THERMAL SEGREGATION OF ASPHALT MATERIAL IN ROAD REPAIR

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ABSTRACT

This paper presents results from a field study of asphaltic pavement patching operations performed by three different contractors working in total of ten sites. Thermal imaging technology was used to record temperatures of the patching material throughout the entire exercise, from the stage of material collection, through transportation to repair site, patch forming and compaction. Practical complications occurring during patch repairs were also identified. It was found that depending on the weather condition and duration of the travel, the temperature of the asphalt mixture can drop as much as 100°C over the entire period of patching work. Cold spots and temperature differentials were also identified between the new and old surfaces as well as along the edge of the pavement. In addition, the temperature loss at various locations on the asphalt mat was found to vary despite the material being laid at the same temperature. For example, over a five minute period, the temperature at one point was reduced by 33% whereas the temperatures of nearby areas were decreased by 65% and 71%. A return visit to the repair sites, three months later, revealed that locations where thermal segregation was noted during the patching operation had failed prematurely.

Keywords: hot mix asphalt, pothole, patch repair, segregation, thermography

INTRODUCTION

A road network constitutes an important asset of developed countries such as the UK. It contributes to the economic and social well-being at all levels. In the UK, flexible pavement is the most usual type of pavement commencing 95% of the road network. Even though the asphaltic surfacing of a flexible pavement is designed to be a less permeable layer compared to other layers of a pavement structure (aggregate sub-base, capping and subgrade), water does permeate into it. The ingress of water into the pavement deteriorates the mastic and the aggregate mastic-bond causing, in combination with traffic loading, initial stripping which rapidly leads to very serious raveling and then to the creation of potholes (Dawson, 2008).

Over recent years, the use of high quality materials, that will protect the surface layer of the flexible pavement from weather conditions and high traffic loading, has been tried (Texas Department of Transportation, 2011). However, increasing traffic volumes and heavier loads, allied with repeated adverse weather is causing significant deterioration of the UK road network, resulting in millions of potholes and failed areas (cracking, stripping, and ravelling). The Automobile Association (AA) survey where more than 22,000 people participated revealed that the 33% have confronted damage to their vehicles due to potholes on roads. In 2012, the number of potholes, which has grown with the passage of the years, was found to have been increased by up to 30% (Knapman, 2013).

The situation is not improving. According to an AA report in 2014, road deterioration in UK had risen to 40% by March 2014 in comparison with October 2013 figures (The Automobile Association (AA), 2016). The figure of increased number of potholes is also confirmed by the Annual Local Authority Road Maintenance (ALARM) report in 2015 (Asphalt Industry Alliance, 2015). The poor riding condition of UK roads has generated significant public dissatisfaction as road distress does not only create dangerous driving conditions but also high repair bills for their vehicles.

However, one of the major problems is that road repairs fail within few years (Rahman and Thom, 2012). Usually, the reasons of this failure are (a) the patching material is laid on failed areas and it is likely that the underlying materials are in poor condition, (b) the quality of the repairs offered by the contractor differs because the skill levels of the teams responsible for the repairs varies, and (c) the variable quality of patch repairs. Other reasons that confirm the failure of road maintenance are the lack of technical quality due to not established guidelines or test methods, inadequate compaction, poor surface preparation and overall inferior workmanship, as well as lack of appropriate guidelines for maintenance engineers on materials suitability in every patch repair situation.

Asphalt pavement fails for several reasons, such as traffic loading and environmental conditions. This leads to severe deterioration, with potholes being one of the worst distresses. Among the causes of pothole formation, segregation is the phenomenon that is of most concern in this research. Segregation is usually categorised into aggregate segregation and thermal segregation. Thermal segregation of hot mix asphalt (HMA) can be defined as *"A lack of homogeneity in the hot mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress"* (Stroup-Gardiner and Brown, 2000, p.79). When the temperature of HMA falls below the cessation temperature, no further compaction can occur. Insufficient compaction leads to reduced density of HMA surface resulting in possible future premature failure.

In comparison with aggregate segregation, thermal segregation cannot be visually identified by the human eye. However, a suitable, well defined method is infrared thermography which was developed by researchers at Texas Transportation Institute (TTI) (Davis, 2012). This is able to recognize and measure the thermal energy emitted from an object that is not possible with the human eye (Flir Systems AB, 2014). Thermography is used in this research to identify thermal segregation of asphalt material in stages of road repair work.

RESEARCH OBJECTIVES

The key objective of this research is to evaluate the extent of thermal segregation in HMA road patch repairs executed by three independent teams of workers (designated companies A, B and C) operating in different weather conditions, method of transportation and repair process, and observe the outcomes after three months. The research involves (a) temperature monitoring during material transportation, (b) temperature monitoring during material placement and after compaction, and (c) the collection of temperature differentiations from several locations over the repair mat. Infrared thermography and a contactless handheld thermometer where used to gather temperature data. Observations were made for five sites in the case of Company A and one and four sites in the case of Company B and Company C respectively. A return visit was made to each of these sites three months after execution of the repairs.

RESEARCH METHODOLOGY

Through examining the activity to three typical road repair contractors, the research is intended as a contribution towards understanding the realities of patch repair work, especially repair material heat loss and the possible implications of this for repair performance. The adopted approach is purely observational, with no attempt to interfere or alter any aspect of the contractors work methods or processes in the handling or use of materials.

To accumulate data for analysis and evaluation regarding the causes of thermal segregation and how possible failure modes are likely to occur, three companies (Company A, B and C) were followed during their patch repair procedure at different locations in UK. The process was: temperature monitored commencing from the material production store through the laying and compaction of the material on each repair site. For each repair site, the surface temperature was collected using a calibrated thermal imaging camera model FLIR B200, having a resolution of 0.08 ^{o}C.

The field investigation relating to Company A was conducted in December 2014. Five different patch repair assignments were monitored, these all located in an urban environment, addressing residential or busy major roads. The depth of the patch repair ranged between 40mm to 50mm. The material used for the repair was HMA and the maintenance of all sites was completed in one day between 9.30am to 15.10pm.

The field investigation relating to Company B was conducted in January 2014. Only one project was monitored. The road repair was conducted in an urban area on a busy major road. The depth of the patch repair was 60mm and the material used was HMA. The maintenance was completed between 10.20am to 12.45pm.

The field investigation relating to Company C was monitored during its patch repair process on a major busy road in an urbanized area and three residential roads of a rural environment. The patch repairs were completed in August 2015 in two different days (two repairs per day). The depth of patch repair, using HMA, ranged between 50mm and 60mm.The maintenance on repair sites 7 and 8 was completed between 08.00am to 15.00pm, and on repair sites 9 and 10 between 10.00am and 13.00pm.

Further, all three companies used a type of end dump truck to transport the asphalt material from the production facilities to the locations of the repair sites (Figure 1(a), (b) and (c)). After the material was loaded into the truck it was covered by an insulating sheet. Company A and B completed their road repairs in the winter and Company C in the summer. They all used the same uncontrolled process of transportation. This data is presented in Table 1.

Table 1: Patch repair data of Company A, B and C

	Repair site	Repair time	Urban area	Rural area	Winter*	Summer**	Busy major road	Residential road	End dump truck	Patch depth 0.40mm	Patch depth 0.50mm	Patch depth 0.60mm	Compaction wacker plate	Compaction Roller
Company A	Repair site 1	930am-15.10pm	✓		✓			✓	✓		✓		✓	✓
	Repair site 2		✓		✓		✓		✓	✓			✓	✓
	Repair site 3		✓		✓			✓	✓	✓			✓	✓
	Repair site 4		✓		✓			✓	✓	✓			✓	✓
	Repair site 5		✓		✓		✓		✓		✓		✓	✓
Company B	Repair site 6	10.20am-12.45pm	✓		✓		✓		✓			✓	✓	✓
Company C	Repair site 7	08.00am-15.00pm	✓			✓	✓		✓		✓		✓	
	Repair site 8			✓		✓		✓	✓		✓		✓	
	Repair site 9			✓		✓		✓	✓			✓	✓	
	Repair site 10			✓		✓		✓	✓			✓	✓	

Weather temperatures: *Company A| all sites: 5 ^{o}C (on-site measurement), Company-B| 0 ^{o}C (from MET office)
**Company C| site 1 and site 3: 15^{o}C-18^{o}C, site 2 and site 4: 21^{o}C-22^{o}C (on-site

(a) (b) (c)

Figure 1: Mode of HMA transportation for (a) Company A, (b) Company B and (c) Company C

OBSERVATIONS IN THE REPAIR ACTIVITY

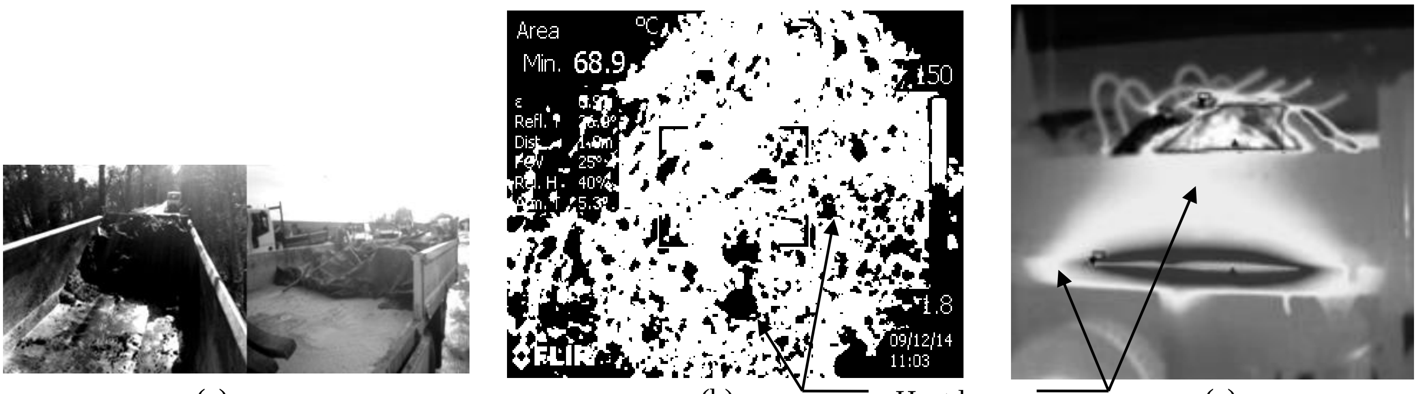
Effect of Transportation Method

The transportation method of HMA is a key factor to study when thermal segregation is to be monitored. Usually, asphalt material is prepared at the asphalt plant and then by using an appropriate vehicle is transported to the paving site. It is during this stage where a great amount of aggregate and thermal segregation is detected on asphalt (Bode, 2012). There are three usual types of vehicle for asphalt transportation named as end dump, bottom dump or belly dump, and live bottom or flo-boy. The design of the three truck types is aimed to maintain asphalt temperature and quality from the time that is received at the production plant to the repair site (Pavement Interactive, 2016). The vehicle used during the observations in this study, for all three companies, was a type of end dump truck (Figure 1).

The way that the material is dropped in the transportation vehicle has a huge impact on the extent of aggregate segregation. Therefore, dropping the material onto the vehicle in one batch is less preferred than in smaller masses. However, this research is more concerned with thermal segregation and, therefore, the effect of aggregate segregation is not studied in more detail, although not ignored. To this extent, it was observed that Companies A and B loaded asphalt onto the truck in one batch whereas Company C loaded asphalt in two batches. However, the truck beds were adequately cleaned and lubricated. Generally, the temperature of the asphalt when loaded onto the truck was uniform throughout, with the truck beds thermally insulated.

Company A

During transportation, asphalt was only covered with a thin sheet (Figure 2(a)). Figure 2(b) is the thermal image taken 2 minutes after the asphalt was loaded onto the truck. At this point thermal segregation had begun to develop, this is shown as black areas on Figure 2(b). The maximum temperature of asphalt at this stage was 150 ^{o}C. Figure 2(c) is a further thermal image taken few minutes after the image in Figure 2(b). This image indicates how heat was being lost through the panels of the truck and the cover sheet. Sections in white color in Figure 2(c) indicate this. Dark areas on the periphery of both images of Figure 2(b) and 2(c) are the surroundings of the asphalt and not the material itself.



(a) (b) (c)

Figure 2: Asphalt transportation and initial temperature monitoring (a) Asphalt location onto the truck, (b) First thermal image 2 minutes after asphalt was loaded onto the truck and (c) Second thermal image where temperature is lost from the panels and the cover sheet

The asphalt with Company A was transported to five different repair sites with a significant distance from the production facility. This led to significant temperature losses of the asphalt through the panel of the truck and the cover sheet (refer to Table 1 for temperature details on each repair site). The results shown on Figure 3 confirm these conditions. Table 2 presents the overall transport time of asphalt from the production plant to each repair site. All projects were completed during the same day.

Table 2: Asphalt transportation time between production plant and each repair site location

No	Location	Transport time (min)
1	Asphalt Plant	
2	Repair site 1	50
3	Repair site 2	115
4	Repair site 3	180
5	Repair site 4	295
6	Repair site 5	445

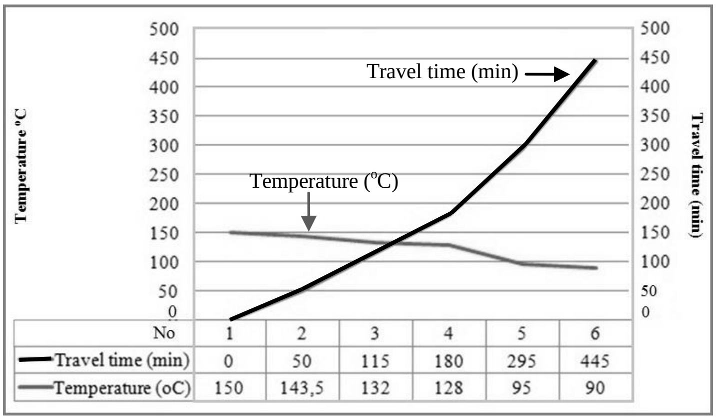


Figure 3: Asphalt temperature variation and transportation time between asphalt production facility and each repair site

There was an initial drop in temperature of 5 ^{o}C after 50min of transportation between the asphalt plant and the first repair site. The temperature reduced by up to 22 ^{o}C between the initial temperature of 150 ^{o}C and that of repair site 4.

There was a sudden drop in temperature between repair sites 3 and 4. The temperature dramatically decreased by 26% reaching 95 ^{o}C, a reduction of 37% from the initial temperature of 150 ^{o}C. In total the temperature decreased 40% between asphalt plant and repair site 5.

<u>Company B</u>

Company B was monitored during their patch repair activity on repair site 6, between the production facility and the single repair site. The process of transportation of Company B is very similar to that of Company A. A type of end dump track was used to transport asphalt. When asphalt was loaded onto the track it was covered by a sheet. The prevailing weather temperature was around 0 ^{o}C (refer to Table 1). Thermal images of the asphalt were taken 5 minutes after it was loaded onto the truck, as shown in Figure 4(a).

Average, maximum and minimum temperatures were determined from the three thermal images with one of them shown in Figure 4(a), these being 138.8 ^{o}C and 79 ^{o}C respectively. Taking into consideration that the initial temperature of the asphalt was around 150 ^{o}C, the temperature had dropped dramatically and reached a difference of 11.2 ^{o}C between initial temperature and average maximum monitored, and a difference of 71 ^{o}C between initial temperature and average minimum. Therefore, it is apparent that the Company A transportation process results in notable heat loss and, thermal segregation. Further, Figures 4(b) and (c) demonstrate a heat loss from the joints at the back and alongside the vehicle respectively.

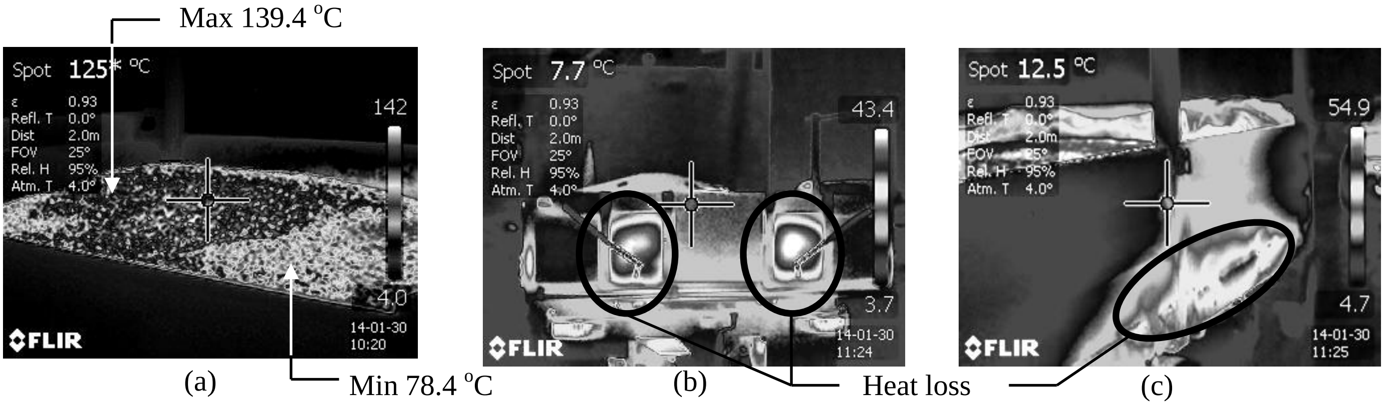


Figure 4: Thermal images indicating heat loss (a) Thermal image of asphalt on back of the truck five minutes after collection, (b) Thermal image on the back of the truck and (c) Thermal image alongside the vehicle

<u>Company C</u>

Four patch repair assignments were followed for Company C. An end dump truck was used to transport the asphalt from the production facilities to all repair sites. Four patch repairs were completed in two days with repair sites 7 and 8 being finished the first day. On each occasion, asphalt was gathered once and kept during the whole patch repair process scheduled for that day. Further, as per Company A and B, asphalt was covered with an insulated sheet. The pothole repairs were all completed in the summer, in contrast with the other two companies that were completed in the winter, and therefore the maximum temperature during morning maintenances (repair sites 7 and 9) was 18 ^{o}C, whereas after 12.00pm the maximum temperature reached 22 ^{o}C (refer to Table 1).

The maximum temperature of the asphalt when gathered from the production plant for both days of the repairs was around 150 ^{o}C with an average of 132.2 ^{o}C. On the day of the repairs at repair sites 7 and 8, the asphalt temperature decreased after loaded onto the truck and ranged between 62.9 ^{o}C and 131.9 ^{o}C with an average temperature of 118 ^{o}C. Therefore, a drop of around 11% had occurred before even the transportation start. The heat loss on this occasion was also measured with a thermometer. During the second day that repair sites 9 and 10 were completed, the average temperature of the asphalt onto the truck had decreased to a 124.7 ^{o}C from an initial 150 ^{o}C (a heat loss of 16.9%).

Figures 5 (a), (b), (c) and (d) present the asphalt and its thermal images when arrived at sites 7, 8, 9 and 10 respectively. Figures 6 (a) and (b) demonstrate the temperature variations when asphalt was loaded onto the truck, and when it was arrived on each repair site. As the results display, during asphalt transportation on day 1 there was an overall heat loss of 69% and on day 2 a temperature decrease of 35.9%.

<table>
<caption>Table 3: Asphalt transportation time between plant and each repair project</caption>
<tr><th>No</th><th>Location</th><th colspan="2">Transport time (min)</th></tr>
<tr><td colspan="4">Day 1</td></tr>
<tr><td>1</td><td>Asphalt Plant</td><td rowspan="2">45</td><td rowspan="3">360</td></tr>
<tr><td>2</td><td>Repair site 7</td></tr>
<tr><td>3</td><td>Repair site 8</td><td></td></tr>
<tr><td colspan="4">Day 2</td></tr>
<tr><td>1</td><td>Asphalt Plant</td><td rowspan="2">40</td><td rowspan="3">210</td></tr>
<tr><td>2</td><td>Repair site 9</td></tr>
<tr><td>3</td><td>Repair site 10</td><td></td></tr>
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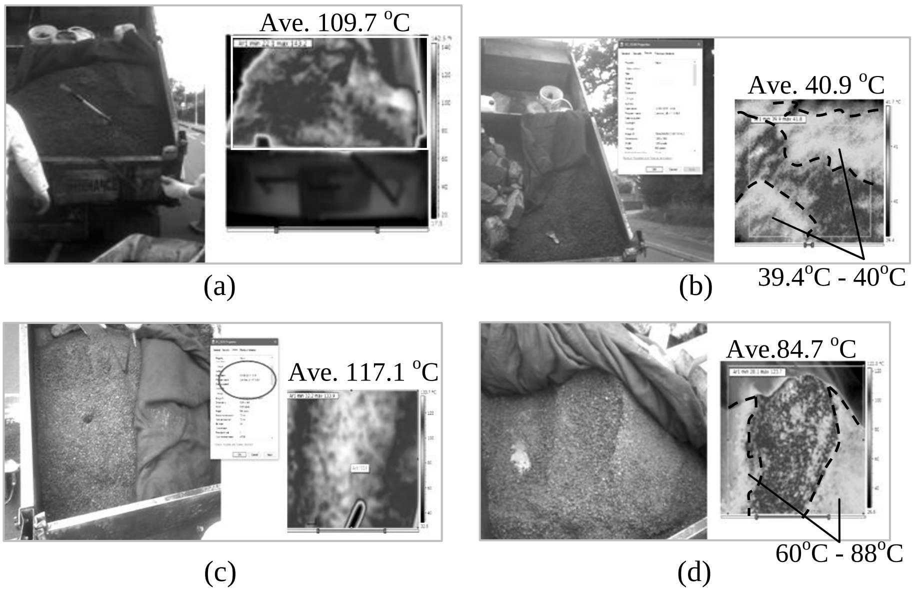

Figure 5: Thermal images of asphalt at (a) Repair site 7, (b) Repair site 8, (c) Repair site 9 and (d) Repair site 10

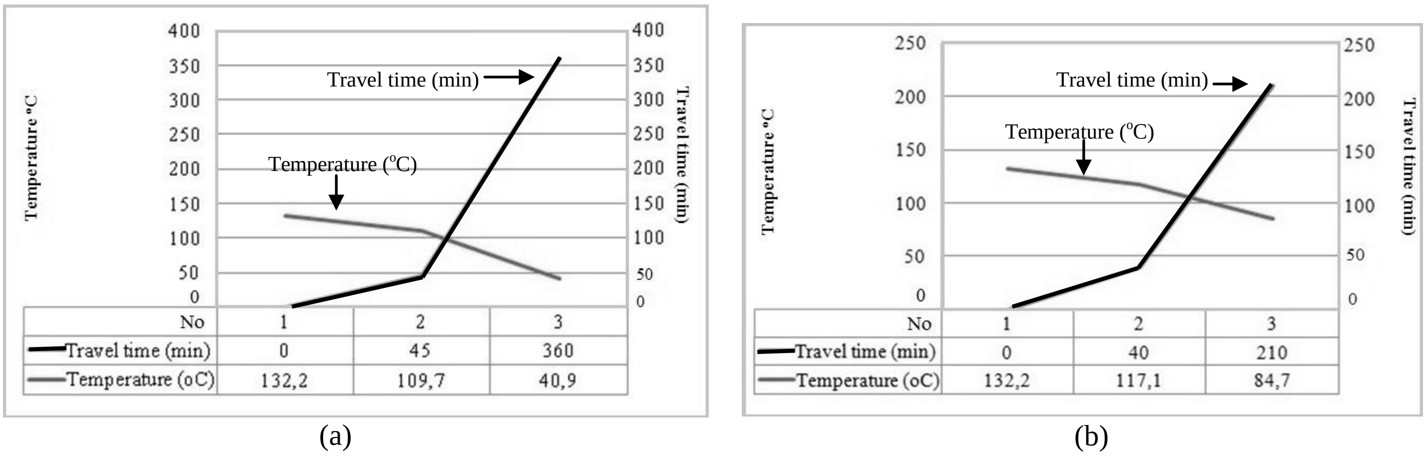

Figure 6: Asphalt temperature variation between asphalt production facilities and each paving site during (a) Day 1 and (b) Day 2

Effect of Compaction

Compaction is a second key factor that plays a major role in the strength and performance of HMA. Ineffective compaction at reduced temperatures can have a detrimental effect on the performance of repaired asphalt surfacing. To investigate this, thermal images where taken after the compaction of the asphalt from all three companies.

<u>Company A</u>

For Company A, Figures 7 and 8 were taken after compaction of the repairs at site 1. Figure 7 presents eleven points taken randomly on the mat. The maximum temperature in the image is 146.5 °C. The temperatures of the eleven points shown on Figure 7 are presented on Table 4. The results indicate uneven temperature distribution. In other words, this means that areas with low temperatures are most likely to fail if these temperatures reach cessation temperature and continue to decrease below that. As revealed from the measurements, most of the points had reached and decreased below cessation temperature. Therefore, the compaction during this stage was ineffective.

Figure 8 is the second thermal image taken after compaction at repair site 1. On this occasion eight points were chosen from the edge of the patch repair. The thermal image recorded a general maximum temperature of 108.7 °C in the mat which means that the compaction could be completed without major problems. However, the eight measurements on the edge of the patch repair revealed temperatures below the cessation temperature (refer to Table 5). Hence, although rollers can continue to improve smoothness and surface texture on the mat, compaction will generally not occur which would result on premature failure of the patch repair

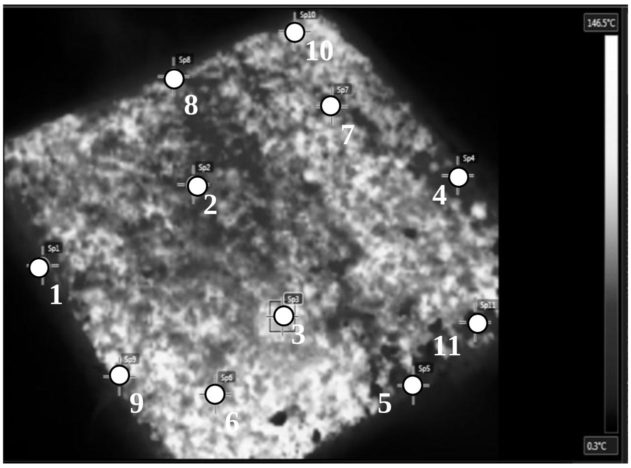

Figure 7: First thermal image of patch repair on paving site 1 immediately after compaction

Table 4: Temperatures measurement related to points of Figure 7

No	Temperature ^oC
Point 1	38.3
Point 2	60.3
Point 3	90.5
Point 4	34.9
Point 5	39.5
Point 6	92.8
Point 7	73.7
Point 8	50.7
Point 9	80.2
Point 10	85.0
Point 11	46.5

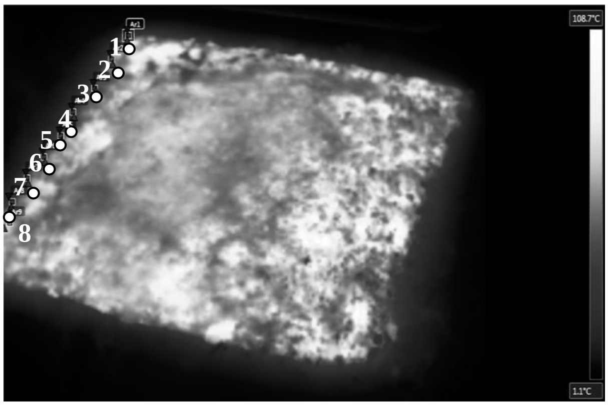

Figure 8: Second thermal image of patch repair on paving site 1 immediately after compaction

Table 5: Maximum and minimum HMA temperatures on collection

No	Maximum ^oC	Minimum ^oC	Average ^oC
Point 1	43.2	27.8	35.5
Point 2	57.9	49.7	53.8
Point 3	51.1	48.7	49.9
Point 4	42.8	33.3	38.1
Point 5	53.5	44.9	49.2
Point 6	50.0	40.3	45.2
Point 7	48.4	39.9	44.2
Point 8	44.8	33.6	39.2

Figure 9 represents the third thermal image taken at repair site 2. After compaction four different points were selected to understand the variation in temperature. Further, for each point seven measurements were collected at different times. Points 1 and 3 were taken on the edges of the mat, and points 2 and 4 in the middle area of the mat. The measurements showed that different locations of the mat exhibit different repair quality. The points located on the edges (points 1 and 3) had lower temperatures than those located in the middle of the mat (points 2 and 4). The temperature reduced, reaching after 19 minutes from the first thermal image shot a temperature difference of 56.4 ^oC for point 1, 30.6 ^oC for point 2, 53.3 ^oC for point 3 and 32.9 ^oC for point 4 (refer to Table 6). This means that the average percentage of temperature reduction on the edges was 51% and in the middle 29%. Consequently, the edges of the repair appear to have a temperature difference with the middle of the mat of around 22%.

Figure 9: Thermal image of patch repair immediately after compaction on repair site 2

Table 6: Temperature collection of points immediately after compaction on repair site 2

Thermal Image No	Time (min)	Temperature ^oC			
		Point 1	Point 2	Point 3	Point 4
1	15:34	109.1	109.1	109.1	109.1
2	15:36	101.2	107.0	100.5	101.5
3	15:37	95.5	104.0	95.0	98.0
4	15:39	84.0	94.0	85.0	90.0
5	15:40	72.0	86.3	75.3	89.0
6	15:43	61.0	84.0	66.8	81.7
7	15:45	52.7	78.5	55.8	76.2

Company B

Figure 10 presents the patch repair area that Company B completed. In this figure there are shown three points where temperature was measured using the thermal imaging camera. Point 1 was situated away from the kerb line and drainage area. Point 2 was located near the kerb line and within the drainage area. Finally, Point 3 was at the edge between the new and old reinstatements. The temperature recordings for each point was as displayed in Table 7 where for each point eight temperature measurement were collected at different time. All points had an initial temperature of 100 ^{o}C. This is a 50 ^{o}C drop from 150 ^{o}C of asphalt temperature when it was collected from the production plant.

Further, the results presented on Table 7 indicate that in a period of 5 minutes temperature dropped for point 1 around 33%, for point 2 around 65% and for point 3 around 71%. As expected, having into consideration the results of temperature drop from Company A, points 2 and 3 displayed greater temperature reduction due to their position near the edge of the repair. As a result, the areas with less temperature of the cessation temperature tend to have lower density and cause failure of the patch repair around them.

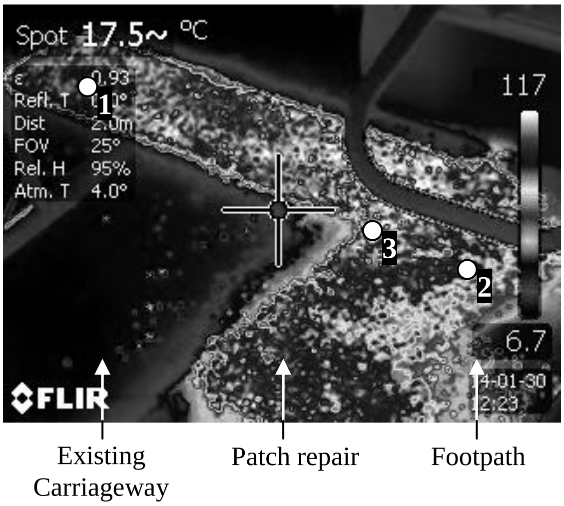

Figure 10: Thermal image of patch repair immediately after compaction on repair site 6

Table 7: Temperature collection of points immediately after compaction on repair site 6

Thermal Image No	**Time (min)**	**Temperature ^{o}C**		
		Point 1	**Point 2**	**Point 3**
1	12:22	100.0	100.0	100.0
2	12:23	98.0	92.7	81.4
3	12:23	92.0	79.0	75.1
4	12:24	84.6	73.6	73.6
5	12:24	77.1	69.2	57.6
6	12:25	76.6	44.3	39.2
7	12:26	73.8	36.5	33.5
8	12:27	66.7	35.2	29.4

Company C

In contrast with the other two companies, temperatures during these repairs were measured on areas and not on specific points. Between sites 7 and 8, which were finalized at the same day with site 7 being completed first, thermal images showed quite acceptable levels of temperature for site 7 with an average temperature of 110.6 ^{o}C. However, on site 8 the average temperature was quite below cessation temperature (determined by pave-cool (Minnesota Department of Transportation, 2016)) and reached an average of 43 ^{o}C. Regarding sites 9 and 10 (completed the second day) the average temperatures were 60 ^{o}C and 65 ^{o}C for site 9, and 46 ^{o}C for site 10. On all repair sites the temperature on the edges was quite low (refer to Figure 11) as was seen on repairs of Company A and B.

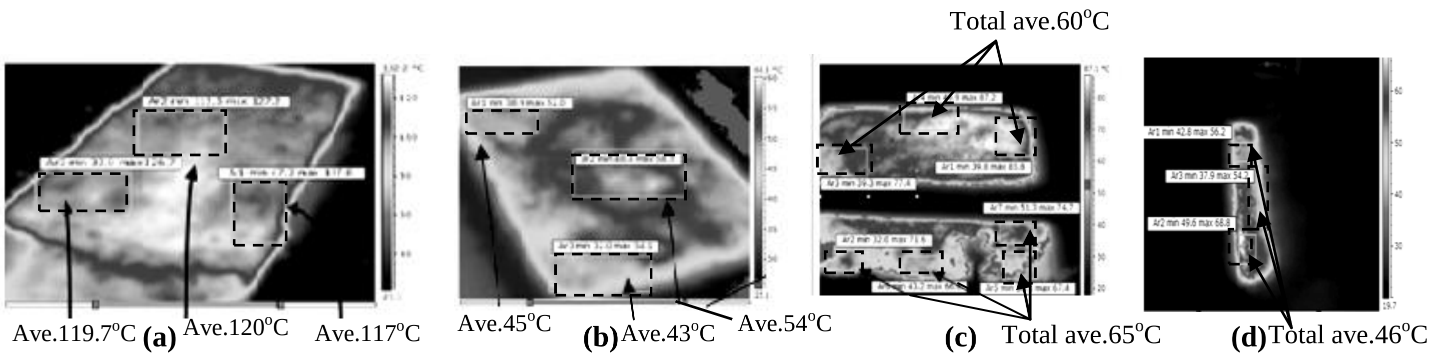

Figure 11: Thermal image of patch repairs immediately after compaction on (a) Repair site 7, (b) Repair site 8, (c) Repair site 9, and (d) Repair site 10

Effect of Patch Repair Process

Patching is an acceptable and well known method repairing localized distresses on roads such us potholes. Company A followed a pothole patching process known as semi-permanent pothole patch. During this process all water and debris was removed from the pothole, the pothole sides were squared up to have the same vertical appearance on all sides. The asphalt was then laid into the pothole and compacted. The compaction started from the center and worked out toward the edges.

Company B used similar patch repair process as Company A. However, the pothole to be repaired was located on a steep hill and the amount of surface run off was quite large as water travelled from higher ground. Therefore, even during compaction the amount of water was significant affecting negatively the compacting process. Another problem confronted during the compaction was the quite thin width of the patch. The roller and the wacker plate had too large areas to properly compact the asphalt laid on the pothole. Company C completed the maintenances during summer. Significant heat was lost during transportation. The asphalt temperature during compaction on sites 7 and 9 were on acceptable levels in contrast with temperatures measurements on sites 8 and 10. The results showed significant low temperatures on the edges of the patch repair, as it was seen on the other two companies too.

REVISITING REPAIRED SITES

All the repaired sites were revisited three months after completion of the repair work. As is shown on the images of Figure 12, along the edges of the reinstatement, the new material had started to fall away. This is considered to be due to temperature differentials between the new and old surfaces, the temperatures in the material dropped below the cessation temperature when was laid and therefore inadequate compaction was occurred. On the other hand, on areas of the patch repair where the temperature was retained at levels over the cessation temperature there was no apparent deterioration.

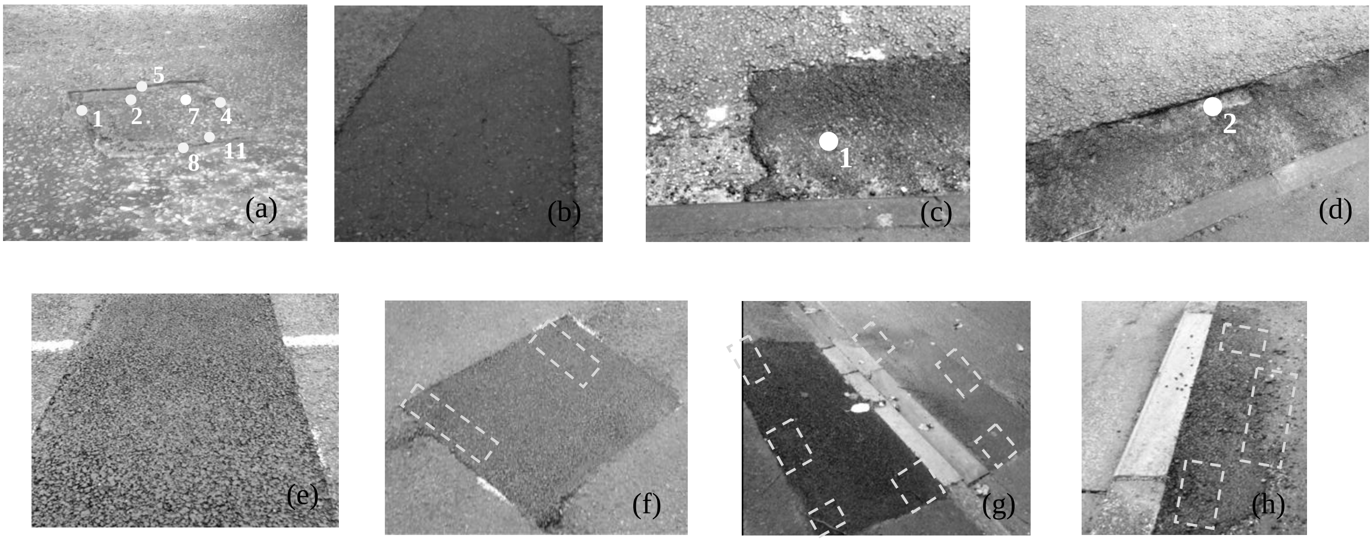

Figure 12: Patch repair sites after three months of completion (a) Repair site 1, (b) Repair site 2, (c) and (d) Repair site 6, (e) Repair site 7, (f) Repair site 8, (g) Repair site 9 and (h) Repair site 10

Further, at all images of Figure 12 are included the points and areas respectively examined under the "Effect of compaction" section of this paper regarding their temperature levels after compaction. Those points and areas are the places with excessively low temperatures that correspond to failures shown on most of the images of Figure 12, excluding the images of 12(b) and (e) that continue to be in good condition. The points of Figure 12(a) and 12(b) are related to Figure 7 and 9 respectively, the points of Figure 12(c) and (d) are related to Figure 10, and the marked areas of Figure 12(e) – 12(h) are related to Figure 11.

OBSERVATIONS AND CONCLUSIONS

The main objective of this research was the understanding of how thermal segregation greatly influences the overall quality of the patch repair operation. Three different companies were studied during their pothole patching using HMA and in total it was gathered information from ten repair sites. Material transportation method and patching repair processes were quite similar between the companies with the difference that Company C completed the repairs during summer. The information gathered from the research was presented on this paper through three sections named as (a) effect of transportation method, (b) effect of compaction and (c) effect of patch repair process.

The analysis of the transportation method used by the three companies revealed that thermal segregation was identified from the time that the material (asphalt) was collected from the asphalt production facilities, within transportation of the material to the repair sites, and during the laying and compaction processes. It was found that the existing practices for transporting material for minor (patch) repair was poorly controlled, and had significant impact on the repair quality. The results from observations on the activity of all ten repair sites showed adverse temperature losses immediately after the material was loaded onto the track. Heat was escaping through the cover sheet, the joints in the back of the truck as well as alongside the truck. The range of temperature loss on this occasion was between 6.5 ^{o}C to even 71.6 ^{o}C for the coolest parts of the material when located onto the truck.

From the analysis of the compaction method was seen that the laying temperatures as well as the temperatures immediately after compaction were significantly lower than the cessation temperature at the edges, and at the center. A repeat visit after three months revealed repair failures had already begun on the areas where the temperature had dropped below the cessation temperature. The deterioration was higher at the edge than at the center in all ten repair sites. The analysis of the patch repair process showed that the process can become challenging when the intended repair is in such position that water exists during the actual compaction. The width of the patch repair affects negatively the compaction process when it is much smaller than the area of the roller or the wacker plate. An example of this negative effect is repair site 10 included on Figure 12(h). Further investigations are underway, to establish a relationship between temperature losses and level of compaction that can be achieved during the repair operation. There are also a number of other issues such as the effect of mixture constituents in relation to temperature, continuous monitoring of temperature loss, compaction process and addition of heat energy within the repair need to be investigated.

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