"Use of Dynamic Modulus (E*) in the Design of Hot-Mix Asphalt (HMA) Pavement"

for Presentation @ Pavement Evaluation Workshop
Newington, Connecticut
September 10, 2002
An FHWA Pooled Funds Project

Lead Agency

Connecticut Department of Transportation
Why is E* Important?

The new 2002 design guide for pavements is based on mechanistic principles. This requires a modulus, analogous to E for steel, to compute stresses and stains in the HMA pavement. E* has been selected for this purpose.
Definition of $E^*$

$E^*$ is the modulus of a visco-elastic material. It is computed by dividing the maximum (peak to peak) stress by the recoverable (peak to peak) axial strain of a test sample subjected to a sinusoidal load at various test temperatures.
Why this Project?

- The 1986 AASHTO pavement design guide contained resilient modulus ($M_R$) to characterize HMA mixes. $M_R$ didn’t work and it took FHWA and others millions of dollars to recognize this flaw.

- Our project is designed to look at the protocol for determining $E^*$ and provide state DOTs recommendations for the application of the protocol in their operations.
Project Objectives

- Determine the applicability of $E^*$ to characterize HMA mixes
- Determine the practical range of the protocol
- Determine any variation in $E^*$ values
Evaluate the determination of $E^*$ for use in operational DOTs

Using existing commercially available equipment
E* Protocol - Overview

- Test 4” diameter – 6” high sample
- 5 Test temperatures
- 6 Load frequencies / temperature
Test Specimen
Coring Apparatus
End Sawing
<table>
<thead>
<tr>
<th>LVDTs per Specimen</th>
<th>Number of Specimens</th>
<th>Estimated Limit of Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>18.0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>13.4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>13.1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>12.0</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>11.5</td>
</tr>
</tbody>
</table>
Load-Test Frame & Environmental Chamber
Table 3. Recommended Equilibrium Times.

<table>
<thead>
<tr>
<th>Specimen Temperature, °C (°F)</th>
<th>Time from room temperature, hrs</th>
<th>Time from previous test temperature, hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 (14)</td>
<td>overnight</td>
<td>-</td>
</tr>
<tr>
<td>4.4 (40)</td>
<td>overnight</td>
<td>4 hrs or overnight</td>
</tr>
<tr>
<td>21.1 (70)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>37.8 (100)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>54.4 (130)</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note that the temperature equilibrium times may vary depending on the type of environmental chamber in use. Some testing laboratories reported as much as 6 hours to reach the equilibrium temperature.*
<table>
<thead>
<tr>
<th>Temperature, °C (°F)</th>
<th>Range, kPa</th>
<th>Range, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 (14)</td>
<td>1400 - 2800</td>
<td>200 - 400</td>
</tr>
<tr>
<td>4.4 (40)</td>
<td>700 - 1400</td>
<td>100 - 200</td>
</tr>
<tr>
<td>21.1 (70)</td>
<td>350 - 700</td>
<td>50 - 100</td>
</tr>
<tr>
<td>37.8 (100)</td>
<td>140 - 250</td>
<td>20 - 50</td>
</tr>
<tr>
<td>54.4 (130)</td>
<td>35 - 70</td>
<td>5 - 10</td>
</tr>
</tbody>
</table>

Note: Axial strain limited to 50 to 150 microstrain
Sample E* Output
Test Date and Time: Tuesday, December 11, 2001, at 4:22pm

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Loading Stress (kPa)</th>
<th>Recoverable axial micro-stain</th>
<th>Permanent axial micro-stain</th>
<th>Dynamic modulus (MPa)</th>
<th>Phase angle (Deg)</th>
<th>Dyn. Modulus/sine (phase angle)</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>293.3</td>
<td>37.7</td>
<td>645</td>
<td>7785</td>
<td>25.07</td>
<td>35873.7</td>
<td></td>
</tr>
<tr>
<td>Cycle #194</td>
<td>303.1</td>
<td>37.7</td>
<td>646</td>
<td>8044.6</td>
<td>24.87</td>
<td>37357.9</td>
<td></td>
</tr>
<tr>
<td>Cycle #195</td>
<td>303.5</td>
<td>37.3</td>
<td>649</td>
<td>8141.9</td>
<td>24.93</td>
<td>37718.8</td>
<td></td>
</tr>
<tr>
<td>Cycle #196</td>
<td>292.9</td>
<td>37.8</td>
<td>650</td>
<td>7752.9</td>
<td>24.64</td>
<td>36329.2</td>
<td></td>
</tr>
<tr>
<td>Cycle #197</td>
<td>298</td>
<td>37.7</td>
<td>652</td>
<td>7911.3</td>
<td>25.27</td>
<td>36174.9</td>
<td></td>
</tr>
<tr>
<td>Cycle #198</td>
<td>298.1</td>
<td>37.6</td>
<td></td>
<td>7927.1</td>
<td>24.96</td>
<td>36690.9</td>
<td></td>
</tr>
</tbody>
</table>

Operator: Jack and Gilbert
Constructed Master Curve

![Graph showing constructed master curve with various temperatures represented by different markers. The graph plots log reduced time versus modulus.

- Diamonds represent 14 °F.
- Squares represent 40 °F.
- Triangles represent 70 °F.
- Crosses represent 100 °F.
- Stars represent 130 °F.

A solid line represents the predicted curve.]
Shift Factor

![Graph showing temperature (°F) vs. log a(T)]
What have we learned to date?

As stated previously, we hope to encounter and overcome any problems with the E* protocol. In other words, we would be in a position to advise DOT personnel on the pitfalls and problems in using this protocol. We have indeed had some problems.
Protocol Changes

Compaction of 7" high - 6" diameter sample was a problem. We finally wound up with a 6.7" high sample which would fit into our Superpave gyratory compactor. An equal amount was sawn from each end to obtain a 6” sample. The tendency for the saw to fray corners was overcome by wrapping two turns of electrical plastic tape around the cut site before sawing.
Compaction & Specimen Tolerances

It turns out that there were several versions of the protocol floating around the United States between 1999 and 2002. On 4/12/02 there was a meeting to consolidate changes and provide a revised protocol for subsequent evaluation. This process was concluded in June 2002 and the resultant protocol used in remainder of the project.
Ruined Sample
Specimen Instrumentation

A template was developed and held in place with rubber bands to overcome alignment problems as gage plugs were glued onto the sides of the test specimen.
Instrumenting Test Specimen
Fabrication & Test Timeframe

- Mix & Compact
- Instrument
- Test
- Construct Master Curve for Mix
Problems with test system

Based on the time to fabricate, prepare, instrument and test the specimens at five temperatures and six frequencies, a single test with two or more specimens will take well over seven full working days to complete. This is a very long time to complete one test. Conditioning the specimens to the test temperature is a big issue. We've also had difficulty in maintaining proper temperature and humidity in the test chamber.
Condensation
Icing Problem
The next slide contains an embedded Microsoft movie. Some older systems may not be able to play this movie.

If viewing these slides as a Powerpoint slide show the movie should start with one mouse click on the movie.

If viewing this in a Powerpoint editing mode then double click on the image.

The movie file is included on this CD. If you are unable to start the movie in Powerpoint then using Windows Media Player the movie should start.

If you need assistance getting the movie to play contact Jim Mahoney at (860) 486-5956
Possible result of Icing
(click image for movie - there is a short pause)
What we’ve learned to date

- Use clamps for coring & sawing
- Use jig to set gage points
- Base temperature on thermal couples in dummy specimens
- Set load for each frequency & temperature
- Test -10C only when humidity is low
E* Round Robin

- NCAT, Western SuperPave Center,
  FHWA, Applied Asphalt Technology

- 6 Universities
  - Arizona State
  - Connecticut
  - Maryland
  - North Carolina State
  - Perdue
  - Washington State
E* Tests of State Mixes

- California
- Connecticut
- Illinois
- Montana
- Nebraska
- Nevada
- North Carolina
Project Completion Date
April, 2003
Thank you for your interest and attention

LIGHTS on PLEASE