB Study
PG58-28 + 22% RAP ... assumed PG64-22
18oC  (TP107; 18C)
Tested in AMPT
REOB Study - Long Term Aged Mixes
PG58-28 + 22% RAP ... assumed PG64-22
18oC (TP107; 18C)
Tested in AMPT
Exploratory RAP Study - Highly Controlled Volumetrics
Virgin PG70-22 + PG94-11 RAP
210C (TP107; 21C)
Tested in AMPT
2013 ALF Reconstruction
20% RAP a.b.r paired with PG64-22; assume PG64-22
40% RAP a.b.r. paired with PG58-28; assume PG64-22
18°C (TP107; 21°C)
Tested in AMPT
2013 ALF Reconstruction - Long Term Aged
20% RAP a.b.r paired with PG64-22; assume PG64-22
40% RAP a.b.r. paired with PG58-28; assume PG64-22
180°C (TP107; 21C)
Tested in AMPT

Cycles to Peak Phase Angle

"Programmed Actuator" Strain Level [microstrain]
Performance Based Mix Design Study, 7% Air Void Compaction
20% RAP a.b.r paired with PG64-22; assume PG64-22
180C (TP107; 18C)
Tested in AMPT
Performance Based Mix Design Study, 9% Air Void Compaction
20% RAP a.b.r paired with PG64-22; assume PG64-22
18°C (TP107; 18C)
Tested in AMPT
| If the |E*| is greater than 11,000 MPa, select 300 microstrain as the first specimen's strain | If 11,000 > |E*| > 5,500 Mpa, select 500 microstrain as the first specimen's strain | If the |E*| is less than 5,500 Mpa, select 800 microstrain as the first specimen's strain |
|---|---|---|---|
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| 650 | - | - | - | 2,022 |
| 700 | - | - | - | 1,640 |
| 750 | - | - | - | 1,190 |
| 800 | - | - | - | 1,330 |
| 850 | - | - | - | 1,021 |
| 900 | - | - | - | 880 |
| 950 | - | - | - | 762 |
| 1,000 | - | - | - | 1,940 |
| 1,050 | - | - | - | 2,250 |
| 1,100 | - | - | - | 2,250 |
| 1,150 | - | - | - | 2,250 |
| 1,200 | - | - | - | 2,250 |
| 1,250 | - | - | - | 2,250 |
| 1,300 | - | - | - | 2,250 |
| 1,350 | - | - | - | 2,250 |
| 1,400 | - | - | - | 2,250 |
| 1,450 | - | - | - | 2,250 |
| 1,500 | - | - | - | 2,250 |
| 1,550 | - | - | - | 2,250 |
| 1,600 | - | - | - | 2,250 |
| 1,650 | - | - | - | 2,250 |
| 1,700 | - | - | - | 2,250 |
| 1,750 | - | - | - | 2,250 |
| 1,800 | - | - | - | 2,250 |
| 1,850 | - | - | - | 2,250 |
| 1,900 | - | - | - | 2,250 |
| 1,950 | - | - | - | 2,250 |
| 2,000 | - | - | - | 2,250 |
Predict life. How much life was lost? Gained?

Hit the target. Walk away.

Binder Content

a number
Performance Prediction
(traffic – structure – climate)

Already has capability

Involved or Perceived as Complicated.

Make it simpler
Performance Prediction
(traffic – structure – climate)

Already has capability

Make it simpler

Functionality has to be added

Involved or Perceived as Complicated.
Recycled Materials

- reclaimed asphalt pavement (RAP)
- reclaimed asphalt shingles (RAS)
  - manufactured scrap
  - roofing tear-offs
- re-refined engine oil bottoms (REOB)
- ground tire rubber (GTR)
- other materials in a pre-aged condition and/or which provide accelerated ageing characteristics and behavior
FHWA Recycled Materials Policy

FHWA longstanding position that any materials used shall not adversely affect performance, safety or the environment of the highway system

- February 7, 2002 FHWA Policy Memorandum
  - “…the policy acknowledges that recycling will not be appropriate in all cases and provides guidance for making that determination.”
  - e.g. recycled/reclaimed/re-used/re-refined …
FHWA Recycled Materials Policy

1. Engineering suitability
2. Environmental suitability
3. Economic assessment
Memorandums to FHWA Division Offices

- Walter C. Waidelich, Associate Administrator for Infrastructure
- Increasing number of state highway agencies reporting pre-mature cracking in relatively new asphalt pavements with high content of recycled asphalt binder
- Increased concerns with high levels of RAS use especially when RAP is already used
  - Potential increased cracking due to low temperatures, thin pavement sections, and increased asphalt ageing
- Reminder to follow sound engineering design and construction practices

20 October 2014
Memorandum to
FHWA Division & FLHD

11 December 2014

- FHWA longstanding position that any materials used shall not adversely affect performance, safety or the environment of the highway system
- Nov 2014 AASHTO SOM survey shows RAS limitations in place/needed
- Need to establish appropriate level of use
- Directs the review of RAS use criteria with State
  - specification changes to mitigate risk of failures
  - ensure AASHTO standard PP 78 use for future Federal-aid projects if performance issues are identified
Recycled Binders - RAS & RAP

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

... more on this later!
<table>
<thead>
<tr>
<th>Recycle Content</th>
<th>Production Temperature</th>
<th>HMA WMA Technology</th>
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<tbody>
<tr>
<td></td>
<td>300°F - 320°F</td>
<td>240°F - 270°F</td>
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<tr>
<td>0%</td>
<td>-</td>
<td>Foam</td>
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<tr>
<td>20% ABR RAP</td>
<td>-</td>
<td>Chem.</td>
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<tr>
<td>≈ 23% by weight</td>
<td>PG64-22</td>
<td>PG64-22</td>
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<tr>
<td>20% ABR RAS</td>
<td>PG64-22</td>
<td>PG64-22</td>
</tr>
<tr>
<td>≈ 6% Shingle by weight</td>
<td>PG64-22</td>
<td>PG58-28</td>
</tr>
<tr>
<td>40% ABR RAP</td>
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<tr>
<td>≈ 44% by weight</td>
<td>PG58-28</td>
<td>PG58-28</td>
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FHWA collaboration with ALF
<table>
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<tr>
<th>ALF Lane #</th>
<th>% ABR</th>
<th>Virgin PG Grade</th>
<th>Drum Discharge Temperature</th>
<th>WMA Process</th>
<th>Cycles to First ALF Crack</th>
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<td>RAP</td>
<td>RAS</td>
<td></td>
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<tr>
<td>1</td>
<td>0</td>
<td>--</td>
<td>64-22</td>
<td>300-320</td>
<td>368,254</td>
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<tr>
<td>2</td>
<td>40</td>
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<td>58-28</td>
<td>240-285</td>
<td>Water Foaming tbd</td>
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<td>3</td>
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<td>64-22</td>
<td>300-320</td>
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<td>20</td>
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<td>64-22</td>
<td>240-270</td>
<td>Evotherm 88,740</td>
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<td>40</td>
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<td>300-320</td>
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FHWA collaboration with ALF
FHWA collaboration with ALF

Texas Transportation Institute

Ingevity

Washington State University

National Center for Asphalt Technology at Auburn University

University of Nevada, Reno

Rutgers

Cracking Resistance
ALF Validation Results (to date)

<table>
<thead>
<tr>
<th>LVECD Structural Prediction</th>
<th>% Nodes Below Critical Damage</th>
<th>Measured ALF Performance</th>
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<tbody>
<tr>
<td>Unaged</td>
<td>Aged</td>
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<tr>
<td>As Built</td>
<td>Perfect Construction</td>
<td>As Built</td>
</tr>
<tr>
<td>L2 9%</td>
<td>L2 11%</td>
<td>L1 12%</td>
</tr>
<tr>
<td>L1 10%</td>
<td>L4 12%</td>
<td>L4 14%</td>
</tr>
<tr>
<td>L4 13%</td>
<td>L6 13%</td>
<td>L9 16%</td>
</tr>
<tr>
<td>L6 13%</td>
<td>L1 14%</td>
<td>L2 18%</td>
</tr>
<tr>
<td>L9 15%</td>
<td>L9 16%</td>
<td>L6 19%</td>
</tr>
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<td>L8 18%</td>
<td>L8 17%</td>
<td>L8 22%</td>
</tr>
<tr>
<td>L11 19%</td>
<td>L11 18%</td>
<td>L11 29%</td>
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<td>L3 31%</td>
<td>L3 31%</td>
<td>L5 42%</td>
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<td>L7 -</td>
<td>L5 35%</td>
<td>L7 66%</td>
</tr>
<tr>
<td>L5 -</td>
<td>L7 46%</td>
<td>L3 -</td>
</tr>
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</table>

Lanes 2, 6, and 8 remain to be tested.
Re-Refined Engine Oil Bottoms

National dialogue on understanding product, use, and limitations:
- non-bituminous additive or modifier?
- UTI improvement or dilutant?
- use in the U.S. market?
- product properties?
- final asphalt binder and mixture properties?
- effect on pavement performance?
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, sustainability, and “Green” initiatives

“Used since mid 1980’s”… as reported by REOB re-refiners/suppliers
(re-refined) REOB...also know as:

- re-refined vacuum tower bottoms (VTB) (RVTB)
- asphalt flux, asphalt cutter
- re-refined asphalt cement
- asphalt flux, asphalt extender
- waste engine oil residue (WEO), WEO residue (WEOR), engine oil residue (EOR)
- re-refined asphalt cutter (RRAC)
- vacuum tower asphalt extender (VTAE),
- engine oil bottoms (EOB), recycled EOB (R-EOB)
- re-refined heavy vacuum distillation oil (RHVDB)

etc. etc. ...
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.
Three National REOB Task Force Groups

- FHWA Binder Expert Task Group (ETG)
- Asphalt Institute
  - under direction of their Technical Advisory Committee (TAC)
  - State of the Knowledge Document
- AASHTO Subcommittee on Materials
  - respond to Standing Committee on Highways (SCOH) resolution
Re-refined Engine Oil Bottoms

REOB Task Force within Binder ETG

Discussions:

- Which rheological parameter
  - critical temperature change ($\Delta T_c$)
  - Glover-Rowe (GR)
  - rheological index (R value)
  - cross over frequency ($\omega_c$)

All of these parameters can be interrelated from understanding the relationship between loading time (or frequency) and temperature.
Re-refined Engine Oil Bottoms

Field Studies - with distress data

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

- Exhibited increased cracking distress
Recycled Binders - RAS & RAP
Re-refined Engine Oil Bottoms

- ETG Task Force efforts and consensus
- Recommendations from ETG to AASHTO Subcommittee on Materials ...

... more on this later in the schedule during the AASHTO and ETG presentations.
Thank You!!

FHWA’s Mobile Asphalt Testing Trailer
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