Variability of Ignition Furnace Correction Factors (NCHRP 9-56)

Carolina Rodezno

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Outline

- Background
- Objectives
- Methodology
- Experimental Plan Results
- Conclusions
- Recommendations/Current Research
Background

- Accurate determination of AC and aggregate gradation critical in control of quality of asphalt mixtures during construction
- Ignition method widely used to determine AC and gradation

**Basic Procedure:**
- Oven uses high temp. to burn asphalt off aggregate
- Procedure terminates when weight of sample stabilizes—indicating there is no more binder to ignite
- CF needed to account for difference between known binder content and ignition test results
Background

Ignition method (AASHTO T 308) and solvent extraction (AASHTO T 164) are the most common methods to measure AC condition. The table below shows the standard deviation and acceptable range of two tests for single operator and multilaboratory conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Standard Deviation</th>
<th>Acceptable Range of Two Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T 308</td>
<td>T 164</td>
</tr>
<tr>
<td><strong>Single Operator Precision: AC (%)</strong></td>
<td>0.069</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Multilaboratory Precision: AC (%)</strong></td>
<td>0.117</td>
<td>0.29</td>
</tr>
</tbody>
</table>
Background

- Share CFs is a practice by some agencies
- Approach violates AASHTO T 308 which indicates CF must be established for each mix and ignition unit
- Some states have aggregates with high mass loss and don’t allow use of ignition tests
- States like Indiana and Wisconsin have reported problems with aggregates such as dolomites
- High CFs result in more variability in measured AC content
Background

*Temperature effect (Kowalski et al, 2010)*

- High temp. during ignition produced decomposition which causes mass loss to continue after binder is burned off
- Mass loss $f$(test temp), higher loss as temp. increases
- Higher test temperature, sooner oven temp. exceeded target and sooner temp peaked
- Decreasing temp. has a significant effect on mass loss and rate of mass loss
**Background**

**Lime effect (Prowell and Youtcheff, 2000)**

- Hydrated lime has a significant effect on CF
- Lime addition decreases CF; CF varied from 0.64 with no hydrated lime to 0.13 with 2% hydrated lime
- Variability reported large enough to cause non-compliance with quality control tests according to VDOT’s specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Average</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5.84</td>
<td>0.64</td>
</tr>
<tr>
<td>+0.5% hydrated lime</td>
<td>5.64</td>
<td>0.44</td>
</tr>
<tr>
<td>+1% hydrated lime</td>
<td>5.47</td>
<td>0.27</td>
</tr>
<tr>
<td>+2% hydrated lime</td>
<td>5.33</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Objectives

- Assess the variability of ignition oven CFs for different ignition brand and mixes
- Evaluate effect of sharing CFs between units
- Evaluate alternatives to minimize variability on asphalt CFs
Methodology

Project encompassed three tasks:

- Survey directed to state DOT and industry, regarding practices (units used, typical CFs) and factors affecting CF with ignition furnaces (temperature, use of hydrated lime, aggregate geology)
- Sensitivity study at NCAT
- Interlaboratory study - Troubleshooting outliers
Agency/ Contractor Survey

- Insight and concerns regarding use of ignition test
- 60 agency responses representing 42/50 US states, 7/10 Canadian provinces and federal lands
- Additional 37 responses from contractors and 7 responses from testing labs
Ignition Furnace Types

- 93.3% - use internal balances
- 56.3% indicated differences in CF with different brands, models or locations
Factors Affecting Ignition Furnace CF

- 92.2% aggregate type significant, follow by test temperature, AC content and use of hydrated lime
- Samples with higher AC/larger samples → more asphalt to burn → higher peak test temperature
- Other factors: RAP/RAS; length of vent pipe, cleanliness of oven, how baskets are loaded

![Bar Chart]

- Hydrated lime: 14.4%
- Asphalt content: 21.1%
- Test temperature: 37.8%
- Aggregate type: 92.2%
Frequency at which CF are Determined/Reevaluated

- More than once a year: 18.6%
- Once a year: 48.8%
- Once every two years: 8.1%
- Longer than two years: 7.0%
- Correction factors are not reevaluated: 17.4%
Typical Sample Burn Times

- < 30 minutes: 7.1%
- 30 minutes - 1 hour: 90.6%
- 1 hour - 1 hour 30 minutes: 9.4%
- > 1 hour 30 minutes: 0.0%
Typical Asphalt Content CF Range

- Majority indicated CF <1
- Some agencies identified CF >1 is common
- Granite, gravel and limestone most common aggregates
## Aggregates/Mixes

Four Aggregates/Mixes, 12.5mm NMAS; PG 67-22

<table>
<thead>
<tr>
<th>Aggregate / Mix</th>
<th>Aggregate Description</th>
<th>Source</th>
<th>Optimum AC %</th>
<th>Expected CF Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limestone and Granite</td>
<td>Calera, AL</td>
<td>5.2</td>
<td>0.0 - 0.5</td>
</tr>
<tr>
<td>2</td>
<td>Limestone and Granite with 1% Lime</td>
<td>Calera, AL</td>
<td>5.2</td>
<td>0.0 - 0.5</td>
</tr>
<tr>
<td>3</td>
<td>Limestone</td>
<td>Barbeau, MI</td>
<td>6.2</td>
<td>0.5 - 1.0</td>
</tr>
<tr>
<td>4</td>
<td>Dolomite</td>
<td>Delphi, IN</td>
<td>6.1</td>
<td>1.0 - 3.0</td>
</tr>
</tbody>
</table>
## Sensitivity Study at NCAT Lab

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovens</td>
<td>Thermolyne, Troxler, Gilson</td>
</tr>
<tr>
<td>Test Temperature</td>
<td>800°F, 1000°F (Default, Option 1 for Troxler)</td>
</tr>
<tr>
<td>Air Flow</td>
<td>30% Open, 100% Open</td>
</tr>
<tr>
<td>Sample Mass</td>
<td>1500, 2000 grams</td>
</tr>
<tr>
<td>AC Content</td>
<td>Optimum AC -1%, Optimum AC +1%</td>
</tr>
</tbody>
</table>
Sensitivity Study

- Primary factor affecting the asphalt CF was the test temperature.
- Decreasing the test temperature from 1000 °F to 800°F decreases the aggregate mass loss for all mixes that do not contain lime.
# Experimental Plan-Interlaboratory Study

<table>
<thead>
<tr>
<th>Labs</th>
<th>18 DOT agencies; 5 Contractors/Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven brand</td>
<td>17 Thermolyne, 8 Troxler, 3 Gilson</td>
</tr>
<tr>
<td>Number of Mixes</td>
<td>Four mixes at their optimum asphalt content</td>
</tr>
<tr>
<td>Test temperature</td>
<td>1000°F (mixes 1-3) and 900°F (mix 4) for convection units (Thermolyne, Gilson); default and option 1 for infrared unit (Troxler)</td>
</tr>
<tr>
<td>Replicates</td>
<td>3 per mix</td>
</tr>
</tbody>
</table>
Interlaboratory Study Results
Asphalt Content CFs - Mix 1

Average = 0.11
Min. = -0.66
Max. = 0.62
Asphalt Content CFs - Mix 2

Average = -0.23
Min. = -0.67
Max. = 0.18

Thermolyne

Gilson

Troxler
Asphalt Content CFs-Mix 3

Average=0.92
Min. =0.55
Max.=1.51
Asphalt Content CFs - Mix 4

Average = 1.25
Min. = -1.57
Max. = 3.58
Interlab. Study Data Analysis

- Test results analyzed per ASTM E 691
- k and h statistics to evaluate consistency of results and possible outliers
  
  \[ k = \text{indicator of how laboratory variability compared with that of other labs} \]
  
  \[ h = \text{indicator of how laboratory average compared with that of other labs} \]

- Critical k and h values recommended in standard
- Each mix test results analyzed separately
k Statistics-Mix 3
(ASTM E 691)

Critical value = 2.22

Lab 17-TH
k value = 2.4 > k critical = 2.22
Thermolyne

Lab 1-TH  Lab 2-TH  Lab 3-TH  Lab 4-TH  Lab 5-TH  Lab 6-TH  Lab 7-TH  Lab 8-TH  Lab 9-TH  Lab 10-TH  Lab 11-TH  Lab 12-TH  Lab 13-TH  Lab 14-TH  Lab 15-TH  Lab 16-TH  Lab 17-TH

Critical value = 2.63

Critical value = -2.63
## Precision Statistics-Interlaboratory Study

<table>
<thead>
<tr>
<th>Mix #</th>
<th>Actual AC %</th>
<th>Measured AC%</th>
<th>CF</th>
<th>$s_r$</th>
<th>$s_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.2</td>
<td>5.32</td>
<td>0.12</td>
<td>0.089</td>
<td>0.131</td>
</tr>
<tr>
<td>2</td>
<td>5.2</td>
<td>4.97</td>
<td>-0.23</td>
<td>0.074</td>
<td>0.111</td>
</tr>
<tr>
<td>3</td>
<td>6.2</td>
<td>7.08</td>
<td>0.90</td>
<td>0.112</td>
<td>0.264</td>
</tr>
<tr>
<td>4</td>
<td>6.1</td>
<td>7.31</td>
<td>1.21</td>
<td>0.178</td>
<td>0.403</td>
</tr>
<tr>
<td><strong>AASHTO T 308</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.069</strong></td>
<td><strong>0.117</strong></td>
</tr>
</tbody>
</table>
## Troubleshooting Outliers from Interlab. Study

**Objective:** Team visit labs to conduct additional testing, document specifics about tests to determine reasons for the differences in CF

<table>
<thead>
<tr>
<th>Mix</th>
<th>Lab</th>
<th>k-value</th>
<th>h-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lab 4-TX</td>
<td>3.4</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Lab 21 TX</td>
<td>3.2</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>Lab 4-TX</td>
<td>4.1</td>
<td>-2.8</td>
</tr>
<tr>
<td></td>
<td>Lab 21 TX</td>
<td>0.4</td>
<td>2.66</td>
</tr>
<tr>
<td>3</td>
<td>Lab 17-TH</td>
<td>2.4</td>
<td>1.69</td>
</tr>
<tr>
<td>4</td>
<td>Lab 16-GS</td>
<td>4.6</td>
<td>-4.1</td>
</tr>
<tr>
<td></td>
<td>Lab 21-TX</td>
<td>3.1</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>Lab 23-TX</td>
<td>1.1</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Critical values:** 2.22, 2.59
Observations from Outlier Study

• Equipment was not functioning correctly
• Equipment was not set up correctly or test procedures not followed
• Need good procedure to validate proper equipment operation
• Need good guidance for when and how to properly maintain equipment
• Need to participate in routine interlaboratory testing
Conclusions

• Study suggested that different precision statements may be necessary for aggregates with higher CFs
  • For mixes 1 and 2 within-lab and between-lab $\sigma$ similar to AASHTO T 308
  • For mixes 3 and 4 as CF increased $\sigma$ also increased
• It also suggests that precision statement in AASHTO T 308 was developed with low mass loss aggregates and are not applicable to aggregates with higher mass loss
Conclusions

- Although not recommended in AASHTO T 308, sharing CFs among different ignition furnaces appears acceptable for low CF aggregates.
- Amount of lime has to be closely controlled during production otherwise this will affect the CF and result in incorrect AC content.
- For mixes that do not contain lime, test conducted at 800°F significantly reduced asphalt CF, particularly for high loss aggregates.
Conclusions

- Causes of differences in CF from troubleshooting study were primarily related to wrong equipment settings or other equipment issues.
- Key product of this research is a Standard Practice for Installation, Operation, and Maintenance of Ignition Furnaces (AASHTO R96-19).
Recommendations/Additional Work

- Conducting ignition test with mixes containing high recycled materials content at 800°F, will allow more accurate determination of AC.

- Additional work in progress as part of NCHRP 9-56A:
  - Assess the variability of asphalt CFs for mixes containing significant amounts of recycled materials compared to those with virgin binder and aggregate only.
  - Evaluate effect of reducing the test temperature of the AASHTO T 308 method to 800°F.
  - Interlaboratory study to establish a new precision statement for AASHTO T 308.
Acknowledgment

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Thank you!
Questions?