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Performance enhancement of asphalt patch repair with innovative heating strategy

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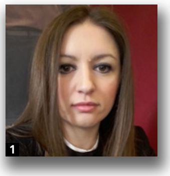


The advantage of controlled preheating of an excavated asphalt surface prior to hot-mix asphalt patch repair, referred to as 'dynamic repair', is presented in this paper. The heating effects are compared with traditional repair, referred to as 'static repair'. Shear bond and immersion wheel tracking tests were performed to assess the quality of both types of repair. Pothole excavations were created in the laboratory environment. For the static repairs, a tack coat was applied at the interfaces of the excavation prior to laying the hot repair material. For the dynamic repairs, infrared heat was applied in heating–cooling cycles prior to filling the excavation with hot-mix material, without the use of a 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 the dynamic repairs was, respectively, 78·2% and 68·4% higher than that of the static repairs. The immersion wheel tracking test showed that the resistance to water-related damage of the dynamic repairs was higher than that of the static repairs. It is concluded that preheating a pothole excavation with infrared heat prior to filling and compaction increases the repair interface bonding strength and durability.

Notation

D	specimen diameter (m)
d	diameter (mm)
h	height (mm)
P_{max}	maximum load applied to specimen (kg)
τ_{max}	maximum shear stress (kg/m^2)

1. Introduction

Asphalt consists of aggregate, bitumen and air voids, with aggregate comprising 94–95% of the mass of hot-mix asphalt (Prowell *et al.*, 2005). Although asphalt pavements can expand and contract under temperature variations and movement, they still deteriorate. The main causes of pavement distresses are repeated traffic loading, environmental conditions, bitumen ageing, a weak subgrade and poor pavement structure (Chatti *et al.*, 2004; Lesueur and Youtcheff, 2013; Mfinanga *et al.*, 1996; Walker, 1984). 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 particles. 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 to be a temporary repair method, which 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 can occur due to the material used, the 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 – the lack of fill mixture adhesion with the old pavement (McDaniel *et al*., 2014) – was the repair failure studied in this research. One method currently used to avoid debonding is infrared patching. When a pothole is repaired using this method, an infrared heater is placed 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 fill the hole fully and finally compacted.

The use of infrared heating in asphalt patching aims to improve interface bonding and repair durability, decrease repetitions of the same patching and reduce the costs of 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 30 years, although they have not been reported under controlled conditions (Clyne *et al*., 2010; Freeman and Epps, 2012; Leininger, 2015; McDaniel *et al*., 2012; Nazzal *et al*., 2014; Uzarowski *et al*., 2011). Furthermore, the effect of the thermal properties of asphalt mixtures in the heating process and the influence of other parameters such as pothole geometry, environmental conditions and temperatures achieved within the repair build have not been considered.

Against this background, the objective of the work reported in this paper was to compare the performance of dynamically heated pothole repairs against static repairs. To this end, shear bond tests and wheel tracking tests were performed. In this paper, a dynamic repair means intermittent infrared-heated pothole excavation prior to its repair, while a 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). These were adopted for the dynamic repairs in this work, with heating times of 10 min 15 s and 21 min 49 s.

2. Materials and experimental methods

2.1 Experimental programme

In total, 18 slabs were fabricated to investigate the 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 the wheel tracking tests, dynamic repairs with 10 min 15 s preheating times were tested. These heating durations were derived from previous work by the authors (Byzyka *et al*., 2018a). The experimental programme and test parameters are summarised 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 courses it can be either 70/100 or 100/150 penetration grade bitumen. Furthermore, for very highly trafficked roads, modified bitumens may also be considered for the 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 (BSI, 2005). Therefore, since the choice of bitumen and aggregates depends on the factors explained above and the number of asphalt mixtures resulting from the above is considerable, one type of dense asphalt mixture was used in this research.

The slabs were made with dense gradation (20 mm dense bitumen macadam (DBM)) comprising coarse and fine granite aggregate and limestone filler. The bitumen used was 100/150 penetration grade. The pothole excavations were repaired with a 6 mm dense graded mixture (AC-6). Figure 1 shows the composition of the asphalt mixtures. The mix design conformed to BS EN 13108-1 (BSI, 2016a) and the bitumen grade conformed to the specifications of Highways England *et al*. (2008). The aggregate, filler and bitumen were heated to 110 ± 5°C and 140 ± 5°C, respectively, prior to mixing and then mixed at 140 ± 5°C in a laboratory mixer for approximately 4 min (BSI, 2016b).

2.3 Description of dynamic heating

Previously reported work on the optimum dynamic heating methods for a 45 mm deep pothole excavation was consulted. Dynamic heating was performed with an experimental infrared heater, as reported by Byzyka *et al*. (2019). Heat was applied in heating–cooling cycles to avoid severe ageing or charring of the surface asphalt binder (Huang *et al*., 2016) and preheating was applied to both the pothole excavation faces and the inside of the host asphalt pavement. For the heating part of the cycle, the heater was set at a heating power of 6·6 kW. The thermal effect of preheating repair interfaces has been previously investigated by the authors (Byzyka *et al*., 2018b).

2.4 Construction of slabs and repairs

Asphalt slabs of dimensions $695 \times 695 \times 100$ mm^3 were constructed in two lifts of approximately 50 mm depth. Each lift

Table 1. Experimental programme

Slab	Size: mm	Pothole size: mm	Pothole A: static repair at room temperature (20 ± 3°C)	Pothole B: dynamic repair with 10 min 15 s heating time at room temperature (20 ± 3°C)	Pothole B: dynamic repair with 21 min 49 s heating time at room temperature (20 ± 3°C)	Shear bond test in vertical repair interfaces at 20 ± 3°C	Shear bond test in bottom repair interfaces at 20 ± 3°C	Wheel track test at 25 ± 1°C	Wheel track test at 4 ± 1°C
S1	695 × 695 × 100	305 × 165 × 45	✓	✓			✓		
S2			✓	✓			✓		
S3			✓	✓			✓		
S4			✓		✓		✓		
S5			✓		✓		✓		
S6			✓		✓		✓		
S7			✓	✓		✓			
S8			✓	✓		✓			
S9			✓	✓		✓			
S10			✓		✓	✓			
S11			✓		✓	✓			
S12			✓		✓	✓			
S13			✓	✓				✓	
S14			✓	✓				✓	
S15			✓	✓				✓	
S16			✓	✓					✓
S17			✓	✓					✓
S18			✓	✓					✓

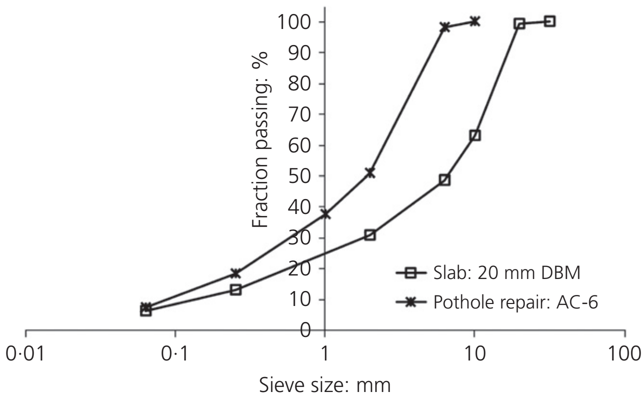


Figure 1. Gradation curves of asphalt mixtures

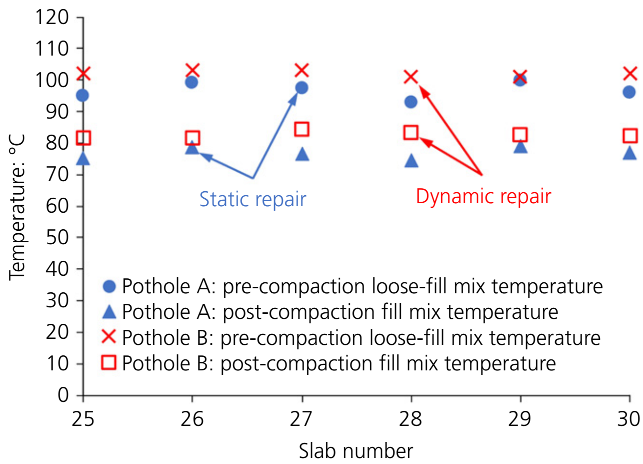
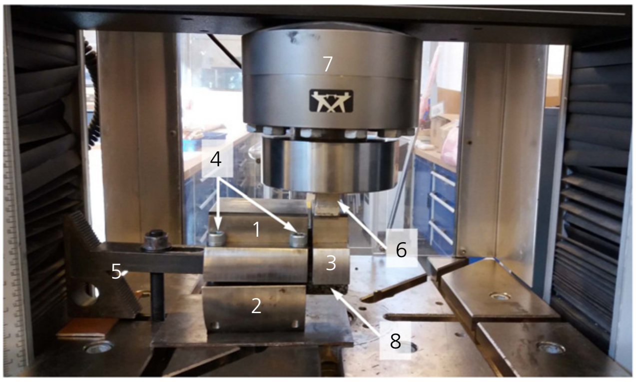


Figure 2. Pre- and post-compaction temperatures of pothole fill mixtures for static and dynamic repairs constructed in slabs S13–S18

was compacted for 7 min with a vibrating plate (BSI, 2016b) and bonded using 3 min infrared heating. Two potholes of dimensions $305 \times 165 \times 45$ 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 the static repairs, a tack coat was applied to the faces of the pothole excavation prior to laying and compacting the hot-mix asphalt. For the dynamic repairs, infrared heat was applied in the pothole excavation prior to the placement and compaction of the hot fill mix, with no tack coat. All the repairs were compacted with a vibrating plate for 6 min. The average pre- and post-compaction fill mixture temperatures for the static repairs were 96·5°C and 77·5°C, respectively, and 102·0°C and 83·8°C for the dynamic repairs. Figure 2 shows the individual mixture temperatures of the repairs constructed for wheel track tests. The individual temperatures of the repairs carried out for the shear bond tests are reported elsewhere (Byzyka *et al.*, 2018b). The slabs were dry before the



1 Upper ring for sample support
2 Lower ring for sample support
3 Shear ring
4 Four bolts for holding upper and lower rings
5 Support for lower ring to keep it stable
6 Aluminium block to separate load head from shear ring
7 Load from Instron hydraulic machine
8 Asphalt sample test

Figure 3. Shear bond test apparatus designed for this study

repairs were carried out, and the slabs and repairs were constructed at room temperature, 20 ± 3°C.

2.5 Air void contents of slabs and repairs

Air void contents in the range 12·43–13·28% were determined for slabs S1–S12 and the repairs in slabs S1–S6 using a previously reported method (Aashto, 2005, 2007; Roberts *et al.*, 1991). The air voids content for the static and dynamic repairs was around 4·5% and 4·7%, respectively. Air void contents were not measured for all the 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 the 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

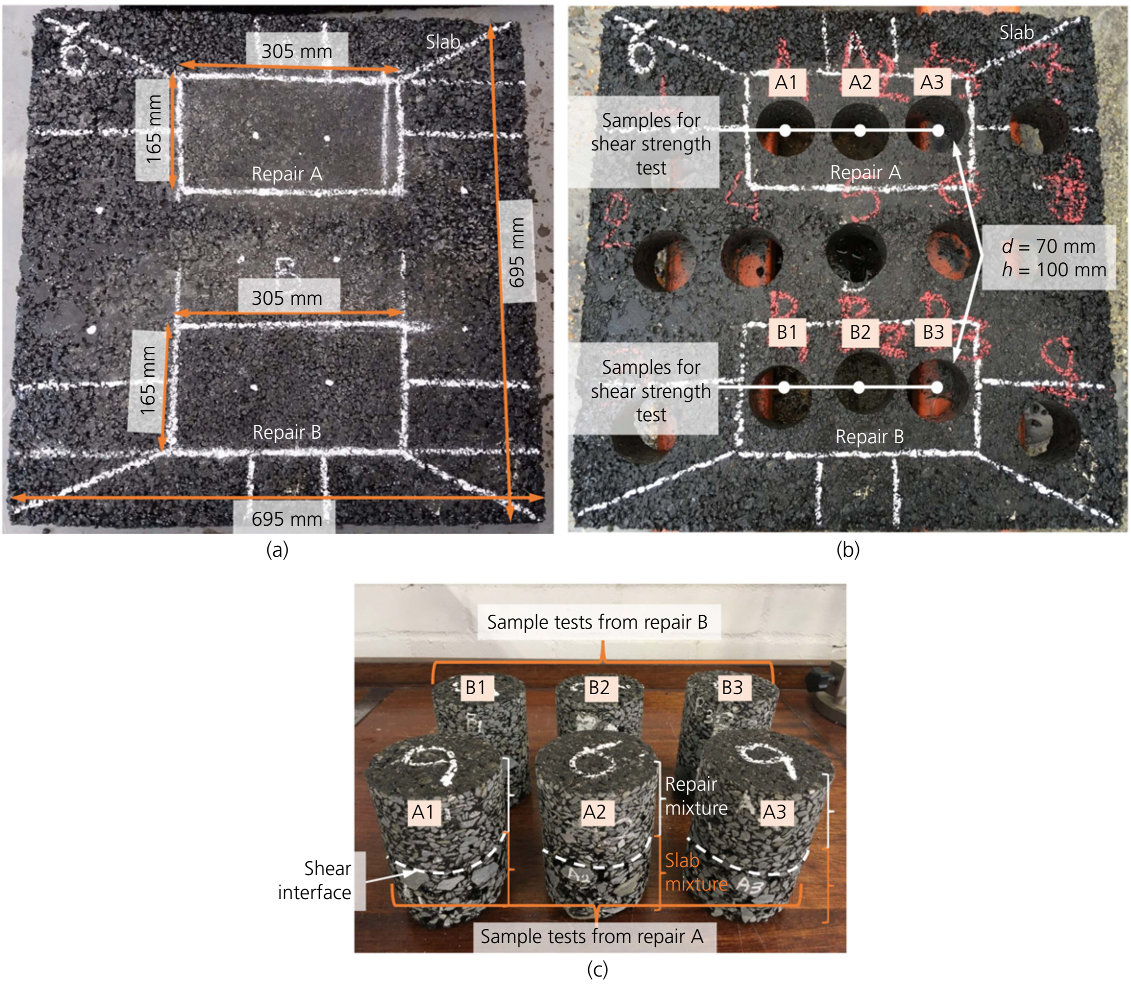


Figure 4. Sample tests for shear bond tests of bottom repair interfaces (slabs S1–S6; see Table 1): (a) asphalt slab; (b) coring; (c) test cores

this study (Figure 3). The shearing rig was designed in accordance with the work of Raposeiras *et al*. (2013) for a 70 mm dia. extracted core. Shear bond testing was conducted as per the work of 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 the vertical repair interfaces, the slabs were first cut into smaller blocks using a wet saw and then cored. The

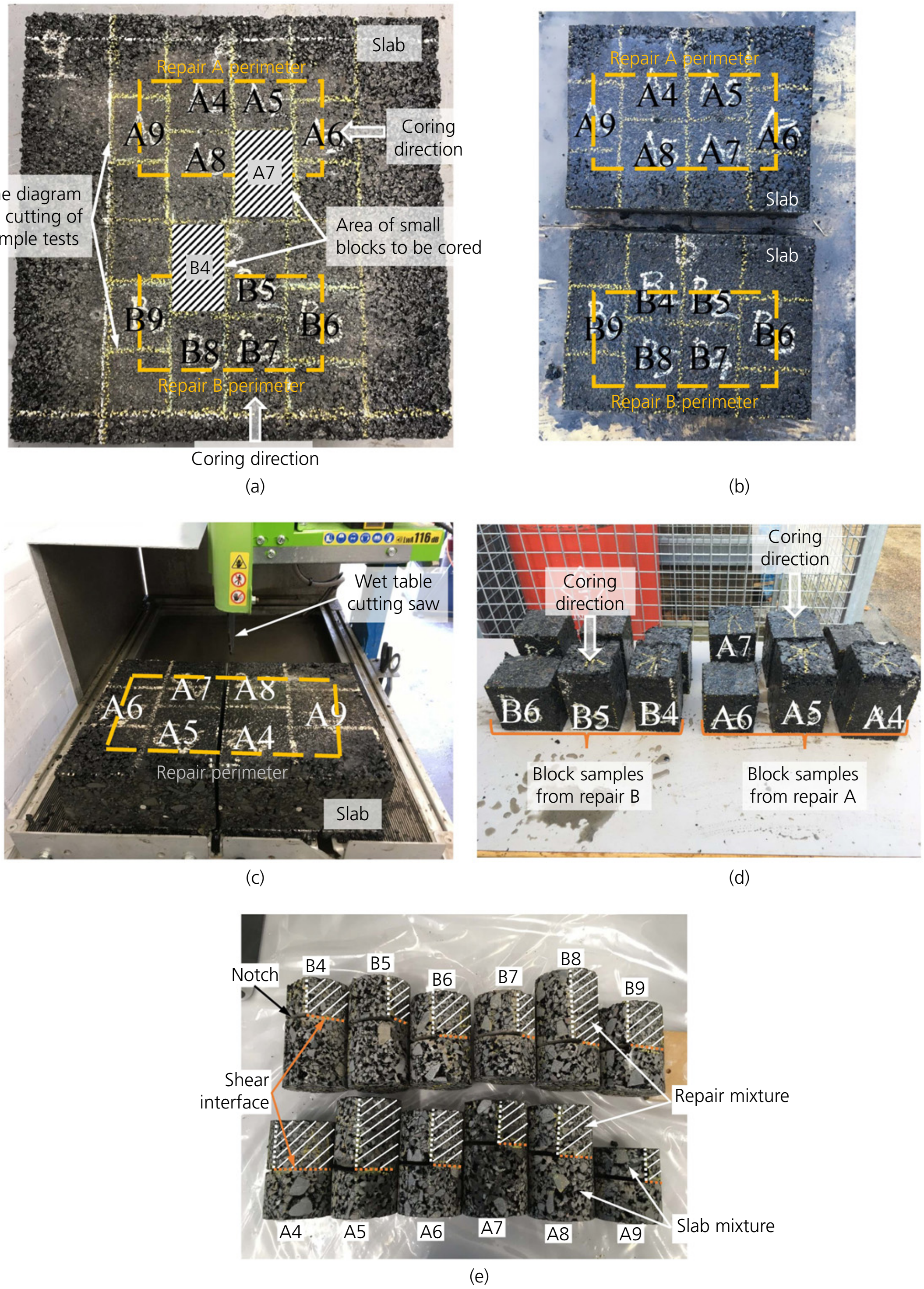


Figure 5. Samples for shear bond tests of vertical repair interfaces (slabs S7–S12; see Table 1): (a) step 1, marking of slab; (b) step 2, cutting of slab; (c) step 3, cutting of slab blocks; (d) step 4, coring of asphalt blocks; (e) step 5, final samples

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 the test cores at room temperature (20 ± 3°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 also conducted at room temperature (20 ± 3°C). The maximum shear stress was calculated using Equation 1 (Du, 2015)

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

where τ_{max} is the maximum shear stress (kg/m^2), P_{max} is the maximum load applied to specimen (kg) and D is the specimen diameter (m).

2.7 Wheel tracking tests

Figure 6 shows the preparation of test samples for the wheel tracking tests. The tests carried out at 25 ± 1°C were conducted using a Hamburg wheel tracking device in accordance with Aashto T 324 (Aashto, 2004) with a test tank and moulds specifically designed for this study. The tests performed at 4 ± 1°C were non-standard but, nevertheless, a similar procedure was followed. The 4 ± 1°C temperature was controlled with a K1 chiller integrated with the wheel tracking device. The static and dynamic repairs were tested simultaneously.

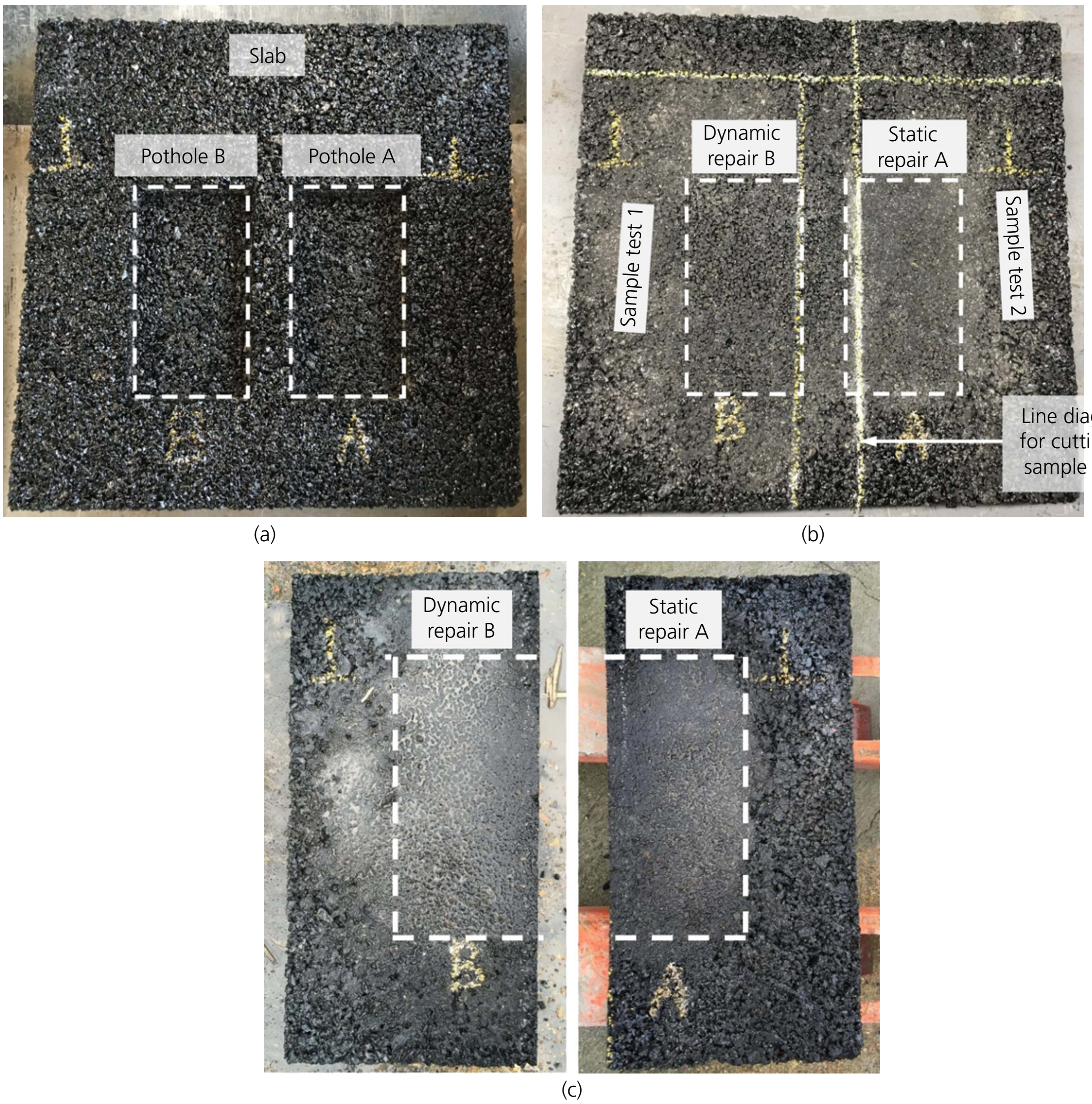


Figure 6. Samples for wheel tracking test: (a) host pavement; (b) repaired potholes in host pavement; (c) sample blocks

20 000 cycles were applied to each repair, as shown in Figure 7. The rutting depth was measured at 4 mm spacings along 96 mm of the repair interface. The tests were conducted 24 h after completion of the repairs.

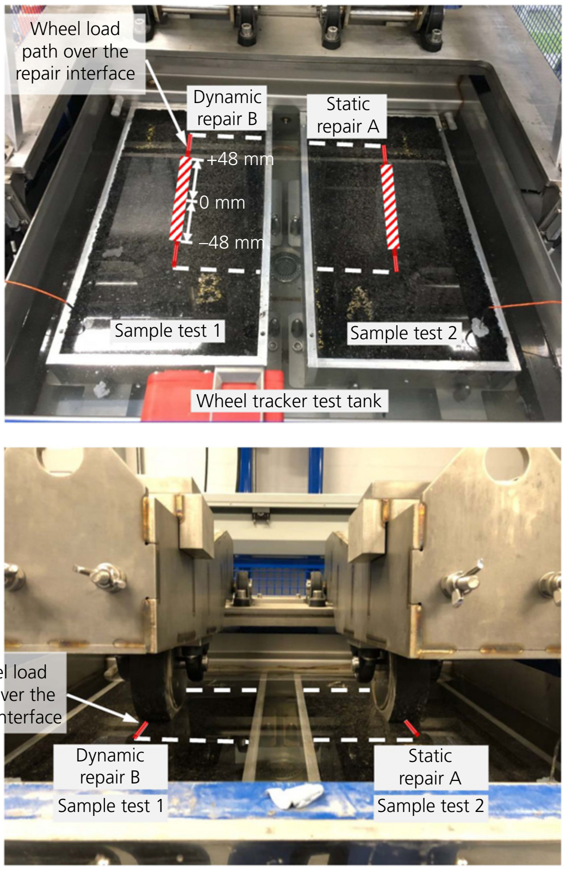


Figure 7. Simulation of wheel loads in the interface of static and dynamic repairs

3. Results, analysis and interpretation

3.1 Interface shear strength testing

Figure 8 shows the average interface shear strengths for the static (samples A) and dynamic (samples B) repair methods with heating durations of 10 min 15 s and 21 min 49 s. To investigate the interface shear strength at the bottom repair interface of the static repairs, 18 test cores were used. Sets of nine cores were tested for both heating durations of the dynamic repairs. 36 cores were used to investigate the shear strength of the vertical repair interface of the static repairs and 18 cores per heating time were used for similar tests of the dynamic repairs. All the tests produced failure of 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 for the static method repairs. The shear strengths at the bottom repair interfaces of the dynamic repairs were consistent, with values of about 0·499 MPa and 0·579 MPa; these values were, on average 78·2% higher than the shear strengths of the static repairs. This is because, for the dynamic repairs, there was a reduction in bitumen viscosity with continuing heating. Lower viscosity means less resistance of the asphalt to flow, higher interlocking between the aggregates of the host pavement and the fill mixture, and adequate adhesion between the repair interfaces. This also justifies the finding that a slightly higher bond strength was obtained for test samples A2 and B2, which were cored in the middle of the repairs where the temperatures during preheating and repair were the highest. Between the heating durations of 10 min 15 s and 21 min 49 s, there was no significant additional influence of heating on the shear bond strength of the bottom interface,

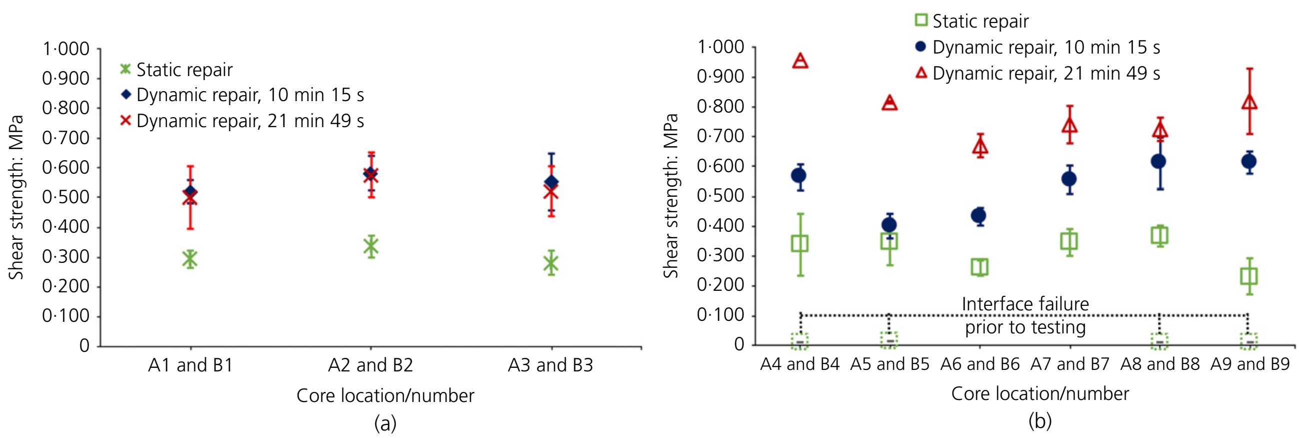


Figure 8. Interface shear strength for static and dynamic pothole repairs: (a) shear strength of bottom repair interface; (b) shear strength of vertical repair interfaces. Sample characterisation (A1–A9 and B1–B9) is given in Figures 3 and 4. The error bars show the standard deviation of each value

despite the natural reduction in bitumen viscosity. This was 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 the asphalt's low viscosity during heating was apparent at the vertical faces of the excavation. These faces were not supported during heating and were free to move as soon as the bitumen softened and compaction of the fill mixture started. Thus, the shear strength of test samples B4 and B5 heated for 21 min 49 s was 0·392 MPa and 0·416 MPa, respectively, higher than that of the samples prepared with a dynamic heating time of 10 min 15 s. For test samples B6–B9, an average strength difference of only 0·185 MPa was observed. The shear strength differed between the test cores of the vertical faces of the dynamic repairs because different temperatures were achieved in pothole preheating. A previous investigation by the authors into similar dynamically heated asphalt excavations (Byzyka *et al.*, 2018a) showed that, at the end of preheating, at the mid-bottom of the excavation surface, temperatures were typically in the range 140–160°C, with lower temperatures (80–120°C) on the vertical faces.

Furthermore, the strength at the vertical repair interfaces of the dynamic repairs was higher than that of the static repairs. In general, the strength of the test samples extracted from the 10 min 15 s dynamic repairs was 68·4% higher than the strength of test samples from the static repairs. The strength of the 21 min 49 s dynamically heated repairs was more than double that of the static repairs.

Considering the shear strength results obtained for the vertical interfaces of the excavation, it seems that there was 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 of the asphalt and the heating of an area larger than expected. This was not obvious for the bottom interface since the slab was confined in its mould when heating was applied. Besides, 21 min of heating would be expected to increase the overall repair time, which is less desirable (Wilson and Romine, 2001). The interface strength of the dynamic pothole repairs at the end of 10 min 15 s of heating was even higher than that of repairs completed with induction heating (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 for tests carried out at 25 ± 1°C and at 4 ± 1°C. Figure 10 shows the average rutting profiles of these repairs along the interface. Six slabs were prepared for the wheel tracking tests. Sets of three static and three dynamic repairs were tested at both test 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 the asphalt surface profile levels fluctuating between ±1·4 mm and ±1·7 mm in all the tests. This fluctuation was correspondingly added or subtracted from the final rutting depth in the results presented. It can be observed that, for the rutting test at 25°C, the dynamic repairs outperformed the static repairs. The average rutting depth of the dynamic repairs was 10·36 mm whereas for static repairs it was 14·82 mm. High-level deformation was observed for the static repair constructed in slab S14, with a rutting depth of 18·66 mm. In general, the rutting depth of the static repairs was not as consistent as that of the dynamic repairs. Furthermore, no stripping was observed in all the tested repairs and no significant rutting occurred for all the repairs tested at 4°C (Figure 9(b)).

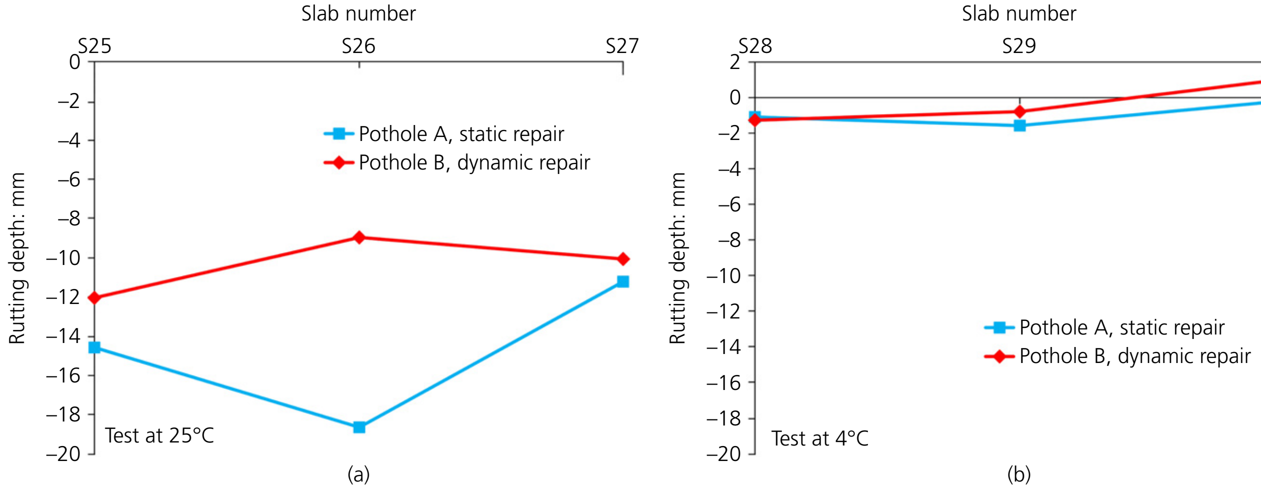


Figure 9. Rutting depth at (a) 25°C and (b) 4°C after 20 000 cycles

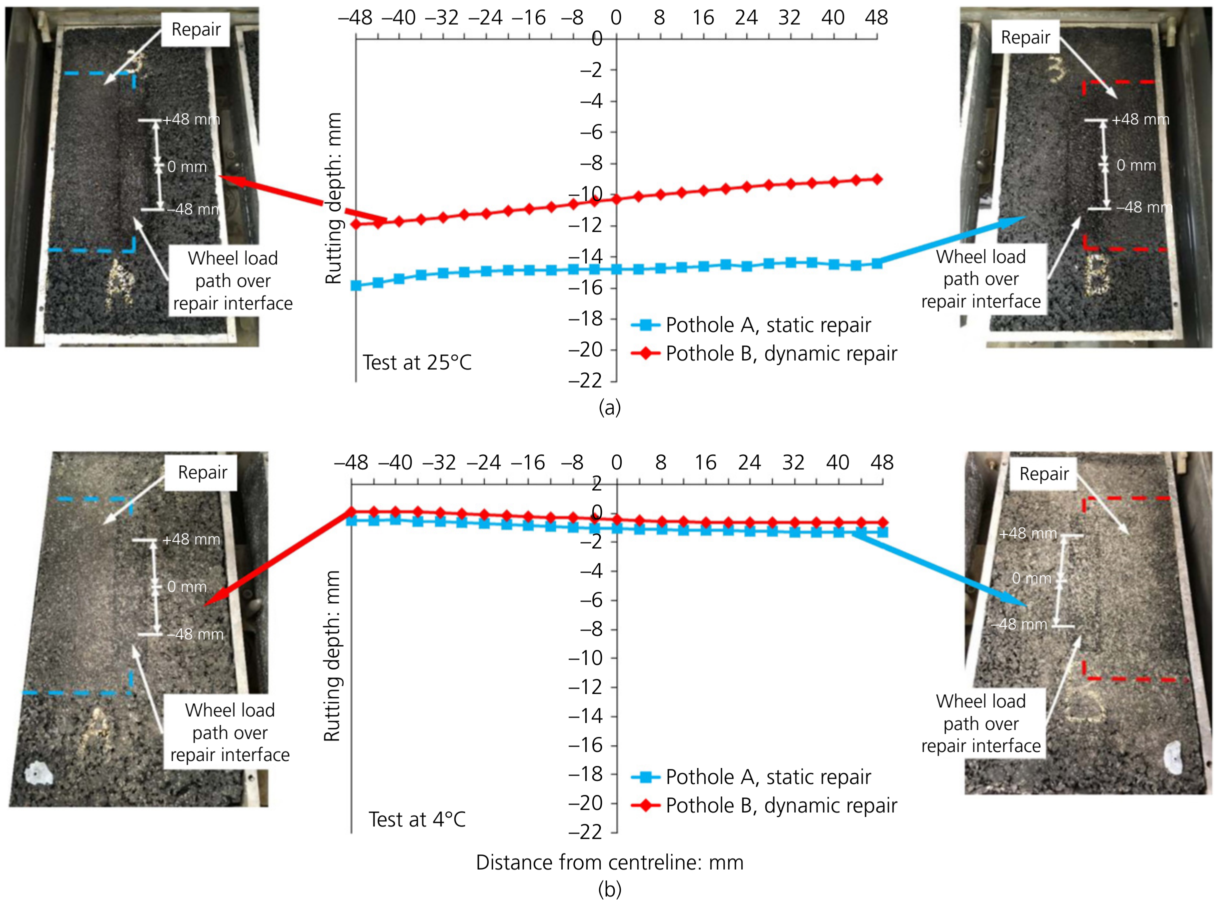


Figure 10. Longitudinal average rutting profile in the repair interface at (a) 25°C and (b) 4°C after 20 000 cycles

4. Conclusions

The following conclusions are drawn from this research.

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

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