Comparison of Fresh Air Content Test Methods and Analysis of Hardened Air Content in Wisconsin Pavements

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Motivation

• Increasing disparities between pressure meter readings and ASTM C457-measured air voids
• Perceptions that new synthetic air entraining agents are not as robust as vinsol resin
• AEA dosing is drifting toward trial-and-error
• Air void systems and durability becoming more uncertain/variable
Motivation

• AEA’s are chemical surfactants that interact with other organic additives
  • Chemical reactions dictate the stabilization of the bubbles, the distribution of bubble sizes and the characteristics of the shell around the air bubble.

• Since concrete samples are to be collected from field work there will be many uncontrolled and even unknown variables.

• Influence of paver further adds to the uncertainty of the final air void system.

• Need to collect as many samples as possible.
Experiments - Objectives

• Identify and characterize the problem
  • Measure
    • ASTM C231B – Fresh concrete air content by pressure meter
    • ASTM C138 – unit weight with air content determination
    • ASTM C173 – volumetric air content
    • ASTM C457 – Method A – Linear traverse
  • Compare
    • Total air content ASTM C231B (AASHTO T152) vs ASTM C457
    • ASTM C138 (AASHTO T121) – unit weight vs C457 air content
    • ASTM C173 (AASHTO T196) - volumetric air content vs ASTM C457
    • Resulting variability's by AEA brand and mix type
    • Air content in front of and behind the paver
Experiments – Project Geography
### Experiments - Project matrix

<table>
<thead>
<tr>
<th></th>
<th>Crushed stone</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projects visited</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Sample sites per project</td>
<td>2</td>
<td>2-4</td>
</tr>
<tr>
<td>Unique samples taken per site</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>(2 cylinders &amp; 1 core)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total ASTM C457 tests</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>from cylinders and cores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASHTO T121 (Gravimetric)</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>AASHTO T152 (Pressure)</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>AASHTO T 196 (Volumetric)</td>
<td>32</td>
<td>20</td>
</tr>
</tbody>
</table>
Experiments - Field Sampling

Plan view of slipform paver

Concrete materials

Spreading auger

Working Direction 

Core

Sample Locations
Results - Pressure vs ASTM C457

![Graph showing relationship between pressure and ASTM C457 results.](image)

Fig. 3-6. Relationship between fresh and hardened concrete air contents. Nagi and Whiting 1994. (# SK20602)
Results - Volumetric vs ASTM C457

The graph compares the air content by volumetric method against the air content of hardened cylinders. The points are categorized into 'In front of paver', 'Behind paver', and the line of equality. The data points show a trend where the air content by volumetric method generally matches the air content of hardened cylinders, with a slight variation above the line of equality.
Results - Pressure: front vs back

![Graph showing the relationship between air content at the front of the paver and behind the paver, with a scatter plot and a trend line.](image-url)
Results - Hardened air: front vs back vs core

Air Contents: Cylinders vs Core

Air Content, %

Site ID

Front
Back
Core
Results - Hardened air: front vs back vs core

Air Contents: Cylinders vs Core

Air Content, %

Site ID

Front
Back
Core
Results - Hardened air: front vs back vs core

Void Frequency: Cylinders vs Cores

Void Frequency, voids/in

Site ID

Front
Back
Core
Results - Summary

• Differences in air content between pressure meter and C457 cylinders are within ±2% air. This is comparable to literature (Whiting and Nagi, 1998)
• Differences in air content between volumetric meter and C457 cylinders are mostly within ±2% air.
• In most cases, cores have higher hardened air content than both front and back cylinders
  • Core – front cylinder = -2.1 to 4.6% (mean = +1.1%)
  • **Core – back cylinder = -0.7 to 4.3% (mean = +1.6%)**
Questions for us

1. **Air in cores > Air in front cylinders:**
   - Paving process increased air
   - Or cylinder sampling process removes air – bubbles unstable

2. **Air in cores > Air in back cylinders:**
   - Air increased during setting of concrete – bleeding process and air movement
   - Or cylinder sampling process removes air – bubbles unstable.
Mechanisms of air void changes in fresh concrete

<table>
<thead>
<tr>
<th>No.</th>
<th>Mechanisms</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coalescence and escape of air bubbles, mostly due to vibration (Fagerlund, 1990)</td>
<td>Less air voids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduced air content</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small change in spacing factor</td>
</tr>
<tr>
<td>2</td>
<td>Dissolution of air from small bubbles into solution and into larger bubbles due to thermodynamic inequilibrium (Mielenz et al., 1958) (Fagerlund, 1990)</td>
<td>Less air voids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased (possibly decreased) air content</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased spacing factor</td>
</tr>
<tr>
<td>3</td>
<td>Entrainment of new air bubbles due to paving operations and availability of AEAs (Eickschen, 2012)</td>
<td>More air voids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased air content</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased spacing factor</td>
</tr>
</tbody>
</table>
Hypotheses for increased air content in cores

1. **Rearrangement of bubble sizes.** Air migrates from small bubbles into larger bubbles due to difference in internal pressures in the bubbles. When air moves from a higher pressure to a lower pressure, it expands, resulting in increased total air content.
Hypotheses for increased air content in fresh concrete

2. **AEA was not fully activated when concrete arrived at site.** Agitation/vibration of slip-form paver may have reactivated AEA and created more air bubbles. Possible causes:
   - Short mixing time
   - High dosage of synthetic AEA

Note: This is more likely to occur with synthetic AEAs because of their high solubility in CaOH solution; whereas Vinsol Resin AEA quickly reacts with CaOH solution in concrete and produces insoluble precipitate.
Approach for solution

1. Evaluating the hypotheses through:
   • Detailed analysis of changes in void size distribution and other parameters (spacing factor, surface area, ...)
   • Identifying any correlation between the changes in air voids and design/construction parameters (AEA type, mixing time, type of hauling trucks, type of paver, ...)

2. Additional laboratory experiments to:
   • Verify the hypotheses
   • Verify/Identify factors affecting the changes in air voids
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