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An innovative asphalt patch repair pre–heating method using dynamic heating

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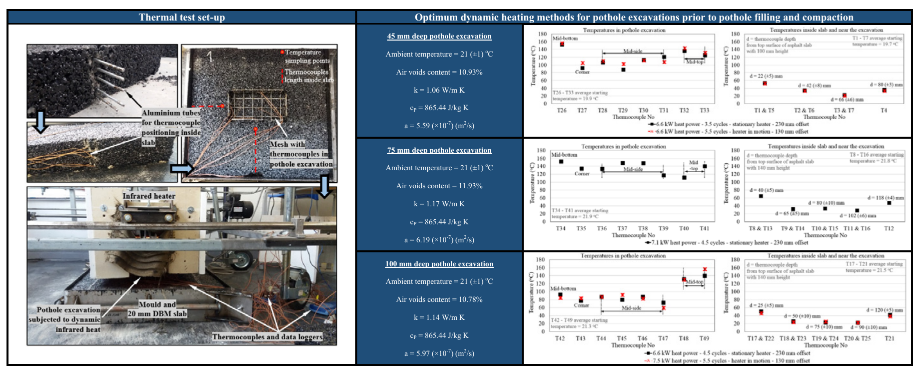
HIGHLIGHTS

- Dynamic infrared heating aims to improve pothole repair interface bonding.
- Shallow and deep pothole excavations were subjected to dynamic infrared heating.
- Temperatures were measured on the excavation wall and inside the slab during heating.
- Temperatures in the excavations were significantly higher than inside the slab mixture.
- Temperatures inside the slab mixture had a lowering trend from the top to the bottom of the slab.

GRAPHICAL ABSTRACT



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ABSTRACT

In hot mix asphalt patch repair, inadequate temperature at the interfaces is one of the influencing factors for inferior compaction and poor interface bonding. To enhance repair performance, a precisely controlled infrared pre-heating method for patch repair has been investigated. Asphalt slabs with 45 mm, 75 mm and 100 mm deep pothole excavations were subjected to dynamic heating with infrared heater operating power from 6.6 kW to 7.7 kW. The heater was kept either stationary or moving slowly across the excavations at 130 mm and 230 mm offsets. The tests included evaluating temperature increase throughout the excavations and inside the slab, recording heat power of infrared heater and heating time to avoid burning the asphalt. Irrespective of excavation depth, heating power and offset, the temperature distribution was found non-uniform in the pothole excavations and into the asphalt slab. The temperatures were higher at the faces of the excavation than inside the slab. Dynamic heating for approximately 10 min yielded better heat distribution while minimising the possibility of asphalt overheating and long pre-heating time. It has been concluded that 45 mm and 100 mm deep pothole excavations can be pre-heated with 6.6 kW and stationary heater or 7.5 kW and moving heater at 230 mm and 130 mm offset respectively. 75 mm deep excavation can be pre-heated with 7.1 kW and stationary heater at 230 mm offset.

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1. Introduction

1.1. Heating technology evolution in asphalt patch repair

One of the major distresses in asphalt pavement is potholes. They can be locally developed and are created due to the presence of water into the pavement and repeated traffic loading [1]. The main objective of permanently repairing a pothole is to create high quality repair in terms of (a) patching lifetime (this meaning quality and durability same as existing pavement), (b) low patching costs (high costs are mainly caused by labor, equipment and traffic control) [2], (c) minimum traffic disruption time ((b) and (c) can be achieved by fewer repetitions of the same patching), and (d) effective patching process (this referring to patching done in any weather conditions) [3]. To reach these objectives, infrared, microwave and induction heating has been used in asphalt paving operations for the last thirty to forty years.

Anderson and Thomas [4] mention that infrared or radiant heat is typically used for repairing overlays, smoothing and blending utility cuts and levelling of old patches. However, they do not recommend the use of infrared heat for full-depth repair. Blaha [3] built an automated patching machine and used infrared technology to heat asphalt to its softening point and ensure high bonding between the new fill mixture and old pavement. A comprehensive description of the machine is given, however, the procedure of the experiments and the study of heat flow to determine productive use of the heating system in asphalt repair are unclear and roughly explained. The study jumps to the conclusion of 1 min heating time for a surface asphalt softening point between 71 °C and 82 °C with the heater set to an extremely high heat power of 58 kW.

Clyne et al. [5], Uzarowski et al. [6], Freeman and Epps [7] and Leininger [8] used infrared or microwave heat to clear failed asphalt and/or heat the pothole fill material. The purpose of preheating was to achieve high adhesion between fill mixture and cold old pavement increasing its temperature. In these studies, only the surface temperature of the formed repairs is measured. The authors suggest a heating pattern and arrangement between the heater and distressed area to soften the asphalt. However, the authors do not acknowledge the influence of the following parameters in preheated asphalt repairs: climatic conditions, asphalt pavement temperature and thermal properties, asphalt ageing, repair geometry and pre-compaction temperatures of fill mixture. Further, the interaction between asphalt mixture and infrared heat has been studied mainly from on-site observations under diverse climatic conditions, not from controlled laboratory tests.

Obaidi et al. [9] performed, analysed and evaluated in the laboratory pothole repairs using asphalt tiles. They were bonded in the pothole cavity with a styrene-butadienestyrene (SBS) membrane filled with metal particles, steel fibres or chicken wire, induction heating and slight compaction. Tensile bond tests (TBT's) and shear bond tests (SBT's) were used to evaluate the tensile adhesion strength and shear strength respectively of the repair interface. The authors found that depending on the number of bonding layers, percentage of open area of loose fibres and induction heating time, maximum TBT and SBT were 0.35 MPa and 0.2 MPa respectively. In the case of the repairs with chicken wire of 37% to 74% open area, the TBT ranged from approximately 0.1 to 0.37 MPa and SBT ranged from 0.04 to 0.13 MPa.

Further, in the same study, test samples repaired with tiles and cold mix and test samples without any repair (original test samples) were tested using the wheel track test. The results showed that tests samples with asphalt tiles suffered 16.9% more rutting than the original test samples. Rutting in test samples with cold mix asphalt was approximately 40 times higher than in the original test samples. Therefore, tests samples with asphalt tiles outperformed repairs with cold mix. However, further research is suggested mainly when the excavated pothole contains loose stones or dirt between the tile and the old pavement or has uneven surfaces [9].

1.2. Infrared heat transfer in asphalt pavement

Thermal radiation is emitted by any object with a temperature above 0° Kelvin (−273 °C). Typical transmission of radiation is by electromagnetic waves that are defined by their wavelength and frequency categorized by the electromagnetic spectrum. The infrared portion of the spectrum is from 0.7 μm (equal to a $7e^{-7}$ m) to 10^3 μm (equal to a $1e^{-3}$ m). The energy transmitted by an infrared heater is proportional to its temperature. The higher the temperature, the shorter the wavelength and the higher the amount of energy radiated [10].

When the transmitted radiation energy of the heater hits the asphalt surface, then infrared heat transfer occurs. A portion of this radiation is absorbed and increases the temperature of the asphalt mixture by conduction, whereas other portions are transmitted or reflected back to the surrounding area [10]. Therefore, in an infrared-heater-asphalt thermal efficient relationship, the effectiveness of radiant energy emittance of the heater (associated with the heater emissivity (ε)), the transmitted percentage of radiative energy by the heater that strikes the asphalt (associated with the view factor (F)) and the amount of this energy absorbed by the asphalt (associated with asphalt emissivity (ε)) are dominant.

Other parameters to add to this relationship are the thermophysical properties of the asphalt mixture. These properties affect heat transfer and storage inside the pavement initiated by the absorbed radiation energy of radiative heat application on the surface of the pavement. There are two distinct categories of these properties: transport and thermodynamic properties. The transport properties relate to energy transfer through asphalt and are absorptivity (a), albedo (1-a), emissivity (ε) and thermal conductivity (k). The thermodynamic properties relate to the equilibrium state of asphalt mixture and are density (ρ) and specific heat capacity (c_P) [11].

Thermal conductivity of asphalt is affected by the mixture type, aggregate type [12], aggregate gradation [13], mixture density [14], mixture temperature [15] and presence of moisture in the mixture [13,14]. For example, Hassn et al. [14] found that as density increases thermal conductivity may increase too since the voids of air in the mixture decrease. In addition, moisture and freezing conditions may also increase asphalt thermal conductivity as reported by Mirzanamadi et al. [13]. However, asphalt thermal conductivity may decrease at temperatures higher than 25 °C reported by Chadbourn et al. [15]. Specific heat capacity and thermal diffusivity are both affected by thermal conductivity levels. For example, Hassn et al. [14] found that when air voids increase, and thermal conductivity decreases then specific heat capacity and thermal diffusivity decrease too.

1.3. Research motivation

As discussed above, heating the underlying layer prior to pothole filling and compaction enhances the bonding between the cold host pavement and the new hot-fill mix. Infrared, microwave and induction heating technologies have been investigated for this purpose. In the case of infrared heated repairs that concern this research, it seems that the current literature lacks fundamental experimental investigation and theoretical analysis of those repairs. To address this, the authors have concluded that the effect of the following parameters in the infrared repair operation should be investigated and fully understood: pothole geometry and depth; ambient temperature; host pavement initial temperature; fill mix-