Heating Longitudinal Joints with Infrared Heaters to Improve Performance
The City of Calgary's Joint Density Specification

Nasir-ul Mulk, P.Eng. Senior Pavement Engineer, City of Calgary

Dinesh Ghimire, BSc. Civil Engineering, Engineering Assistant, City of Calgary

Vince Aurilio, P.Eng. President, VA Asphalt Pavement Technologies Inc.

Paper prepared for presentation at the "Innovations in Pavement Management, Engineering and Technologies" of the 2023 TAC Conference & Exhibition, Ottawa, ON

September 24-27, 2023

ABSTRACT

Premature longitudinal joint failures due to low density, water intrusion, cracking, and ravelling is a common and significant issue in asphalt roadways. Joints often fail first despite the rest of the mat being constructed properly with suitable mixes. Premature joint deterioration reduces the pavement's life cycle and requires increased maintenance, wastes time, budget, environmental and safety concerns due to traffic accommodation.

In 2021 and 2022, the city conducted pilot studies using infrared heaters during paving to create heated joints. The city is continuing its study through 2023. To facilitate implementation of the joint density specification and to evaluate the overall effectiveness, the contractor was required to heat the construction joint using an infrared joint heater supplied by Heat Design Equipment in 2021. Preliminary results were encouraging with improved densities and reduction in air voids. As such, the City decided to proceed with the joint density specification on contracts in 2022/2023.

This paper presents the preliminary results of the longitudinal heated joints from the City's 3-year study, including the development of specifications, best construction practices, challenges, and maintenance. The city plans to continue heating joints, particularly on high-volume roadways and multi-lane pavements, and further improve the current specifications.

INTRODUCTION

The relatively poor performance of longitudinal joints continues to be a concern across Canada and throughout North America. Recent research has shown that the average onset of low-severity cracking is 4 years, and that medium-severity cracking occurs after an additional three years. [1] A summary of the data reported in Wisconsin Highway Research Program (WHRP) Project 21-05 based on a survey of the attendees at a Transportation Research Board (TRB) Webinar (82 % of which were DOTs) is presented in Table 1. [1, 2] The webinar participants were asked “How many years do you expect your longitudinal joints to last before a repair is needed?” The responses clearly show the significance of the problem and emphasize the need to raise the bar when it comes to constructing long-lasting, durable longitudinal joints.

Table 1. TRB Webinar Participant's Responses [1]

Years	Number of Responses	Percentage of Reponses
1-3	31	10 %
4-6	142	44 %
7-9	83	26 %
10-12	49	15 %
12-14	18	6 %

Longitudinal Joint

The longitudinal or construction joint is formed between two adjacent passes of the paver, where typically the first pass is unconfined and allowed to cool. Improperly constructed longitudinal joints can cause premature deterioration of HMA pavements in the form of cracking and raveling. The distress, caused by relatively low density (high air voids) and surface irregularity at the joints, can largely be avoided through proper placement/compaction techniques and/or equipment.

Longitudinal Joint Failure

Premature longitudinal joint failure is the major problem in asphalt pavements. Pavement deterioration at the centerline joint begins with water and air infiltration which causes the joint to open up and ultimately crack.

Typically the rest of the mat is properly compacted, however, low joint density and increased permeability at the joint may be caused during construction by the following:

- Lack of edge support at the cold uncompacted edge leads to poor or low density.
- No thermal bond or seal between each pass of the paver means increased permeability.
- Poorly compacted density at the cold joints means high voids and shorter service life.
- Premature failure equals constant maintenance and expense of valuable time and budget.

The main cause of the poor performance can be attributed to low density (i.e., high air voids) and the resulting higher permeability, primarily with the unconfined edge. The longitudinal or construction joint is the edge between two separate passes of the paver; typically, the first pass is generally unconfined during compaction and regularly becomes 'cold', while the second pass is placed hot and usually well confined by the first pass. The first pass (or the unconfined edge) generally leaves an area of low density along the edge of the mat. The challenges of good joint construction are depicted in Figure 1. [3]

One of the most critical problems in asphalt pavement construction today is achieving a long-lasting longitudinal joint. It is costing agencies significant funds worldwide to repair premature failures at the joints. In the City of Calgary, it is estimated that 60% of the construction joints require repair. Low density (i.e., high air voids) in general HMA is a problem that can lead to numerous distresses including decreased stiffness, reduced fatigue life, accelerated aging/decreased durability, rutting, raveling and moisture damage. Usually, a well-constructed joint will be about 1-2% less dense than the rest of the lane away from the joint, however, a poorly constructed joint can have significantly lower density.

The problem stems from a lack of density on the edge of the first paved lane, due to lack of confinement. This results in a push sideways at the edge, and lower density on the outer 7-15mm, typically 4-6 percent less than the density of the mat. This lack of density, according to considerable research, can translate into a reduction of 20-35% in the life of a pavement, because a low density means more water penetration, more freeze-thaw action, and more moisture deterioration of the bitumen/aggregate bond. Further, it means a lower strength that is not capable of withstanding today's heavy traffic loads, and once the crack occurs, a concentration of load on each side of the crack as the wheel passes over, will further stresses the joint area resulting in cracking of varying severities. The cost of sealing the longitudinal joint is in the order of $5.00 to $7.00 per linear metre.

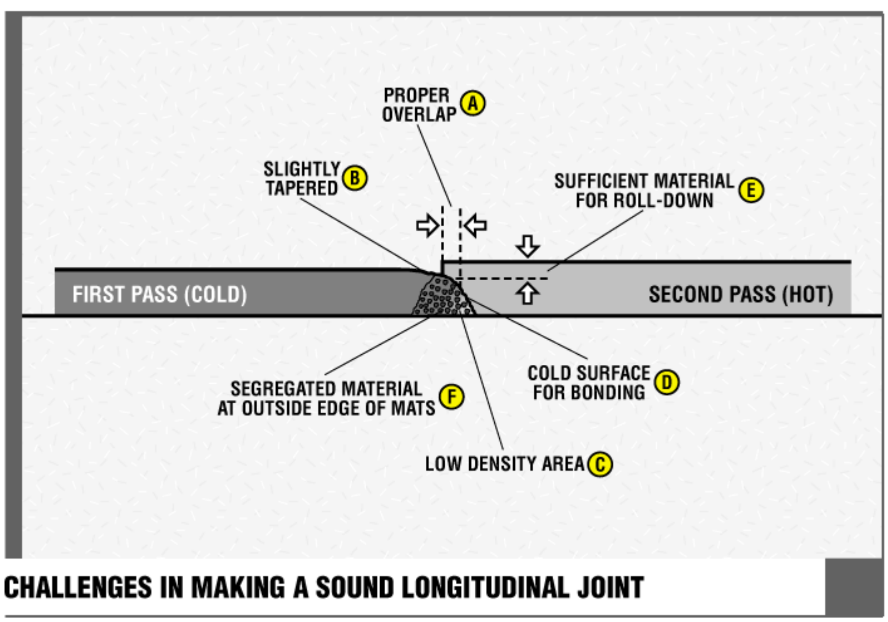

Figure 1. ASTEC Technical Bulletin 130

Longitudinal joints that are not constructed properly tend to fail prematurely generally resulting in cracking and loss of mix or raveling and eventually potholes. Properly constructed joints on the other hand provide the desired long-term performance, which results in lower maintenance and rehabilitation costs. The following photographs (Figure 2) show the contrast between poor performing and well-constructed (i.e., good-performing joints). [3]

Figure 2 (a) Poorly Constructed; (b) Well constructed Longitudinal Joint [3]

IMPORTANCE OF COMPACTION

It is well known that good compaction is critical to ensure long-term pavement performance. One of the key factors affecting joint performance is generally insufficient compaction or low density (i.e., high air voids). Low-density or high in-place air voids can lead to numerous distresses (e.g., raveling, moisture damage, cracking etc.), reduced fatigue life, and accelerated aging, resulting in raveling and moisture damage. Achieving the proper density or good compaction is essential. As a rule of thumb, in-place air voids greater than 7 percent result in inter-connected interstitial voids in the pavement that exacerbate the ingress of water and air. This affects the overall durability of the longitudinal joint. Essentially, the joint ‘opens up’ prematurely and becomes the inherent weak spot in the pavement. It is estimated that a 1 percent increase in air voids (from the target air voids of 7 %) can lead to a 10 percent decrease in the life of the pavement. [4, 5]. These findings have been reported and validated by the Asphalt Institute and NCAT over the years.

ON-GOING LONGITUDINAL JOINT RESEARCH

The National Center for Asphalt Technology (NCAT) started evaluating longitudinal joint construction in the early 1990s. One of the first studies completed and reported by NCAT was in 1996. Seven different longitudinal joint construction techniques were used on Interstate 25 in Colorado in 1994 [7]. Various techniques were studied including different rolling procedures, the use of cutting wheel, and rubberized joint tack coat. In about the same time a similar study was also undertaken in Pennsylvania on I-79; this study included the use of the New Jersey type wedge joint. These early studies indicated the 3:1 taper or wedge joint and rolling the joint from the hot side provided better densities. Various other significant studies were reported in 2002 also by NCAT [7, 8].

The notched wedge joint consists of joint taper placed on the first pass of the mat. A paver attachment on the screed forms the mat edge into a tapered section that is about 0.3 m (1 ft.) from the edge and the notch depth relates to the nominal maximum aggregate size of the mix. The second or hot pass overlaps the cold mat notch by about 12.5 to 25 mm (0.5 to 1 inch) and is bumped back to the notch to ensure enough material at the notch for adequate compaction.

The notched wedge joint also provides more surface area to properly tack the joint to ensure good bond at the joint.

In addition, the notched wedge joint provides a safe ramp for traffic transition between the cold lane and the yet unpaved portions of the hot lane. Other techniques such as cutting wheels, joint makers and edge restraining devices have also been used over the years to improve joint density to varying degrees of success.

The Tennessee Department of Transportation (TN DOT) conducted a similar study in 2009 to evaluate various methods to construct longitudinal joints. [9] The key findings of the study are presented in Figures 3 and 4. Based on this study the use of the infrared joint heater provided better overall density (i.e., lowest air voids) and the lowest permeability [6]. A similar study conducted in Arkansas validated the TN DOT findings.

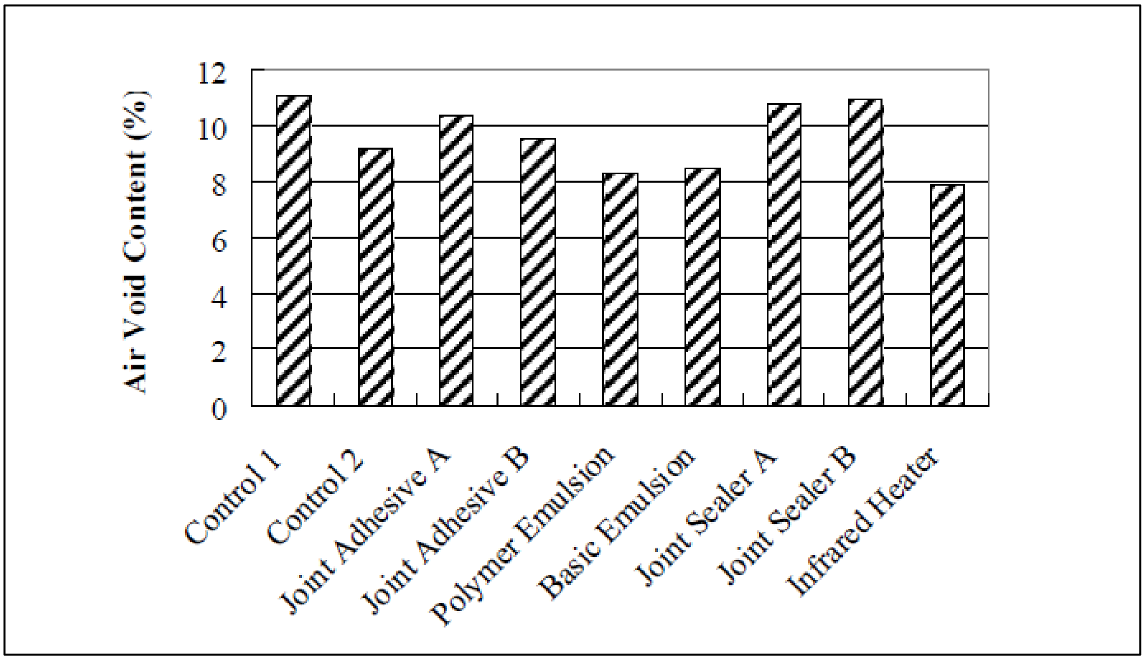

Figure 3 Tennessee DOT [9] Study Air Voids

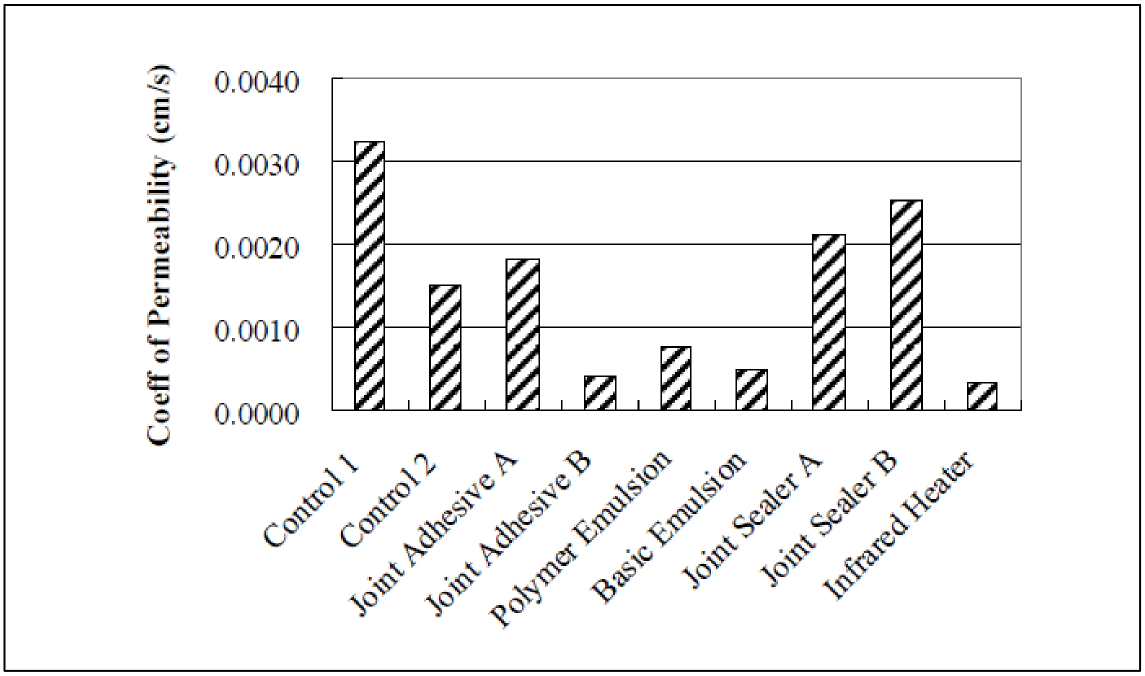

Figure 4 Tennessee DOT [9] Study Permeability

The Authors [9] stated the following conclusions:

"The infrared heater exhibited the best performance among all the joint construction techniques used in the study. The infrared heater was effective in reducing air void content and water permeability and increasing IDT strength. The air voids distribution obtained from the X-ray CT images shows that the effectiveness of infrared heater in improving joint quality was through increasing the compaction degree of longitudinal joint deep to the overlay bottom and thus making the joint denser."

INFRARED HEATING TECHNOLOY [10]

As discussed previously, early joint deterioration leads to costly repairs and replacement of centerline/lane edge longitudinal joints. Recognizing that reheating the cold & uncompacted edge immediately before the second paver pass could improve in-place joint density, Heat Design Equipment Inc. (HDE) developed a paver attached longitudinal joint heater. HDE infrared joint heaters are currently being used in various parts of the US and Canada.

The infrared joint heater works on the same principle as the infrared patcher. The heater is attached to the paver as shown in Figure 5 [10]. HDE uses a vaporizer to ensure a consistent pressure of propane to the system at temperatures down to -25°C (-15°F). The liquid propane, which is drawn from the bottom of a standard LPG cylinder, is heated in the vaporizer and converted to gas. Using a vaporizer empties the tanks without any "freeze up," which is the most common problem with any vapor system. This happens because the heating system draws more vapor propane than the tank can naturally produce. More importantly, the vaporizer ensures a constant pressure to the infrared heater ensuring uniform consistent heat throughout the day as the tank empties. The vaporizers are used on all joint heaters and all asphalt patchers larger than 36 square feet. The HDE mini heaters operate on 20-to-40-pound vapor draw cylinders.

HDE joint heaters are designed to be expanded depending on paving requirements. Slower paver speeds may require an HDE 300-PA, within 10 minutes it can be changed into a HDE 500-PA for highway paving. After the initial installation, the JMH-PA can be attached to any brand of paver within 10 minutes, as all electrical and propane connections are quick connect.

Figure 5 Heat Design Infrared Joint Heater

Each unit is pre-wired for electronic ignition and both manual and automatic modes. When operating on automatic, the heater will switch from operating pressure (35 psi) to low pressure (5 - 10 psi). If there is a delay in the paving operation and paving is stopped, the unit will switch to low and heat the joint slowly without burning the mix. When the paving operation resumes, the heat will switch to operating pressure. The heating width can be adjusted based on the paving width by sliding the heater along the 50 mm (2”) chrome shaft.

CURRENT SPECIFICATIONS

The following is an excerpt from the Federal Aviation Administration (FAA) P-401 [11] specification:

401-4.14 Joints. *The formation of all joints shall be made to ensure a continuous bond between the courses and obtain the required density. All joints shall have the same texture as other sections of the course and meet the requirements for smoothness and grade.*

The roller shall not pass over the unprotected end of the freshly laid asphalt except when necessary to form a transverse joint. When necessary to form a transverse joint, it shall be made by means of placing a bulkhead or by tapering the course. The tapered edge shall be cut back to its full depth and width on a straight line to expose a vertical face prior to placing the adjacent lane. In both methods, all contact surfaces shall be coated with an asphalt tack coat before placing any fresh asphalt against the joint.

*Longitudinal joints which have been left exposed for more than four (4) hours; the surface temperature has cooled to less than 175°F (80°C)**)**; or are irregular, damaged, uncompacted or otherwise defective shall be cut back with a cutting wheel or pavement saw a maximum of 3 inches (75 mm) to expose a clean, sound, uniform vertical surface for the full depth of the course.*

All cutback material and any laitance produced from cutting joints shall be removed from the project. Asphalt tack coat in accordance with P-603 shall be applied to the clean, dry joint prior to placing any additional fresh asphalt against the joint. The cost of this work shall be considered incidental to the cost of the asphalt.

Cut back of all cold joints is required as specified above.

The Contractor may provide additional joint density QC by use of joint heaters at the Contractor's expense. Electrically powered infrared heating equipment should consist of one or more low-level radiant energy heaters to uniformly heat and soften the pavement joints. The heaters should be configured to uniformly heat an area up to 18 inches (0.5 m) in width and 3 inches (75 mm) in depth. Infrared equipment shall be thermostatically controlled to provide a uniform, consistent temperature increase throughout the layer being heated up to a maximum temperature range of 200 to 300°F (93 to 150°C).

Propane powered infrared heating equipment shall be attached to the paving machine and the output of infrared energy shall be in the one to six-micron range. Converters shall be arranged end to end directly over the joint to be heated in sufficient numbers to continuously produce, when in operation, a minimum of 240,000 BTU per hour. The joint heater shall be positioned not more than one inch (25 mm) above the pavement to be heated and in front of the paver screed and shall be fully adjustable. Heaters will be required to be always in operation.

The heaters shall be operated so they do not produce excessive heat when the units pass over new or previously paved material.

Similarly, the Department of National Defense (DND) [12] in Canada specifies a re-heating method as follows:

Joint Re-Heating Method

1 Re-heat the edge of the previously laid mat (lane) using a longitudinal joint infrared heater to produce a welded joint, without scorching or burning the mix.

2 The surface of the reheated asphalt shall not be heated above 121ºC. The heat shall penetrate and soften a minimum depth equal to one size larger than the nominal size of the aggregate to enable re-compaction of the edge, and form a seamless bond with the cold lane, without crushing the aggregate against a hard, un-softened surface.

3 Uniformly heat a minimum width of 200 mm along the edge of the cold lane plus a 200 mm strip of the existing asphalt to which the new hot mix is being applied. Re-heating of the cold edge shall be done without slowing the normal rate of paving.

On completion, the joints shall present the same texture as the remainder of the surface and meet the requirements for smoothness and grade as specified herein.

LONGITUDINAL JOINT COMPACTION ACCEPTANCE

Longitudinal joint compaction test results shall meet the sublot and lot requirements give in the following table as per Table 9 of the specification [12].

Sublot	Lot	Action	Lot Pay Factor, E_x (% Payment)
93.0 or greater	94.0 or greater	Acceptable	100
92.5 to 92.9	93.0 to 93.9	Minor Borderline	95
92.0 to 92.4	92.5 to 92.9	Major Borderline	90
Less than 92.0	Less than 92.5	Rejectable	Remove and replace

Longitudinal Joint Compaction Table 9 DND Specification [12]

ALASKA DOT EXPERIENCE

The Alaska DOT has employed a density specification since 2017 with excellent success. A summary of the 2017 data is presented in Table 2 [13].

The results clearly show that improved joint density (as increased compaction) is not only achievable, but the compaction is typically as good as the main lane. Contractors are achieving this using the HDE paver attached infrared joint heater.

Table 2 Alaska DOT 2017 Compaction Summary [13]

Compaction Summary - 2017 Data		
	% Compaction	
	Bulk/MSG	Bulk/MSG
	Panel	Joint
SB-L1 Average Panel Density (20 Cores)	94.8	
NB-L1 Average Panel Density (17 Cores)	95.4	
SB-L2 Average Panel and Joint Densities (33 Cores)	94.9	94.1
SB-L3 Average Panel and Joint Densities (3 Cores)	95.5	93.4
NB-L2 Average Panel and Joint Densities (28 Cores)	94.7	95.0
Project Averages	**94.9**	**94.5**
Max	97.6	97.8
Min	92.3	90.9
Note:		
50 of 101 (50%) of Panel Cores 95.0% or Higher		
26 of 64 (41%) of Joint Cores 95.0% or Higher		

Work to evaluate joint compaction and improve the overall performance in 2021 continues. The Alaska DOT first started using Intelligent Compaction (IC) at the Sitka Airport in 2013. Various demonstration projects were completed and in 2016 the PaveIR was specified on the Glenn Highway-Hiland to Eklutna [13]. The first demonstration of the PaveScan Rolling Density Meter (RDM) was performed on the same project in September 2016.

The PaveScan RDM provides approximately 10 Dielectric readings per foot of travel at 4 mph walking speed per antenna generated from 400,000 pulses per second processed with Equivalent Time Sampling to produce 60 scans (dielectric readings). A photograph of the PaveScan RDM is shown in Figure 6. A plot of the percent compaction versus the dielectric readings is presented in Figure 7 based on the Alaska DOT research.

The Alaska DOT specification requires a minimum joint compaction of 92 percent based on the maximum theoretical density. A joint density bonus of $1.50 per lineal foot is currently provided for compaction greater than 93 %. Joint sealant is required for all sections with lower than 92 percent compaction, including bridge decks [13].

Figure 6 PaveScan Unit measuring Joint and Mainlane Percent Compaction [13]

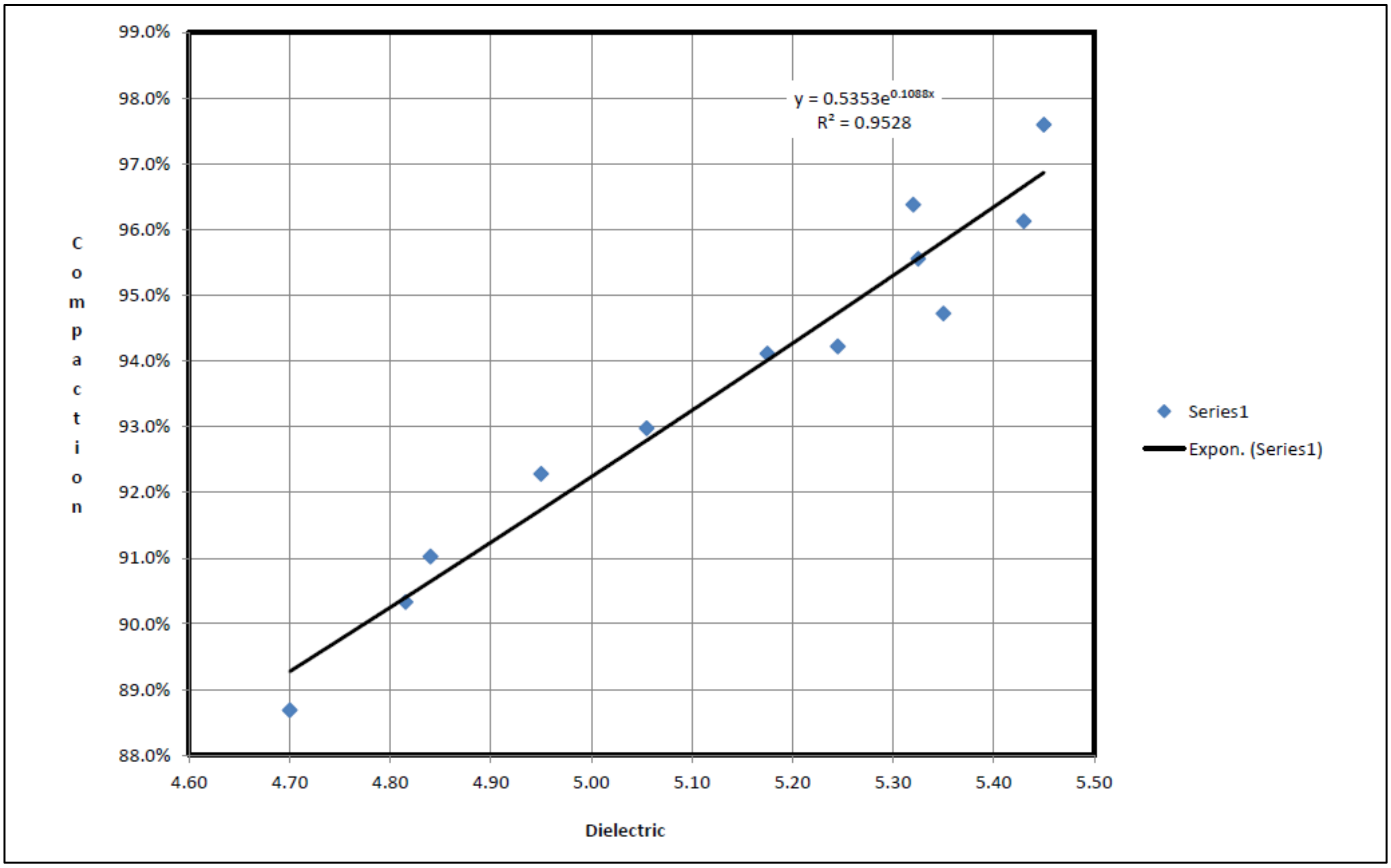

Figure 7 Plot showing Percent Compaction vs. Dielectric Reading [13]

USE OF INFRARED JOINT HEATER IN ONTARIO

City of Hamilton

The City of Hamilton has been using infrared joint heaters since 2007 for low-volume urban projects and high-volume urban projects that are not accessible for echelon paving. The use of joint heaters allows for paving with one paver but ensures that the longitudinal joint is hot when the paver places the second lane of HMA. Quality assurance testing results indicate that the compaction achieved at these joints is the same or very close to the compaction in the middle of the mat [14].

MTO Special Provisions

The Ministry of Transportation of Ontario (MTO) continues to evaluate joint density specifications. In West Region, the MTO specifies the use of infrared joint heaters by a Non-Standard Special Provision (NSSP), which has been used on most contracts for several years. This NSSP is based on meeting temperature requirements and does not permit overheating of the mat.

The MTO is also exploring different ways of measuring the density at the joint; for instance, the latest 'trials' include coring on the joint itself to measure the percent compaction. NSSP BITU0024 includes an End Result Specification (ERS) for joint density based on a lower limit of 1.5 percent lower than the main-lane compaction, where the lower limit is 90.5 percent. Cores are typically obtained on the confined and unconfined edges staggered and offset by 150 mm from the joint.

The specification is being phased in and is now part of the ERS for acceptance of HMA on MTO contracts.

Figure 8 HDE Infrared Joint Heater Attached to the Paver [10]

City of Calgary Experience with Infrared Joint Heaters

In 2021 and 2022, the city conducted pilot studies using infrared heaters, supplied by Heat Design Equipment Inc., to heating the joint. As a result of the successful pilot projects, the city is continuing the study through 2023. To facilitate implementation of the joint density specification and to evaluate the overall effectiveness, the contractor was required to heat the construction joint using an infrared joint heater in 2021. Preliminary results were encouraging with improved densities and reduction in air voids. As such, the City decided to proceed with the joint density specification on contracts in 2022/2023.

Field density test summary:

City conducted pilot study in city projects. The summary results and finding on Cold vs. Heated joints conducted in 2021, 2022 in Hot Mix Asphalt (HMA) and 2023 in Warm Mix Asphalt (WMA) are presented below:

Year	**Parameter**	**Cold Joint Air Voids % G_{mm}**	**Heated Joint Air Voids % G_{mm}**
2021	Average Densities using Nuclear Gauge verified by core test (HMA)	87.9	91.4
	Core Analysis – Air Voids	10.6%	8.8%
2022	Average Densities using Nuclear Gauge verified by core test (HMA)	89.8	91.6
	Core Analysis -Air Voids	10.2%	8.5%
2023	Average Densities using Nuclear Gauge verified by core test **(WMA)** SP12.5 mm Average	87.8	88.6
	Core Analysis -Air Voids	12.2%	11.4%

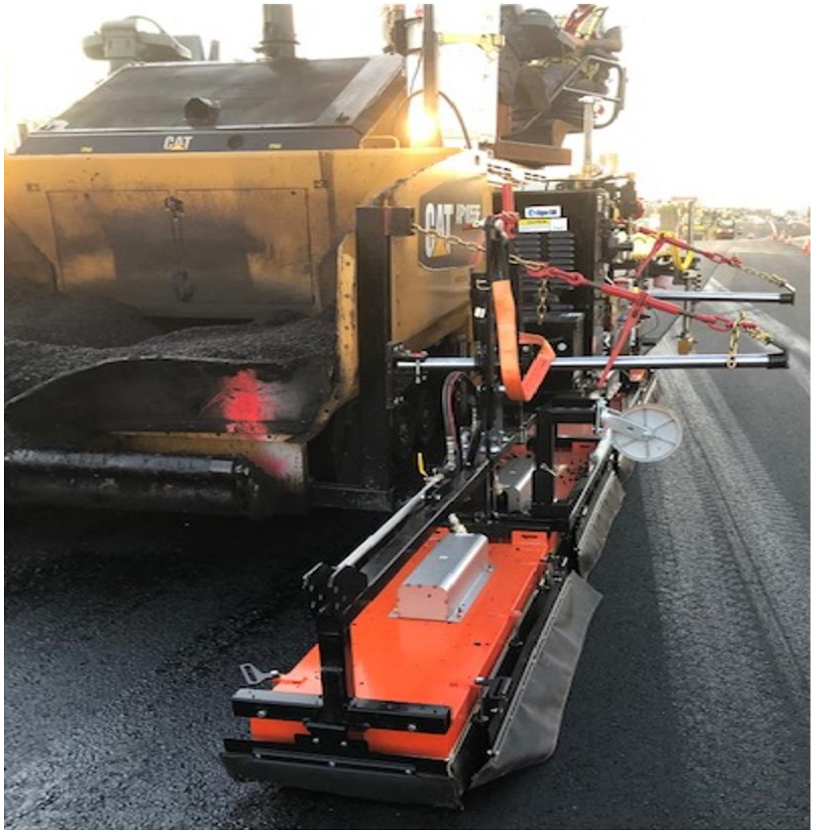

Figure 9 Joint Heater Attached to the Paver on City of Calgary Projects

PILOT PROJECT RESULTS

Quite encouraging results were found as there have being improvements in densities and in air voids reduction. The infrared heater increased the cold longitudinal joint temperature by approximately 100 degrees allowing the rollers to compact the joint to an average density of greater than 91.5% and an almost seamless longitudinal joint.

HEATED LONGITUDINAL JOINT DENSITY SPECIFICATION – THE CITY OF CALGARY

The formation of all joints shall be made to ensure a continuous bond between the lanes to obtain the required density. All joints shall have the same texture as throughout the lanes and meet the requirements for smoothness and grade.

All contact surfaces shall have a tack coat applied before placing any fresh lift against the joint. The Contractor shall provide minimum density quality control by use of infrared joint heaters. The infrared joint heater shall be used to preheat the cold edge of the previously compacted lane with infrared heat (typically from a propane fired heater) before placement of the lift. The purpose of the preheating is to improve the adhesion between cold and hot lanes and make pavement compaction easier.

The heaters should be configured to uniformly heat an area up to 0.5 m in width and 75 mm in depth. Infrared equipment shall be thermostatically controlled to provide uniform, consistent temperature increases throughout the layer is heated up to a maximum temperature range of 93 - 150 °C. Propane-powered infrared heating equipment shall be attached to the paving machine and the output of infrared energy shall be in the one to the six-micron range. Converters shall be arranged end-to-end directly over the joint to be heated in sufficient numbers to continuously produce a minimum of 240 000 BTU per hour when in operation. The joint heater shall be positioned not more than 25 mm above the pavement to be heated and shall be fully adjustable. Heaters are required to be always in operation. The heaters shall be operated so they do not produce excessive heat when the units pass over new or previously paved material.
All activities related to this item will be covered within the lump sum unit rate of the agreement.

If the contractor chooses echelon paving, no joint heating is required. The contractor shall get approval for echelon paving from City Traffic and the project manager.

The minimum density requirement for the top lift heated longitudinal joint shall be **92.0 % of the Maximum Relative Density** (MRD).

Longitudinal joints shall be formed in such a manner that the joint meets the minimum density requirements of 92.0 % of the maximum relative density. The density shall be tested using nuclear gauges at 25 linear metre intervals verified by cores. The contractor shall submit separate Quality Control reports for heated longitudinal joints for each day's operation including total average lot density and total linear metre.

Heated Longitudinal Joint Price Adjustment

The city may perform quality assurance testing on the heated joints. If the heated joint density average for the lot is less than **91.0 % of the MRD**, the longitudinal price adjustment of **$7.00 per linear metre deduction** is applied or as directed by the Engineer. Cores can be extracted as directed by the city Engineer to verify density results in case of disagreement or other dispute resolution.

Challenges

- Impact on the efficiency of the paving operation
- Safety concerns particularly when the lane width is narrow
- Tapers, turning lanes and where lane widths are variable
- Mostly appropriate for major roadways with 3,4 lanes in each direction
- Based on City's experience, this could be issue for urban setup and can not be done in local roads

RECOMMENDATIONS & CONCLUSIONS

Based on the results from 2021 and 2022 it is concluded that:

- The results from pilot projects confirmed significant improvements in longitudinal joint densities (87.9 % to 91.6%) for HMA. Also, there was an improvement in the air voids from 10.6% to 8.5%.

- The results from 2023 WMA heated joint are not meeting the expectation of City Of Calgary.
- Continue heating joints, particularly on high-volume roadways and multi-lane pavements.
- Due to narrow lane widths e.g. 3.3 m or less, heating the joint using the infrared joint heaters may not be a viable option or may impact project efficiency.
- Revise or to adjust the specification in the future as required.
- Workmanship is critical to achieving quality and long-term performance of longitudinal joints.

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