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Application of Infrared Camera for Quality Control during Paving

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Abstract

Segregation in asphalt pavements is one of the most common and costly problems in the paving industry. This paper deals with the thermal segregation of hot mix asphalt (HMA) pavement.

HMA is produced and placed at high temperatures (e.g. 155 – 163°C and 140 – 155°C, respectively) and is therefore subject to thermal segregation due to differential cooling, which typically occurs during transport of HMA material and construction of pavement. If the temperature of the asphalt material is not consistent, pavement will eventually show signs of temperature differential damage (TDD) in the locations of the cold spots. Construction-related temperature differentials are large material temperature differences resulting from placement of a significantly cooler portion of HMA material into the new pavement. Placement of this cooler material can create areas near or below cessation temperature (commonly taken as 80°C) which tend to resist adequate compaction. These isolated cooler areas do not fulfil asphalt layer density requirements.

The objective of this study was to utilize an infrared camera to identify thermal segregation in asphalt pavements during construction and possible causes of the temperature differentials which affect compaction and lead to premature distress of the pavement. Temperature data was obtained using an infrared camera (thermal sensitivity 60 mK, geometric resolution 640x480 pixels, FOV 24°) at the paving site. Infrared camera was able to clearly discern cool areas of uncompacted and compacted asphalt material, as well as to determine the temperatures of loose mix in trucks and pavers.

Keywords: thermal segregation, temperature differentials, pavement distress, cessation temperature, infrared camera

1 Introduction

The benefits of hot mix asphalt (HMA) range from its high performance and environmental friendliness to its low cost. Thus, today HMA is engineer's material of choice for pavement construction of most traffic areas (low and heavy duty roads, runways, bridges, parking lots, driveways etc.).

Since the laid down of the first ˝true˝ asphalt pavement in 1870 (Newark, New Jersey) till today, the production and placement of asphalt pavement has evolved from hand mixing and manual placement with rakes and shovels to computerized plants and automated remixing, placement and compaction equipment. During this time, it has been recognized that mix temperature is critical factor affecting aggregate coating, mix stability during production and transport, ease of placement and compaction as well as the performance of the finished pavement.

HMA temperature has a direct effect on the viscosity of the bitumen, and thus compaction. As the HMA temperature decreases, bitumen becomes more viscous, which result in a smaller reduction in air voids for a given compactive effort [1]. Thus, for successful construction of asphalt pavement, each step in production and placement of HMA must be accomplished within the proper temperature range.

If the mix temperature is inconsistent the degree of compaction (i.e. density) can vary, which will ultimately result in poor performance of finished pavement. Research conducted in late 1990s [2], has shown that variability in density can be caused by temperature differentials on in-placed HMA pavement. This discovery introduced the concept of HMA thermal segregation. Thermal segregation is generally considered difficult to identify by visual inspection, so the potential of using a thermal camera in identifying areas of fresh laid HMA pavement that have substantial temperature differentials has been examined.

Ability of infrared camera to detect temperature of HMA material in paving machinery as well as on large pavement areas makes it suitable tool for quality control during paving.

2 HMA Compaction

Compaction is a process that reduces the volume of mix by the application of external forces to form a dense mass [3]. Compaction of HMA is necessary to achieve optimum air-void content (i.e. density) and to increase the load-bearing capacity of the pavement. Previous studies have shown that for every 1% increase in air void, road life is reduced by 10% [4]. Therefore, improper compaction leads to pavement premature failure, mostly due to permanent deformation, ravelling, cracking and moisture damage.

2.1 Factors affecting HMA compaction

HMA compaction is influenced by numerous factors, some related to the environment, some determined by mix and structural design and some under contractor control during construction (table 1) [5]. Among them most critical seems to be those that influence HMA temperature and cool-down rate. These are production temperature, haul time and distance, initial mat temperature, mat thickness, temperature of the surface on which the mat is placed, ambient temperature and wind speed [1].

Table 1. Factors affecting compaction [5]

Environmental Factors	**Mix Property Factors**	**Construction Factors**
Temperature	**Aggregate**	**Rollers**
- Ground temperature - Air temperature - Wind speed - Solar flux	- Gradation - Size - Shape - Fracture faces - Volume	- Type - Number - Speed and timing - Number of passes - Lift thickness
	Bitumen	**Other**
	- Chemical properties - Physical properties - Amount	- HMA production temperature - Haul distance - Haul time - Foundation support

2.2 HMA temperature

The upper temperature limit for production of HMA is approximately 175°C [6]. Higher production temperatures may result in damage to the asphalt. During transportation from plant to construction site mix will cool down. Cool-down rate depends on environmental conditions (air temperature, wind speed), haul time and distance. After the mix is placed rate of cooling depends not only on air temperature and wind speed but also on the base (ground) temperature and the thickness of in-place layer. Temperature of the placed mix is lost in two directions downward into the base and upward into the air. As HMA temperature decreases mix becomes more viscous and resistant to deformations, which results in smaller air-void reduction. If HMA cools below cessation temperature (80°C) it becomes so stiff that additional rolling is ineffective.

Within these limits (80°C-175°C), the best temperature to begin compaction is the maximum temperature at which the mix will support the roller without damaging the mix (e.g. horizontal movement, mix sticking to roller, etc.) [6]. The temperature between 120°C and 175°C will enable the achievement of maximum density at initial phase of rolling (breakdown rolling). The compaction (intermediate rolling) should be completed before HMA temperature drops below cessation temperature. After that rollers can still operate to provide smooth riding surface but without any additional compaction. This is the last phase of rolling (finish rolling) that normally takes place within the temperature range of 85°C to 70°C [7].

Required compaction can be accomplished only if temperature of placed HMA is higher than 80°C and temperature differentials are not greater than 14°C [8]. Due to numerous factors affecting HMA temperature this is very difficult to achieve. Thus, HMA is subject to thermal segregation, i.e. occurrence of temperature differential damage.

3 HMA thermal segregation

One of the most common and costly problems in the paving industry associated with HMA pavement is segregation. Segregation is defined as ˝...*lack of homogeneity in the hot mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress(es).˝* [9]. Constituents should be interpreted as bitumen, aggregates, additives, and air voids. Segregation is generally put in two categories, one is aggregate segregation and the other is thermal segregation which will be described below.

Thermal segregation also known as temperature differential damage (TDD) is a form of segregation that occurs during the construction of HMA pavement, and it is result of placing portion of cooler HMA material into the new pavement. Cooler material tends to resist compaction creating pavement areas of low density and high air void content that are prone to distresses like raveling, moisture damage, cracking, etc. Cooling of material within the transport truck and improper paver operation are two main reasons for the appearance of temperature differentials in HMA.

During transport from the plant to the construction site material closest to the exterior walls of the truck cools of at a higher rate than material towards the center of the truck. When HMA is loaded into the paver colder material collects on the wings located at the sides of paver hopper. Thus, is longer exposed to ambient temperatures and is usually dumped at the end of the load resulting in areas of temperature differentials in new pavement (˝end of load segregation˝). Besides this, temperature differentials in the pavement may originate from the colder crust formed on the top of the loose mix during transportation. Although colder material from the crust and hot interior material are remixed in paver hopper, time that HMA stays in the paver is insufficient to achieve uniform temperature before placement.

Thermal segregation, resulting from any of above mentioned reasons appears in three patterns, cold spots, cold runs or V-shaped segregation [10]. Cold spots are localized circular areas of low temperature material. Cold runs can be described as long and narrow bands of cooler martial that runs parallel to the direction of paving. V-shape segregation is cooler material that cyclically occurs at the end of truckload.

Pavements areas that exhibit thermal segregation are not always visually apparent and are not easily noticeable during construction. Therefore, traditional means of detecting segregation, may not work when thermal segregation is an issue. Because of this, infrared camera has been recognized as an effective tool in identifying thermal segregation during construction.

4 Quality control during paving

Currently applicable regulations in Croatia prescribe control of HMA temperature during construction in accordance with EN 12697-13. According to this standard HMA temperature must be measured after mixing and during storage, transportation and placement with contact measuring devices (e.g. thermometers) at each HMA sampling point. Data obtained in such manner give information about temperature at selected points, thus areas of low temperature can easily be missed. If the quality control is performed on this way it is very likely that areas affected by thermal segregation will not be detected.

An alternative to thermometers is infrared camera that has the ability to give continuous plot of temperatures. Infrared camera can be applied as a means of quality control in all processes that require the participation of thermal energy. As all objects emit thermal energy in the form of heat, which can be detected by infrared sensor, with infrared camera it is possible to gain a visual image of temperature distribution on large areas. Temperatures are record and displayed as thermograms i.e. colored images with reference scale. Thus, infrared camera could identify areas of different HMA temperature at load out, in the truck during transportation and prior to dumping, in the paver, behind the paver prior to compaction, as well as during compaction.

5 Field measurements

As already mentioned, the objective of presented study was to utilize an infrared camera to identify temperature differentials in HMA pavement which could affect compaction and lead to premature distress of the pavement.

The measurements were performed on June 18th, 2011 between midnight and 03.30 am. The air temperature during the examination was 13°C at the beginning of the test and dropped to 10°C towards the end of testing. The sky was cloudy and it started to rain slightly at the end of testing, which caused the termination of the paving process.

Temperature data was obtained using an FLIR P640 infrared camera (thermal sensitivity 60 mK, geometric resolution 640x480 pixels, FOV 24°).

Infrared camera was used to determine the temperature of the HMA during dumping process in order to estimate the possibility of its proper placement.

Figure 1 shows the HMA mix in the truck at the beginning of the dumping process to the paver.

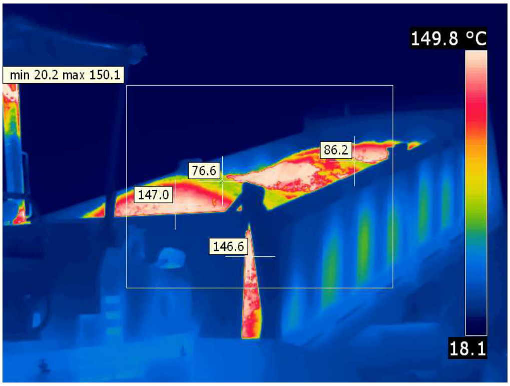

Figure 1. Thermogram of the begining of HMA mix dump into the paver

From the figure, it can be seen that cold crust formed on the top of the HMA, the temperature of the cold crust is between 76.6 and 86.2 °C while the temperature of the HMA below the cold crust was 147°C. Thermogram shows that HMA of cooler temperatures is being dumped into the paver; this creates pavement temperatures near cessation temperature. In the case of this specific site, the reason why the cold crust was formed was waiting time before the HMA could be dumped to the paver, since haul distance was very short it didn´t influence as much.

After the paving, cool areas of uncompacted and compacted HMA were clearly discerned at the paving site, figures 2 and 3.

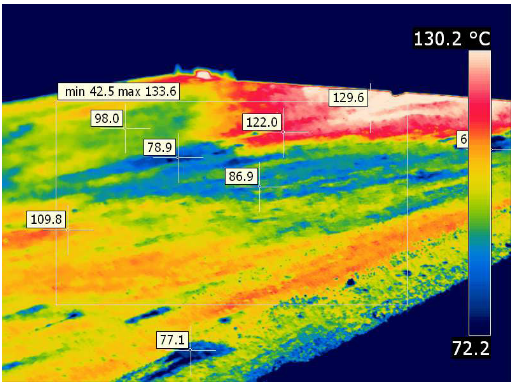

Figure 2. Thermogram showing V-shaped thermal segregation

Figure 2 shows the characteristic V-shaped thermal segregation pattern that cyclically appears in the pavement after the end of dumping and with the change of trucks. The temperatures measured were very close to cessation temperature (80°C), in few places even lower (78.9°C). With the additional cooling of the HMA before finishing of the compaction process, the sufficient compaction of the pavement will not be achieved.

Figure 3, shows the area of uncompacted HMA mix with minimal thermal differentials over the whole encompassed surface. The minimal measured temperature is higher than 100°C. The temperature gradient over the surface is 15°C, while lower temperatures are found only on the edges of paved surface where crumbled over spilled material was pushed back in the area that will be compacted.

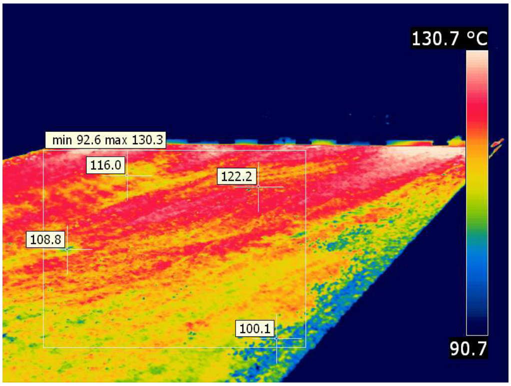

Figure 3. Thermogram showing minimal thermal differentials in a HMA material

The characteristic of IR thermography is that it can show in real time the distribution of temperatures over a large area, the IR images, thermograms can be saved to serve as a proof of the quality of paving process.

6 Conclusion

Negative effects of poor compaction on HMA pavement performance are known for many years. Even with the perfect design, if HMA is not properly compacted, pavement will not serve its intended purpose throughout its design lifetime. The key factor affecting HMA compaction is mix temperature. Every process during pavement construction (mix production, transport, placement and compaction) needs to be completed within the proper temperature range. In order to avoid occurrence of thermal segregation great attention should be paid to temperature control.

Thermometers have long been used to control HMA temperature, and though they provide accurate data, temperature can be measured only in limited number of selected points, thus low temperature areas are easily missed. To ensure proper quality control is necessary to find new methods that will allow the determination of HMA temperature characteristic on large pavement areas before and during compaction as well as in truck and paver.

As presented in the paper infrared camera allows effective monitoring of HMA temperature variations during entire construction process. Infrared cameras are non-contact devices, relatively fast and simple to use. By measuring temperature during construction process it is possible to detect areas of inadequate temperature and apply appropriate measures to avoid temperature differentials. If combined with GPS device it is possible to map temperature characteristics of the entire pavement and thus identify exact locations of areas that could be subject of thermal segregation.

Current studies indicate that infrared camera is an effective tool that can be applied for quality control during paving. But further researches are needed before infrared camera will be used as a reliable specification.

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