PAPER • **OPEN ACCESS**

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To cite this article: I K Mizwar *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **527** 012049

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Thermal properties of cool asphalt concrete containing phase change material

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Abstract. Building and pavement, due to their impervious nature, are listed as some of the main causes for Urban Heat Island (UHI) phenomena where the temperature in the urban area is higher than that of surrounding areas. Due to its characteristic that can absorb and release heat at a specific temperature, Phase Change Materials (PCM) has been widely used in building infrastructure as thermal regulation to combat UHI. However, the application of PCM in pavement infrastructure is still very limited due to a lack of study on this. This study analyses the Phase Change Material in asphalt concrete focussing on thermal properties, which is surface temperature. Experiments were carried out on a slab of wearing course with the PCM substituting the equivalent amount of mineral filler, and then compared with a slab of conventional wearing course. The study showed that the potential of PCM used in pavement mixture decreased the surface temperature of the pavement. The maximum difference of temperature of PCM and asphalt concrete mixture reached 120C.

1. Introduction

Building and pavements are some of the main causes for Urban Heat Island (UHI) phenomena due to their impervious material. These built-up areas lead to increase surface temperature [1–4]. Surface urban heat island means that land surface temperature in the urban area is higher than the land temperature in the surrounding area (local level). UHI can occur at any latitude and happen during the day and night [5]. Santamouris reported data of UHI intensity and characteristics for Asian and Australian cities. The magnitude of the temperature differences varies in time and place [6].

Cool pavement is an alternative approach to mitigate UHI. The cool pavement can be classified as reflective pavement, porous pavement, PCM pavement, and hydronic pavement. Reflective pavement has been mostly applied because they are easy to build. Its drawback is that the reflective effect has a bad impact on its surrounding, building, and pedestrian. This is especially significant in urban canyon areas. The bad impact includes a contribution to glare, thermal comfort, and skid performance. This is because of two parameter reflective pavements are white/ light colored of the pavement and smoother surfaced [7, 8]. Porous pavement is pavement design that eliminating fine aggregate to allow water pass through the void of pavement to the side of a road. It contributes to road safety and stormwater runoff but the effectiveness of this pavement depends on rainfall [9]. Hydronic asphalt pavement is a technology to harvest solar energy. It has pipes network that can circulate groundwater. The circulating water through the pipes cools the warm pavement [10, 11]. PCM, phase change material, is materials used for latent heat energy storage. PCM has been widely used in cool building materials. The studies

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proved that an appropriately PCM choice was able to decrease the heat gains through building envelopes [12]. The feasibility of using PCM in asphalt pavement showed in some research [13, 14]. Both studies utilized Paraffin as PCM but with a different incorporated method. Chen [13] put paraffin in graphite, as porous structure, and depend on the capillary and surface tension forces to prevent leakage of the melted paraffin. Meanwhile, Kheradmand [14] utilized waterproofing materials to cover the porous material that has impregnated with paraffin.

In this work, the effect of PCM in AC, focussing on thermal properties, will be examined. The cool pavement was fabricated by incorporating asphalt with microencapsulated organic Phase Change Material (PCM). Subsequently, thermal properties of this pavement were investigated. This work will provide an insight into the preparation of cool pavement.

2. Material and Experiment Set-up

In this study, bitumen penetration grade 60-70 was used during sample preparation. Table 1 presents the different properties of bitumen in this study. Granite and river sand were used for coarse aggregate and fine aggregate, respectively. Table 2 presents the aggregate design gradation and specification according to Malaysia specification. MPCM 43 was applied as Phase Change Material in this study. MPCM 43 is paraffin that has been encapsulated in micro size and 43 is referred to phase change temperature of paraffin. This PCM in wearing course mixture is treated as filler substitution. Wearing course mixture was produced based on Malaysia specification (JKR specification). Two types of the mixture are PCM an AC. PCM refers to the asphalt concrete mixture with PCM 6% as filler. AC refers to the conventional mixture with cement 6% as filler.

Table 1 Properties of Bitumen

Test	ASTM	Result	Specification limit
Penetration (0.1 mm)	D 5-06	65	60-70
Softening Point (Celsius)	D 36-06	47	45-55
Ductility (cm)	D 113-99	100	> 95

Table 2 Aggregate Gradation

Sieve Size	Design	Specification Limit	
mm	Gradation	Lower	Upper
14	93	90	100
10	79	76	86
5	51	50	62
3.350	49	40	54
1.180	34	18	34
0.425	16	12	24
0.150	6	6	14
0.075	5	4	8

Asphalt concrete slab (30cm x 30cm) was subjected to sun radiation for 6 x 24 hours. Thermocouples type K, connected to a data logger, were placed on the slabs measuring its surface temperature and

bottom temperature in every 15 minutes. All measurements of temperature were taken in conditions of direct sunlight.

3. Result and Discussion

This experiment is limited to study that the pavement material has high surface temperature. This study did not cover effect this material to air temperature. The effect of pavement material to air temperature can be found in other studies [2,3]. Thus the air temperature can take from nearest weather station. There is no direct measurement of air temperature above the sample slab.

A study in Putra Jaya [15] highlighted that the maximum temperature of AC occurs around 12 pm to 3 pm. However, this study found that the maximum temperature of AC occurs around 3 pm to 4 pm. The reason for this could be due to the interval time of measurement that is shorter (every 3 hours compared with every 15 minutes). This means that temperature still can be varied within 3 hours. In general, maximum temperature of the mixture is around 60˚C. This result agrees with previous study [15].

Figure 1 represents a temperature profile at bottom of both samples, which are AC and PCM mixture. The maximum temperature of both mixtures coincided, around 3 pm to 4 pm, except the first day. The maximum temperature of PCM mixture occurred 4 hours later than AC mixture on the first day. The difference of max temperature of bottom PCM mixture and bottom AC are 1.9, 3.6, 6.4, 5.2, 4 and 5.4 °C. The average is 4.42°C.

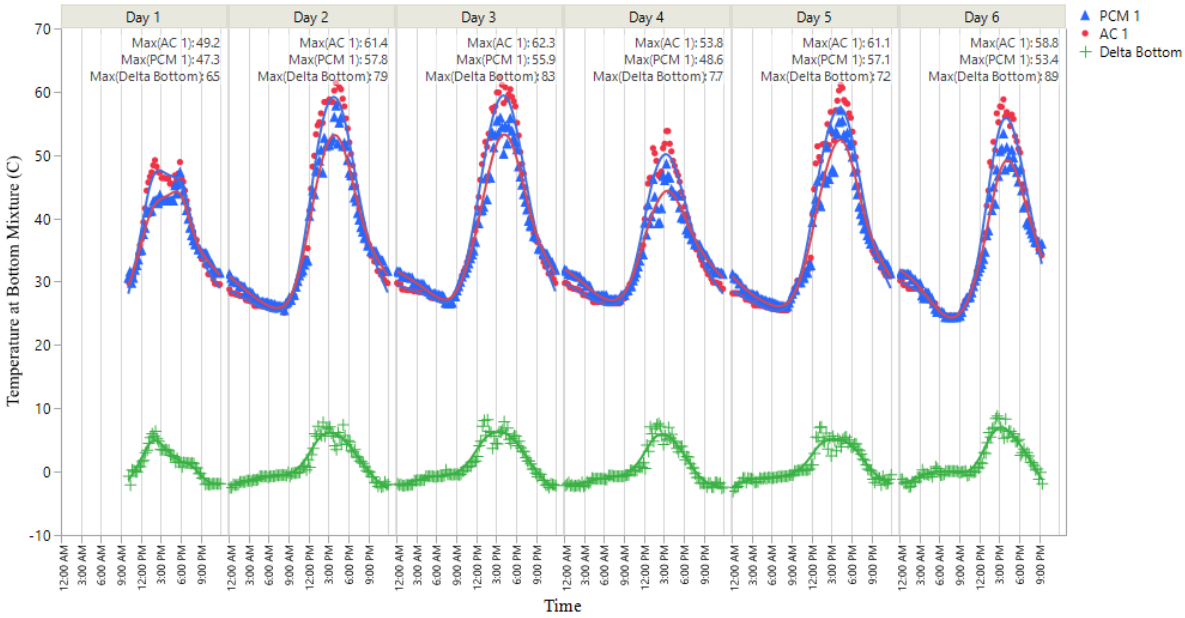

Figure 1 AC vs PCM at the bottom mixture

Figure 2 shows a temperature profile at the surface of both samples. Similar to the bottom side, the maximum temperature of PCM mixture occurred 4 hours later than AC mixture. The difference of max temperature of surface PCM mixture and surface AC mixture are 0.9, 2, 2.3, 2.8, 2.2 and 2.6 °C. The average is 2.13°C. The difference between surface and bottom is 2.29°C.

The difference of temperature of the bottom PCM mixture and bottom AC can reach 8.9°C and the difference of temperature of the surface PCM mixture and surface AC can reach 12°C (Figure 3). These differences happened before the mixtures achieved their maximum temperature.

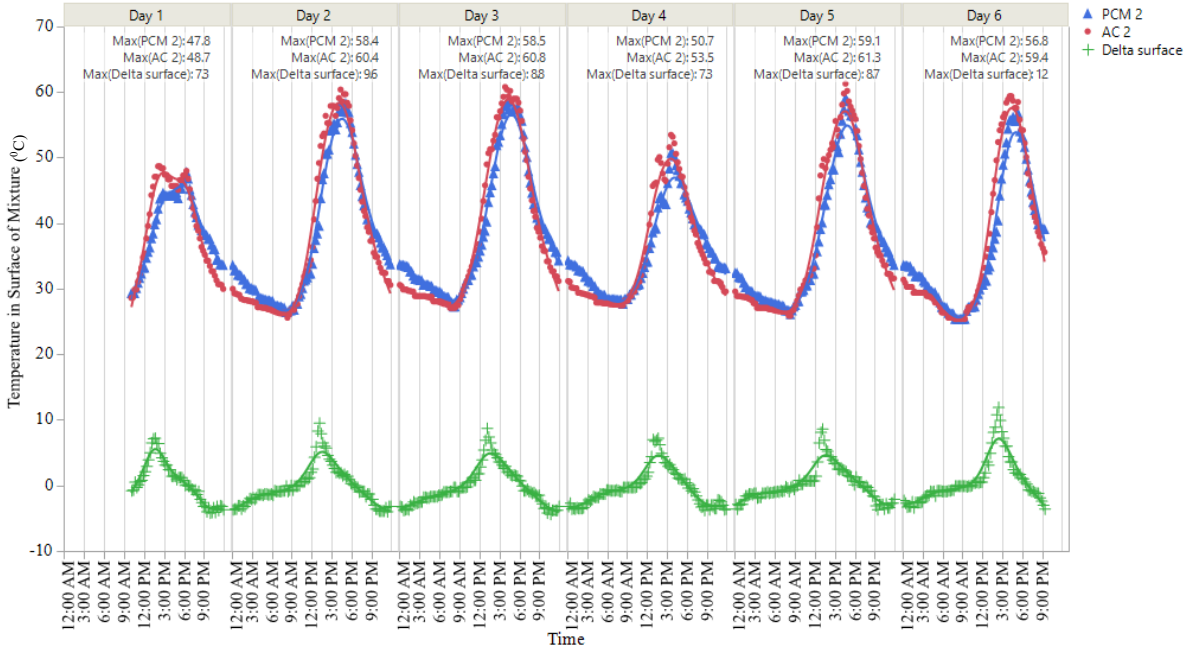

Figure 2 AC vs PCM at the surface of the mixture

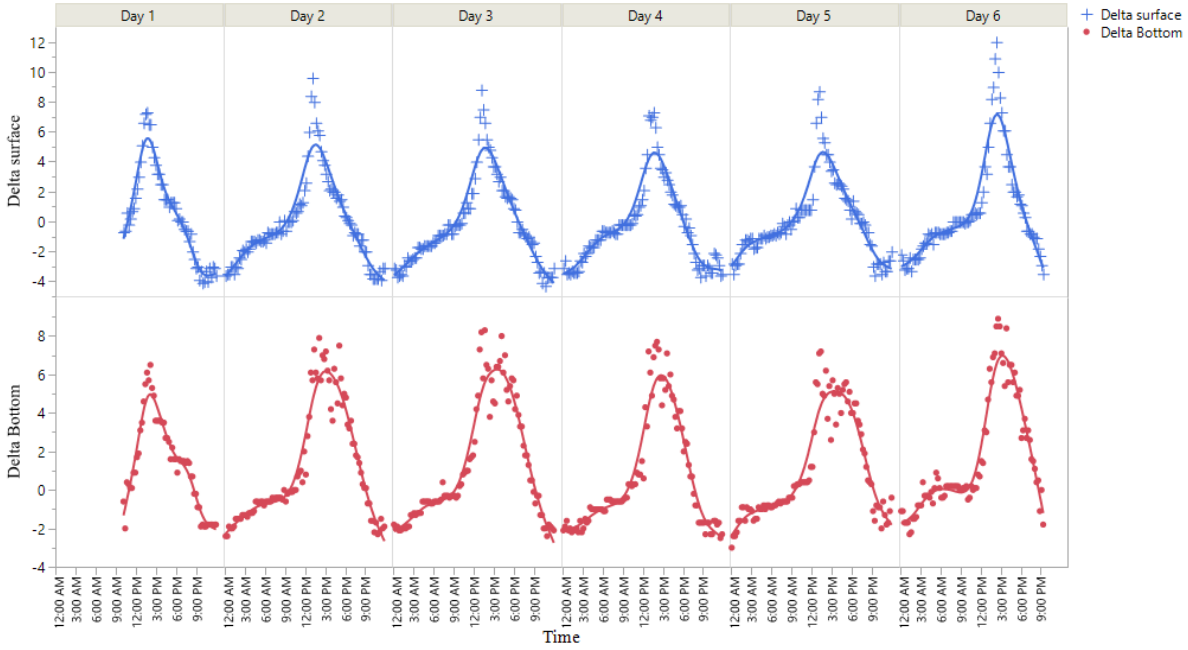

Figure 3 Delta Temperature at surface and bottom of the mixture

4. Conclusion

In this research, the temperature of PCM asphalt mixture was tested and compared with conventional asphalt mixtures. Important conclusions are obtained as follows: maximum temperature of pavement occurs around 3 pm - 4 pm. The average difference of maximum temperature of the bottom PCM mixture and the bottom AC is 4.42°C. The average difference of maximum temperature of the surface PCM mixture and surface AC is 2.13°C. However, the maximum difference of temperature of PCM and AC mixture reached 12°C.

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