Flow Activation Energy: Prediction Model For Compaction Effort

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Outline

- Review current state of the art: $T_{\text{mix}}, T_{\text{comp}}$
- Status of research Project NCHRP 9-39 @ NCAT July, 2005 to Dec 2007
- Kinetic model to predict compaction effort
- $E_f$: Flow activation energy
- $E_f$ binder results: ranking compaction effort
- Conclusions and future research
Current Practice and methods

- Not many issues for unmodified binders
- \( T_{\text{mix}}, T_{\text{comp}} \) procedures per: AASHTO T245/T312; ASTM D2493; binder suppliers
- Low and high shear methods
- Final compaction temperature determined with a test strip.
- \( T_{\text{mix}}, T_{\text{comp}} \) for modified binders from Suppliers
Update from NCAT: NCHRP-9-39*:
Determine $T_{mix}$, $T_{comp}$ for Binders

- Review literature and survey DOT
- Steady Shear flow by DSR to 500 Pa
- High shear viscosity by rotational viscosity
- Evaluate binder phase angle with DSR
- Study 12 binders
- Determine shear resistance of mixes
- Validation and procedure

* Source NCAT/Randy West
Another view on Compaction Effort
Kinetic model (Boltzmann distribution) and viscosity

- Viscosity is resistance to flow.
- Intermolecular forces in liquid asphalt are responsible for resistance to flow.
- Energy is needed to overcome resistance to flow.
- Temperature is the property that tells us the direction of the flow of energy or a measure of the average kinetic energy of molecules.
As temperature increases, the probability of finding molecules at higher energy increases. The Boltzmann distribution can be described by the equation:

$$\eta = Ae^{\frac{\Delta E_n}{RT}}$$
As temperature increases, the probability of finding molecules at higher energy increases.

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

Distribution showing the average fraction of molecules with energy greater than \( \Delta E \) that will flow and hence workable for compaction.

\( \Delta E_\eta \)

\( \Delta E \)

Is the flow activation energy
**Arrhenius Law**

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

\( \Delta E_\eta \): Activation Energy

R: Universal Gas Constant, 8.314 J/mol K

A: a constant

\[ \ln \eta = \ln A + \frac{\Delta E_\eta}{RT} \]
Ranking binders by flow activation energy, $E_f$

- Modify base asphalt, e.g. PG 64-28
- Determine viscosity at several temperatures
- Obtain high shear rate viscosity data
- Determine $E_f$ from the Arrhenius equation
- Rank binders according to their flow activation energy
Typical Arrhenius plot for binders: viscosity measured at 110°C (230°F), 135°C (275°F), 160°C (320°F)
Typical viscosity shear rate dependence @ 320 F, 275 F

Viscosity, mPa s
shear rate (1/sec)

PG 76-28

Neat Asphalt @ 275° F
Arrhenius plot for various binders @110°C(230°F), 135°C(275°F), 160°C(320°F): flow activation energy

\[ \ln(\eta) \text{ (Pa.S)} \]

- PG52-40: 54.55
- PG70-28: 65.90
- PG76-28: 78.82
- 0 - pen: 88.54
Activation Energy vs. "film thickness"

Spindle Size

0.785 mm: 70.3 KJ/mol
1.13 mm: 70.0 KJ/mol
3.65 mm: 69.7 KJ/mol
Effects of modifier types on the $E_f$ for the same grade, PG70-28
Flow activation energy, $E_f$, for different binders relative to PG64-28
Effect of aging on the flow activation energy

- Original
- RTFO
- PAV

<table>
<thead>
<tr>
<th>Material</th>
<th>Original</th>
<th>RTFO</th>
<th>PAV</th>
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<tr>
<td>PG64-28</td>
<td>69.1</td>
<td>74.8</td>
<td>79.6</td>
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<tr>
<td>0-pen</td>
<td>88.5</td>
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<tr>
<td>PG 70-28 (Chemical 1)</td>
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<td>93.1</td>
<td>107.0</td>
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<tr>
<td>PG70-28 (SBS-1R)</td>
<td>70.2</td>
<td>78.2</td>
<td>88.2</td>
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</tbody>
</table>
Conclusions and future research

- The kinetic model (Boltzmann distribution) is proposed as a model for understanding compaction effort of binders.
- The Arrehnius law, $\ln \eta = A + E_f/RT$, is used to obtain $E_f$.
- The magnitude of $E_f$ is governed by the intermolecular forces between molecules of the liquid binder and explains the viscosity differences of binders.
- The use of flow activation energy provides a procedure for predicting rational compaction effort of a mix.
- Shear resistance of the mix obtained from SGC would offer a more complete description of compaction effort.