Monitoring hot mix asphalt temperature to improve homogeneity and pavement quality

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ABSTRACT: Controlled compaction practices leads to better quality asphalt. Therefore, it is important that during compaction operations the mixture is at a suitable temperature in order to achieve the specified degree of compaction. The University of Twente's Asphalt Paving Research and Innovation unit's main aim is to professionalize the road construction industry. One of the focus research issues is developing a deeper understanding of the Hot Mix Asphalt (HMA) cooling process and the variation in the mix temperature during compaction and lay-down operations. Temperature measurement has become easier over the last decade due to the development of new infrared cameras, line scanners and sensors. We used this new technology to study asphalt temperature characteristics on test sections constructed in 2007 and 2008. It provided several insights into the cooling and variation in temperature of some asphalt mixtures used in The Netherlands. This paper will present and discuss the temperature measuring equipment used and the techniques applied to analyze and visualize the temperature data. The trials show that asphalt surface temperature is a good indicator of temperature homogeneity and process control. Also, that contractors will pay more attention to enhanced integration of HMA temperature as operational parameter in the compaction process given that the measurement technology is now easily within their reach. In the future, we expect a revival of research into cooling processes of HMA.

Keywords: Asphalt paving, temperature monitoring, pavement quality.

1 INTRODUCTION

Innovation is seen as an important source of competitive advantage (Slaughter, 2000 and Dulaimi, 2002) and the implementation of innovations in construction has subsequently received much attention (Mitropoulos & Tatum 2000, Ling 2003, Hartmann 2006).

Bossink (2004) found that innovation drivers' e.g. technological capability and knowledge transfer are used by managers of the authorities, clients, architects, consultants and contractors to stimulate and facilitate innovation processes. This underscores the role of innovation. More significantly, over the last four years since the Dutch parliamentary enquiry into the construction sector, the business environment within the road construction sector has changed dramatically. According to Dorée (2004) the collusion structure that regulated competition has fallen apart. Public clients have introduced new contracting schemes containing incentives for better quality of work (Sijpersma & Buur 2005) and therefore play a critical role in the construction innovation process.

Road construction companies, in turn, seek better control over the construction process, over the planning and scheduling of resources and work, and over performance. Improved control would also reduce the risks of failure during the guarantee period. To be able to achieve these goals, the relevant on-site operational parameters need to be known and the relationships between these parameters need to be thoroughly understood.

Several authors have emphasized the importance of different factors influencing the Hot Mix Asphalt (HMA) mixture such as the material temperature, bitumen content and angularity of the particles on compactibility of the mix (ter Huerne 2004). Compactibility is a measure of the ease to which a mixture can be compacted to a specific density. If the compactibility of a mixture is better than it is also easier to compact the asphalt mat in the field to the target density.

For asphalt paving companies to be able to improve HMA compaction and therefore process performance, they now more than ever acknowledge they need to develop intricate understanding of the asphalt paving process and the interdependencies within the process. The ASPARi (Asphalt Paving Research & Innovation) group of the University of Twente focuses on the asphalt paving process and the critical steps during lay-down operations. Several trials have been carried out by ASPARi to monitor some of the key HMA paving process parameters. These include HMA temperature data, weather data, equipment movement data (rollers and the asphalt paver), and layer density data during the trials (Miller et al. 2007). In this paper we focus on the gathering of temperature data using different techniques and measuring equipment, and compare the different techniques we use for temperature profiling. The test sections all are located in The Netherlands. The temperature profiling techniques were used in the following test sections;

No.1.) Highway A35, à handheld infrared (IR) cameras,
No.2.) Aziehavenweg, à a fixed industrial infrared camera mounted on the paver,
No.3.) Heerenveen à an automated infrared line-scanner mounted on the paver.

We started with relatively simple equipment (the handheld cameras) and gradually improved the system using more sophisticated equipment (fixed mounted automated cameras and scanners). Using the more appropriate equipment reduces the time for post-processing from a few days displaying the temperature in real-time whilst paving.

Also, we monitored the in-asphalt temperature using digital thermometers. The local weather conditions were monitored using a portable weather station to determine its influence on the cooling rate of the asphalt. One of the goals of the ASPARi team is to make temperature related information of the HMA mat available in real-time during rolling operations. This information can then be used to assist roller operators make better decisions on where to compact at what moment.

The paper is structured as follows: After the short introduction, we provide a short literature review of the importance of temperature profiling. Then we describe the three temperature devices we used on the test sections. We describe how they can be used, what results they give and how the output is used to create Temperature Contour Plots. Finally, we present conclusions and recommendations for practice in the context of conducting temperature profiling during the HMA construction process.

2 THE REASON FOR TEMPERATURE PROFILING:

Temperature differentials in the asphalt mat can produce density differentials, which will affect the life of the pavement (Mahoney et al. 2000, Willoughby et al. 2002). Temperature segregation occurs because of differential cooling of portions of the mix on the surface of the mix in the haul truck, along the side of the truck box, and in the wings of the paver (Asphalt-Institute 1989, NCAT 1991, Mahoney et al. 2000). Stroup-Gardiner & Brown (2000) defined segregation as a lack of homogeneity in the HMA constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress.

According to Stroup-Gardiner (2000), Read (1997) is credited with the initial observation that temperature differentials in the HMA during construction was a strong indicator of a segregated mix. Several researchers have since used IR camera images to fully document temperature differentials during all aspects of HMA paving operations and identified IR camera images as a useful method for determining temperature differentials for detecting, locating, and measuring segregation (Brock & Jakob 1997, Stroup-Gardiner & Brown 2000, Stroup-Gardiner et al. 2002, Stroup-Gardiner et al. 2004). Their research showed that areas in the HMA mat with temperature differentials of more than 10°C were potentially segregated areas and areas with temperature differentials of more than 20°C were likely to be highly segregated.

There are several factors e.g. wind and solar radiation that strongly affect the cooling of a paved layer (Pilate 2006). Also, the compaction of HMA mixes is seen as one of the most crucial phases in achieving quality. Because mechanical material behavior is so much temperature dependent it is logical that large variations in temperature of the newly paved asphalt layer results in differences in the final compacted state. Therefore large variations in temperature and thus in compaction levels, impairs quality consistency of the constructed lane. For quality improvement it is necessary to have insight into the HMA temperature and its variability for two reasons: firstly, to improve temperature homogeneity, and secondly to change the compaction rolling patterns to deal differently with hot and cold spots. Countering the variability in temperature requires a comprehensive thermal representation of the HMA layer. Therefore we started to explore full-width infrared (IR) monitoring of the surface temperature of the HMA paved directly beyond the screed of the paver, and at fixed staked positions along the length of the road. We combined this with in-asphalt temperature monitoring to determine cooling rates for asphalt surface temperature and in-asphalt temperature.

3 HIGHWAY A35 TEST SECTION, APRIL 2007

In 2006, the Dutch Ministry of Transport organized an innovation competition, challenging contractors to put forward ideas to extend the mean service life of the dual layer porous asphalt system from seven to nine years. The porous asphalt system consists of a 25 mm thick upper layer with a maximum grain size of 8 mm and a 45 mm thick lower layer with a maximum grain size of 16 mm. The twin layer system is specifically designed for high reduction of traffic noise (between 5-7 dB(A) at normal traffic flow). The project was aimed at improving the homogeneity of the asphalt mix during production, transport and application. The essential rationale: the more homogenous the HMA and the paving/compaction, the less bad spots and therefore less or later failure of the road surface. The designated road section was a 460m long stretch of the A35 highway in the east of The Netherlands that needed resurfacing. The project required the removal of the existing surfacing layer followed by repaving with the dual layer porous asphalt paver. The work had to be done in two consecutive nights (between 19:00h and 7:00h) whilst the highway was kept in service.

To monitor the surface temperature four IR cameras were used. The handheld infrared camera (see Figure 1) is a relatively affordable piece of equipment and is simple to operate. Two operators took the IR images in a predetermined routine at 10 meter intervals on the A35 test section. A typical IR image taken behind the screed of the paver is shown in

Figure **2**. An operator also registered the in-asphalt temperature using a digital thermometer placed into the center of the HMA layer.

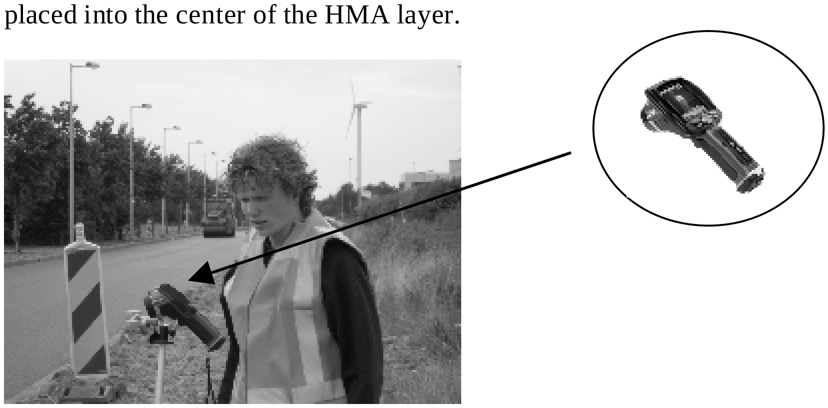

Figure 1. The use of a handheld infrared camera

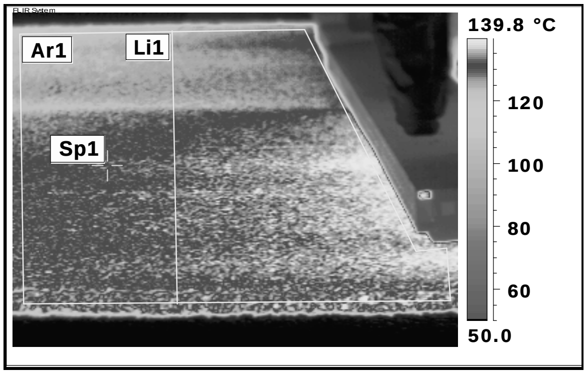

Figure 2. Typical infrared image taken behind the paver screed

The data source to data transformation to visualization requires extensive post-processing. For the A35 trial this process was carried out manually. The thermal images can be analyzed in three ways with functions for spot analysis (Sp1), area analysis (Ar1) and line analysis (Li1) as shown in
Figure 2. The software was used to undertake the initial analysis of the individual thermal images with the temperature data transferred to matrices in a spreadsheet for further analysis.

3.1 *Results from temperature profiling using the handheld infrared cameras.*

The temperature data were analyzed in two ways. Firstly, to visualize the initial HMA surface temperatures, we prepared two-dimensional Temperature Contour Plots (TCP) by combining the data from the thermal images taken directly behind the screed of the HMA paver. Secondly we combined the images per location to analyze the surface cooling over time for both surface temperature and in-asphalt temperature measured using the digital thermometer.

Figure 3 shows the surface TCP for one of the five lanes paved. The data are presented on both distance and time axes. The contour plot shows several operational issues. Firstly, the cooling of the HMA due to a stop-and-go situation at staked position 140 at 00h41. Secondly, the cooling of the mix at staked position 210 when the last material is used up in the paver hopper. Lastly, a reasonable consistent temperature between staked positions 10 and 110 meters.

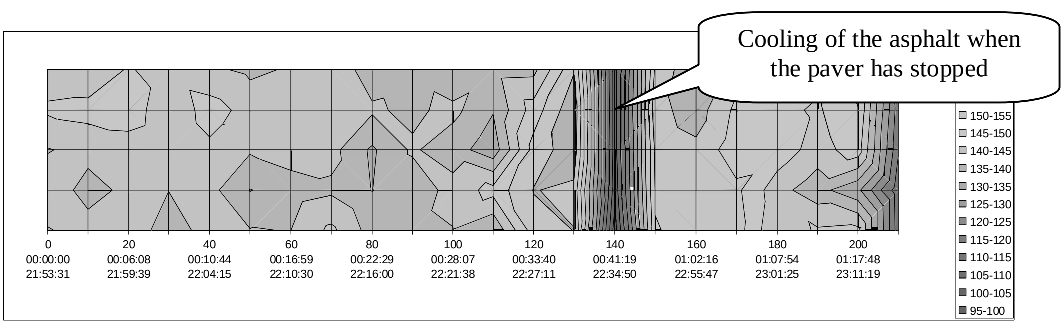

Figure 3. Typical Temperature Contour Plot (TCP)

3.2 *Some thoughts on the use of the handheld IR cameras*

- Investments for the equipment are relatively low.
- The equipment is relatively easy to use with no skilled personnel needed.
- The equipment must be used in a predetermined protocol to generate sufficient data for producing the TCP.

- The TCP provides insights into the extent of variability and operational issues requiring attention.
- Data transfer from the individual IR images to the data matrix is laborious and time-consuming.
- The HMA paver when equipped with a GPS receiver can be synchronized with the IR camera's time stamp. This can then be used to accurately determine the exact positions that pictures were taken at.

4 TEST SECTION, AZIEHAVENWEG, JULY 2008, AMSTERDAM.

We undertook the second trial during the rehabilitation of the Aziëhavenweg in Amsterdam. The aim of this project was to improve the temperature homogeneity of the HMA during production, transport and application. The scope of the project required the removal of the existing surfacing layer followed by repaving the 7m wide road with two layers of asphalt. An asphalt paver and shuttle buggy combination was used to separately pave a 70mm thick Bituminous Treated Basecourse (BTB) layer and the 30mm Stone Mastic Asphalt (SMA) layer. The ASPARi research team monitored the following process parameters during the project: surface temperature, in-asphalt temperature, weather conditions, compaction coverage, density and truck logistics. More detailed information of the project can be found in Miller (2008).

An automated industrial IR camera, was used to automatically monitor the surface temperature of the HMA during paving operations. The industrial camera mounted on the back of the asphalt paver as shown in Figure 4, recorded thermal images at five-second intervals for the duration of the paving of the BTB and SMA layers. Images were continually downloaded to a portable computer. The HMA paver was also equipped with a GPS receiver, working in a local DGPS configuration set-up. The GPS data and fixed mounting of the camera made it possible to permanently geo-reference the thermal images during post-processing.

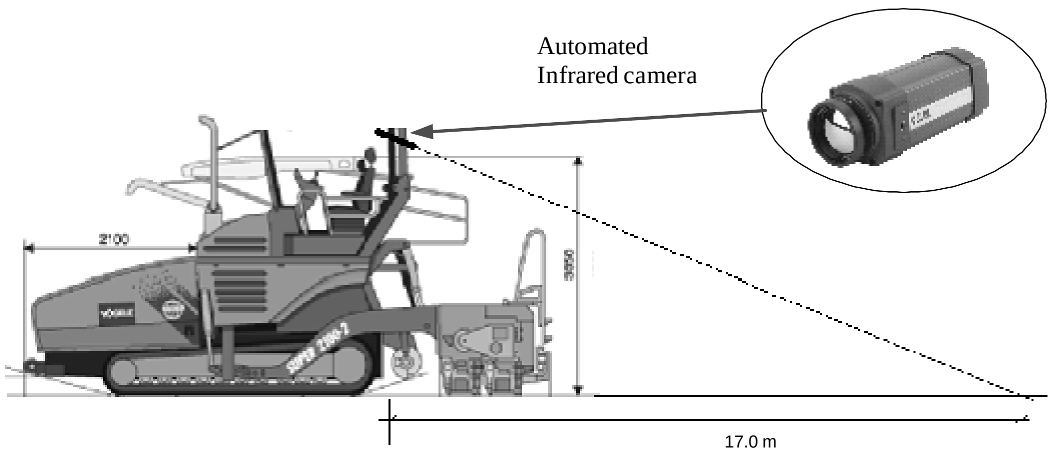

Figure 4. The automated IR camera mounted on the back of the HMA paver

The software supplied with the camera was used to undertake the initial analysis of the thermal images. Spot temperatures were "tagged" across the full width of the paved lane. These spot temperatures are transferred to a data matrix using a program embedded in the spreadsheet software. The data matrix is then used to produce the two-dimensional Temperature Contour Plots (TCP) in Figure 5 showing the extent of surface temperature homogeneity.

4.1 *First results on the use of the automated IR camera*

The industrial IR camera images, when played back in sequence, shows as a "movie" of the entire paving process. As was the case with the handheld IR cameras, the data can be used to produce TCP's showing the extent of temperature variability across the width and length of the paved lane. The TCP provides more detail of the HMA cooling process at stop-and-go positions with the start and end of the paver stops and HMA surface temperatures clearly visible.

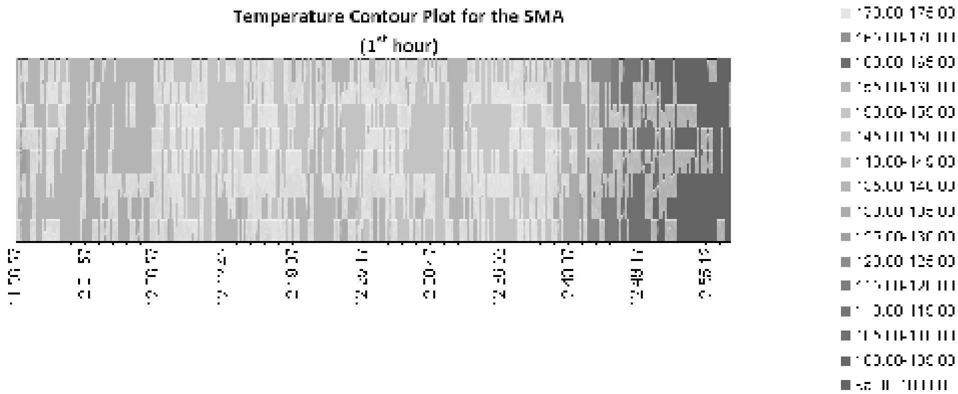

Figure 5. Typical TCP from the automated IR camera data

4.2 *Some thoughts on the use of the automated IR camera*

- The camera can be easily mounted on the back of the paver.
- Data source to data transformation to visualization is much easier when compared to the data processing undertaken with the handheld cameras.
- The initial investment for the industrial IR camera is 3-5 times more than the handheld camera. The camera requires a laptop or PDA to register and store the images.
- The industrial camera was equipped with a standard optical lens. This lens had a rather narrow angle of view. As a consequence it had to be aimed 17 meters behind the paver to obtain a full view of the 7m wide road (seeFigure 4). It may be better to use a wide angle lens and to adjust the camera position so that the HMA paver screed is in view.

5 TEST IN NOVEMBER 2008, HEERENVEEN.

The third trial took place during the paving of a 6,7m wide Bituminous Treated Basecourse (BTB) layer in an industrial area in Heerenveen, The Netherlands. The 45mm thick BTB layer had a maximum stone size of 16mm with approximately 1500 linear meters paved in the 8 hour day.

We tested an automated IR line scanner previously reported on by Ulmgren (2000). The scanner provides real-time thermal imaging and measures multiple temperature points across a line scan. The fast scan rate up to 150 Hz allows fast detection of temperature non-uniformities. The scanner was mounted on a beam attached to the roof of the HMA paver at a height of 3,70m (see Figure 6) with a GPS receiver placed next to the scanner. Rotating optics collect data at 256 points within a 90º field of view set to within 1.0m of the paver screed. Two-dimensional images can be formed as the material moves according to the scanner's field of view. The analogue output needs to be recorded and stored by a portable computer. As was the case with the handheld and industrial cameras, spot temperatures are transferred to a data matrix using a program embedded in the spreadsheet software. For the Heerenveen test, the 3,5m wide lane was divided into 10 zones with readings taken every 3 seconds. This resultant data from the 35mm by 275mm temperature tile was transferred to the data matrix. The data transition software makes it possible to simultaneously view cross-section temperature profiles, contour graphs, and thermograms in multiple windows as shown in Figure 7's screenshot.

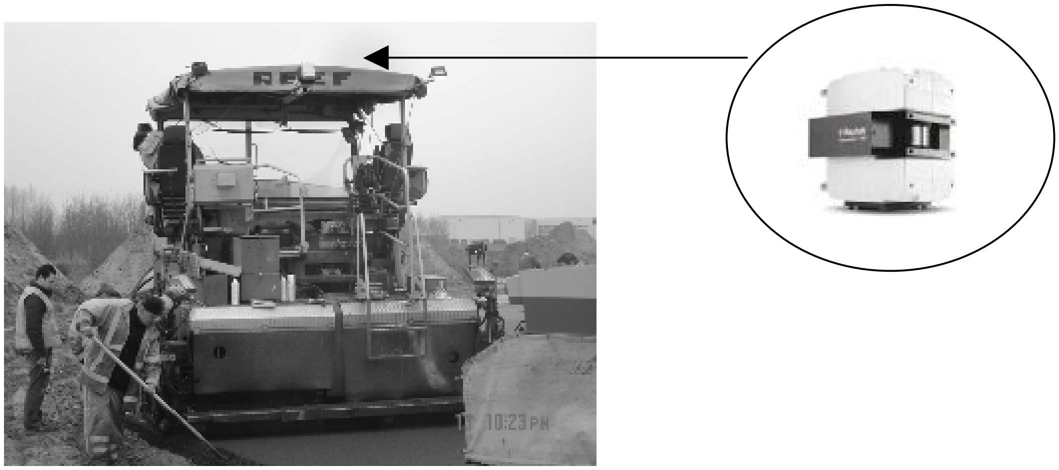

Figure 6. Industrial line scanner mounted on the back of the HMA paver

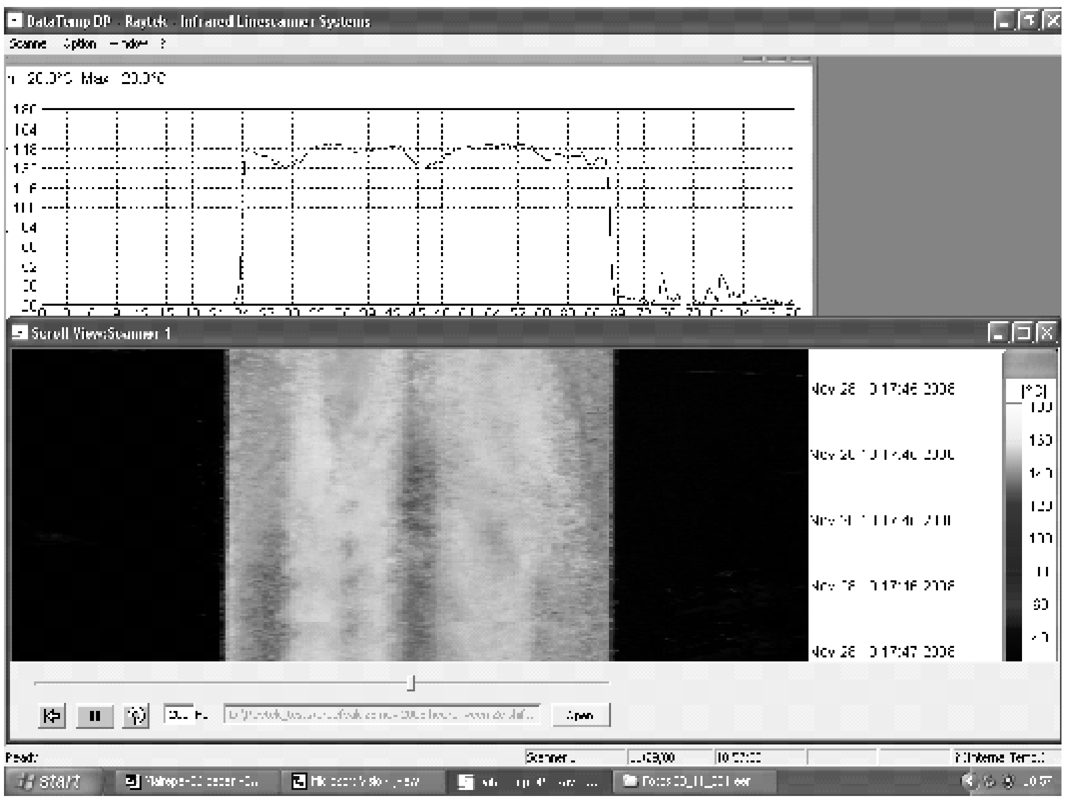

Figure 7. Screenshot of the real time line scanner output

5.1 *Some thoughts on the use of the automated line scanner*

- The line scanner can be easily mounted on the back of the paver.
- The line scanner also requires a portable computer to register and store the images.
- Data source to data transformation to visualization is the easiest when compared to the data processing undertaken with the handheld the industrial IR cameras.
- The line scanner is similarly priced to the industrial IR camera.

- The measuring process is almost completely automated. Temperature Contour Plots are provided in real-time enabling the asphalt paver and screed operators to make adjustments to their operations if necessary.
- Depending on the width of the lane to be paved the line scanner should be mounted at a height that the scanner is able to “scan” the whole width of the lane. In the most ideal situation the scanner should scan the asphalt temperature just behind the screed of the paver. However, operators walk periodically on the screed causing the scanner view to be obstructed. The scanner should therefore be mounted higher and at an angle with little or no obstructions.

6 SURFACE TEMPERATURES VERSUS IN-ASPHALT LAYER TEMPERATURES

IR imagery opened up possibilities to measure the surface temperature of the asphalt across the full width and length during HMA paving operations. But what about the inner temperature of the HMA layer? The surface will cool much quicker than the core of the layer. Several factors influence the difference in temperature between the surface and the in-asphalt temperature including, the layer thickness, the type of HMA and weather conditions. Core temperature is relevant for compaction operations. The surface might be cool enough to start compaction, but the core might still be too hot. Many rollers are currently equipped with IR instruments that present surface temperature data to the roller operator. Since that is the only figure the operator gets he actually “guesses” the core temperature. That is a genuine operational risk for the end quality. Thus, the temperature profiling will have real added value when surface temperature could be used as (a calibrated) predictor for core temperature. It would significantly enhance quality control in compaction.

In the trials on the A35 and Aziehavenweg both surface and core temperature were registered over a certain time at a number of points. The data series for both were tabulated and cooling equations were fitted statically. All paved lanes showed a strong correlation, based on R^2 values, with most values above 0,9. This strong correlation opens up the opportunity to use the surface temperature as reliable indicator for the core temperature. This work is currently being extended to study the cooling rates for different HMA mixes in the Netherlands.

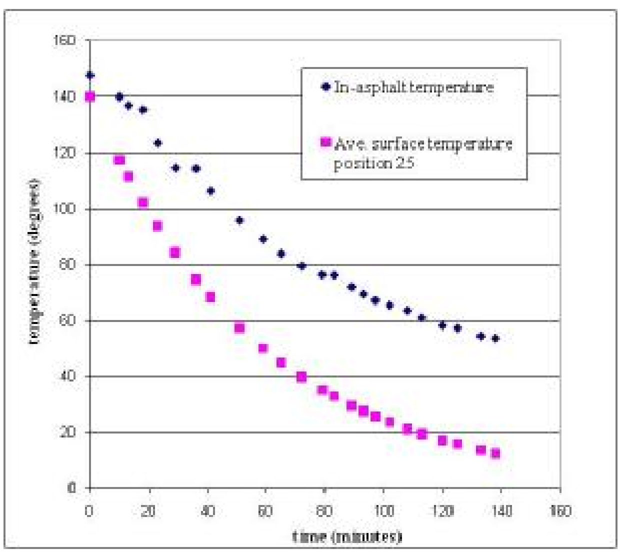

Figure 8. Comparison of surface and in-asphalt temperature

7 FINAL THOUGHTS AND CONCLUSIONS

The importance and impact of temperature in the HMA paving/compaction process and quality of road surface is already WIDELY acknowledged. This paper builds on that and presents ongoing research into the use of thermal imaging to improve the paving and compaction process. The focus is on the temperature measuring devices, protocols and the practicality for use on site. Three trials were considered. The overall sense is that thermal imaging can add significantly to the quality control of paving and compaction processes. The trials have shown that the IR technology is mature and manageable. The price for the devices has dropped to acceptable levels.

Different devices and different techniques are described: in particular the handheld IR cameras, the automated IR camera and the automated IR line scanner. Results of the temperature profiling are introduced, advantages and disadvantages given. All devices can be used to collect sufficient temperature information for full road coverage, although there is some concern over the industrial IR camera lens' angle of view as explained in Section 4. The handheld IR cameras are relatively affordable but require operators and more laborious post-processing. The industrial IR camera is more expensive initially but requires less operational effort and cost. The price of an automated IR line-scanner is in between those of a handheld IR camera and the industrial IR camera. The line scanner data streaming is automated and requires minimal attention whilst running. Images comparable to TCP's are generated in a relative simple way. The apparatus is heavy but relatively robust.

The combination of thermal imagery and geo-referencing is the basis for the Temperature Contour Plots. These plots give a good view and record of temperature homogeneity during the HMA paving operations. The contractor's representatives confirm that they extract meaningful information from these plots. We have devised provisional measures and scales for homogeneity which will be tested and developed over the next few years.

The results of the research confirm the relevance. The trials demonstrated that the temperature profiles are relevant as a means of gaining more insight into operational issues. The added value will be even greater when the surface temperature can be used as reliable indicator for the (core) in-asphalt temperature. First results in that direction are promising. In the coming years we will develop and refine the devices and protocols to generate this reliable indicator on the construction site.

Using thermal imagery fits in two coinciding trends visible at global scale: new types of contracts that push more risks to contractors and a proliferation of SMART technologies (Self-Monitoring, Analysis and Reporting Technology). New types of contracts, tougher competition and the urge to make a distinction in the market, spur the companies to advance in product and process improvement. To reduce risks and liability road construction companies seek better control over the construction process and over performance. New technologies and methods for temperature profiling provide insight in the variability of key process parameters of the asphalt paving process. This makes it possible to take process control and quality to new higher levels.

8 ACKNOWLEDGEMENTS

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REFERENCES

Asphalt-Institute, 1989. *The Asphalt Handbook.* Lexington: The Asphalt Institute.
Bossink, B.A.G., 2004. Managing Drivers of Innovation in Construction Networks. *Journal of Construction Engineering and Management,* 130(3): p. 337.

Brock, J. D. & Jakob, H. 1997. *Temperature Segregation/Temperature Differential Damage.* Astec Industries, Inc.

Dorée, A.G., 2004. Collusion in the Dutch construction industry: an industrial organization perspective. *Building Research and Information,* 32(2): p. 146-156.

Dulaimi, M.F., et al. 2002. Enhancing integration and innovation in construction. *Building Research & Information,* 30(4): p. 237 - 247.

Hartmann, A., 2006. The context of innovation management in construction firms. *Construction Management and Economics,* 24(6): p. 567 - 578.

Huerne, H.L. ter, 2004. *Compaction of asphalt road pavements : using finite elements and critical state theory.* Enschede: University of Twente.

Ling, F.Y.Y., 2003. Managing the implementation of construction innovations. *Construction Management and Economics,* 21(6): p. 635 - 649.

Mitropoulos, P. and C.B. Tatum, 2000. Forces Driving Adoption of New Information *Technologies. Journal of Construction Engineering and Management,* 126(5): p. 340.

Mahoney, J. P., Muench, S. T., Pierce, L. M., Read, S. A., Jakob, H. & Moore, R. 2000. Construction-related temperature differentials in asphalt concrete pavement - Identification and assessment. *Construction 2000*, 93-100.

Miller, S.R., Huerne, H.L. ter, & Doree, A.G. 2007. A35: test section 3, *Temperature profiling and monitoring of equipment movements during construction.* Enschede: University of Twente.

NCAT 1991. *Hot Mix Asphalt Materials, Mixture Design and Construction,* NAPA Research and Education Foundation.

Read, S. A. 1997. *Construction Related Temperature Differential Damage in Asphalt Concrete Pavements.* Seattle: University of Washington.

Simons, B.J.A.G. 2006. *Op weg naar een beheerst asfaltverwerkingsproces (in Dutch). Universityof Twente,* Enschede.

Slaughter, E.S., 2000. Implementation of construction innovations. *Building Research & Information,* 28(1): p. 2 – 17.

Stroup-Gardiner, M. 2000. Identifying segregation in hot mix asphalt pavements using rolling nuclear gage measurements and infrared imaging. *Journal of Testing and Evaluation*, 28, 121-130.

Stroup-Gardiner, M., Wagner, C. T., Hodgson, D. T. & Sain, J. 2002. Effect of temperature differentials on density and smoothness. *ASTM Special Technical Publication.* 1433 ed.

Stroup-Gardiner, M., Nixon, J. & DAS, P. 2004. Automated temperature profiling during hot-mix asphalt construction. *Transportation Research Record*, 41.

Stroup-Gardiner, M. & Brown, E. R. 2000. NCHRP Report 441: *Segregation in hot mix asphalt pavements.* Washington, Transportation Research Board - National Research Council.

Sijpersma, R. and A.P. Buur, 2005. *Bouworganisatievorm in beweging. Economisch Instituut voor de Bouwnijverheid:* Amsterdam, p. 66.

Ulmgren, N., 2000. Temperature scanner an instrument to achieve a homogenous asphalt pavement, Eurobitume/EAPA conference, Barcelona.

Willoughby, K. A., Mahoney, J. P., Pierce, L. M., Uhlmeyer, J. S. & Anderson, K. W. 2002. Construction-related asphalt concrete pavement temperature and density differentials. *Construction 2002,* 68-76.