Thermal Imaging Technology: Quality Control and Quality Assurance for Construction of Warm and Hot Mix Asphalt Pavements

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ABSTRACT: During the construction process, consistent temperature distribution along and across a newly laid hot mix asphalt mat helps to promote consistent compaction and ultimately better performance of the resulting pavement. This is of particular importance at longitudinal joints, which are typically constructed with a hot layer placed beside an existing colder or older layer. Reduced density at longitudinal joints has been linked with premature failure at these locations, leading to premature failure of the pavement in general. Thermal imaging is able to better assess the quality of newly laid asphalt layers by observing areas of variable temperature during the construction process. This paper presents the details of a pilot study carried out both warm and hot asphalt mixes on Victoria Road in Ottawa, Canada using infrared imaging equipment to investigate the temperature distribution and evolution of the asphalt surface and the joints between mats during construction. The preliminary results suggest that rapid heat loss at the edges of newly placed hot mix asphalt lanes likely leads to reduced density and performance of the longitudinal joints, whereas less heat loss was observed with the warm mix.

KEY WORDS: Thermal imaging, quality, construction, warm mix asphalt, hot mix asphalt.

1 INTRODUCTION

One of the critical issues during the construction of a new asphalt road is the temperature distribution along and across the newly laid hot mix, which affects the resulting density and ultimately the performance of the mat. At longitudinal joint locations, this is of particular importance as they are most often constructed with a hot layer placed beside an existing colder or older layer. Reduced density at longitudinal joints has been linked with premature failure at these locations, as well as the pavement in general. Thermal imaging offers the opportunity to better assess the quality of newly laid asphalt layers by observing areas of low, high and/or variable temperature during the construction process that might affect the resulting mix density or quality.

This paper presents the details of a pilot study carried out on both warm and hot asphalt mixes placed on Victoria Road in Ottawa, Ontario in 2007. Infrared imaging equipment was used to analyze the temperature distribution and evolution of the asphalt surface and the joints between mats during construction. The performance of the two sections after two winters in service is also presented.

2 BACKGROUND

2.1 Infrared Thermography

All objects above 0°K (-273°C or -459.67°F) emit electromagnetic radiation, with the emissive power of a surface defined as the total energy transferred from the respective object to its surroundings. Objects that follow Planck's Law absorb and radiate all incident radiation in a continuous spectrum and are referred to as "blackbodies" (Gaussorgues 1994). Most objects are not perfect blackbodies and therefore have an emissivity ratio of less than unity – i.e. not all of the incident radiation is absorbed or radiated. While the emissivity of an object is not constant and depends on temperature, wavelength and direction, it may be considered constant within a certain bandwidth, range of temperature and cone of direction.

The emissive power of an object varies in relation to its temperature. As such, infrared sensors are able to determine surface temperature remotely, so long as the emissivity is known or estimated. Fortunately, asphalt concrete has a high emissivity ratio (0.96 to 0.98) and is therefore a good candidate for infrared thermography.

2.2 Previous Use of Infrared Thermography for Asphalt Pavement Construction

The use of infrared thermography for studying the surface temperature of Hot Mix Asphalt (HMA) during the paving process has been the subject of various research papers. Mahoney et al. (2000) used an infrared camera to identify cooler regions of the asphalt mat and found that a relationship existed between these cooler regions and the amount of air voids in the surrounding pavement. That research was extended by Willoughby et al. (2001) who showed that pavements with large temperature differentials (greater than 25°F or 13.9°C) during placement had substantial density issues.

Sebesta and Scullion (2003) compared infrared imaging and ground-penetrating radar to identify areas where segregation was present in HMA overlays. The authors concluded that both imaging techniques could delineate variation in as-constructed asphalt properties. More recently, Sebesta et al. (2006) expanded their previous approach by devising a dedicated thermal imaging system comprising of 10 infrared sensors mounted to the back of a paver to monitor the surface temperature of the asphalt as it is laid.

Henault and Larsen (2006) argued that the HMA temperature and the condition of underlying pavements were more important than temperature differentials to explain new pavement performance. They also concluded that thermal and particle segregation could not be distinguished by infrared imaging. However, they agreed with previous research that the pavement smoothness can be adversely affected by temperature differentials across the mat. In Québec, infrared technology is already employed by the Ministère des Transports (MTQ) for quality control during asphalt placement (Lavoie 2007), with a pay factor adjustment applied to a lot based on minimum and maximum temperatures, as well as "thermal segregation" – the presence of areas with widely varying temperature across the newly placed mat.

3 DATA COLLECTION

3.1 Test Sites

In addition to the desire for reduced environmental impact, the City of Ottawa commenced trials of Warm Mix Asphalt (WMA) technology in 2007 to observe whether industry claims of enhanced field performance would justify the additional cost of the additives. A total of 5983 tonnes of WMA were placed using three different technologies; Evotherm® (3433 tonnes), Hypertherm (1600 tonnes), and Sasobit® (950 tonnes).

Given the considerable size of these "trials," the respective WMA additive suppliers documented the construction and have individually reported on initial performance at the 2008 conference of the Canadian Technical Asphalt Association (CTAA). The Evotherm® trial on John Quinn Road was documented by Davidson (2008) while the details of the Hypertherm trial on Katimavik Road, Westleigh Road and Carlisle Circle were presented by Manolis et al. (2008).

Aurilio and Michael (2008) presented the Sasobit® trial on Victoria Road. This trial involved full depth reclamation of the existing asphalt and stabilization with expanded (foamed) asphalt, followed by a 50 mm asphalt concrete overlay. A one-kilometre section was paved with WMA produced with Sasobit®, while the remainder was placed with standard HMA. There were no differences between the warm and hot mix designs other than the addition of 1.5 percent Sasobit to the WMA. The base mix was a Superpave 12.5 Level C with PG 58-34 asphalt cement and 15 percent Reclaimed Asphalt Pavement (RAP).

The City of Ottawa retained Carleton University to record infrared video during paving operations on Victoria Road.

3.2 Infrared Video Equipment and Image Collection

Infrared imaging sequences were acquired using an A40 infrared camera from FLIR Systems, which uses a solid state uncooled microbolometer Focal Plane Array (FPA) of 320×240 pixels, operating in the thermal infrared spectrum (7.5 to 13 µm). It has a 24 mm germanium lens with an anti-reflective coating. This gives a 24°×18° field of view with a minimum focus distance of 30 cm. Its spatial resolution is 1.3 mrad, which means that at a distance of 1 m, each pixel represents a square of 1.3×1.3 mm. Its thermal resolution is 0.05°C at 30°C. The camera was connected to a laptop via a Firewire interface, thereby capturing sequences of 14 bit digital thermal images at 30 frames per second.

Two different arrangements were used to image the newly placed HMA and WMA layers, as well as the joint between successive paver passes. Figure 1 displays the stationary arrangement where the infrared imaging equipment was located on the right side of the lane being paved.

Sections 10 m (33 ft) in length were imaged at various locations before and during placement of the new asphalt mat, as well as after each pass of the roller. To measure the temperature of the joint, the camera was held 50 cm (20 in) above the pavement and moved along the longitudinal joint for each 10 m long section.

3.3 Warm Mix Asphalt Section

3.3.1 Mainline Paving

Figure 2 presents a representative example of the temperature video and profiles obtained during placement of the WMA. Although no Material Transfer Vehicle (MTV) was used for this project, the WMA displayed a very consistent temperature profile during placement. Figure 2a shows the freshly placed WMA directly behind the paver (prior to rolling), with a corresponding cross sectional temperature profile provided in Figure 2e. As shown, the surface temperature of the WMA ranged between 90 and 100°C with very little variation across (or along) the mat prior to compaction.

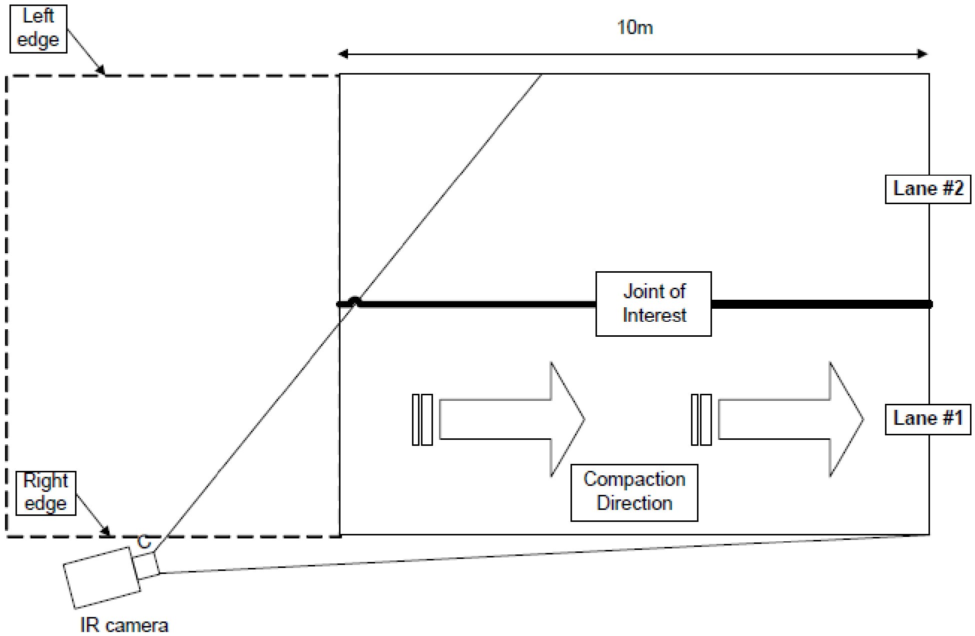
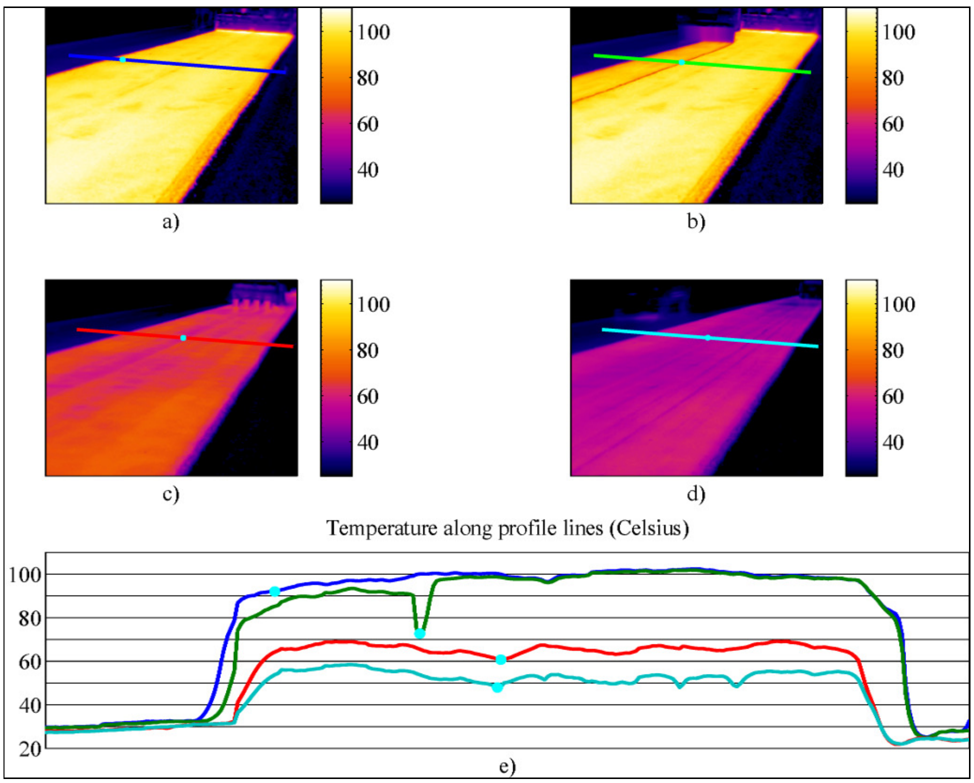


Figure 1: Infrared Video Collection Arrangement



a) Sasobit® WMA as placed behind paver screed prior to compaction.
b) After single pass with steel drum breakdown roller.
c) After multiple passes with breakdown roller and first pass of rubber-tired roller.
d) After multiple passes with rubber-tired roller and finish steel drum roller
e) Transverse temperature profiles for images a) through d)

Figure 2: Thermal Video and Profiles of Warm Mix Asphalt Section of Victoria Road

3.3.2 WMA Longitudinal Joint

WMA has the potential to improve longitudinal joint performance through various mechanisms. First, by not heating the asphalt cement to the same high temperatures as HMA, less oxidation occurs thereby promoting a stronger bond at the joint. Second, WMA improves mix compaction and therefore there is greater opportunity for achieving good compaction at the longitudinal joint.

The longitudinal WMA joint on Victoria Road was thermally evaluated immediately after final compaction of the second lane. The joint between the newly placed and compacted WMA lane and the initial WMA lane is presented in Figure 3. Temperature profiles across the joint were calculated every 5 mm and averaged. As shown, the average temperature gradient shows a consistent, almost linear transition, suggesting normal heat transfer. As shown, a 19°C range in temperature remained.

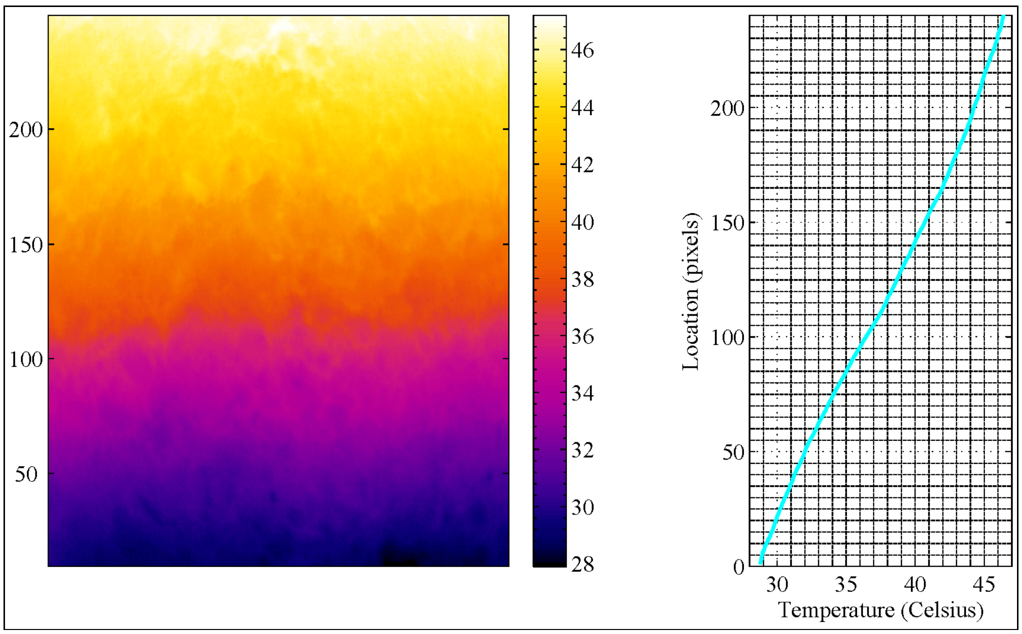


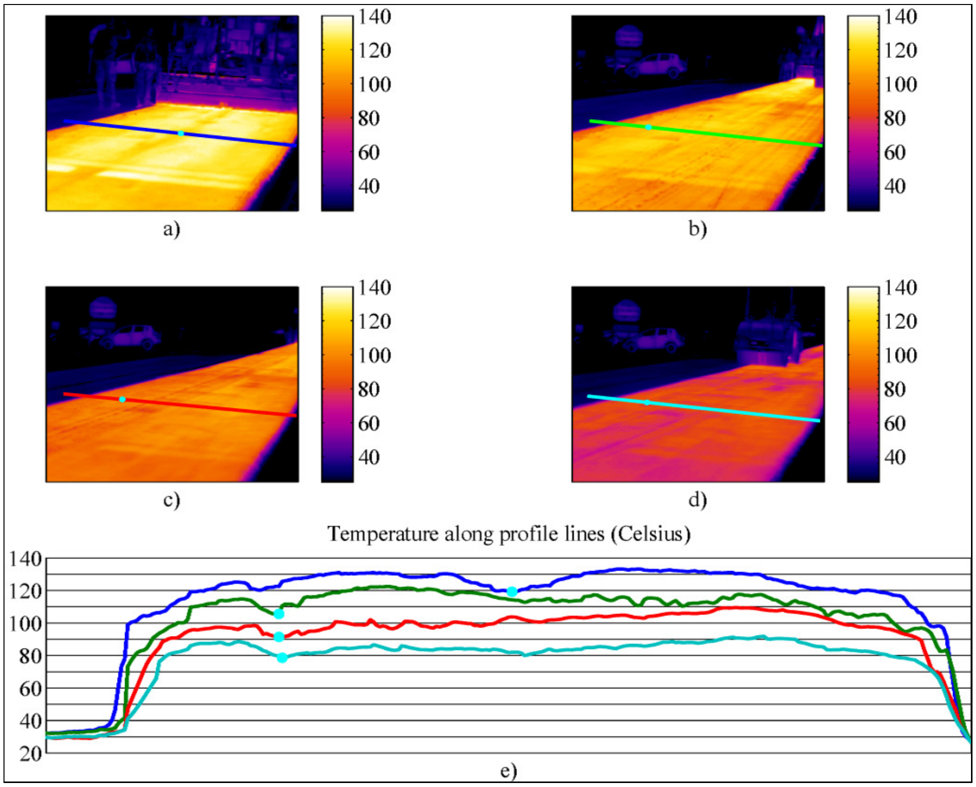
Figure 3: Heat Transfer Across Newly Constructed Warm Mix Asphalt Joint

3.4 Hot Mix Asphalt Section

3.4.1 Mainline Paving

Figure 4 presents a representative example of the temperature video and profiles obtained during placement of the HMA. The surface temperature of the freshly laid HMA before compaction (Figure 4a) was clearly not as uniform across the mat as the WMA and displayed a streak of reduced temperature along the middle of the mat that is most likely associated with the gearbox for the paver augers.

As with the WMA, the right edge of the steel drum breakdown roller (Figure 4b) reduced the surface temperature of the mix considerably during its first pass, however this reduction was permanent as illustrated in Figures 4c through 4e and may have affected compaction consistency.



a) HMA as placed behind paver screed prior to compaction.
b) After single pass with steel drum breakdown roller.
c) After multiple passes with breakdown roller and first pass of rubber-tired roller.
d) After multiple passes with rubber-tired roller and finish steel drum roller
e) Transverse temperature profiles for images a) through d)

Figure 4: Thermal Video and Profiels of Hot Mix Asphalt Section on Victoria Road

The most interesting observation during the thermal evaluation of the HMA placement effort was the immediate and considerable loss of temperature at the free edges of the mat. As shown in Figure 4a and 4e, the surface temperature at the edges of the mat directly after placement was 100°C, a full 25 to 33°C lower than the rest of the HMA. Such a considerable temperature variation would not promote consistent compaction at the edges of the mat. Since these edges form one of the interfaces for longitudinal joints, it is apparent why density variations across joints are common.

The final HMA surface temperature after compaction (Figure 4d) was approximately 85°C (average) and additional time would be required before trafficking or additional layers could be placed upon the mat (if a base course). This additional cooling time could significantly delay the construction process, particularly if placed during the middle of the summer when ambient temperatures prevent rapid cooling. In contrast, the final WMA temperature of 55°C would allow trafficking or placement of additional layers almost immediately after compaction.

3.4.2 HMA Longitudinal Joint

The joint between the newly placed and compacted HMA lane and the initial HMA lane is presented in Figure 5. The minimum and maximum temperature values were 43 and 70°C, respectively – a difference of 27°C as opposed to the 19°C difference observed with the WMA joint.

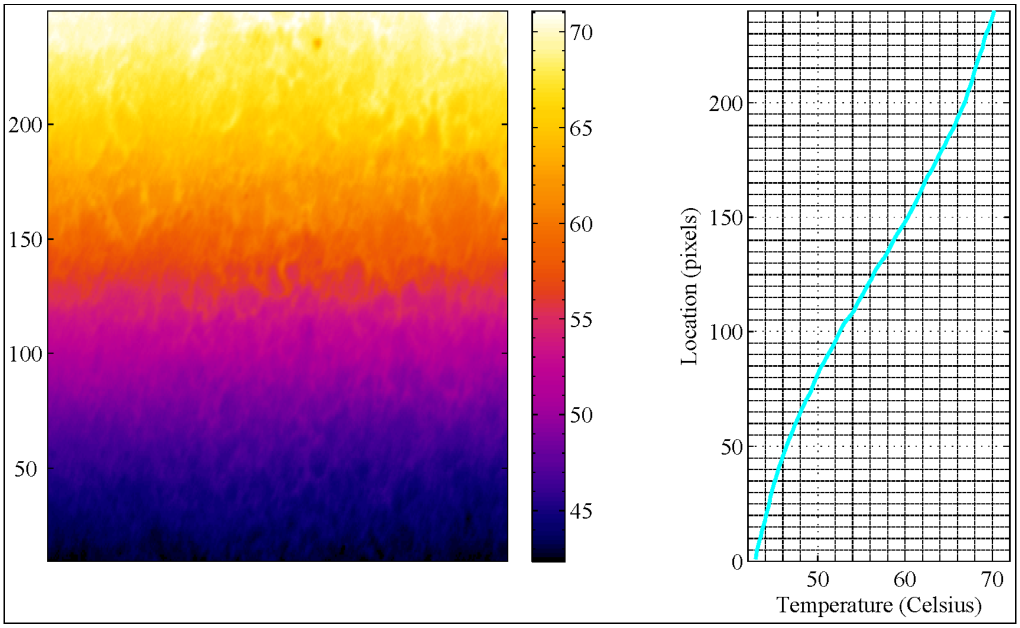


Figure 5: Heat Transfer Across Newly Constructed Hot Mix Asphalt Joint

The slope of the temperature gradient from the newly compacted HMA and the existing HMA is therefore considerably greater. These observations suggest that longitudinal joints between old and hot mix need more attention due to the more rapid loss of temperature across the layer, which may affect its bonding characteristics and subject the joint to future separation and deterioration.

4 EARLY LONGITUDINAL JOINT PERFORMANCE

A pavement condition assessment was completed at Victoria Road in March 2009 after 2 winter seasons in service. Overall, both sections are performing well, however the surface of the HMA section displayed very slight ravelling (loss of fine aggregate material) whereas the WMA section remains very tight. No fatigue or thermal cracking was observed (nor expected) and riding quality was good.

In fact, the only distress observed was related to the longitudinal joints. For the Sasobit® WMA section, the joint has opened with slight severity (3 to 6 mm crack width) for 280 m of the total section length of 1262 m, or 22.2 percent of the section length. For the HMA section, the longitudinal joint had opened with slight severity for 760 m over the total section length of 1838 m, or 41.3 percent of the section length.

Figure 6 displays a comparison of the typical joints for the hot (6a) and warm mix (6b) sections. Continuing evaluation is required, but initial performance suggests that WMA provides better longitudinal joint performance than HMA (all else equal). The performance of Victoria Road will be monitored with time to confirm these initial results. It is interesting to note that the other two WMA trials (Evotherm® and Hypertherm™) currently display no opening of the longitudinal joints for either their respective WMA or HMA sections.

a) Typical Joint Opening in Hot Mix Asphalt Section of Victoria Road

b) Typical Joint in Warm Mix Asphalt Section of Victoria Road

Figure 6: Longitudinal Joint in Hot and Warm Mix Asphalt Sections After 2 Winters

5 SUMMARY AND RECOMMENDATIONS

No definitive conclusions were drawn given the early age of the test sections, although the following are provided as points of interest:

- Although no Material Transfer Vehicle (MTV) was used for the Victoria Road project, the
- Warm Mix Asphalt (WMA) displayed very consistent temperature along and across the newly placed mat (< 10°C variation), whereas considerable variation was observed at the Hot Mix Asphalt (HMA) section (25 to 33°C variation).
- A low temperature streak was observed in the middle of the HMA lane and was likely the result of the paver augers. No such streak was observed with the WMA.
- The edges of the freshly laid HMA were up to 33°C lower than the rest of the mat. Consistent compaction would therefore not be expected.
- The final surface temperature of the WMA section was 55°C, which was sufficiently low to allow immediate trafficking or placement of subsequent layers, whereas the HMA would require additional cooling time thereby delaying the paving process or opening to traffic.
- Initial performance data suggest that WMA provides better longitudinal joint performance than HMA. Specifically, the WMA section displayed approximately half of the longitudinal joint cracking as compared to the HMA section after 2 years in service.

Density testing of the longitudinal joints is considered appropriate to relate the observed temperature variations with density and ultimately performance of the pavement. A request to the City of Ottawa will be made to conduct a limited coring investigation at the pavement edges and longitudinal joint to determine the in-place density of the HMA versus WMA.

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