Prediction of the in-asphalt temperature for road construction operations

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ABSTRACT

During the construction of new asphalt roads, compaction is the final step. Proper compaction is crucial for the road's lifetime. The temperature of the asphalt mixture directly impacts on the compactability and therefore the construction process strategy. Ideally compaction should be done within a certain in-asphalt temperature window, with lower and higher temperature boundaries, to achieve high quality road surface. But, as there are no available systems to predict in-asphalt temperature, roller operators have to guess the actual temperatures. This paper describes a method and proposes an implementation of this method to predict in-asphalt temperature at any given position. Calculations are based on an initial asphalt mix temperature during paving operations and the automated computing of a cooling function for a specific mix within certain ambient weather conditions. The implementation of the method was tested using position and temperature information collected by following a real paving project. Outcome of the method - the resulted visualization - aims to provide information about in-asphalt temperature to support decisions of machine operators when to start and stop rolling process to obtain the high quality road surface more reliable.

INTRODUCTION

Road infrastructure is a vital component of any transportation system. As growth of the economy is accompanied by increasing travel demand (WSDOT, 2011), there is a clear need for continuous improvement of road systems. Therefore, construction companies introduce new materials and require new working methods from the personnel on site. The changes often require an asphalt team to perform paving operations under new conditions, where lack of previous experience can make the results of the paving process uncertain (Ter Huerne, 2004). Despite these changes, the current asphalt paving process still heavily relies on the skills and experiences of people working on the construction site and depends on personnel craftsmanship often without instruments to monitor key process parameters (Miller, 2010). Therefore additional instruments to support road construction professionals in their working tasks are needed.

Once a paving job has begun, operators deal with the issues of temperature and cooling by adjusting the lag time between the paver and the roller (Chadbourn, 1996). Ideally, the compaction process takes place when the asphalt mix temperature is within a certain temperature window - with high and low boundaries depending on the mixtures' characteristics. To the authors' best knowledge, currently there are no systems, available to predict in-asphalt temperature during road construction. To address this gap, this paper introduces a method to predict in-asphalt temperature at any given location.

The proposed method is based on combination of the document temperature of the asphalt mixture during lay-down phase (Fig. 1, a) and cooling of the mixture (Fig.1, b) according to the ambient conditions. In the next section, we outline the role of the temperature during road construction operations. Later, we describe current state of technology in documenting temperature and calculating the cooling rate and, then, propose a method to predict in-asphalt temperature.

ROLE OF THE TEMPERATURE IN ROAD CONSTRUCTION OPERATIONS

The paving or finishing machine lays the hot-mix asphalt mixtures (HMA) at temperatures between approximately 225°-300° F (~110°-150° C) depending on the mixture characteristics, layer thickness and ambient conditions (MAPA, 2011). The deployed mixture normally does not have homogeneous temperature due to truck delays, discontinuity of the paver movement and paver characteristics (Figure 1, a). The material should be compacted before the mix temperature falls below a lower bound compaction temperature. The temperature window is determined according to a particular mixture (Wise and Lorio, 2004). Moreover, recommendations by the mix designers can include pre-determined temperature windows for more than one roller (Sullivan, and De Bondt, 2009). Those recommendations should be considered by the roller operators during the compaction process and this task requires understanding of the in-asphalt asphalt temperature. Although currently available systems do document and inform machine operators about surface temperature of the asphalt layer, there are no solutions to predict in-asphalt temperature at any given location. To make operational decisions more well-founded a system to predict in-asphalt temperature of the asphalt mixture during road construction operations is needed.

AVAILABLE SOLUTIONS TO DOCUMENT TEMPERATURE OF THE ASPHALT MIX

Documenting the laydown temperature of the asphalt mixture provides opportunity to verify homogeneity of the temperature and, later, to predict in-asphalt temperature at any location of the paved layer. Technologies like infrared cameras and temperature linescanners (Vasenev et al., 2011) are able to provide essential information of the asphalt surface temperature during compaction - without direct contact with the asphalt layer. Different schemes for utilizing such devices were recently developed. For example, a sensing device can be fixed on a paver (Baker et al., 2004) to collect and deliver information about surface temperature to the operator's cabin. In a more advanced approach temperature of the deployed mixture is obtained using sensors on pavers and, later, the expected cooling model is refined by sensor readings from rollers (Glee et al., 2009). Several industrial solutions to visualize and record the asphalt temperatures are created by asphalt machinery producers. To record temperature of the paved layer temperature readings can be obtained from an infrared bar in combination with geographic coordinates using the PAVE-IR system, located on a paver (Swaner, 2010). Also, the compaction control system (CCS900) for rollers, introduced by Trimble manufacturer, in addition to compaction information provides readings from temperature sensors on a roller. Another approach, available in scientific literature, is based on the general prediction of the cooling in a form of a generic formula (Miller et al., 2011). One must keep in mind that while all these devices measure and provide only surface temperature, the mix behavior highly depends on the inner temperature of the layer.

The above described available visualization methods do document machine movements, but are not applicable to predict in-asphalt temperature, as they do not take asphalt cooling inside the layer into consideration. Therefore, utilization of these systems by machine operators to adjust their work is questionable, as the in-asphalt temperature is the dominant factor in compaction. To be able to predict in-asphalt temperature it is needed not only to document the initial temperature of the asphalt mixture, but also predict the in-asphalt cooling rate.

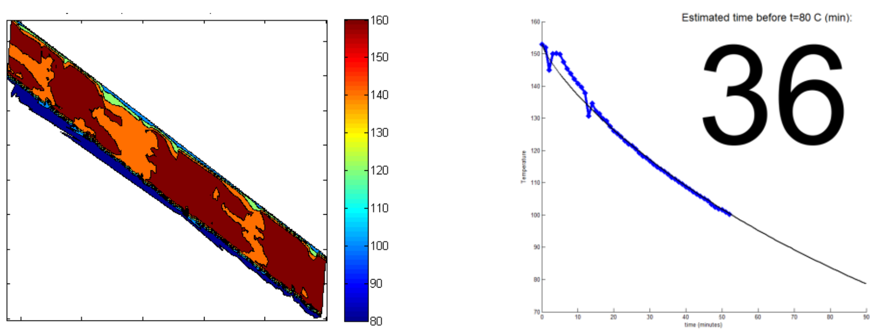
EXISTING APPROACHES TO CALCULATE THE ASPHALT MIXTURE COOLING RATE

The information about a cooling rate of the deployed asphalt mixture is a valuable characteristic of the paving process. The cooling rate significantly depends on ambient weather condition, such as wind, air temperature, humidity and solar radiation. To assist paving teams by providing expected cooling rate, specialized software programs were developed recently. For example, cooling rate for a single layer can be calculated with the PaveCool program (Chadbourn et al., 1996). PaveCool consists of a user interface, a pavement cooling model and a knowledge-based expert system. The cooling models were further developed in the CalCool software. CalCool extends the single layer solution to multi-layers based on theoretical heat transfer considerations (Timm et al., 2001). Also, an additional research on asphalt cooling in special conditions was conducted, such as cooling during night road constructions (Chang et al., 2009). In particular, night construction is usually combined with low ambient temperatures and high wind speeds, thus creating adverse conditions for hot-mix asphalt paving.

Although specialized software and mathematical modeling can calculate the asphalt mixture cooling rate, it demands entering a number of parameters and, thus, additional tasks for personnel on site. Moreover, the prediction is highly dependent on accuracy of the measurements, such as wind speed and the latitude of the paving job, entered to the simulation software. Another approach is to utilize temperature sensors in real-time and calibrate the mixture cooling rate based on obtained readings. For those purposes we developed (Vasenev et al., 2012) an Automated Temperature Unit (ATU) to:

- measure surface- and in-asphalt temperature real time;
- predict the cooling rate and;
- provide information to the operators.

The implemented system can predict asphalt cooling based on previously obtained readings. In particular, readings from thermocouples and infrared sensors are stored and used to find a fitting function to predict further temperature changes. We utilized a formula (Bossemeyer, 1966) for the asphalt cooling rate, where two variable characterize cooling rate of the mixture. The automatically calculated variables, called time factor and pole value incorporate thermal conducting ability, thickness of the layer, thermal conduction and thermal transition coefficients. Example of sensors readings and a predicted fitting function are represented on Fig. 1, b. With increasing number of readings the prediction of cooling rate is changing according to the accumulated sensors data. Using the ATU it is possible to predict the time interval, before the asphalt mixture will cool down to a certain temperature at the given location.



a b

Figure 1: a. Asphalt temperature as measured during laydown;
b. Readings from ATU's thermocouples and prediction
of the mixture cooling rate

The automatically calculated cooling rate of the asphalt mixture at a particular sport, calculated by the ATU, can be used to predict in-asphalt temperature at other points, if their initial temperature and paved time are known. By combination of the calculated cooling rate and previously documented temperature of the asphalt mixture it becomes possible to predict in-asphalt temperature of the asphalt layer.

THE PROPOSED METHOD TO PREDICT IN-ASPHALT TEMPERATURE DURING COMPACTION OPERATIONS

By combining the documented temperature of the asphalt mixture during lay-down phase and the calculated cooling rate of the mixture by ATU, it is possible to predict in-asphalt temperature at any given location (Fig. 2). Firstly, information from location and temperature sensors is used to document temperature of a newly paved layer. Then, the temperature of the placed asphalt layer is combined with automated prediction of the asphalt cooling to predict in-asphalt temperature within the layer. To represent temperature of the placed asphalt and the predicted in-asphalt temperature in a convenient form we utilized temperature contour plots.

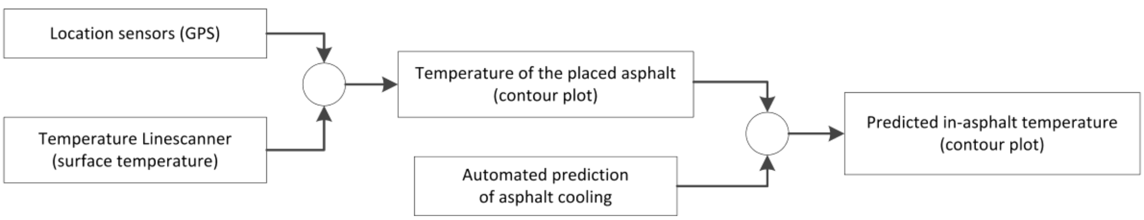


Figure 2. The proposed method to predict in-asphalt temperature

To be able to predict the temperature of the asphalt mixture we assume that the thickness of the asphalt layer is constant within the area of interest and only one layer is paved. Furthermore we assume a constant temperature over the height of the layer at moment of laying the asphalt mix. In this way we consider the obtained temperature readings during the asphalt laydown not only as a surface temperature, but also as an initial temperature distribution at any depth of the freshly constructed layer. Next, when the thickness of the asphalt layer is constant, the cooling process is assumed to run similar at any given location. Within the scope of this paper we limit the explication to construction of a single layer.

The proposed method is to be implemented as follows. All the sensors reading, related to the asphalt temperature and paver location are collected during the road construction project. In particular, the asphalt laydown temperatures are documented and visualized by combining GPS and IR-linescanner data from instruments located on a paver (Fig. 1, a). Also, temperature readings from the thermocouples, injected into the newly paved asphalt layer at a particular depth are used to predict cooling rate of the mixture (Fig.1, b). The thermocouples' readings are used to predict the cooling rate by ATU. With the predicted cooling rate we can predict in-asphalt temperature at other locations and times. The automatically calculated values can be applied to every other point to calculate the expected temperature, with [a] the given initial temperature and [b] time interval passed after the mixture deployment.

To verify the described method for the in-asphalt temperature prediction we developed and tested data collection and processing infrastructure to computing in-asphalt temperature. The infrastructure includes sensing devices to collect data, computers to pre-process readings and transfer data to a database, a server which stores the sensor readings and a visualization client. The communication between sensors can be described as follows. An IR-Linescanner, located on a paver, is connected to a computer, that transmits the real-time information to a server by wireless connection. Also, another computer sends the thermocouples' readings in real-time to the server. Sensors readings are stored at the server in MySQL database and are accessible to a client computer with the visualization software. Calculation and visualization components are implemented using Matlab.

The initial tests of the described method were based on real sensor readings, collected in cooperation with Dutch road-building contractors. By applying the proposed method we created visualization of in-asphalt temperature contour plots from the documented temperature of the asphalt mixture during the laydown phase and predicted cooling rate. An example of the visual representation of in-asphalt temperature, based on information collected during a real paving project near the Dutch city of Alkmaar, is represented on Fig 3 and 4.

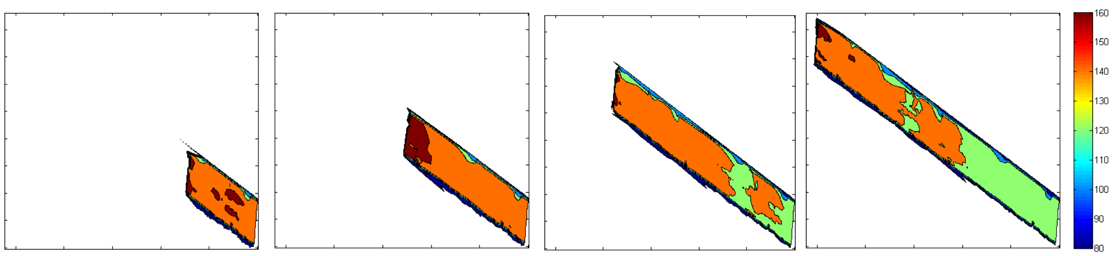


Figure 3. In-asphalt temperature after 4, 8, 12 and 16 minutes after paver started moving.

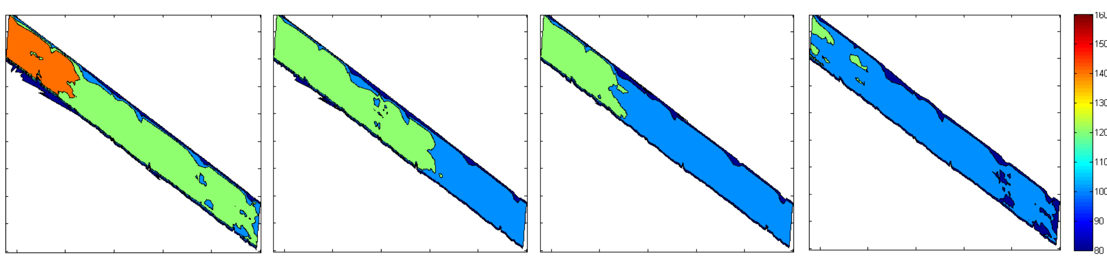


Figure 4. In-asphalt temperature of the paved area after 5, 10, 15 and 20 minutes

The obtained visualization showed applicability of the proposed method to automatically predict in-asphalt temperature during paving processes. As the main advantage of this method we see the automated prediction of in-asphalt temperature, that incorporates numerical parameters of the physical process, such as temperature differences within the freshly paved layer and discontinuity of the paver speed, into a clear visualization. The resulted visualization can be used to analyze the paving process in retrospective, or, when used in real-time, to support machine operators in decisions when and where to compact the asphalt layer.

CONCLUSIONS AND FUTURE WORK

Understanding of in-asphalt temperature by roller operators is needed to perform compacting within a desired temperature limits. Nevertheless, according to the authors' best knowledge, in the current paving practice there was no possibility to automatically predict in-asphalt temperature. To address this gap we developed a method to predict in-asphalt temperature based on documenting the initial temperature during lay-down phase and the asphalt cooling using specialized sensors. The method incorporates information collection and processing from different sensors: GPS, temperature (linescanner) and thermocouples, deployed within the asphalt layer. The temperature contour plots can be used to analyze the paving project and to assist roller operators in their decisions when and where to roll, according to the asphalt mixture characteristics. The proposed method was tested on the data from a real paving project to obtain in-asphalt temperature contour plots.

Currently, the described implementation incorporates solution to predict cooling rate only for a single paved layer. Nevertheless, we believe that with additional information, such as readings from thermocouples at the bottom and at the top of the asphalt layer it is possible to predict temperature changes for more than one paved layer. Further research effort will also be devoted in analyzing visual representation of the temperature to assist machine operators in their tasks during road construction operations.

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