Mixing and Compaction Temperatures for Modified Asphalt Binders

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Outline

- Background
- Methods
  - Currently proposed for estimation of temperature
  - High shear or low shear viscosity?
- State of the Practice
- State of research Project NCHRP 9-39
  - NCAT July, 2005 to Dec 2007

Laboratory vs. Construction

- Stated mixing and compaction temperatures are for mix design only. Purpose is to obtain uniformity between laboratories.
- Construction mixing parameters may be established according to ASTM D-2489
- Construction compaction practice may be determined with a test strip.
- Mix design temperatures must not be specified for construction

Current Method and Problems

- Mixing and compaction viscosities of neat asphalts are independent of shear rate
- Viscosities of PMA binders are shear rate dependent
- Binders of the same grade may have different mixing and compaction temperatures
- Mixing viscosity: 170 mm²/sec (cSt)
- Compaction viscosity: 280 mm²/sec (cSt)
- Many modified binders reach these viscosities only at high temperatures when measured with a kinematic viscometer

Problem Statement

- Current method (equiviscous) of unaged binder
  - Mixing viscosity - 170 ± 20 mm²/s
  - Compaction viscosity - 280 ± 30 mm²/s.
- Many modified binders reach these viscosities at very high temperatures leading to degradation or high volatile loss.
- Some binders may clog kinematic tube giving erroneous values.
- PG binders of the same grade do not require the same compaction effort if modified differently.

Problem Statement, Cont.

- Mix Design Laboratories need mixing and compaction temperatures that correlate with construction
  - Different viscometers operate at different shear rates
  - With PMA, each viscometer will give a different result
  - RTFO residue viscosities relate to the in place viscosities from a pug mill mixed at 325°F
  - Residue from a drum mixer has a considerably lower viscosity because:
    - Operated at a lower temperature
    - About 25% lower oxygen content because of burner
    - Further reduction of oxygen partial pressure from moisture
Viscous Modulus, $G''$

$\mu = G'' S/d$

Storage Modulus, $G'$

Complex Modulus, $G^*$

$\delta$

Complex Modulus is the vector sum of the storage and viscous modulus

$d$

$S = $shear rate

$\sin \delta \approx 1$ for neat asphalt

$\sin \delta < 1$ for PMA

Dynamic Modulus (DSR)

Neat Asphalt

PMA

Typical viscosity shear rate dependence @ 320 F, 275 F

Shear Rate dependence of a PG 76-28 binder at 285 F (source: Texas)
**Shear Rate Dependency of Polymer modified binders**

Viscosity Curve @ 329 F

- **Low Shear**
- **High Shear**

Viscosity Curve @ 275 F

**NAPA Mixing Temperature Recommendation**

<table>
<thead>
<tr>
<th>PG Grade</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58-28</td>
<td>261</td>
<td>309</td>
</tr>
<tr>
<td>PG 58-34</td>
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<td>PG 64-22</td>
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<td>320</td>
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<td>PG 64-34</td>
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<td>320</td>
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<tr>
<td>PG 70-28</td>
<td>275</td>
<td>325</td>
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<tr>
<td>PG 76-22</td>
<td>286</td>
<td>334</td>
</tr>
<tr>
<td>PG 76-28</td>
<td>280</td>
<td>331</td>
</tr>
</tbody>
</table>

Reference: NAPA EC101 Best Management Practices to Minimize Emissions During HMA Construction

**A different view: Ranking the flow energy of binders**

- Modify base asphalt, e.g. PG 64-28 (85/100)
- Determine viscosity at several temperatures
- Obtain high shear rate viscosity data
- Determine activation energy from the Arrhenius equation
- Rank binders according to their activation energy for flow

**What is viscosity?**

- Viscosity is resistance to flow
- Intermolecular forces are responsible for resistance to flow
- Viscosity is a non-equilibrium transport process of a fluid
- Energy is needed to overcome resistance to flow

**Simplified distribution**

\[
\eta = Ae^{\Delta F_r / RT}
\]

At temperature increases, the probability of finding molecules at higher energy increases.

This distribution gives the average fraction of molecules with energy greater than \(\Delta E_r\) that is flow and hence workable for compaction.
**Arrhenius Law**

\[
\eta = Ae^{\frac{\Delta E}{RT}}
\]

- \(\Delta E\): Activation Energy
- \(R\): Universal Gas Constant, 8.314 J/mol K
- \(A\): a constant

\[
\ln \eta = \ln A + \frac{\Delta E}{RT}
\]

**Typical Arrhenius plot for binders**

**Activation Energy vs. film thickness**

**Effects of modifier types on the activation energy for flow**

**Activation energy for flow for different asphalt binders**
Effect of aging on the activation energy for flow

Preliminary conclusions

- The presence of shear susceptibility in PMA binder confuses the determination of laboratory mixing and compaction temperatures.
- Mixing and compaction temperatures used for mix design should not be specified for construction.
- It is proposed that the activation energy for flow can be used to better rank binders with respect to rheological properties.
- Air blown asphalts have higher activation energies than similar PG grades.
- Chemically modified binders made from the same base asphalt have activation energies similar to air blown.
- PAV aging increases the activation energy by at least 10 kJ/mole.

Preliminary conclusion, Cont.

- The activation energy for flow for binders should be related to the necessary compaction effort (after the effect of aggregate is taken into consideration).
- The viscosity of the asphalt residue from a drum mixture cannot be predicted from a RTFO test at 325°F.
- The use of activation energy might provide a better procedure for obtaining rational laboratory and field mixing and compaction temperatures.

Thank You!!  Gracias!!

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