The use of thermal camera for quality assurance of asphalt pavement construction

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Background and goals

- Background for this study were the previous Finnish and foreign research on the use of a thermal camera during paving operations.
- In Finland, the latest studies including the use of a thermal camera were conducted in 2011 and 2012 by Roadscanners Oy.
- The goal of this study was to determine how well a thermal camera is suited to the assurance of pavement uniformity and how the requirements for using thermal camera in asphalt paving contracts should be defined.
Research methods

- The research comprised two parts: literature research and field research.
- The literature research involved a survey of the previous Finnish and foreign research on the use of a thermal camera during paving.
- The field research examined the data produced by the thermal camera at three test sites during the summer of 2013, and reviewed the experiences of using a thermal camera at these sites.
- Core samples were taken from the test sites for laboratory analysis in order to be able to better study the effect of the application temperature on the characteristics of the pavement.
Findings from literature research

- the suitability of a thermal camera for the segregation analysis of asphalt mass and pavement was studied for the first time in late 1980s.
- Studies have been conducted for example in United States, Sweden, Norway and Croatia.
- Lower temperatures of the pavement can reduce the durability of the asphalt pavement.
- Limit values for the temperature differentials varies in different studies depending on the pavement type.
- It has been noticed that the material transfer vehicles (MTV’s) can reduce temperature differentials and improve durability of the pavement.
Foreign methods for measuring temperatures

- In United States temperatures of the pavement can be measured with a handheld thermal camera or with the infrared bar attached to the paver.
  - Limit values for the temperature differentials from maximum temperature: 25-50 °F (14-28 °C)

- In Sweden temperatures are measured with a so-called linescanner.
  - Limit values for temperature differentials from average pavement temperature: +/- 10 %
  - If temperature differentials are under the limits: Bonus
  - If temperature differentials are over the limits: Sanction

- In Norway, the same method is used as in Sweden
Test sites

- Thermal camera was used at three test sites during the summer of 2013. Camera was mounted at the back of the paver and the temperature of the pavement was measured before compaction.

- Test site VT4:
  - Length 6140 m + 1585 m
  - Pavement type SMA 22 (120 kg/m2)

- Test site VT1:
  - Length 8287 m + 8215 m
  - Pavement type SMA 16 (100 kg/m2)

- Test site VT3:
  - Length 8790 m + 5240 m
  - Pavement type SMA 16 (90 kg/m2)

- Target temperature was set to 150 °C
Temperature mats (Roadscanners Oy)

Truck end load:

Middle of the truck load:
Determining temperatures

- The temperature of the pavement in the core samples was determined using the data stored by the thermal camera.
- The data was analysed using a Web service developed by Roadscanners Oy and the Matlab calculation software.
Core samples

- 32 samples were taken from each site, 16 of which were taken at the location of a load change and 16 from the middle of a load.
- Each core sample was analysed for bulk density, the maximum density of the asphalt mass, void content, binder content and gradation. Additionally, eight samples were chosen from each site and analysed for strength and stiffness.
Temperature and air voids

A comparison of the temperature of the asphalt pavement and the void content of the core samples showed that the void content increased as the temperature decreased. The result was similar to the observations of a Swedish study.
Findings from laboratory analyses

- Binder content (%)
  - VT4 (SMA22)
  - VT1 (SMA16)
  - VT3 (SMA16)

- Bulk density (Mg/m³)
  - VT4 (SMA22)
  - VT1 (SMA16)
  - VT3 (SMA16)
Indirect Tensile Strength and stiffness

Eight samples were chosen from each site and analyzed for their indirect tensile strength (ITS) and stiffness.
Binder content and gradation: example

Test site VT4, SMA22

Matlab:

<table>
<thead>
<tr>
<th>Sample 17</th>
<th>Sample 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>154</td>
</tr>
<tr>
<td>Temperature °F</td>
<td>310</td>
</tr>
</tbody>
</table>
At site VT4, the average temperature difference between load changes and mid-loads was around 13 °C. The largest void content was measured at this site due to the larger particle size of the aggregate compared to the other sites. The void content of the pavement increased significantly at temperatures below 140 °C.
## Test site VT1 (SMA16)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>max-min</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Middle of the load 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33,60 0,72 1,78 2,27</td>
</tr>
<tr>
<td></td>
<td>160,7 5,80 18,6 2,00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Truck end load 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>151,1 5,55 18,0 2,72</td>
</tr>
<tr>
<td></td>
<td>158,9 5,99 19,1 1,85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Middle of the load 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>140,0 5,84 18,0 1,94</td>
</tr>
<tr>
<td></td>
<td>148,6 6,00 19,8 1,92</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Truck end load 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>140,1 6,05 19,0 1,50</td>
</tr>
<tr>
<td></td>
<td>170,1 6,16 19,0 0,86</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Middle of the load 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>163,2 6,27 19,4 0,46</td>
</tr>
<tr>
<td></td>
<td>173,6 6,27 19,4 0,46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fuel consumption</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,20 155,2 161,4 159,1 157,5</td>
</tr>
<tr>
<td><strong>Dust content (%)</strong></td>
<td>0,29 6,00 6,04 6,04 5,75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2 mm sieve (%)</strong></td>
<td>1,13 18,6 18,9 19,5 18,4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Air voids (%)</strong></td>
<td>1,63 1,79 0,94 1,32 2,57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

At site VT1, the average temperature difference between load changes and mid-loads was around 18 °C.
Test site VT3 (SMA16)

At site VT3, however, the temperature difference was the lowest, only 9 °C on average. At this site, the largest void content was observed at the edge of the lane, which suggests problems with compacting.
**Bonus calculation method**  
*(Roadscanners Oy)*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Bonus limits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paver stops</strong></td>
<td>number of stops over 2 min are registered</td>
</tr>
<tr>
<td></td>
<td>0 pauses on 1 km = 100% bonus, 1 pause = 90%, 2 pauses = 80% ... 9 pauses = 0%</td>
</tr>
<tr>
<td><strong>Cold spots</strong></td>
<td>areas where the temperature is below 120 °C</td>
</tr>
<tr>
<td></td>
<td>less than 0.1% of the paving area (m²/km)</td>
</tr>
<tr>
<td><strong>Risk areas</strong></td>
<td>areas where the temperature is below 90% of the mean temperature</td>
</tr>
<tr>
<td></td>
<td>less than 5% of the paving area (m²/km)</td>
</tr>
</tbody>
</table>

- Roadscanners Oy had prepared a bonus calculation system, based on which contractors were paid a bonus for good performance. The bonus calculation system examined the number of stops the paver made, the share of cold spots and the share of risk areas.

- The bonus for the contract was determined as a sum of the bonuses paid for the paver stops, cold spots and risk areas.
Bonus calculations: test sites

<table>
<thead>
<tr>
<th></th>
<th>VT1</th>
<th>VT3</th>
<th>VT4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C (average)</td>
<td>158</td>
<td>153</td>
<td>156</td>
</tr>
<tr>
<td>Cold spots (%/km)</td>
<td>0.5</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Risk areas (%/km)</td>
<td>7.7</td>
<td>4.9</td>
<td>5.5</td>
</tr>
<tr>
<td>Paver stops (pcs/km)</td>
<td>0.4</td>
<td>1.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>

- bonuses were paid almost entirely for number of paver stops only.
- The bonus criteria for cold spots and risk areas were not met.
- At site VT1, the share of risk areas was clearly larger than at the other sites, because the hauling distance was long and the surface of the mass cooled down during transport more than at the other sites.
- At site VT3, the average temperature of the paving material was lower than at the other sites; as a consequence, the share of cold spots was also larger than at the other sites. The number of paver stops was also highest at this site.
Impact of the paver speed

- Adjusting the paver speed can result in changes in the thickness or pre-compaction grade of the pavement, if the paver settings are not adjusted when its speed changes.
- Due to the bonuses paid for contracts, the contractors tried to avoid stopping.
- The speed of the paver was adjusted at every test site.
Contractors comments about thermal camera

- The contractors considered the thermal camera equipment to be a good tool for their own quality assurance purposes.
- The temperature gradient of the pavement and the truck end loads can easily be seen on the display of the thermal camera.
- The contractors consider the bonus calculation system's requirements concerning cold spots and risk areas to be too strict. The number of paver stops was considered to be fine.
- The size and positioning of the equipment on the paver should also be developed further.
Conclusions

- During load changes (truck end loads), the pavements temperature was lower and the void content higher.
- Aggregate segregation was detected in some places at load changes. Low temperature did not, however, always result in segregation.
- The research also showed that compacting has a significant effect on void content. Even if the temperature of the pavement is low, a sufficient level of density can be achieved with effective rolling.
- A larger particle size was found to affect the susceptibility to segregation and increase the void content.
  - At site VT4, the void content of the pavement increased significantly at temperatures below 140 °C.
  - With the SMA 16 mass, a corresponding increase in void content could not be observed.
- A reduction in hauling distance could decrease temperature differentials.
Recommendations

- The research recommends follow-up studies of the test sites of summer 2013 during the coming years in order to determine whether the pavement starts becoming damaged from the truck end loads or the cold spots of the pavement.

- Measuring the number of paver stops should be avoided, because the continuous adjustment of the paver’s speed may cause quality variation in the finished pavement and reduce the uniformity of the pavement.

- The limit values set in the bonus system should be based on the asphalt mass, as different masses behave in different ways.
  - For example, temperature appears to have a larger effect on the uniformity of the pavement's quality as the particle size increases.

- The employees should receive better instructions on the use of the thermal camera equipment in order to increase the benefits from the equipment.
THANK YOU!