Positive proof of global warming.


Flat, Black, Beautiful
6 Months Later
End of Load Segregation
WHY?

THERMAL SEGREGATION
Temperature Differentials
- WDOT & University of Washington-1996
  Stephen Read/Dr. Joe Maloney
- Lead states of Washington, Texas, Minnesota
- Specs in Washington, Arkansas, Texas, Massachusetts, Missouri, South Dakota, South Carolina, Ontario, Illinois, etc. (26 states)
- Increased Interest (Auburn, Clemson, & TTI)
- ROADTEC Research-Technical Assistance

The Problem
- Localized “spots” of coarse surface texture
- Premature failure due to fatigue cracking, raveling, and moisture damage
- Increased roughness
The Problem

- Cooling of mix during transport is not remixed during the laydown process.
- Results in erratic mat temperatures that are not apparent to the laydown crew. (Unseen)

Damage Mechanism

- Placement of this cooler HMA creates pavement areas near cessation temperature (about 175°F)
- No significant compaction occurs below cessation temperature

Effects on Pavement
What Are We Trying to Avoid?

- Cool area – usually seen in a cyclic pattern.
- Streak – either down the center of the paved lane or either side of center.

Effects on Pavement

- Insufficient compaction
  - Increased raveling and moisture damage
  - Reduced fatigue life
  - Increased roughness
- One percent increase in air voids results in a minimum of ten percent reduction in pavement life (a rule of thumb)

3/8" HMA APA Fatigue Results

![Graph showing the relationship between compaction temperature and APA cycles to failure.](image)

Courtesy of PTI and Ron Collins
Time Line for Temperature and Density Differentials—Washington State

- 1998: Four paving projects examined
- 1999: Approximately 40 paving projects examined
- 2000: Eighteen paving projects examined
- 2001-2006: Continued field monitoring and the development and evolution of specifications to address the problem

1998 Study Objectives

- Are WSDOT dense-graded mixes experiencing aggregation segregation, temperature differentials resulting in higher air voids, or a combination thereof?
- What specific roles do mix temperature differentials play in the “cyclic segregation” problem?

Study Description

- Four WSDOT paving projects—summer 1998
- Use infrared camera (provided by Astec Industries) and material tests by WSDOT Mat Lab
- Look for segregation
- Look for temperature differentials
- Measure effects
1998 Conclusions

- None of the 4 projects experienced significant aggregate segregation.
- All 4 projects experienced significant temperature differentials.
- Concentrated areas of significantly cooler HMA generally resulted in lower than desirable compaction of those areas.

1998 Conclusions (cont.)

- Concentrated areas of cooler HMA commonly occur during construction (based on this study and others).
- Good rolling practices can partially offset temperature differential related compaction problems.
- MTVs not specifically examined.
- Temperature differentials are easily identified by infrared imaging.

1999 Study Objectives

- Investigate the effectiveness of different MTVs and remixing devices/methods
- Investigate other possible mitigation techniques
- Reexamine criteria for when and where to use MTVs
Data Collected

- Haul distance and time
- Weather conditions
- Equipment
  - Type of truck
  - MTV/MTD
  - Paver
  - Roller
- Nuclear density data
- Temperature data
  - Infrared camera
  - Probes
  - Hand held infrared thermometer
- Plant information
  - Temperature of mix
  - Loading operations
- Mat Placement

End Dump/No MTV

End Dump/No MTV
Summary of Findings—1999

- Large temperature differentials were observed under a variety of paving conditions.
- Generally, the higher the temperature differentials, the higher the as-compacted air voids associated with the cooler portions of the mat.
- Temperature differentials generally decreased when the air temperature $\geq 85 \, ^\circ F$ (limited data).
- Large temperature differentials occurred over a wide range of pavement surface temperatures.
Temperature Differential Spots

-10 ft 0 ft 10 ft 20 ft 30 ft 40 ft

Longitudinal Profile Line

Location of nuclear density tests

Direction of paving

Passing Density Profile

<table>
<thead>
<tr>
<th>Average</th>
<th>(\Delta T=29^\circ F) Readings (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>134.6</td>
</tr>
<tr>
<td>Maximum</td>
<td>135.4</td>
</tr>
<tr>
<td>Minimum</td>
<td>133.5</td>
</tr>
<tr>
<td>Ranges</td>
<td>1.9</td>
</tr>
<tr>
<td>Max-Min</td>
<td>1.9</td>
</tr>
<tr>
<td>Ave-Min</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Failing Density Profile

<table>
<thead>
<tr>
<th>Average</th>
<th>(\Delta T=66^\circ F) Readings (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>128.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>133.5</td>
</tr>
<tr>
<td>Minimum</td>
<td>121.9</td>
</tr>
<tr>
<td>Ranges</td>
<td>11.6</td>
</tr>
<tr>
<td>Max-Min</td>
<td>11.6</td>
</tr>
<tr>
<td>Ave-Min</td>
<td>6.6</td>
</tr>
</tbody>
</table>
End Dump/No MTV

- Density Profile #1
- Readings
  - Average 152.7
  - High 156.4
  - Low 149.8
- Ranges
  - High – Low = 6.6
  - Ave – Low = 2.9
- $\Delta T = 48^\circ F$

End Dump/Roadtec Shuttle Buggy

- Density Profile #3
- Readings
  - Average 140.7
  - High 142.9
  - Low 138.4
- Ranges
  - High – Low = 4.5
  - Ave – Low = 2.3
- $\Delta T = 11^\circ F$

Summary of Findings—2000

- In general, the occurrence of temperature differentials decreased when compared to the 1999 data (more transfer devices used)
- The higher the temperature differentials, the higher the in-place air voids associated with the cooler portions of the mat
- Temperature differentials decreased when remixing occurred
Summary of 1999-2000 Projects

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Number of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTVs</td>
<td>22</td>
</tr>
<tr>
<td>Windrow Elevators</td>
<td>20</td>
</tr>
<tr>
<td>No MTV/End Dumps</td>
<td>9</td>
</tr>
<tr>
<td>Other Combinations</td>
<td>2</td>
</tr>
</tbody>
</table>

Summary of 1999-2000 Projects

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Normal</th>
<th>Cool</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No MTV</td>
<td>0</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Blaw-Knox MC-30</td>
<td>3</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Paddles working</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Paddles not working</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Roadtec Shuttle Buggy</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Cedarapids MS-3</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Cedarapids MS-2</td>
<td>6</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Other Windrow Elevator</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>CMI MTP-400</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Windrow Elevator/MC-30</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

"Cool" defined as $\Delta T > 25^\circ F$

Bottom Line 1999-2000 Projects

- Temperature and density differentials can be a significant issue on paving projects.
- Approximately $\frac{1}{2}$ of projects (28 out of 53) studied during 1999 and 2000 regularly had temperature differentials $\geq 25^\circ F$.
- Following three years of data collection and analyses, differential densities resulting from cooler than desirable mix can be significant. How significant?
1999 Study Objectives

- Investigate the effectiveness of different MTVs and remixing devices/methods
- Investigate other possible mitigation techniques
- Reexamine criteria for when and where to use MTVs

Bottom Line 1999-2000 Projects

- How significant is the problem?
- Densities 3 pcf less than the density lot mean result in an air void increases of about 2%.
- The following table provides examples:

<table>
<thead>
<tr>
<th>Percent of Rice Density Mean</th>
<th>Mix Air Voids @ Density Mean</th>
<th>Mix Air Voids @ Mean - 3 pcf</th>
<th>Mix Air Voids @ Mean - 6 pcf</th>
</tr>
</thead>
<tbody>
<tr>
<td>95%</td>
<td>5.0%</td>
<td>7.0%</td>
<td>9.0%</td>
</tr>
<tr>
<td>94%</td>
<td>6.0%</td>
<td>8.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>93%</td>
<td>7.0%</td>
<td>9.0%</td>
<td>11.0%</td>
</tr>
<tr>
<td>92%</td>
<td>8.0%</td>
<td>10.0%</td>
<td>12.0%</td>
</tr>
</tbody>
</table>

(1) Assumed Rice Density of 155 lb/ft³; (2) Long Term WSDOT Average 92.7%
A number of State DOTs have developed and implemented specifications to address this issue.

WSDOT’s current specification
- Cyclic density areas are defined as less than 99.0 percent of maximum density.
- If four or more low cyclic density areas are identified in a lot, a price adjustment will be assessed for that lot (a lot is 400 tons).
- The price adjustment will be calculated as 15% of the unit bid price of HMA represented by that lot.
- This assessment starts with examining the mat for temperature differences of 25°F or greater. If these do not exist, then no further special density testing is performed.

Washington Conclusions 2009
- Survey results of DOT & Contractors—Use of MTV greatest improvement in quality.
- Temperature testing and MTV use increased life of HMA by 50%
- All 2010 projects require use of MTV
Segregation Free area

Spot 1
226.0

Spot 2
224.5

Spot 3
214.2

Spot 4
206.5

Spot 5
297.2

“Birth of a Pot Hole”
MAT BEHIND CATERPILLAR 1055B PAVER

MAT BEHIND CEDARAPIDS 551 REMIX PAVER

Last 10 feet of windrow
Thermal Segregation

- 20° Differential-1% to 2% Air Voids
- Over 7% Air Voids Reduces Life
- Each 1% Over-Reduces Life 10%

3/8" HMA APA Fatigue Results

Courtesy of PTI and Ron Collins

Alaska Overlay w/o MTV

[Image of FLIR thermal image]
Fairbanks Airport/Shuttle Buggy

UPDATE

- **TTI** - Research on thermal segregation---Tom Scullion/Steve Sebeste
- **Auburn** ---Dr. M. Stroup-Gardiner
- **TRB** Report---“Initial Ride Quality of HMA Pavements”
- **Clemson** ---Dr. Serji A. Amirkhanian

TTI Development Team

Tom Scullion
Wenting Liu
Gerry Harrison
Real Time Thermo-imaging in Texas

TTI

Sensor Bar

MLS Test Pad Ty D sample IR data
**CONCLUSION:**

- Initial Ride Quality can be improved by minimizing stops and including a material transfer device.
- When used properly, MTV's improved the ride quality and eliminated thermal & physical segregation.
- Results show no significant thermal segregation when a material transfer device was used.

**SAVINGS**

- Eliminate Truck Delay
- Reduce Trucking Costs (25%)
- Increase Productivity (25%)
- Smoother Roads

**OWNERSHIP:**

<table>
<thead>
<tr>
<th>Purchase Price</th>
<th>$375,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% Residual Value</td>
<td>$75,000</td>
</tr>
<tr>
<td><strong>NET:</strong></td>
<td>$300,000</td>
</tr>
<tr>
<td>5 Year Depreciation</td>
<td>$60,000</td>
</tr>
<tr>
<td>1% Annual Insurance</td>
<td>$3,000</td>
</tr>
<tr>
<td>1% Tax</td>
<td>$3,000</td>
</tr>
<tr>
<td><strong>Annual TOTAL:</strong></td>
<td>$66,000</td>
</tr>
</tbody>
</table>

**Hourly Cost Based**

<table>
<thead>
<tr>
<th>500 hrs</th>
<th>750 hrs</th>
<th>1000 hrs</th>
<th>1200 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$132.00</td>
<td>$119.00</td>
<td>$106.00</td>
<td>$93.00</td>
</tr>
</tbody>
</table>
### Operational Costs

<table>
<thead>
<tr>
<th>Category</th>
<th>Rate ($/hr)</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor: Operator</td>
<td>$20.00</td>
<td>20.00</td>
</tr>
<tr>
<td></td>
<td>$20.00</td>
<td>20.00</td>
</tr>
<tr>
<td></td>
<td>$20.00</td>
<td>20.00</td>
</tr>
<tr>
<td></td>
<td>$20.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Fuel: 12 gal/hr</td>
<td>$2.25</td>
<td>27.08</td>
</tr>
<tr>
<td></td>
<td>$27.00</td>
<td>27.08</td>
</tr>
<tr>
<td></td>
<td>$27.00</td>
<td>27.08</td>
</tr>
<tr>
<td></td>
<td>$27.00</td>
<td>27.08</td>
</tr>
<tr>
<td>Daily Maintenance: Grease, Oil, Filters, etc.</td>
<td>$2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>$2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>$2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>$2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Repairs &amp; Parts: 100,000</td>
<td>$20.00</td>
<td>40.00</td>
</tr>
<tr>
<td></td>
<td>$32.00</td>
<td>32.00</td>
</tr>
<tr>
<td></td>
<td>$24.00</td>
<td>24.00</td>
</tr>
<tr>
<td></td>
<td>$15.00</td>
<td>15.00</td>
</tr>
</tbody>
</table>

**Subtotal:** $89.00

**Overhead:** 15% | $19.80 | 13.20 |
| | $9.90 | 6.60 |

**Total Cost/Hour:** $240.80

**Cost/Ton @ 300t/h:** $0.81

**Annual Cost:** $132,400

### Roadtec Services

- Thermography Research
- Certified Thermographer
- Research on your projects, your materials, your timetable
- Equipment
- "Birth of a Pothole" (Technical Papers)
- Recommended Specifications