THERMAL INFLUENCE IN THE PERFORMANCE OF STATIC AND DYNAMIC HOT MIX ASPHALT POTHOLE REPAIRS

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ABSTRACT

The advantage of controlled preheating of existing asphalt surface, referred as “dynamic repair”, prior to hot mix asphalt patch repair has been presented in this paper. The heating affects are compared against traditional hot mix repair, referred as “static repair”. Shear bond tests and immersion wheel tracking tests were performed to assess the quality of both types of repair. Pothole excavations were artificially created in the laboratory environment. In static repairs, tack coat was applied at the interfaces of the excavation prior to laying hot repair material. In dynamic repairs, infrared heat was applied in heating-cooling cycles prior to filling the excavation with hot mix material. No tack coat was used in the repair process. The heat was applied using an experimental infrared heater operating with 6.6 kW at an offset 230 mm from the pothole excavation. To ensure consistency, both repairs were compacted in same way by a vibrating plate. 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 pre-heating a pothole excavation with infrared heat prior to filling and compaction increases the repair interface bonding strength and therefore repair durability.

Keywords: Asphalt, pothole repair, interface failure, infrared heat, adhesion

INTRODUCTION

Asphalt is a hydraulically-bound material with bitumen as binding agent. It consists of aggregate, bitumen and air voids with aggregate making 94% to 95% of hot mix asphalt mass (*1*). Although an asphalt pavement can expand and contract under temperature variations and movement, it still deteriorates. Repeated traffic loading, environmental conditions, asphalt ageing, week subgrade and poor pavement structure contribute to failures in asphalt pavement (*2 – 5*). Typical asphalt failures are cracking, rutting, ravelling and potholing (*6*). Potholes are localised road defects and they can cause traffic disruptions and accidents to road users.

In addition to traffic and temperature related damage, exposure to water also causes aggregate dislodging distresses like stripping and ravelling. Ravelling results from water infiltration into the pavement which weakens the mastic and mastic – aggregate bond strength. Repeated traffic loading and water action, leads from initial stripping to severe ravelling and then to potholing (*7*). Therefore, many potholes usually appear after wet weather conditions and are dramatically increased after freezing and thawing cycles (*8*).

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 defined as a permanent repair method and, except potholes, it may be 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 (*8*). Daniel et *al*. (*9*) recommends choosing aggregate size considering patching depth.

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Failures in asphalt patching may be occurred due to the material used, repair process or nearby pavement deterioration (*9*). Common failures are bleeding or flushing, dishing, debonding, ravelling, pushing and shoving (*10*). Debonding, lack of fill mixture adhesion with the old pavement (*9*), 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 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.

The use of infrared heating in patching aims to improve interface bonding and repair durability, decrease repetitions of same patching and thus decrease repair costs from savings in labour, equipment, traffic control costs and long disruption time (*11)*. Infrared and microwave technology have been used in patching operations and repair of asphalt cracks for more than thirty years. Studies have been performed by references (*11 – 16*). However, they are mainly based from on-site observations. 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.

As a result, the objective of this study is to assess the performance of dynamically heated pothole repair against static repair and suggest if this method improves repair bonding with host pavement. Dynamically heated repairs are called repairs that part of the process is pre-heating of the pothole excavation, prior to pothole filling and compaction, applied in heating-cooling cycles using infrared heat. Reference (*17*) describes optimum heating methods for patching using infrared heat. Static repairs are common practice repairs used in the industry without any pre-heating of the excavated pothole or in-situ material heating in the repair process.

MATERIALS AND EXPERIMENTAL METHODS

Experimental program

In total, eighteen slabs were built in the laboratory to assess repair interface bonding and rutting performance of both static and dynamic pothole repairs. Two artificial pothole excavations were repaired per slab for simultaneous testing of the mentioned repair methods. Twelve slabs were used to produce 108 test samples for shear bond test. For this test, two different heating times (10 min 15 s and 21 min 49 s) were tested for dynamically heated repairs. The heating time was selected from earlier research by the authors (Ref). Six slabs were used to perform wheel tracking test at two different test temperatures for in total twelve repairs. Heating time for dynamic repairs in this group of tests was decided after the completion of shear bond tests. The described experimental program and test parameters are presented in Table 1.

TABLE 1 Experimental program.

Slab no.	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			✓	✓					✓

Materials

The slabs were built with dense gradation (20 mm Dense Bitumen Macadam (DBM)) comprised of granite coarse and fine aggregate and limestone filler. The bitumen used was 100/150 pen. The artificial pothole excavations were repaired with 6 mm dense graded mixture (AC-6). Figure 1 presents the composition of the asphalt mixtures. The design of the mixtures and bitumen grade conforms to BS EN 13108 (*18*) and Standard Series 900 Road pavements - Bituminous bound materials (*19*) respectively. 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 (*20*).

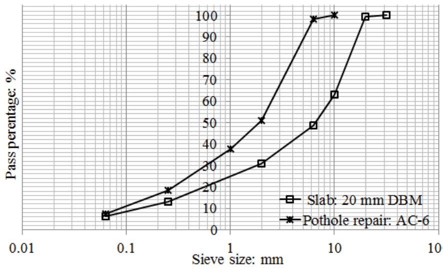


FIGURE 1 Asphalt mixtures gradation curves.

Description of dynamic heating

The optimum dynamic heating methods in 45 mm deep pothole excavations are presented in reference (*17*). These methods are: (a) 6.6 kW heat power and stationary heater at an offset 230 mm above the excavated pothole, and (b) 7.5 kW heat power and heater in motion moving with a constant speed 0.04 m/s at an offset 130 mm above the excavated pothole. The effect of these heating methods in temperature distribution in the repair interface is presented in reference (*21*).

The present study used method (a) to complete the dynamically heated repairs and assess the bonding of the repairs with the host pavement. Therefore, dynamic heating was performed with an experimental infrared heater presented in reference (*22*). Heat was applied in heating-cooling cycles to avoid severe ageing or charring of surface asphalt binder (*23*) and pre-heat both pothole excavation external surfaces and asphalt mixture inside the host pavement. Two heating times were used in this paper as presented in Table 1.

Construction of slabs and repairs

The construction of the slabs and repairs used to produce sample tests for shear bond tests is described in reference (*21*). A similar method was followed for the slabs and repairs used to produce asphalt blocks for wheel tracking tests. In short, slabs 695 × 695 × 100 mm^3 were constructed in two lifts of approximately 50 mm deep. Each lift was compacted for 7 min with a vibrating plate (*19*) and bonded with 3 min infrared heating. Two artificial potholes 305 × 165 × 45 mm^3 were created per slab. One pothole was statically repaired and the other one dynamically. The repairs were performed 24 h after the construction of the slabs.

In static repair, tack coat was applied to the interfaces of the pothole excavation prior to laying hot mix asphalt. The mixture was then evenly spread out and compacted. In dynamic repairs, first infrared heat was applied using method (a) described in the previous section and then hot fill mix was poured on top of preheated area, evenly spread out and finally compacted. No tack coat was used in the repair process. All repairs were compacted with a vibrating plate for 6 minutes. Average pre- and post-compaction fill mixture temperatures for static repairs were 96.5 ^oC and 77.5 ^oC respectively and for dynamic repairs were 102.0 ^oC and 83.8 ^oC respectively. Slabs and repairs were constructed at room temperature (20 ±3) ^oC.

Air voids content of slabs and repairs

Air voids were measured in slabs S1-S12 and for repairs in slabs S1-S6 using equations from references (*24 – 26*). An air voids range 12.43% to 13.28% was achieved in the slabs. On average, 4.5% and 4.7% air voids were measured for static and dynamic repairs respectively. Air voids content was not possible to be 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 slabs and repairs due to the consistency followed in slab construction and preparation of repairs. The consistency in measured air voids supports also this assumption.

Shear bond test

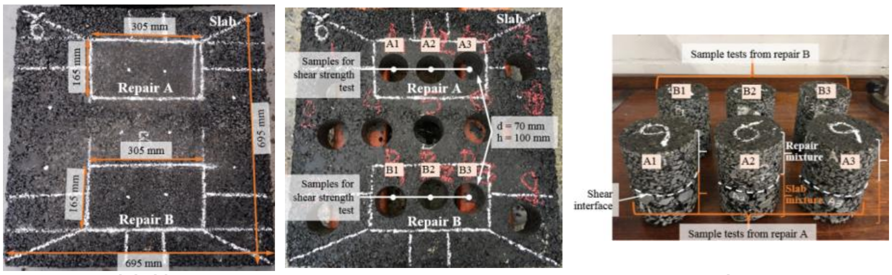
Shear bond tests were used to evaluate the bonding strength in the interfaces of static and dynamic pothole repairs constructed in slabs S1-S12. The tests were conducted using an Instron hydraulic machine and a shearing rig specifically designed for the dimensions of the tests samples used in this study. The design of the shearing rig followed instructions from reference (27). The shear bond test was conducted as per reference (*28*).

The test samples, 70 mm in diameter, were obtained from larger asphalt blocks. For shear bond test of bottom repair interfaces, sample tests were simply cored along each repair as shown in Figure 2. For vertical repair interfaces, the constructed 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 allow testing only on the repair interface (Figure 3).

After coring, the samples were cured at a room temperature (20 ±3) ^oC for 24 h prior to testing. The shear displacement rate was 20 mm/min, applied until the interface failed. The gap between the shearing platens was 5 mm and the tests were conducted at a room temperature (20 ±3) ^oC. The maximum shear stress was calculated using Eq. 1 (*28, 29*):

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

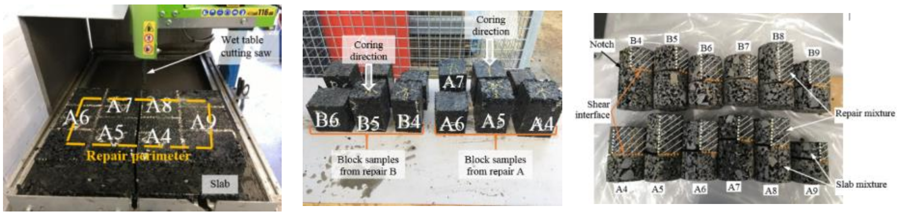
where τ_{max} = maximum shear stress, kg/cm^2; P_{max} = maximum load applied to specimen, kg; D = specimen diameter, cm.



Asphalt slab Coring Sample tests

FIGURE 2 Sample tests for shear bond tests of bottom repair interfaces (slabs S1-S6, Table 1).

Step 1 Step 2 Step 3: end of first cutting phase

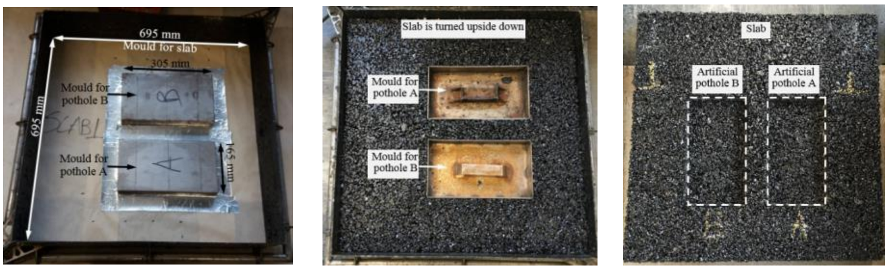


Step 4 Step 5 Step 6: end of second cutting phase

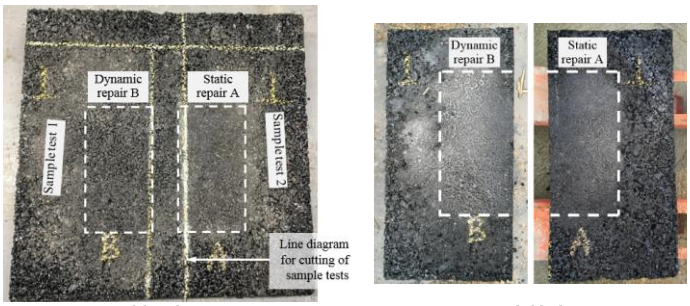
FIGURE 3 Sample tests for shear bond tests of vertical repair interfaces (slabs S7-S12, Table 1).

Wheel tracking testing

In total, six slabs with repairs were prepared for wheel tracking tests (Figure 4 and Table 1). Six repairs (3 static repairs + 3 dynamic repairs) were tested at (25 ±1) ^{o}C and six repairs at (4 ±1) ^{o}C. The tests were conducted using Hamburg wheel tracking device according to AASHTO T324-04 (*30*) with test tank and moulds specifically designed for the dimensions of the tests samples used in this study. Tests methods conducted at (4 ±1) ^{o}C are not part of the standard, nevertheless, a similar procedure was followed with the difference in test temperature. The temperature in this occasion was controlled with a K1 chiller connected with the wheel tracking device. Static and dynamic repairs were simultaneously tested. In total 20,000 cycles were completed per repair with the wheel load applied in the repair interface as shown in Figure 5. Rutting depth was measured in increments of 4 mm distance, in a total length of 96 mm over the repair interface. The tests were conducted 24 h after the completion of each group of pothole repairs.



Moulds arrangement Constructed slab Pothole moulds removed



Slab with repairs Sample blocks

FIGURE 4 Preparation of asphalt samples for wheel tracking test.

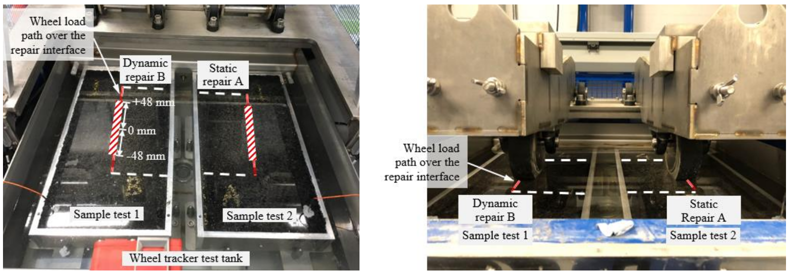


FIGURE 5 Simulation of wheel load in the interface of static and dynamic repair.

RESULTS, ANALYSIS AND INTERPRETATION

Shear bond strength test

Figure 6 shows the average shear strength in static (A samples) and dynamic (B samples) repairs repaired with 10 min 15 s and 21 min 49 s. Eighteen specimens were used for bottom interlayer testing of static repairs and nine samples per heating time for similar testing of dynamic repairs. Whereas, thirty-six samples were used to test the bonding strength in the vertical repair interface of static repairs and eighteen samples per heating time for similar testing of dynamic repairs. During the tests, all the test samples broke through the bonding interface. Four sample tests 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 6. Further, four sample tests were lost during the tests due to Instron device error.

The first observation from the results is that the shear strength between dynamically heated and static repairs was significantly higher. The shear strength in bottom repair interfaces between dynamically heated repairs was similar and ranged between 0.499 MPa and 0.579 MPa. In average, it was 78.2% higher than static repairs. Dynamic repairs were conducted with pre-heating and in reference (*17*) it was seen that during dynamic heating of 45 mm deep pothole excavation, temperatures were non-uniformly distributed in both pothole excavation and inside the slab. In the mid-bottom of the excavation, temperatures were from 140 ^{o}C to 160 ^{o}C. The lowest temperatures were received on the sides ranging between 80 ^{o}C to 120 ^{o}C. At the same time, temperatures inside the slabs ranged between 20 ^{o}C and 80 ^{o}C with the highest temperatures received nearer the top surface of the host pavement. However, after approximately 10 min of heating, similar temperature levels were observed in the pothole excavation and mixture inside the slabs.

Therefore, it seems that between 10 min and 21 min of heating there is no significant effect of temperatures in the bonding strength of the bottom interface layers although the viscosity between the two heating times is different and likely to be lower for 21 min of heating. Lower viscosity, means less resistance of asphalt to flow, higher interlocking between the aggregates of the host pavement layer and the fill mixture layer and therefore adequate adhesion between interlayer surfaces (*31*). This justifies the fact that slightly higher bonding strength was received for test samples A2 and B2 located in the middle of the repairs where temperatures during heating and repair were the highest according to references (*21*) and (*17*) respectively.

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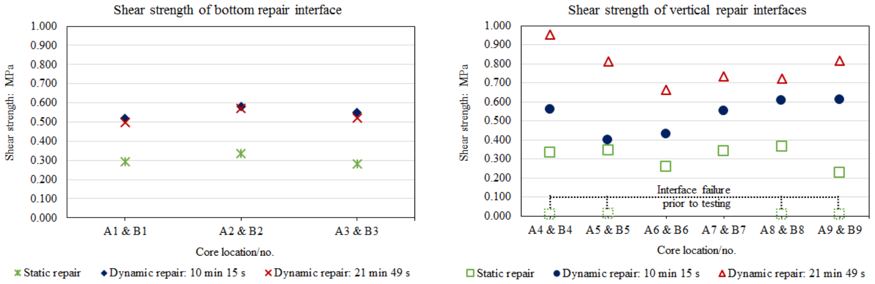


FIGURE 6 Shear strength of static (A) and dynamic (B) pothole repairs on the repair interfaces. Sample characterisation (A1-A9 and B1-B9) is in Figures 2 and 3.

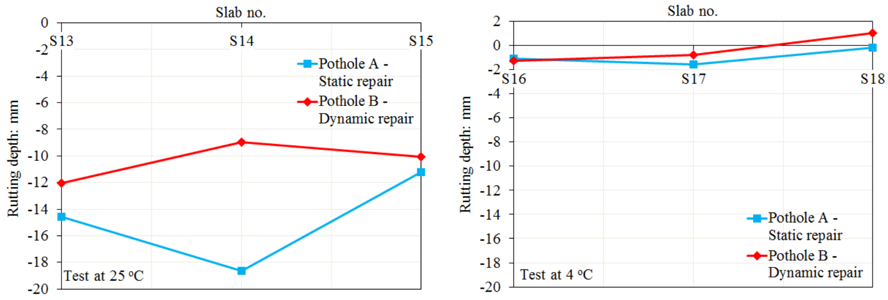
The strength in vertical repair interfaces of dynamic repairs was also higher than that of static repairs. It can be seen that in general, the strength of the test samples taken from 10 min 15 s dynamically heated repairs was 68.4% higher than of the test samples of static repairs. The strength of 21 min 49 s dynamically heated repairs more than doubled that of static repairs. Between dynamically heated repairs, 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 samples prepared with 10 min 15 s heating. However, an average strength difference of 0.185 MPa was only observed for sample tests B6 - B9.

Considering the shear strength results received for the sides of the excavation, it seems that there is a higher effect of temperatures in the interface strength. However, during the two heating times of the pothole excavation, it was observed that the sides became increasingly loose after 21 min of heating showing evidence of overheating the asphalt, affecting its properties and heating larger area of mixture 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 (*32*). The 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 reference (*28*).

Finally, it was observed that the interface strength on the sides of the repair differed. This is expected to have happened because of the non-uniformity in temperature distribution during heating of the pothole excavation and repair, and variation in mixture distribution in the pothole excavation which affect aggregate interlocking between asphalt layers and therefore interlayer bonding strength.

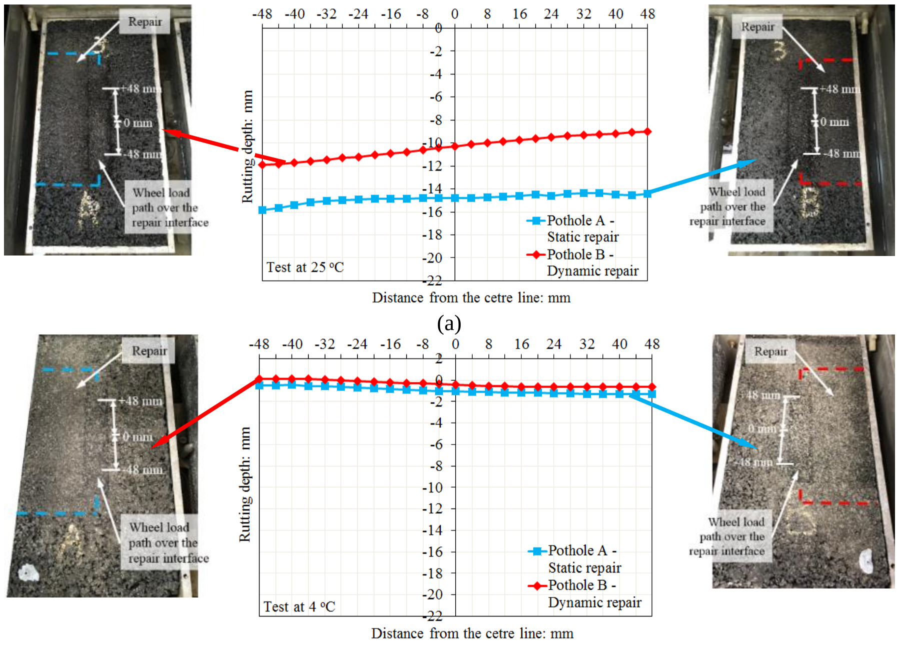
Immersion wheel tracking testing

Figure 7 shows the permanent deformation of static and dynamic repairs in the repair interface at 25 °C and 4 °C. Figure 8 presents the average rutting profile of these repairs along the repair interface. 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 tests performed at 25 °C and 4 °C respectively. This fluctuation has been considered (added or subtracted from the final rutting depth) in the presented results. It can be observed that at 25 °C rutting test, 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 of 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 °C (Figures 7(b) and 8(b)).



(a) (b)

FIGURE 7 Rutting depth at (a) 25 °C and (b) 4 °C after 20.000 cycles.



(a)

(b)

FIGURE 8 Longitudinal average rutting profile in the repair interface at (a) 25 ºC and (b) 4 ºC after 20.000 cycles.

CONCLUSIONS

The following conclusions are drawn from the research:

- Dynamically heating an empty and clean 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 to avoid overheating the asphalt, affect asphalt properties or heat larger area of mixture than expected.
- The rutting resistance of dynamic repairs in the repair interface is higher than that of static repairs. However, further tests are suggested to evaluate stripping point and fully characterise pre-heater repair interface susceptibility to moisture.
- It has been concluded that pre-heating a pothole excavation with infrared heat prior to filling and compaction increases repair durability.

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