Visco-Elastic Determination of Laboratory Mix & Compaction Temperatures

Excerpts from NCHRP 9-39 research for discussion

John Casola, Malvern Instruments
&
Randy West, NCAT
Outline

- Introduction
- Review NCHRP 3-39 goals
- Concept of the approach to determine Mix & Compaction Temperatures
- Review some of the data
- Compare predicted results with mix results
Why a new method?

Equi-viscous method to determine Mix & Compaction temperatures has been used for many years and works well with neat, unmodified asphalt binders.
Why a new method?

- Equi-viscous method to determine Mix & Compaction temperatures has been used for many years and works well with neat, unmodified asphalt binders.

- However, engineered binders which are modified are not as easy to predict with this method.
Why a new method?

- Equi-viscous method to determine Mix & Compaction temperatures has been used for many years and works well with neat, unmodified asphalt binders.

- However, engineered binders which are modified are not as easy to predict with this method.

- In fact, using the equi-viscous method generally over predicts the temperatures which would cause over heating of the liquid asphalt binder, destroying the beneficial properties of the modifier.
Equi-Viscous Method
(rotational viscosity or Brookfield test)

![Graph showing viscosity vs. temperature with compaction and mixing ranges marked.](image-url)
Modified have significantly different temperature susceptibility.
Research Approach for 9-39

- Evaluate several binder properties using most promising techniques.

- Determine temperature limits that cause binder degradation and emissions problems.

- Use mix tests to validate mixing and compaction temperatures.

- Use ‘test of reasonableness’ to recommend the best procedure.
Candidate Methods for Determining Mixing & Compaction Temperatures

- High Shear Rate Viscosity (Yildirim, U/Texas)
- Steady Shear Flow (Reinke, MTE)
- Dynamic Shear Rheology (Casola, Malvern)
NCHRP 9-39 Work Plan

Part 1: Binder Testing
- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP

Part 2: Mix Testing
- Mix Coating Tests
- Mix Workability Tests
- Mix Compaction Tests

14 Asphalt Binders

Predict Mix & Compaction Temps
Predict Mix & Compaction Temps
Predict Mix & Compaction Temps
Establish Max Temp to Avoid Emissions
Establish Max Temp to Avoid Degradation

Correlations

Correlations & Reasonableness

Check for Excessive Temps
Determine Minimum Mixing Temps
Determine Intermediate Mix Handling Temps
Determine Compaction Temps Range
Determine Effect of Temps on Mix Props
IDT Creep & Strength Test

Select Best Method

Validation of Method

4 Asphalt Binders

Mix Coating Tests
Mix Workability Tests
Mix Compaction Tests

Draft New Test Method for Establishing Mixing & Compaction Temperatures
Work Plan Involved 14 Binders

14 Asphalt Binders

Part 1: Binder Testing
- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP

Part 2: Mix Testing
- Predict Mix & Compaction Temps
- Correlations & Reasonableness
- Determine Minimum Mixing Temps
- Mix Coating Tests
- Determine Intermediate Mix Handling Temps
- Mix Workability Tests
- Determine Compaction Temps Range
- Mix Compaction Tests
- Determine Effect of Temps on Mix Props
- IDT Creep & Strength Test

Correlations

Select Best Method
- 4 Asphalt Binders

Validation of Method
- Mix Coating Tests
- Mix Workability Tests
- Mix Compaction Tests

Draft New Test Method for Establishing Mixing & Compaction Temperatures
Both Mix Testing & Binder Testing

Part 1: Binder Testing
- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP
- Predict Mix & Compaction Temps
- Determine Minimum Mixing Temps
- Determine Intermediate Mix Handling Temps
- Determine Compaction Temps Range
- Determine Effect of Temps on Mix Props
- Check for Excessive Temps
- Establish Max Temp to Avoid Emissions
- Establish Max Temp to Avoid Degradation
- Correlations & Reasonableness
- Select Best Method
- Validation of Method

Part 2: Mix Testing
- Mix Coating Tests
- Mix Workability Tests
- IDT Creep & Strength Test
- Mix Compaction Tests

14 Asphalt Binders

Draft New Test Method for Establishing Mixing & Compaction Temperatures
Part 1: Binder Testing

- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP

Part 2: Mix Testing

- Mix Coating Tests
- Mix Workability Tests
- Mix Compaction Tests
- IDT Creep & Strength Test

Correlate the Mix & Binder Results

14 Asphalt Binders

Select Best Method

- 4 Asphalt Binders

Draft New Test Method for Establishing Mixing & Compaction Temperatures

Correlations & Reasonableness

Predict Mix & Compaction Temps

Determine Minimum Mixing Temps

Check for Excessive Temps

Determine Intermediate Mix Handling Temps

Establish Max Temp to Avoid Emissions

Establish Max Temp to Avoid Degradation

Determine Compaction Temps Range

Determine Effect of Temps on Mix Props

IDT Creep & Strength Test

Mix Workability Tests

Validate of Method

Mix Coating Tests

Mix Compaction Tests
Ensure Temperatures are in Range

14 Asphalt Binders

Part 1: Binder Testing
- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP

Part 2: Mix Testing
- Predict Mix & Compaction Temps
- Predict Mix & Compaction Temps
- Predict Mix & Compaction Temps
- Establish Max Temp to Avoid Emissions
- Establish Max Temp to Avoid Degradation
- Check for Excessive Temps
- Determine Minimum Mixing Temps
- Determine Intermediate Mix Handling Temps
- Determine Compaction Temps Range
- Determine Effect of Temps on Mix Props
- Mix Coating Tests
- Mix Workability Tests
- Mix Compaction Tests
- IDT Creep & Strength Test

Correlations & Reasonableness

Select Best Method

4 Asphalt Binders

Validation of Method

Draft New Test Method for Establishing Mixing & Compaction Temperatures

Mix Coating Tests
Mix Workability Tests
Mix Compaction Tests

Ensure Temperatures are in Range
Determine the Best Method

Part 1: Binder Testing
- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP

Part 2: Mix Testing
- Mix Coating Tests
- Mix Workability Tests
- Mix Compaction Tests
- IDT Creep & Strength Test

14 Asphalt Binders

Predict Mix & Compaction Temps
Predict Mix & Compaction Temps
Predict Mix & Compaction Temps
Establish Max Temp to Avoid Emissions
Establish Max Temp to Avoid Degradation
Correlations & Reasonableness
Determine Minimum Mixing Temps
Determine Intermediate Mix Handling Temps
Determine Compaction Temps Range
Check for Excessive Temps
Determine Effect of Temps on Mix Props
Select Best Method

4 Asphalt Binders
Validation of Method

Draft New Test Method for Establishing Mixing & Compaction Temperatures
Draft a Procedure

14 Asphalt Binders

Part 1: Binder Testing
- Steady Shear Flow Tests
- Rotational Viscosity Tests
- Dynamic Shear Rheology
- Smoke & Emissions Potential Test
- Grade Binders Before & After SEP

Part 2: Mix Testing
- Mix Workability Tests
- Mix Compaction Tests
- IDT Creep & Strength Test

Predict Mix & Compaction Temps

Correlations & Reasonableness

Determine Minimum Mixing Temps

Determine Intermediate Mix Handling Temps

Determine Compaction Temps Range

Determine Effect of Temps on Mix Props

Select Best Method

4 Asphalt Binders

Validation of Method

Draft New Test Method for Establishing Mixing & Compaction Temperatures
This discussion will focus on DSR method.
# Binders In the Test Plan

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<td>J</td>
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<td>O</td>
<td>I</td>
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- **unmodified grade**
- **modified grade**
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<td>302-313</td>
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<td>307-313</td>
<td>267-273</td>
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<td>L</td>
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<td>H</td>
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<td>71.8</td>
<td>-29.2</td>
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<td>J</td>
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<td>-20.7</td>
</tr>
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<td>K</td>
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<td>L</td>
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<td>Crumb Rubber + SBS</td>
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<td>-25.5</td>
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<td>O</td>
<td>PG 64-28</td>
<td>None</td>
<td>65.6</td>
<td>-29.7</td>
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</tbody>
</table>
Concept

- Use of Visco-Elastic criteria for the ranking & determination of laboratory mix & compaction temperatures.

- Identify a range of temperatures
- Compile a Master Curve via TTS
- Identify a threshold for comparison
  - A clear point where the material is no longer Newtonian
  - Frequency where the Phase angle equals 86°
- Correlate to actual Lab Mix performance
- Compare to Manufactures recommendations
- Compare to EC-101
Some Background On Why This Approach

- Mixing stresses & shear rates are extremely complex.
- The ability to coat & compact differ from Neat to Modified binders.
- Elastic contributions are significantly different in modified binders which is the likely cause of these differences.
- The transition from Newtonian to non-Newtonian behavior would make for an easily identifiable threshold.
- We are unable to clearly see these differences at or around the mixing temperature.
- In order to quantify visco-elastic differences the sample temperature must be lowered.
- Simply put, a phase angle above 86° is considered in the Newtonian region. A Phase Angle of 86° is an easily identifiable transition point of the material exhibiting VE behavior for comparison.
- To see this transition over a reasonable range of frequency, we will investigate the samples at a temperature of 80°C
Dynamic Shear Rheology
Comparing 2 Binders; Neat vs. Modified

![Graph showingDynamic Shear Rheology](image)
Sample A
Frequency Sweeps at Several Temperatures
Asphalt A
Time Temperature Superposition to 80°C
Sample A
Identify Freq at Phase of $86^\circ$ at a Temperature of $80^\circ\text{C}$

Freq = 118.45 rad/sec    Phase = 86.06°    Temp = 80°C
## Comparison of TruGrade vs. DSR

<table>
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<th>Spec Grade</th>
<th>TruGrade</th>
<th>Spec Grade</th>
<th>Freq at 86</th>
<th>Type</th>
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<td>C PG 70-34</td>
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<td>C PG 70-34</td>
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<td>H PG 76-22</td>
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</table>
Mix Testing Performed by NCAT

Mix Coating Tests

- Lab Pugmill Mixer and Bucket Mixer to simulate Batch Plant and Drum Plant Mixing
- Mix binders with a standard aggregate blend at four temperatures for a set time
- Rate aggregate coating percentage
Mix Workability Test

\[ y = 0.0004x^3 - 0.1377x^2 + 14.446x - 131.98 \]

\[ R^2 = 0.8169 \]
Mix Compactability

- Four compaction temperatures
- Use SGC at low gyrations to amplify effect of binder stiffness

Diagram:
- Compaction Resistance vs. Temperature
  - Binder A
  - Binder B
  - Binder C

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Estimated Mix Temperature Chart

![Temperature vs. Frequency Graph](image)
Model the relationship

Mixing Temperature (°F) = 325ω⁻⁰.⁰₁³₅
(°C) = 163ω⁻⁰.⁰₁₃₅

Compaction Temperature (°F) = 300ω⁻⁰.⁰₁²
(°C) = 149ω⁻⁰.⁰₁²

where ‘ω’ is the frequency in rad/s where the measured phase angle equals 86° at a temperature of 80°C
## Predicted Mix & Compaction Temperatures

<table>
<thead>
<tr>
<th>Binder ID</th>
<th>Performance Grade</th>
<th>Modification</th>
<th>TruGrade High</th>
<th>TruGrade Low</th>
<th>Frequency at T=80°C, δ=86°</th>
<th>Mix Temp (°F)</th>
<th>Compaction Temp (°F)</th>
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<tr>
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</table>
EC-101 Recommendations

![EC-101 Recommendations Graph]

- **Mix Temperature**
  - Min EC101
  - Max EC101
  - Midpoint EC101
  - Poly. (Midpoint EC101)

- **Grade**
  - 46
  - 52
  - 58
  - 64
  - 70
  - 76
  - 82

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Comparison to Manufacturer’s Recommendations

Predicted vs. Mfg

Temperature (F)

Sample

B C D E F G H I J K O

Min Mfg Max Mfg Predicted
### Summary of Results

**Compare to Equi-Viscous Method**

<table>
<thead>
<tr>
<th>Row</th>
<th>Binder I.D.</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>M</th>
<th>N</th>
<th>O</th>
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<tbody>
<tr>
<td>1</td>
<td>True PG</td>
<td>69.3-</td>
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<td>Modification Type</td>
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<td>Air Blown</td>
<td>none</td>
<td>SBS+PPA</td>
<td>SBS</td>
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<td>none</td>
<td>Sase-flex</td>
<td>SBS</td>
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</table>

**Table 7. Summary of Binder and Mixture Experiment Results for Mixing and Compaction Temperatures, °F**

- **Equiviscous Mix. Temp.**
  - 354
  - 388
  - 295
  - 293
  - 320
  - 379
  - 365
  - 333
  - 295
  - 295
  - 372
  - 433
  - 318

- **DSR Mix Temp.**
  - 310
  - 315
  - 296
  - 299
  - 297
  - 321
  - 315
  - 307
  - 291
  - 290
  - 319
  - 301

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## Summary of Results

**Compare to Mix & Compaction Results**

### Table 7. Summary of Binder and Mixture Experiment Results for Mixing and Compaction Temperatures, °F

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<th>Row</th>
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<th>M</th>
<th>N</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>69.3-37.3</td>
<td>75.1-38.9</td>
<td>60.3-31.7</td>
<td>60.9-33.1</td>
<td>67.8-23.5</td>
<td>82.5-24.5</td>
<td>78.3-27.7</td>
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<td>85.4-19.4</td>
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<td>65.6-29.7</td>
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<tr>
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<td>70-34</td>
<td>68-28</td>
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<td>Modification Type</td>
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### DSR Mix Temp.

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<th>291</th>
<th>290</th>
<th>319</th>
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<tbody>
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<td>361</td>
<td>322</td>
<td>244</td>
<td>243</td>
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<td>334</td>
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<tr>
<td>Bucket Mix. Temp for 97% Coating</td>
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<td>277</td>
<td>280</td>
<td>302</td>
<td>327</td>
<td>378</td>
<td>284</td>
<td>302</td>
<td>291</td>
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<tr>
<td>Max. Temp. for 5% Opacity</td>
<td>343</td>
<td>283</td>
<td>336</td>
<td>322</td>
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<td>&gt;374</td>
<td>330</td>
<td>305</td>
<td>311</td>
<td>323</td>
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<td>&gt;374</td>
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# Summary of Results

Compare to Mix & Compaction Results

## Table 7. Summary of Binder and Mixture Experiment Results for Mixing and Compaction Temperatures, °F

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<tr>
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<td>SBS+PPA</td>
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<table>
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<th>296</th>
<th>299</th>
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<th>321</th>
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<td>334</td>
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<tr>
<td>11</td>
<td>Bucket Mix. Temp for 97% Coating</td>
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<td>277</td>
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<td>327</td>
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<td>381</td>
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<td>12</td>
<td>Max. Temp. for 5% Opacity</td>
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<table>
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<th>276</th>
<th>276</th>
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<th>291</th>
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<th>270</th>
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<td>16</td>
<td>Comp. Temp. for 92.9%Gmm</td>
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<td>417</td>
<td>354</td>
<td>257</td>
<td>317</td>
<td>345</td>
</tr>
</tbody>
</table>
Regarding the Comparison to Industry Guidelines

- Everything fell within the EC-101 Guidelines.
  - Not a very useful method for first approximation

- Most of the predicted mix temperatures fell within the Manufacturer’s guidelines which, are a much narrower temperature range to that of EC-101.

- Of those that fell outside of the Mfg’s guidelines:
  - all predicted temperatures were lower.
In Summary

- Initial review appears to rank and predict within reason.

- Some of the samples were predicted to be lower than the Mfg’s recommendations.

- Conclusion of the project is nearing with a formal report to follow.

- Testing is quick & easy
Thank you for your time

Questions!

- 973-740-1543
- john.casola@malvern.com