Ground Tire Rubber (GTR) Field Projects (Part 2)

Matthew Corrigan P.E.
FHWA Mixture Expert Task Group Meeting
September 18, 2014

Mobile Asphalt Testing Trailer
MATT GTR Field Projects

PA1397-Pennsylvania
- PG 64-22 + Evotherm 3G (0.5% Wt. of Binder)
- 15.9 % GTR
- 30 mesh supplied
  - 100% passing No. 16
  - 75% passing No. 30
- No control sections

NJ1499-New Jersey
- PG 64-22 + Evotherm M1 (0.5% Wt. of Binder)
- 20% GTR
- 30 mesh supplied
  - 100% passing No. 16
  - 98% passing No. 30

Mobile Asphalt Testing Trailer

Federal Highway Administration
Why do agencies specify these GTR percentages and gradations?

ASTM D 8 Standard Terminology Relating to Materials for Roads and Pavements

- **asphalt-rubber, n**—a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles.
Why do agencies specify these GTR percentages and gradations?

ASTM D 6114 Standard Specification for Asphalt-Rubber Binder

• NOTE 1—It has been found that at least 15 % rubber by weight of the total blend is usually necessary to provide acceptable properties of asphalt-rubber.

• Recommended that no rubber particles should be retained on the 2.36 mm (No. 8) sieve.
Why do agencies specify these GTR percentages and gradations?

ASTM D 6114 Standard Specification for Asphalt-Rubber Binder

- Rubber gradation should be agreed upon between purchaser and asphalt-rubber supplier for the specific mixture applications.

- NOTE 3—It has been found that rubber gradation may affect the physical properties and performance of hot paving mixtures using asphalt-rubber binder.
Project Description

- Project Location:
  - Lewisburg, Pennsylvania
    SR-15 to SR-11 near Shamokin Dam
- Produced by Eastern Industries Inc.
- Pavement Structure: Surface Layer
  - 3 - 30 MESAL
  - $N_{\text{design}} = 100$
  - $\text{NMAS} = 12.5 \text{ mm}$
Materials

- **Binder**
  - PG 64-22 + Evotherm 3G (0.5% Wt. of Binder)

- **GTR**
  - Manufactured by Mahantango Enterprises, Inc.

- **Aggregate Stockpile**
  - A7-SS: Sandstone (Coarse)
  - A8-SS: Sandstone (Coarse)
  - B3-LS: Limestone (Fine)

- **Mix**
  - PMLC (7 Samples) and LMLC (6 mixes)
## GTR Gradation

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Percent Passing (%)</th>
<th>PennDOT Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.36 (No. 8)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>100</td>
<td>90-100</td>
</tr>
<tr>
<td>0.6 (No. 30)</td>
<td>74.3</td>
<td>25-100</td>
</tr>
<tr>
<td>0.3 (No. 50)</td>
<td>16.1</td>
<td>0-45</td>
</tr>
<tr>
<td>0.15 (No. 100)</td>
<td>1.2</td>
<td>-</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>0.0</td>
<td>0-5</td>
</tr>
</tbody>
</table>

ASTM D5644 allows up to 10% oversize material for 30 to 100 mesh GTR stockpiles.

**ASTM D5644 Standard Test Methods for Rubber Compounding Materials—**
**Determination of Particle Size Distribution of Recycled Vulcanizate Particulate Rubber**
Materials

- **Binder**
  - PG 64-22 + Evotherm 3G (0.5% Wt. of Binder)
  - PMLC4 (Full Reaction)
    - \( \text{PG 64-22} + 0.5 \% \text{ Evotherm} + 15.9 \% \text{ GTR} \)
  - PMLC6 (Full Reaction)
    - \( \text{PG 64-22} + 0.5 \% \text{ Evotherm} + 15.9 \% \text{ GTR} \)
  - PMLC7 (Full Reaction)
    - \( \text{PG 64-22} + 0.5 \% \text{ Evotherm} + 15.9 \% \text{ GTR} \)
Testing

- **Fabrication of Specimens**
  - Pre-blend Samples
  - Reheated at 160°C - 175°C

- **DSR**
  - 25 mm Parallel Plate
  - 1 mm gap setting
Videos of Reheating Procedure

5 Gallon Container

Gallon Container
Images of PA64-22 plus GTR

Sample Before Mixing

Sample Poured in Silicone Mold

Stirring with Mechanical Mixer

Asphalt Being Poured
Images of PA64-22 plus GTR
RTFO Conditioning Issues

- Sample crawled out of the bottles

Asphalt binder dripping out during test

Asphalt Binder dripped onto Heating Elements inside RTFO Oven
Deviation from Standard

– Tilted the RTFO oven by +1°
Result

• Bottles did not coat completely

RTFO bottles after aging
Images of BBR Beams

PG 64-22 + GTR (Original) BBR Beams
No RTFO or PAV conditioning

Difficult to prepare GTR test specimens for BBR, DTT, and ABCD
**Results**

- **Performance Grade (M320 and M332)**

<table>
<thead>
<tr>
<th>Binder ID</th>
<th>AASHTO M320</th>
<th>Critical Low Cracking Temperature (°C)</th>
<th>J_{nr3.2} (1/kPa)</th>
<th>J_{nrdiff} (%)</th>
<th>AASHTO M332</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M320 T1</td>
<td>M320 T2</td>
<td>M320 T1 Continuous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG 64-22+Evotherm</td>
<td>PG 64-22</td>
<td>PG 64-22</td>
<td>PG 67.0-26.1</td>
<td>-23.6</td>
<td>1.170</td>
</tr>
<tr>
<td>PMLC4 - full reaction</td>
<td>PG 88-22</td>
<td></td>
<td>PG 88.3-24.9</td>
<td></td>
<td>0.042</td>
</tr>
<tr>
<td>PMLC6 - full reaction</td>
<td>PG 88-22</td>
<td></td>
<td>PG 88.7-26.6</td>
<td></td>
<td>0.059</td>
</tr>
<tr>
<td>PMLC7 - full reaction</td>
<td>PG 82-22</td>
<td></td>
<td>PG 85.0-25.9</td>
<td></td>
<td>0.093</td>
</tr>
</tbody>
</table>

**These results are not reliable due to issues with oven conditioning, deviations from the AASHTO standard procedure, and GTR particle size of these GTR modified binders!!**
Challenges

- DSR Testing
  - Reheating and processing GTR modified binders
  - Sample Trimming and Edge Effects
  - GTR Particle Size Limits
  - Distribution of GTR Particles within sample or test specimens
  - High GTR percent by weight of binder
Observations

- GTR percentage should be established through engineering and a targeted final PG grade; not simply to meet ASTM definition.
- GTR binders should be handled carefully. Special attention must be given for blending, reheating, and mixing process. These include equipment selection, mixing time, temperature, and rotation speed.
- GTR evaluation should include gradation (particle sizes), distribution, and settlement/segregation.
- Test specimen preparation and trimming is not a trivial item when testing GTR samples in PP geometry.
Observations

- Investigate machine compliance when testing PAV-aged GTR samples.
- The Concentric Cylinder (CC) test geometry configuration should be considered to overcome some of the PP geometry and specimen issues.
- Practical limits on GTR percentage should be established to ensure the current grading system is applicable.
- Alternative evaluation of GTR-based mastics or Fine Aggregate Mixes (FAM) should be investigated and may be more appropriate at high GTR percentages.
## Mixes

### 7 PMLC Samples
- PMLC1 GTR 16.7%
- PMLC2 GTR 16.7%
- PMLC3 GTR 16.7%
- PMLC4 GTR 15.9%
- PMLC5 GTR 15.9%
- PMLC6 GTR 15.9%
- PMLC7 GTR 15.9%

### 6 LMLC Mixes
- LMLC1 GTR 15%
- LMLC2 GTR 15%*
- LMLC3 GTR 5%
- LMLC4 GTR 10%
- LMLC5 GTR 15%
- LMLC6 GTR 20%

* GTR modified binder field blended by the contractor
Pb Verification

![Pb Verification Graph](image-url)
Mix Plant

- **Production rate**
  - 500 tons/hrs.
  - Bag-house Collector System
AMPT Capabilities

- **Dynamic Modulus (|E*|)**
  
  *Stiffness*

- **Fatigue (S-VECD)**
  
  *Fatigue Cracking*

- **Flow Number (Fn)**
  
  *Permanent Deformation*

- **Overly Tester**
  
  *Reflective/Fatigue Cracking*
PMLC (log-log)

Dynamic Modulus, $|E^*|$ (MPa)

Reduced Frequency (Hz) ($T_{ref} = 21.1°C$)

- PMLC1 GTR 16.7%
- PMLC2 GTR 16.7%
- PMLC3 GTR 16.7%
- PMLC4 GTR 15.9%
- PMLC5 GTR 15.9%
- PMLC6 GTR 15.9%
- PMLC7 GTR 15.9%
PMLC (semi-log)

Dynamic Modulus, $|E^*|$ (MPa)

Reduced Frequency (Hz) ($T_{ref} = 21.1 \degree C$)

- PMLC1 GTR 16.7%
- PMLC2 GTR 16.7%
- PMLC3 GTR 16.7%
- PMLC4 GTR 15.9%
- PMLC5 GTR 15.9%
- PMLC6 GTR 15.9%
- PMLC7 GTR 15.9%
Selection of Test Temperature

Closest Weather Station
PA 7931 (Selinsgrove, PA)

Adjustments
50% Reliability
20 mm Depth
PG Temp = 54.0 °C
## Flow Number Test

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Unconfined FN (Confinment = 0 kPa)</th>
<th>Confined FN (Confinment = 69 kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>600 kPa</td>
<td>690 kPa</td>
</tr>
<tr>
<td>LMLC1 GTR 15%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>LMLC2 GTR 15%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>LMLC3 GTR 5%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LMLC4 GTR 10%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LMLC5 GTR 15%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LMLC6 GTR 20%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PMLC1 GTR 16.7%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PMLC2 GTR 16.7%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PMLC3 GTR 16.7%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PMLC4 GTR 15.9%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PMLC5 GTR 15.9%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PMLC6 GTR 15.9%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PMLC7 GTR 15.9%</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

- 4 Replicates for each mix
- Stopping Criterion: 10,000 Cycles or 50,000 Microstrain
**PMLC (600/0 kPa)**

TP79 min. Flow Number criteria is 190 for HMA designed for 10 to <30 MESAL
LMLC (Unconfined)

Flow Number (Cycle)

- LMLC1 GTR 15%
- LMLC2 GTR 15%
- LMLC3 GTR 5%
- LMLC4 GTR 10%
- LMLC5 GTR 15%
- LMLC6 GTR 20%

Pressures:
- 600 kPa
- 690 kPa
- 800 kPa
Hamburg Test

- AASHTO T324 Test Protocol
- Specimen (Diameter, Height): 150 X 61±1 mm
- Temperature: 50 °C
- Target Air Voids: 7+0.5%
- Wheel Load: 705+4.5 kN
- Stopping Criterion:
  20,000 Passes or 20 mm Rut
- PennDOT does not currently specify Hamburg test requirements
Hamburg Test

Post-compaction

Creep Slope

Good Mix

Stripping Inflection Point

Poor Mix

Typical Mix

Stripping Slope

Rut Depth (mm)

Number of Passes
## Hamburg Test

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>No. of Replicate</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMLC1</td>
<td>4 Replicates</td>
<td>Plant Produced</td>
</tr>
<tr>
<td>GTR 16.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC2</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 16.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC3</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 16.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC4</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 15.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC5</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 15.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC6</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 15.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC7</td>
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</tr>
<tr>
<td>GTR 15.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMLC1</td>
<td>4 Replicates</td>
<td>Mix Design Replication</td>
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<tr>
<td>GTR 15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMLC2</td>
<td>4 Replicates</td>
<td></td>
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<tr>
<td>GTR 15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMLC3</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMLC4</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMLC5</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMLC6</td>
<td>4 Replicates</td>
<td></td>
</tr>
<tr>
<td>GTR 20%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PMLC (GTR 16.7%)
PMLC (GTR15.9%)
Creep Slope
Stripping Slope

-0.50
-0.40
-0.30
-0.20
-0.10
0.00

PMLC1 GTR 16.7%
PMLC2 GTR 16.7%
PMLC3 GTR 16.7%
PMLC4 GTR 15.9%
PMLC5 GTR 15.9%
PMLC6 GTR 15.9%
PMLC7 GTR 15.9%
LMLC1 GTR 15%
LMLC2 GTR 15%
LMLC3 GTR 5%
LMLC4 GTR 10%
LMLC5 GTR 15%
LMLC6 GTR 20%
Stripping Inflection Point

![Stripping Inflection Point Graph]

- PMLC1 GTR 16.7%
- PMLC2 GTR 16.7%
- PMLC3 GTR 16.7%
- PMLC4 GTR 15.9%
- PMLC5 GTR 15.9%
- PMLC6 GTR 15.9%
- PMLC7 GTR 15.9%
- LMLC1 GTR 15%
- LMLC2 GTR 15%
- LMLC3 GTR 15%
- LMLC4 GTR 15%
- LMLC5 GTR 15%
- LMLC6 GTR 20%
Fatigue ($S$-$VECD$)

- AASHTO TP 107
- Simplified Viscoelastic Continuum Damage ($S$-$VECD$) Model
- Damage Characteristic Curve (C versus S)

$$C = e^{aS^b}$$

C = Material Integrity or Pseudo Stiffness
S = Amount of Damage

- S-$VECD$ Test Includes:
  - $|E^*|$ Linear Viscoelastic (LVE) Test
  - $|E^*|$ Dynamic Modulus (Finger Print) Test
  - Pull-Pull Fatigue Test
Fatigue ($S$-VECD)

- At least 3 Replicates
- Frequency = 10 Hz
- Temperature = 21 °C

$\text{Temp. (°C)} = \min (21^\circ \text{C}, \frac{PG \ (High+Low)}{2} - 3)$

- Three on-specimen Strain Levels
  - 350, 450, and 600 µstrain
Fatigue (S-VECD)

- ALPHA-Fatigue Software
- Failure Mechanism → Mid-Failure
- Stopping Criterion
  - Sudden Drop in Phase Angle

![Graph showing the sudden drop in phase angle at a certain number of cycles](image)
Endurance Limit (PMLC)

![Endurance Limit Graph]

- PMLC1 GTR 16.7%
- PMLC2 GTR 16.7%
- PMLC3 GTR 16.7%
- PMLC4 GTR 15.9%
- PMLC5 GTR 15.9%
- PMLC6 GTR 15.9%
- PMLC7 GTR 15.9%
Endurance Limit \textbf{(LMLC)}

Fatigue performance similar for mixtures using 5-15\% lab reacted GTR binders.
Why does fatigue performance decrease for the 20\% GTR mixture?
Endurance Limit (LMLC)

Why does fatigue performance decrease for the 20% GTR mixture?
Project Findings

- Overall, GTR increases the overall stiffness, and improves permanent deformation and moisture damage properties of the asphalt mixes.
- Fatigue resistance of the LMLC mixes consistent up to 15% GTR content.
- Binder content is shown to affect the performance of the PMLC mixes.
- Handling GTR mixes is not trivial.
Acknowledgments

- PennDOT
- Eastern Industries, Inc.
  - Gregory Brouse (QC Manager)
  - Steven Grimm (QC Tech)
- Mobile Asphalt Testing Trailer Program - Engineers and Technicians
Ground Tire Rubber (GTR)
Field Project NJ1499

(Preliminary Results)

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Eyoab Teshale
Satish Belagutti

Mixture Expert Task Group Meeting
Sept 18, 2014
Project Description

- Project Location:
  - Ocean County, New Jersey
    Routes US 9 and 72 (Maintenance and Repair)

- Produced by:
  - ECOPATH Contracting LLC
  - Western Technologies Inc. (WT)

- Pavement Structure: Surface Layer
  - 0.3 - 3 MESAL
  - $N_{\text{design}} = 75$
  - NMAS = 12.5 mm
Materials

- **Binder**
  - PG 64-22 + Evotherm M1 (0.5% Wt. of Binder)
  - Supplier: Axeon Asphalt Refinery, Paulsboro, NJ

- **GTR**
  - Supplier: ECOPATH Industries, LLC

- **Aggregate Stockpile**
  - MFG Sand
  - Birdsboro#7
  - Birdsboro#8
  - Birdsboro#10
  - RAP
Materials

- Mix (GTR=20% and RAP=10%)
  - PMLC1-GTR20-RAP10
  - PMLC2-GTR20-RAP10

- Mix (GTR=20% without RAP)
  - PMLC3-GTR20
Mixture Design

- 0.3 - 3 MESAL
- \( N_{\text{design}} = 75 \)
- NMAS = 12.5 mm

<table>
<thead>
<tr>
<th>Property</th>
<th>Contractor JMF</th>
<th>PMLC1</th>
<th>PMLC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Grade</td>
<td>PG 64-22</td>
<td>PG 64-22</td>
<td>PG 64-22</td>
</tr>
<tr>
<td>Evotherm (%)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>GTR (%)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>RAP (%)</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Sampling Temp (°F)</td>
<td>300-310</td>
<td>292.8</td>
<td>301.4</td>
</tr>
<tr>
<td>Compaction Temp (°F)</td>
<td>285</td>
<td>285</td>
<td>285</td>
</tr>
<tr>
<td>( P_b ) (%)</td>
<td>7.7</td>
<td>7.71</td>
<td>7.38</td>
</tr>
<tr>
<td>( V_a ) (%)</td>
<td>4.0</td>
<td>6.0</td>
<td>2.3</td>
</tr>
<tr>
<td>VMA (%)</td>
<td>22.2</td>
<td>23.0</td>
<td>18.8</td>
</tr>
<tr>
<td>VFA (%)</td>
<td>81.8</td>
<td>73.8</td>
<td>87.8</td>
</tr>
<tr>
<td>( F/P_{be} )</td>
<td>0.6</td>
<td>0.33</td>
<td>0.68</td>
</tr>
</tbody>
</table>

\( P_b \): binder content; \( V_a \): air voids; VMA: voids in mineral aggregates; VFA: voids filled with asphalt; and \( F/P_{be} \): dust to effective binder ratio

<table>
<thead>
<tr>
<th>Property</th>
<th>Contractor JMF</th>
<th>PMLC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Grade</td>
<td>PG 64-22</td>
<td>PG 64-22</td>
</tr>
<tr>
<td>Evotherm (%)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>GTR (%)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>RAP (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sampling Temp (°F)</td>
<td>300-310</td>
<td>290</td>
</tr>
<tr>
<td>Compaction Temp (°F)</td>
<td>285</td>
<td>285</td>
</tr>
<tr>
<td>( P_b ) (%)</td>
<td>7.6</td>
<td>7.20</td>
</tr>
<tr>
<td>( V_a ) (%)</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td>VMA (%)</td>
<td>21.9</td>
<td>20.7</td>
</tr>
<tr>
<td>VFA (%)</td>
<td>81.8</td>
<td>81.0</td>
</tr>
<tr>
<td>( F/P_{be} )</td>
<td>0.6</td>
<td>0.53</td>
</tr>
</tbody>
</table>

\( P_b \): binder content; \( V_a \): air voids; VMA: voids in mineral aggregates; VFA: voids filled with asphalt; and \( F/P_{be} \): dust to effective binder ratio
Mixture Design

[Graph showing percent passing (%)]

Sieve Size (mm) Raised to 0.45 Power

Percent Passing (%)
Mixture Design

![Graph showing percent passing vs sieve size raised to 0.45 power for MDL, JMF Contractor, and PMLC3-GTR20.](image-url)
## GTR Gradation

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Passing (%)</th>
<th>NJDOT Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.36 (No. 8)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>100</td>
<td>65 - 100</td>
</tr>
<tr>
<td>0.6 (No. 30)</td>
<td>98</td>
<td>20 - 100</td>
</tr>
<tr>
<td>0.3 (No. 50)</td>
<td>29</td>
<td>0 - 45</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>1.1</td>
<td>0 - 5</td>
</tr>
</tbody>
</table>

ASTM D5644 allows up to 10% oversize material for 30 to 100 mesh designated GTR stockpiles.
Mix Plant
GTR Reaction Plant
AMPT Capabilities

- **Dynamic Modulus (|E*|)**
  - Stiffness

- **Fatigue (S-VECD)**
  - Fatigue Cracking

- **Flow Number (Fn)**
  - Permanent Deformation

- **Overly Tester**
  - Reflective/Fatigue Cracking
Dynamic Modulus, $|E^*|$ (MPa)

Reduced Frequency (Hz) ($T_{\text{Ref}} = 21.1 \, ^\circ\text{C}$)

- PMLC1-GTR20-RAP10
- PMLC2-GTR20-RAP10
- PMLC3-GTR20
PMLC (semi-log)

Dynamic Modulus, $|E^*|$ (MPa)

Reduced Frequency (Hz) ($T_{\text{Ref}} = 21.1 \, ^\circ \text{C}$)

- PMLC1-GTR20-RAP10
- PMLC2-GTR20-RAP10
- PMLC3-GTR20
PMLC (Phase Angle)

Phase Angle, $\phi$ (deg.)

Reduced Frequency (Hz) ($T_{\text{Ref}} = 21.1 \degree\text{C}$)

- PMLC1-GTR20-RAP10
- PMLC2-GTR20-RAP10
- PMLC3-GTR20
Selection of Test Temperature

Closest Weather Station
NJ 684331
(Pemberton, NJ)

Adjustments
50% Reliability
20 mm Depth
PG Temp = 54.1 °C

LTPPBind V3.1
Flow Number Test

- 4 Replicates
- Unconfined FN Test
  - 600 and 800 kPa
- Confined FN Test
  - 600 and 800 kPa
- Stopping Criterion
  - 10,000 Cycles, or
  - 50,000 Microstrain
Unconfined FN Test

No TP79 min. Flow Number criteria for HMA designed for <3 MESAL
Hamburg Test

- NJ DOT does not currently specify Hamburg test requirements

- Replicates
  - LMLC1-GTR20-RAP10 (10 Replicates)
  - LMLC2-GTR20-RAP10 (8 Replicates)
  - LMLC3-GTR20 (8 Replicates)
Hamburg Test

LMLC1

Number of Passes

Rut Depth (mm)

-20
-15
-10
-5
0
0 5000 10000 15000 20000

PMLC 1 SP 2&8 LWP
PMLC 1 SP 3&9 RWP
PMLC 1 SP 5&10 LWP
PMLC 1 SP 6&7 RWP
PMLC 1 SP 1&4 LWP
Hamburg Test

![Graph showing Rut Depth (mm) vs Number of Passes for Hamburg Test with different samples labeled as PMLC 2 SP 7&10 RWP, PMLC 2 SP 5&8 LWP, PMLC 2 SP 4&9 RWP, and PMLC 2 SP 6&11 LWP.]

LMLC2
Hamburg Test

![Diagram showing rut depth vs number of passes for different samples.]

- PMLC 3 SP 7&12 LWP
- PMLC 3 SP 4&5 RWP
- PMLC 3 SP 10&11 LWP
- PMLC 3 SP 8&9 RWP

LMLC3
Fatigue \( (S-VECD) \)

- AASHTO TP 107
- Simplified Viscoelastic Continuum Damage (S-VECD) Model
- Damage Characteristic Curve (C versus S)

\[
C = e^{as^b}
\]

\( C = \text{Material Integrity or Pseudo Stiffness} \)

\( S = \text{Amount of Damage} \)

- S-VECD Test Includes:
  - \(|E^*|\) Linear Viscoelastic (LVE) Test
  - Pull-Push (Finger Print) Test
  - Pull-Pull Fatigue Test
Fatigue ($S$-VECD)

- Stopping Criterion
  - Sudden Drop in Phase Angle

- ALPHA-F Software
Fatigue (S-VECD)

- At least 3 Replicates
- Frequency = 10 Hz
- Temperature = 21 °C

\[ \text{Temp. (°C)} = \min (21°C, \frac{PG (High+Low)}{2} - 3) \]

- Three on-specimen Strain Levels
  - 450, 550, and 600 Microstrain
Fatigue ($S$-VECD)

- **LMLC1-GTR20-RAP10**
  - Failure Mechanism $\rightarrow$ Mid-Failure
  - On-specimen Strains (Microstrian)
    - 450
    - 550
    - 600
Endurance Limit

Endurance Limit (Microstrain) vs. Temperature (°C)

- PMLC1-GTR20-RAP10
- PMLC2-GTR20-RAP10
- PMLC3-GTR20
Project Findings

- The Asphalt Mixes Included in the Study Exhibited Similar Performance Results
  - Stiffness ($|E^*|$)
  - Fatigue Cracking Resistance (S-VECD)
  - Permanent Deformation (FN)
  - Rutting and Stripping (Hamburg)

- The Inclusion of RAP (10%) did not Significantly Impact Performance Test Results.
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- Keith Sterling (A. E. Stone Inc)

Mobile Asphalt Testing Trailer Program - Engineers and Technicians