- Submission date: 17/09/2019
- Word count: 2,999 words text
- Number of figures and tables: 10 figures and 1 table

Performance enhancement of asphalt patch repair with innovative heating strategy

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Abstract

The advantage of controlled preheating of excavated asphalt surface prior to hot mix asphalt patch repair, referred as “dynamic repair”, is presented in this paper. The heating effects are compared against traditional repair, referred as “static repair”. Shear bond and immersion wheel tracking tests were performed to asses the quality of both types of repair. Pothole excavations were created in the laboratory environment. For static repairs, tack coat was applied at the interfaces of the excavation, prior to laying hot repair material. For dynamic repairs, infrared heat was applied in heating-cooling cycles prior to filling the excavation with hot mix material, without use of tack coat. Heat was applied using an experimental infrared heater set at 6.6 kW with a 230 mm offset from the excavation. The results showed that the shear strength at the bottom and vertical interfaces of dynamic repairs was 78.2% and 68.4% higher respectively than that of static repairs. The immersion wheel tracking test showed that the resistance to water-related damage of dynamic repairs was higher than that of static repairs. It has been concluded that preheating a pothole excavation with infrared heat prior to filling and compaction increases the repair interface bonding strength and durability.

Keywords
Roads & highways, thermal effects, failure

1. Introduction

Asphalt consists of aggregate, bitumen and air voids with aggregate making 94% to 95% of hot mix asphalt mass (Prowell et al., 2005). Although an asphalt pavement can expand and contract under temperature variations and movement, it still deteriorates. Main causes of pavement distresses are repeated traffic loading, environmental conditions, bitumen ageing, weak subgrade and poor pavement structure (Walker, 1984; Mfinanga et al., 1996; Chatti et al., 2004; Lesueur and Youtcheff, 2013). Typical failures are cracking, rutting, ravelling and potholing (Adlinge and Gupta, 2013). Potholes are well known for causing traffic disruptions and accidents to road users.

In addition to traffic and temperature related damage, exposure to water causes aggregate dislodging, stripping and ravelling. Ravelling results from water infiltration into the pavement which weakens the mastic cohesion and mastic adhesion bond to the coarse aggregate particle. Repeated traffic loading and water action leads to initial stripping, severe ravelling and then to potholing (Dawson, 2008). Therefore, many potholes usually appear after wet weather conditions and are dramatically increased after freezing and thawing cycles (Lavin, 2003).

Common pothole repair practices are pothole filling and patching. Pothole filling is considered as a temporary repair method and is further divided into ‘throw and go’, ‘throw and roll’, semi-permanent and injection. Patching is a permanent repair and, except for potholes, is used to treat other asphalt pavement distresses such as alligator cracking, pavement depressions, rutting, corrugations, and slippage cracks. Typically, pothole filling is performed as an emergency repair, mainly during winter time, until a permanent repair is provided. Dense-graded hot mix asphalt is commonly used for patching. Typical nominal aggregate sizes for small patches are 12.5 mm and 9.5 mm (Lavin, 2003). However, the depth of the pothole should be considered when choosing the aggregate size (McDaniel et al., 2014).

Failures in asphalt patching may occur due to the material used, repair process or nearby pavement deterioration (McDaniel et al., 2014). Common failures are bleeding or flushing, dishing, debonding, ravelling, pushing and shoving (Prowell and Franklin, 1996). Debonding, lack of fill mixture adhesion with the old pavement (McDaniel et al., 2014), is the repair failure that concerns this research. One method currently used to avoid this is infrared patching. When a pothole is repaired with this method, an infrared heater is put above the distressed area at a chosen offset to soften the asphalt. At the end of the heating, the heater is removed and the heated area is scarified. Then, rejuvenator is added to the old mixture to reinstate its properties, new hot mixture is poured to fully fill the hole and finally compacted.

Use of infrared heating in asphalt patching aims to improve interface bonding and repair durability, decrease repetitions of same patching and costs in labour, equipment, traffic control and long disruption times (Nazzal et al., 2014). Both infrared and microwave technology have been used in patching operations and repair of asphalt cracks for more than thirty years, although not reported under controlled conditions (Nazzal et al., 2014; Clyne et al., 2010; Uzarowski et al., 2011; McDaniel et al., 2012; Freeman and Epps, 2012; Leininger, 2015). Further, the effect of thermal properties of asphalt mixtures in the heating process has not been considered as well as the influence of other parameters such as pothole geometry, environmental conditions and temperatures achieved within the repair build.

Reflecting the above, the objective of this study is to compare the performance of dynamically heated pothole repair against static repair. For this reason, shear bond tests and wheel track tests were performed. In this study, dynamic repair means intermittent infrared hated pothole excavation prior to its repair. Static repair is a non-heated traditional pothole repair. Dynamic heating regimes for shallow and deep potholes using infrared heat have previously been investigated by the authors (Byzyka et al., 2018a) and adopted for the dynamic repairs of this paper with 10 min 15 s and 21 min 49 s heating times.

2. Materials and experimental methods

2.1 Experimental program

Eighteen slabs were built to investigate repair interface bonding and rutting performance of static and dynamic repairs. Two pothole excavations were repaired per slab for simultaneous testing of the repair methods. For shear bond tests, two dynamic heating times (10 min 15 s and 21 min 49 s) were used to make the dynamic repairs. For wheel tracking tests, dynamic repairs with 10 min

15 s pre-heating time were tested. These heating durations were derived from previous work. The experimental program and test parameters are presented in Table 1.

2.2 Materials

The selection of the constituent materials of an asphalt mixture for the construction of a pavement in a particular area depends mostly on traffic, climate and layer thickness. For pavement structures designed to facilitate high traffic loading, a 40/60 penetration grade bitumen binder is suitable for both base and binder courses, whereas the use of a harder bitumen such as 30/45 penetration grade bitumen binder is suitable for surface courses. In the case of a pavement structure designed for lower traffic loading, a softer bitumen type can be used for all courses. Therefore, for base and binder courses the binder can be 70/100 penetration grade bitumen and for surface course it can be either 70/100 or 100/150 penetration grade bitumen. Further, for very high trafficked roads, modified bitumens may also be considered for surface course. The choice of aggregates for all pavement courses depends on the demand in traffic for the specific area for which the pavement is being designed and the in-place conditions where the pavement is going to be constructed (BS 594-1, 2005). Therefore, since the choice of bitumen and aggregates depends on the factors explained above and the number of asphalt mixtures that results from the above is considerable, this study used one type of dense asphalt mixture to conduct the research.

Thus, the slabs were built with dense gradation (20 mm Dense Bitumen Macadam (DBM)) comprising coarse and fine granite aggregate and limestone filler. The bitumen used was 100/150 pen. The pothole excavations were repaired with 6 mm dense graded mixture (AC-6). Figure 1 gives the composition of the asphalt mixtures. The mix design and bitumen grade conform to BS EN 13108-1 (2016b) and (Highways England et al., 2008) respectively. The aggregate, filler and bitumen were heated to (110 ± 5) ^{o}C and (140 ± 5) ^{o}C respectively prior to mixing and then mixed at (140 ± 5) ^{o}C in a laboratory mixer for approximately 4 min (BS EN 12697-35, 2016a).

2.3 Description of dynamic heating

Previously reported work in introduction for optimum dynamic heating methods for a 45 mm deep pothole excavation was applied. Dynamic heating was performed with an experimental infrared heater reported in Byzyka et al. (2017). Heat was applied in heating-cooling cycles to avoid severe ageing or charring of surface asphalt binder (Huang et al., 2016) and preheat both pothole excavation faces and the inside of the host asphalt pavement. For the heating part of the cycle, the heater was set at 6.6 kW heat power. The thermal effect of preheating in temperatures at the repair interfaces has been previously investigated by the authors (Byzyka et al., 2018b).

2.4 Construction of slabs and repairs

Asphalt slabs 695 × 695 × 100 mm^3 were constructed in two lifts of approximately 50 mm depth. Each lift was compacted for 7 min with a vibrating plate (BS EN 12697-35, 2016a) and bonded using 3 min infrared heating. Two potholes 305 × 165 × 45 mm^3 were created per slab. After 24 h of curing, one pothole was repaired by the static method and the other pothole by the dynamic method.

For static repair, tack coat was applied at the faces of the pothole excavation prior to laying and compacting the hot mix asphalt. In the dynamic repairs, infrared heat was applied in the pothole excavation prior to placement and compaction of the hot fill mix with no tack coat inclusion. All repairs were compacted with a vibrating plate for 6 min. Average pre- and post-compaction fill mixture temperatures for static repairs were 96.5 ^oC and 77.5 ^oC respectively and for dynamic repairs 102.0 ^oC and 83.8 ^oC respectively. Figure 2 shows the individual mixture temperatures of repairs constructed for wheel track test. Individual temperatures of repairs constructed for shear bond test are published in authors' previous work (Byzyka et al., 2018b). The condition of the slabs before the repair was dry. Slabs and repairs were constructed at room temperature (20 ±3) ^oC.

2.5 Air voids content of slabs and repairs

Air voids in the range of 12.43% - 13.28% were determined for slabs S1-S12 and repairs in slabs S1-S6 using previously reported method (AASHTO T166, 2007; AASHTO T209-05, 2005; Roberts et al., 1991). Air voids for static and dynamic repairs were in the 4.5% and 4.7% range respectively. Air voids were not measured for all slabs and repairs because they were cut to perform different tests. However, a similar level of air voids was expected to have been achieved for all samples due to the consistency of slab construction and repair formation.

2.6 Shear bond tests

Shear bond tests were used to evaluate the bonding at the interfaces of both static and dynamic repairs in slabs S1-S12. These tests were conducted using an Instron hydraulic machine together with a shearing rig specifically designed for this study (Figure 3). The design of the shearing rig was done in accordance to Raposeiras et al. (2013) for a 70 mm diameter extracted core. The shear bond test was conducted as in Obaidi et al., 2017.

To determine the bonding at the bottom interface of the repairs, test samples were cored for each repair as shown in Figure 4. For vertical repair interfaces, the slabs were first cut by a wet saw into smaller blocks and then cored. The coring direction was perpendicular to the repair interface. A notch was created in the cores to concentrate loading on the repair interface (Figure 5).

After curing test cores at a room temperature (20 ±3) ^{o}C for 24 h, they were sheared to failure. The shear displacement rate was 20 mm/min. The gap between the shearing platens was 5 mm and the tests were conducted at a room temperature (20 ±3) ^{o}C. The maximum shear stress was calculated using Equation 1 (Du, 2015):

$$\tau_{max} = \frac{4P_{max}}{\pi D^2} \qquad 1.$$

where τ_{max} = maximum shear stress, kg/m^2; P_{max} = maximum load applied to specimen, kg; D = specimen diameter, m.

2.7 Wheel tracking tests

Figure 6 shows the preparation of test samples for wheel tracking tests. The tests at (25 ±1) ^{o}C were conducted using a Hamburg wheel tracking device in accordance with AASHTO T324 (2004) with test tank and moulds specifically designed for this study. Tests performed at (4 ±1) ^{o}C are non- standard, nevertheless, a similar procedure was followed. The (4 ±1) ^{o}C temperature was controlled with a K1 chiller integrated with the wheel tracking device. Static and dynamic repairs were simultaneously tested. 20,000 cycles were applied to each repair, as shown in Figure 7. Rutting depth was measured at 4 mm spacing along 96 mm of repair interface. The tests were conducted 24 h after the completion of the repairs.

3. Results, analysis and interpretation

3.1 Interface shear strength testing

Figure 8 shows the average interface shear strength for static (A samples) and dynamic (B samples) repair methods with 10 min 15 s and 21 min 49 s heating duration. Eighteen test cores were used to investigate this at the bottom repair interface of static repairs. Sets of nine cores were tested for both heating durations of dynamic repairs. Thirty-six cores were used to investigate the shear strength on the vertical repair interface of static repairs and eighteen cores per heating time for similar testing of dynamic repairs. All testing produced failure on the bonding interface. Four cores taken from the vertical interface of static repairs failed as soon as they were put on the shearing rig. These failures are included in Figure 8. Four further tests were aborted due to equipment failure.

The first observation from the results was that the interface shear strengths with the dynamic repair method were significantly higher those from the static method repairs. The shear strength at the bottom repair interfaces of dynamic repairs was consistent, in the 0.499 MPa and 0.579 MPa range, averaging, 78.2% higher than static repairs. This happened because, for dynamic repairs, there was a reduction in bitumen viscosity with continuing heating. Lower viscosity means less resistance of asphalt to flow, higher interlocking between the aggregates of the host pavement and the fill mixture and adequate adhesion between repair interfaces. This justifies also the fact that slightly higher bond strength was received for test samples A2 and B2 cored in the middle of the repairs where temperatures during preheating and repair were the highest. Between 10 min 15 s and 21 min 49 s heating durations there was no significant additional heating influence on shear bond strength on the bottom interface, in spite of the natural reduction in bitumen viscosity. This happened because the bottom face of the excavation was confined by the whole asphalt mixture of the host pavement during heating and repair compaction.

However, the effect of asphalt low viscosity during heating is apparent at the vertical faces of the excavation. These faces are not supported during heating and are free to move as soon as bitumen softened, and compaction of the fill mixture started. Thus, the shear strength of test samples B4-B5 heated for 21 min 49 s was 0.392 MPa and 0.416 MPa respectively higher than samples prepared with 10 min 15 s dynamic heating time. For test samples B6-B9 an average strength difference 0.185 MPa was only observed. The reason that the shear strength differed between the test cores of the vertical faces of dynamic repairs was the different temperatures achieved in pothole preheating. Previous investigation (Byzyka et al., 2018a) into similar dynamic heated asphalt excavations shows that, at the end of preheating, at the mid-bottom of the excavation surface, temperatures typically range from 140 ^{o}C to 160 ^{o}C, with the lower temperatures on the vertical faces, in the 80 ^{o}C to 120 ^{o}C range.

Further, the strength at the vertical repair interfaces with dynamic repair was higher than that of static repair methods. In general, the strength of the test samples extracted from 10 min 15 s dynamic repairs was 68.4% higher than of the test samples of static repairs. The strength of 21 min 49 s dynamically heated repairs more than doubled that of static repairs.

Considering the shear strength results gained for the vertical interfaces of the excavation, it seems that there is a higher influence of temperature on the strength of the interface. However, during the two heating durations of the pothole excavation, it was observed that the sides became increasingly loose after 21 min of heating showing evidence of overheating the asphalt and heating of a larger area than expected. This is not obvious for the bottom interface since the slab is confined in its mould when the heating is applied. Besides, 21 min of heating would be expected to increase overall repair time which is less desirable (Wilson and Romine, 2001). The interface strength of dynamic pothole repairs at the end of 10 min 15 s of heating was even higher than repairs completed with induction heating presented in Obaidi et al. (2017).

3.2 Immersion wheel tracking testing

Figure 9 shows the permanent deformation of individual static and dynamic repairs at the repair vertical interface at (25 ±1) ^{o}C and at (4 ±1) ^{o}C. Figure 10 presents the average rutting profile of these repairs along the interface. Six slabs were prepared for wheel tracking tests. Sets of three static and three dynamic repairs were tested for both testing temperatures. During the tests it was observed that the profile of the tested surfaces was non-uniform. This was captured from the wheel tracking machine at the first four passes with asphalt surface profile levels fluctuating between ± 1.4 mm and ± 1.7 mm for all tests. This fluctuation has been correspondingly added or subtracted from the final rutting depth in the presented results. It can be observed that for the rutting test at 25 ^{o}C, dynamic repairs outperformed static repairs. The average rutting depth of dynamic repairs was 10.36 mm whereas for static repairs was 14.82 mm. High level deformation was observed for static repair constructed in slab S14. In this occasion, the rutting depth was 18.66 mm. In general, the rutting depth of static repairs was not as consistent as that of dynamic repairs. Further, no stripping was observed for all tested repairs and no significant rutting for all repairs tested at 4 ^{o}C (Figure 9(b)).

4. Conslusions

The following conclusions are drawn from the research:

- Dynamically heating a pothole excavation increases pothole repair interface bonding. This happens due to higher interlocking between the aggregates of the host pavement and the hot fill mixture.
- To achieve higher interface bonding for dynamic repairs, an approximate heating time of 10 min was found sufficient. This avoids overheating the asphalt and heating larger area of mixture than expected or needed.
- The rutting resistance of dynamic repairs at the repair interface is higher than that of static repairs. However, more tests are suggested to find stripping point and evaluate resistance to moisture damage of dynamically heated repairs.
- It has been concluded that preheating a pothole excavation with infrared heat prior to filling and compaction increases repair durability.

Acknowledgements

This work was financially supported by International Chem-Crete Corporation, Texas, USA, EPSRC, Brunel University, Epicuro Ltd and DAC Consulting (UK) Ltd. Nynas UK AB and Conexpo (NI) Ltd supported by providing materials. Laboratory work was supported by Brunel University technical staff Neil Macfadyen and undergraduate student Aaron Mann.

The authors would like to express their appreciation for Cooper Technology in the UK in providing wheel tracking machine specifically designed for the dimensions of the tests samples used in this study and the support of their engineering team.

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Figure captions

Figure 1. Asphalt mixtures gradation curves

Figure 2. Pre- and post-compaction temperatures of pothole fill mixtures for static and dynamic repairs constructed in slabs S13-S18

Figure 3. SBT apparatus designed for this study

Figure 4. Sample tests for shear bond tests of bottom repair interfaces (slabs S1-S6, Table 1): (a) Asphalt slab; (b) Coring; (c) Test cores

Figure 5. Samples for shear bond tests of vertical repair interfaces (slabs S7-S12, Table 1): (a) Step 1-marking of slab; (b) Step 2-cutting of slab; (c) Step 3-cutting of slab blocks; (d) Step 4-coring of asphalt blocks; (c) Step 5-final samples

Figure 6. Samples for wheel tracking test: (a) Host pavement; (b) Repaired potholes in host pavement; (c) Sample blocks

Figure 7. Simulation of wheel load in the interface of static and dynamic repair

Figure 8. Interface shear strength for static (A) and dynamic (B) pothole repairs on the repair methods (sample characterisation (A1-A9 and B1-B9) is given in Figures 3 and 4, the error bars show the standard deviation of each value)

Figure 9. Rutting depth at: (a) 25 ^{o}C and (b) 4 ^{o}C after 20.000 cycles

Figure 10. Longitudinal average rutting profile in the repair interface at (a) 25 ^{o}C and (b) 4 ^{o}C after 20.000 cycles

Table captions

Table 1. Experimental program