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Experimental evaluation of thermal performance of cool pavement material using waste tiles in tropical climate

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ABSTRACT

Thermal performance are important parameter that represent the characteristic of cool pavement. The purpose of this paper is to present the findings on experimental result of thermal performance of the coating materials, which were developed from three types of waste tile aggregate, namely Full Body Porcelain (FBP), Monoporosa (MP) and Porcelain Glaze (PG). The samples were prepared based on the optimal design mix as proposed during optimization process based on surface temperature behavior of the samples. Experimental work was conducted in 24-h basis for continuously 14 days at actual tropical weather climate. The results showed that sample M1 with 100% of FBP provided the best result in terms of thermal performance, also the material was able to obtain highest surface temperature reduction up to 6.4 °C during peak period and solar reflectance of 0.49 at near infrared region. Statistical analysis shown that sample M4, 100% of PG tile aggregate, depicted a less desirable result due to its surface temperature reduction was not significant as compared with other investigated samples, which is only 4.32° during peak period. Overall result conclude that both material FBP and MP have a good potential to be used as cool pavement coating material based on its thermal and spectral performance. Thus, this study provides a useful information on the selection of tiles material that could be used as cool-pavement coatings, and contribute for a more potential measurement in mitigating urban heat island effects.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), nearly all land and ocean surfaces around the world have experienced roughly 0.85 °C (1.53 °F) of average temperature increase in the period from the year of 1880–2012 and this average will continue to rise [1]. This phenomenon is getting more intense in urban areas and affecting the microclimate, which is possibly due to several factors: the reduction of green cover areas, a tremendous growth in population in urban areas, increase of mixed-urban or built-up land, human activities, the use of construction materials such as concrete, asphalt and tar which have significantly changed the energy balance of the urban areas. It is often causing the ambient temperature to increase than its surrounding areas thus resulting in what is referred to as urban heat island (UHI) effect. The previous study indicates that the effects of UHI have contributed to the raise in the overall ambient temperature of urban cities than its surrounding rural area in the range of 2–5 °C [2–4].

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This phenomenon is usually observed in the specific areas of city presenting high density, low environmental quality and results in the serious reduction of ambient thermal comfort levels and poor indoor insulation [5–8].

Pavement structure covers significance percentage of city skin surface, which about 29–45% of the urban land. Many studies have shown that the effect of heating mechanism of pavement plays an importance role in the formation of UHI. A conventional or typical pavement is commonly made of dark color asphalt, which presents a low albedo (0.04–0.45). It absorbs huge amount of heat emitted from the solar radiation during the daytime and reradiate the heat during the nocturnal period. When the incoming solar radiation heats the asphalt surface during daytime, the asphalt pavement has the possibility to experience a high surface temperature, range from 48 °C to 67 °C [9–15]. Thermal properties, such as heat capacity and thermal conductivity, surface reflectance and permeability are importance parameters of asphalt pavement that significantly affect the thermal performance of building environment [16–18].

Cool-pavement is considered as an alternative mitigation technology that can potentially lower the surface temperature of asphalt pavement and help in reducing the amount of heat released by the pavement into the atmosphere [14]. Cool pavement is a paving materials that has low surface temperature due to its ability to reflect more incoming solar energy, enhance water evaporation or being modified to remain cooler. Recently, researchers found that there were many materials that can be used as added materials into pavement design to enhance its performance as cool pavement. Another approach of achieving cool pavement criterion is by implementation of pavement coatings, grass paving, etc. There is no official standard or labelling program to designate cool paving materials. Many studies related with cool-pavement technology have been extensively carried out to find the ways in reducing the effects of UHI.

They are several existing cool pavements with the concept of coated surface [19]. Several recent studies have shown that pavement surfaces play a very determinant role on the overall urban thermal balance and by reducing the pavement surface temperature, it can highly contribute for enhancing the thermal conditions in cities suffering from high urban temperatures [9,12,15]. The developed cool pavements contain advanced materials and are available for urban environments. Cool pavements are mainly based on the use of surfaces presenting a high albedo to solar radiation combined to a high thermal emissivity (reflective pavements). As described by in [20], crystalline mineral particles like quartz can have high solar heat reflectance. Another study shows that pure SiO_2 has 89.4% of solar reflectance [21].

In this study, we are exploring the potential of waste tile to be used as cool pavement material, which applied as coating on asphalt surface. Previous study shows that three types of waste tile used in this study, which are Full Body Porcelain (FBP), Monoporosa (MP) and Porcelain Glaze (PG) contained of near infrared reflective compound, such as Ferric Oxide (Fe_2O_3), Silica (SiO_2), Aluminum Oxide (Al_2O_3) and Titanium Dioxide (TiO_2) [22]. The experimental work were conducted to evaluate the thermal performance for each of the tested samples, which are prepared according to optimal mix composition of thus selected type of tiles in the form of aggregate. The surface temperature and solar reflectance of tested samples were measured and further statistical analysis was carried out to determine the significances of obtained data from the experiment. Proposed cool pavement material in this study could be suitable to be applied on existing or new constructed asphalt pavement surface, such as parking lots and also the urban pedestrian walking spaces, which potentially be part of mitigation measure of urban heat island phenomenon.

Table 1
Optimal mix composition of selected tile aggregates as cool pavement coating materials.

Sample	Tiles Mix Composition (%)		
	Full Body Porcelain (FBP)	Monoporosa (MP)	Porcelain Glaze (PG)
M1 (*Coated*)	100	0	0
M2 (*Coated*)	50	50	0
M3 (*Coated*)	0	100	0
M4 (*Coated*)	0	0	100
M5 (*Control*)	0	0	0

2. Methodology

2.1. Preparation of tested samples

The selected waste tile for cool pavement coating material in this study were obtained from Malaysian Mosaic Berhad (MMB) located at Kluang, Johor, Malaysia. The company provide three type of waste tile, which are Full Body Porcelain (FBP), Porcelain Glaze (PG) and Monoporosa (MP). Collected tiles were crushed separately using crushing machine to obtain it in the form of fine aggregate. Then, each of tiles aggregate were sieved to obtained aggregate size between 0.5–2.0 mm. After that, tile in the form of aggregate were washed using clean water to remove impurities and dust, which can improve bonding strength between tile aggregate and epoxy. Tile aggregate is ready to be used after dried using oven at temperature of 110 ± 5 °C for 24 h. As conducted in previous study in [23], the result of optimization for mixing composition of selected tiles material is shown in Table 1, and samples were denoted as M1, M2 and M3. Meanwhile, PG material were not been suggested for cool-pavement material, however, it was included in this study for comparison of thermal performance and denoted as sample M4, while M5 was added as control asphalt sample. Mixture of the materials were prepared based on the proportion suggested in Table 1. Then, the prepared aggregate samples (in the form of aggregate) from Table 1 will be applied as coating on the surface asphalt sample with the size of 150 mm (width) × 150 mm (length) × 50 mm (thick). The aggregate materials were coated onto the asphalt surface using high grade epoxy as binder materials, called CoalCut-R, which is supply by Nichireki of Japan.

2.2. Experimental setup

In order to study the thermal performance of five different pavement samples, M1–M5, the surface temperature of the sample was measured on a 24-h period under actual ambient environment of tropical climate, (our case is in Malaysia) for 14 days continuously, starting from 11th Oct 2015 until 25th Oct 2015. The equipment that was used to measure the surface temperature of materials consisted of surface temperature sensors which connected to a data logging system. The sensors used were thermocouple type T (Model TT-T-24) and connected to data logger (Graphtec 220) for recording the temperature. Surrounding ambient temperature at 1.5 from ground surface were using HOBO U12 data logger (Model U12-011). Thermocouples were placed at the center of the surface for each pavement models. The surface temperature of the model and together with ambient temperature was recorded at every 15 min interval. The intensity of solar radiation was measured simultaneously by pyranometer (MS-602), which connected to Graphtec Data Logger to record the data. All the experimental pavement models were placed on a horizontal insulated platform as shown in Fig. 1 and the data collection was carried in October 2013. The experimental period was divided into four sub-periods which includes daily period (from 08:00 to 19:00 h), nocturnal period

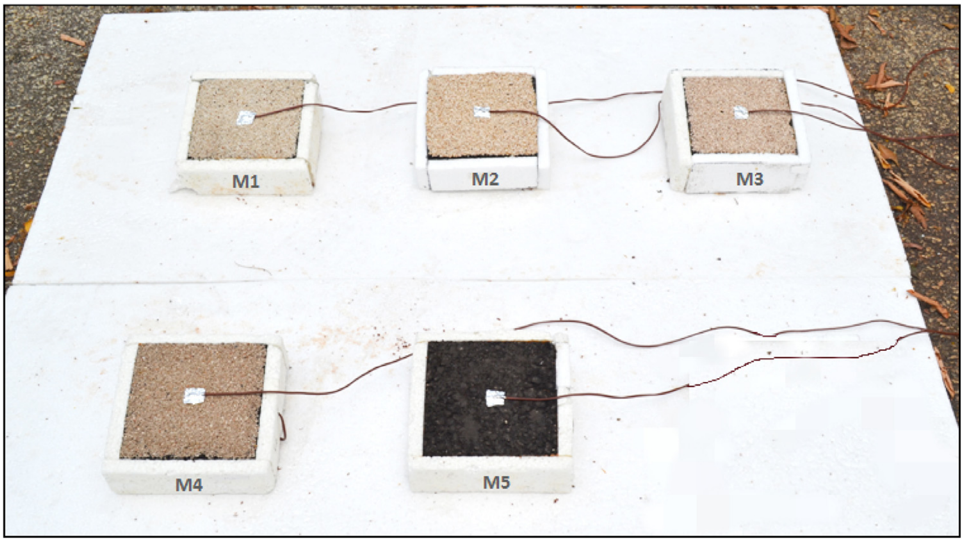

Fig. 1. Tested samples on polystrene platform at testing site.

(from 22:00 to 05:00 h), diurnal period (from 00:00 to 00:00 h), and peak period (from 12:00 to 15:00 h) for the surface temperature analysis. The experiment of the surface temperature were performed with the sub-period in order to identify which period give the most significant difference of the surface temperature between the tested models. Polystyrene foam boards were used as insulated platform for placing the experimental models in order to eliminate the heat transfer effects occurring between road surface and the models. The low thermal conductivity of polystyrene (approximately 0.03 W/mk) was assumed to be the best solid insulator where vacuum or gas state of insulator is hard to be fabricated in the laboratory.

The spectral reflectance of all the sample was measured along with control sample using UV/VIS/NIR Spectrophotometer (*Field Spec* Analytical Spectral Device) in the wavelength ranging from 400 to 2100 nm. The experiment was conducted in the laboratory using spotlight (500 W) as a source of light energy. This spotlight used to simulate the sunlight as the source of energy, and the samples were located at 500 mm below the spotlight. The experiment was performed in a control condition to avoid influence of environmental factors, such as cloud cover and variation of solar radiation intensity during investigation period, which may interfere the result. Thus, the experiment was conducted inside the heating box (controlled condition) and the data of reflectance were recorded using the Spectrophotometer (as mentioned above) equipment. The tested samples and white reflectance were placed at 25° angle as shown in Fig. 2. The heating box was made from wood, and the side of the inner walls of the box were covered with aluminum foil to make sure no heat was radiated out from the box and the heat will accumulate in the box. Thus, all the heat that generated by the spotlight will be trapped in the box and absorbed by the tested samples.

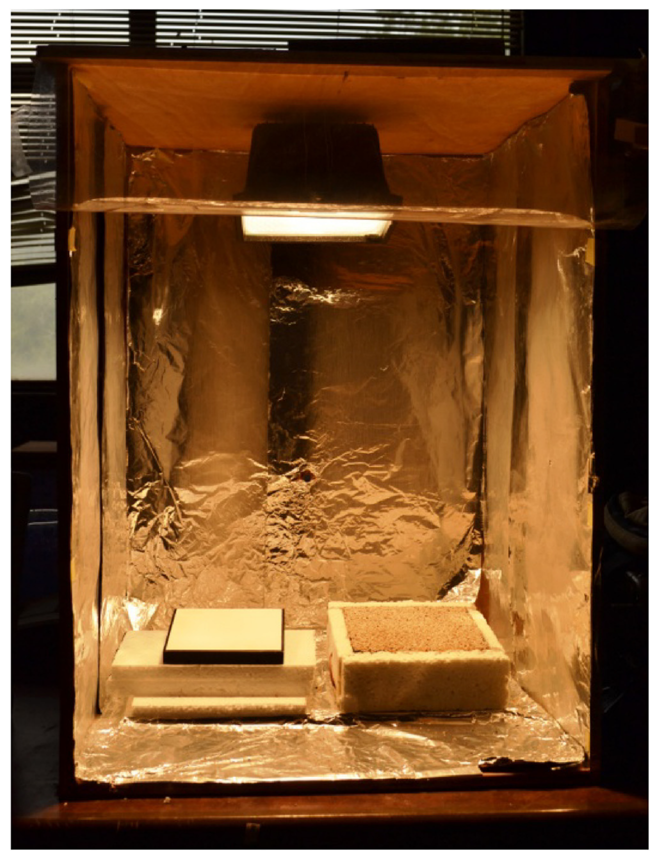

Fig. 2. Surface reflectance measurement under control environment.

3. Results and discussion

3.1. Analysis of solar reflectance of the tested samples

The solar reflectance (SR) obtained for each of the tested samples are shown in Fig. 3. All of the coated samples, M1, M2, M3 and M4 exhibited high reflectance and their spectral curves were found to be similar when compared to the control asphalt sample, M5. Summary of calculated solar reflectance value on solar region for each of the tested samples are shown in Table 2. Overall, all the

Table 2
The solar reflectance value of each tested samples.

Sample	SR	SR_{VIS}	SR_{NIR}
M1	0.48	0.40	0.49
M2	0.47	0.37	0.49
M3	0.48	0.36	0.51
M4	0.33	0.24	0.35
M5	0.05	0.02	0.07

Note:
Wavelength Range VIS: 400–700 nm.
Wavelength Range NIR: 700–2000 nm.

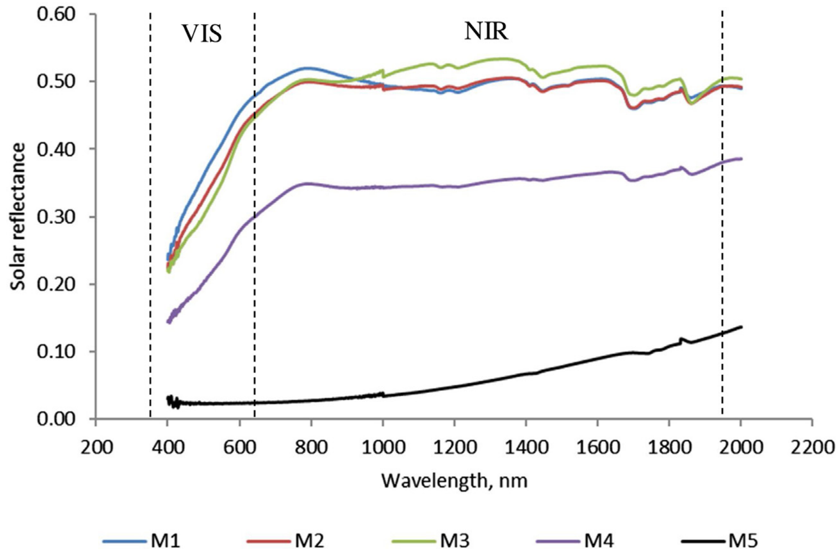

Fig. 3. Solar reflectance of tested samples.

coated samples (M1-M4) provide higher reflectance value compare to control sample, M5 at any solar region. The total solar reflectance of the coated samples are significantly higher compared to control sample (0.06), which range from 0.33 to 0.48.

Sample M1, consisting of 100% FBP tile aggregate material showed the highest reflectance value of 0.40 at visible part of light spectrum (VIS), followed by sample M2 and M3. It indicate that sample M1 is comprises of brighter aggregate material compare to other coated sample, since it related with the color of the material. White or brighter surface have high albedo in the visible spectrum of light compared to the dark colored surface. However, too high reflectivity at this region will cause glare effect, which is not good for users.

On the other hand, model M3 had showed the highest reflectance value of 0.51 for near infrared reflectance (NIR) reflectance. Besides that, the optimized samples of M1, M2 and M3 also showed similarity on the reflectance value with each other. Sample M4, which consist of 100% porcelain glaze tile aggregate as coating material provided the lowest NIR reflectance value compared with other coated samples, but higher compare to the control sample, M5 with the reflectance value of 0.20.

Theoretically, about 50% of sun's energy occurs in the visible region and 45% is from infrared region of solar spectrum [24]. That mean coating samples that has higher reflectivity at visible region of solar spectrum more effectivity reduce the heat penetration through the coating surface. However, for the application as cool-pavement, higher reflectivity on visible region will cause the glaring problem that could affect the human vision. In that case, another alternative solution is considered, which is by increasing the surface reflectance at near infrared region of solar spectrum, since 45% of the solar energy is from this region. Thus, through the findings of this study, all of the coating materials have the potential to reduce the heat penetration into the pavement due to its high reflectance at the near infrared region.

These correspond to the results shown in Table 2 where the mean reflectance values in the near infrared (NIR) region of the solar spectrum for each of the tile-coated pavements were higher when compared to the visible region of the solar spectrum. Most of the tile-coated pavements have the tendency to absorb the visible solar spectrum instead of reflecting it and hence, it clearly shows that these tile-coated pavements are able to perform better in the absorption of visible part of solar spectrum in order to perform as dark in appearance but exhibit high reflection in the NIR part of the solar spectrum. High reflectivity in NIR region could provide a better thermal comfort as near-infrared rays are not likely to raise skin temperature in human body as they are ultraviolet and visible rays, resulting in a much cooler sensation [25]. Besides that, the dark appearance in mind of the tile-coated pavements could potentially avoid glare problems especially during driving [26–28].

3.2. Analysis of thermal performance of the tested samples

The temperature profile for 24-h period of each of the tested models were shown in Fig. 4. The temperature data were collected continuously for 14 days, which included both sunny and rainy days which representing the actual weather condition in tropical region. In the afternoon, the graph from Fig. 4 clearly shows that the surface temperature of control sample M5 is higher compared with the coated samples M1, M2, M3 and M4. Surface temperature of the control sample could achieved up to 60.0 °C in the afternoon for sunny day. During daytime, all the tested samples showed higher surface temperature compared with the air temperature. Meanwhile at night, the surface temperature of the tested samples were found closer or slightly lower compared to the ambient temperature. This is due to the emissivity factor of the tested material's surfaces that could release the absorbed heat faster at night time due to night-sky radiative cooling [29].

The occurrence of rainfall and cloudy event seem significantly affects the temperature of the tested samples. From the graph, the rainfall is observed on the second day of the experiment periods, which was on 12th Oct 2013. The maximum surface temperature of the control samples drastically dropped into 40 °C at the peak solar intensity hour. The water from the rainfall plays a major role as a cooling agent to keep the surface temperature of the asphalt models at lower temperature [30]. Furthermore, the cloudy weather condition from 13th Oct 2013 until 17th Oct 2013 directly affecting the maximum surface temperature achieved by the tested samples. From the graph in Fig. 4, maximum surface temperature achieved by the control sample M5 was found significantly lower as compared to the sunny day period, which can rise up closed to 60 °C. The presence of cloud cover will block some of the solar intensity and thus less radiation energy would be received by the pavement on the earth surface. Thus, there was less amount of heat generated by the asphalt surface and this will keep the surface of the tested asphalt samples at low temperature.

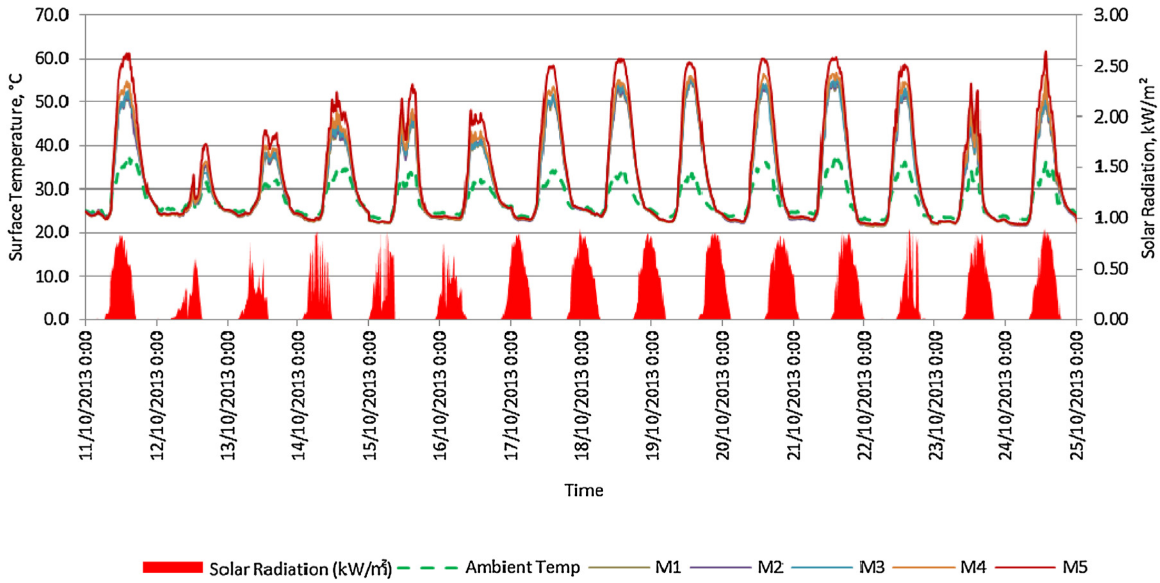

Fig. 4. Temperature profile of tested samples under actual weather condition.

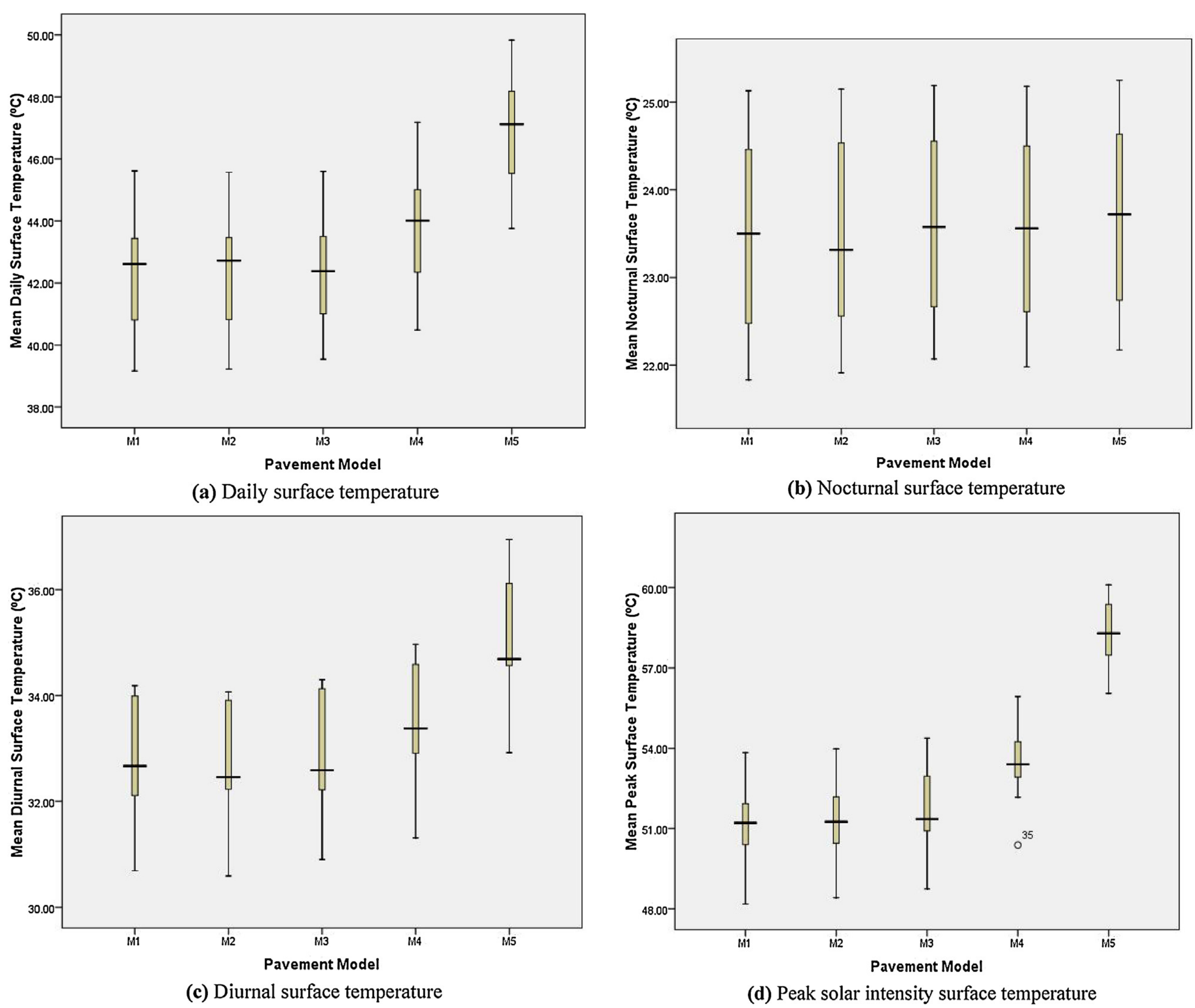

Fig. 5. (a) Daily surface temperature. (b) Nocturnal surface temperature. (c) Diurnal surface temperature. (d) Peak solar intensity surface temperature. Box-plot of the surface temperature.

Table 3
Summary of mean surface temperature of the tested models.

Experiment Period	Mean Surface Temperature (°C)				
	M1	M2	M3	M4	M5
Daily	39.07	39.18	39.24	40.38	43.24
Nocturnal	23.51	23.53	23.66	23.60	23.76
Peak	46.17	46.45	46.68	48.20	52.52

Table 5
Difference of mean surface temperature between the coated and uncoated pavement, M5 (control).

Period	M1 (°C)	M2 (°C)	M3 (°C)	M4 (°C)
Daily				
Temperature Difference with M5	4.17	4.06	3.99	2.86
Nocturnal				
Temperature Difference with M5	0.25	0.23	0.10	0.15
Diurnal				
Temperature Difference with M5	2.11	2.04	1.94	1.43
Peak				
Temperature Difference with M5	6.35	6.08	5.84	4.32

Next, the estimated mean daily, nocturnal, diurnal, and peak surface temperature obtained for each of the pavement models are summarized in Table 3 and all respectively results was transformed in a statistical box-plots as demonstrated in Fig. 4. Based on box plot as shown in Fig. 5, mean surface temperature of the reference control sample (T_{ref}), maximum surface temperature (T_{max}), and minimum surface temperature (T_{min}) were indicated in the form of dotted lines. The box-plots represent a statistical distribution of the measured surface temperatures for each of the pavement model. Besides that, the median, lower and upper quartile values were also presented in the box plots. The outliers were the data with its value beyond the ends of the tail. From Fig. 4, It is clearly showed that the pavement models with the smallest average temperature were presented at the most left part of each graph which is labeled as M1, while the warmest average surface temperature were presented at the right part, which is labeled as M5. M5 (uncoated pavement) was considered to be a conventional type of pavement that can reach surface temperature of 48–67 °C [6,31,32]. The box-plots show the difference in surface temperature for the different sub-periods and it was also found that during the peak period the samples portrayed a larger distance of dotted lines between the T_{min} and T_{ref} as compared to other sub-periods. Moreover, Table 4 exhibited the summary of maximum and minimum surface temperature of the tested models. Throughout all the period, sample M4, which is coated 100% by PG aggregate material shows the highest surface temperature. Meanwhile, other coated samples M1, M2 and M3 recorded the surface temperature almost similar to each other and lower compared to sample M4 and M5 (control sample).

Table 5 showed the difference of mean surface temperature between the coated and uncoated pavement, M5 (control). Based on the results, highest difference of mean surface temperatures between the coated and uncoated pavement are occurred during the peak hour. The presence of tiles as coating materials could reduce the mean surface temperature of asphalt sample up to 6.35 °C during the peak period, but only 0.25 °C for nocturnal period. The overall result shows that tile coating materials were able to reduce the surface temperature of conventional pavement. As a result, it is found that, M1 (Full Body Porcelain) has a greater potential in reducing the surface temperature as it was able to achieve the highest surface temperature reduction when compared to M2, M3 and M4.

3.3. Statistical analysis of the mean surface temperature for the tested models

Statistical analysis was carried out to investigate the thermal performance of the tile-coated pavements throughout the experimental period. The data presented in Table 6–8, were analyzed statistically using IBM-SPSS Statistics 16. However, in order to achieve absolute thermal performance without the interference of other influential surface temperature factors, certain data collected during the rainy days was excluded. Therefore, the collected data on October 11th to 25th, 2013 was only considered. The analysis was made based on 24-h measurement throughout the experimental period. As stated earlier, the experimental period for the surface temperature was divided into four sub-periods started from 08:00 to 19:00; 22:00 to 05:00, 00:00 to 00:00, and 12:00 to 15:00. The division of the sub-periods were carried out in order to study the thermal performance of the tile coatings during daily, nocturnal, diurnal and peak periods respectively.

Table 6 shows the descriptive statistic for the surface temperature of the tested samples. During daily, diurnal and peak period, the mean surface temperature of pavement models were found to exceed, 27 °C. In contrast, there are only mean surface temperature of pavement models at the nocturnal period was found below 27 °C. The highest mean surface temperatures of 46.90 °C (daily period), 23.70 °C (nocturnal period), 34.93 °C (diurnal period), and 58.36 °C (peak period) were obtained by M5 (daily period), M4 (nocturnal period), M5 (diurnal period) and M5 (peak period) respectively. Meanwhile, the lowest mean surface temperatures found at the temperature of 42.39 °C, 23.48 °C, 32.68 °C and 51.24 °C was observed in M1.

ANOVA F test [33] was applied to the mean surface temperatures of all the tested samples for between and within the group. The F-test that have the significant value less than 0.05 ($p < 0.05$) indicates that there is a statistically significant difference between the means. Meanwhile, if the significant, *sig* value larger than 0.05 ($p > 0.05$) it indicates that there is no difference between the means [34]. Based on Table 7, it was found that the mean temperature between the pavement models during daily, diurnal and peak periods are found to be quite different where the $\rho < 0.05$. On the other hand, the pavement models during nocturnal period is not statistical significantly where $p > 0.10$, meaning that there is no difference

Table 4
Summary of maximum and minimum surface temperatures during the experimental period.

Experimental Period	Surface Temperatures (°C)									
	M1		M2		M3		M4		M5	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Daily Period	45.62	28.76	45.57	28.84	45.60	28.65	47.18	29.20	49.83	31.08
Nocturnal Period	25.04	21.83	25.12	21.91	25.19	22.07	25.07	21.98	25.18	22.17
Diurnal Period	34.19	26.77	34.06	26.86	34.23	26.83	34.97	27.03	36.95	28.04
Peak Period	53.83	28.02	53.87	28.02	54.38	28.22	55.94	28.35	60.11	30.22

Table 6
Result of statistical analysis for surface temperature of the tested samples.

Sub-period	Pavement Model	Sample No.	Mean(°C)	Max(°C)	Min(°C)	Standard deviation	Standard Error
Daily	M1	9	42.39	45.62	39.16	1.98	0.66
	M2	9	42.39	45.57	39.22	1.92	0.64
	M3	9	42.52	45.6	39.54	1.95	0.65
	M4	9	43.79	47.18	40.48	1.96	0.65
	M5	9	46.9	49.83	43.76	2.07	0.69
Nocturnal	M1	8	23.48	25.13	21.83	1.2	0.42
	M2	8	23.49	25.15	21.91	1.19	0.42
	M3	8	23.61	25.19	22.07	1.15	0.41
	M4	8	23.56	25.18	21.98	1.16	0.41
	M5	8	23.7	25.25	22.17	1.13	0.40
Diurnal	M1	9	32.68	34.19	30.69	1.31	0.44
	M2	9	32.67	34.07	30.59	1.27	0.42
	M3	9	32.8	34.3	30.9	1.28	0.43
	M4	9	33.4	34.97	31.31	1.28	0.43
	M5	9	34.93	36.95	32.92	1.36	0.45
Peak	M1	9	51.24	53.83	48.17	1.74	0.58
	M2	9	51.45	53.98	48.42	1.79	0.60
	M3	9	51.79	54.38	48.75	1.85	0.62
	M4	9	53.51	55.94	50.38	1.64	0.55
	M5	9	58.36	60.11	56.05	1.29	0.43

Table 7
ANOVA F test of the surface temperature of tested samples.

Sub-period		Sum of Squares	df	Mean Square	F	Sig.	Results
Daily	Between Groups	135.174	4	33.793	8.634	0	Significance ($p < 0.05$)
	Within Groups	156.553	40	3.914			
	Total	291.726	44				
Nocturnal	Between Groups	0.273	4	0.068	0.05	0.995	Not Significance($p > 0.10$)
	Within Groups	47.484	35	1.357			
	Total	47.757	39				
Diurnal	Between Groups	33.247	4	8.312	4.906	0.003	Significance ($p < 0.05$)
	Within Groups	67.773	40	1.694			
	Total	101.02	44				
Peak	Between Groups	320.784	4	80.196	28.635	0	Significance ($p < 0.05$)
	Within Groups	112.024	40	2.807			
	Total	432.808	44				

between the mean surface temperature. This is because during the nocturnal period, the majority of the coating tile pavements exhibited their mean surface temperatures to be similar or little lower when compared to uncoated pavement.

In order to categorize the tile coatings, Fisher's *Least Significant Difference* (*LSD*) multiple comparison test of mean was performed. The significant level was again chosen to be $\alpha = 0.05$ and the results obtained are shown in Table 8.

It is found that during all sub-periods the primary factors affect the thermal performance of pavement models due to the presence of tiles coatings and its type. Therefore, pavement which is coated with tiles could potentially lower the surface temperatures when compared to the uncoated pavement model (M5). The comparison of mean surface temperatures between the pavement model of M5 and other pavement models seem to be significantly different, while the rest of them were not found to be different. These obtained results can be compared to Table 3, whereby almost a liner relation was found between the mean surface temperature and solar reflectance. It was leading to the understanding that higher is the reflectance, cooler is the pavement model. However, Table 8 shows that particularly during the peak solar intensity period the significant difference were not only observed between M5 and other pavement models but it was also found between the pavement model, M4 and other pavement models. Although all the tile-coated pavements were characterized with a high solar reflectance, Porcelain Glaze tiles-coated pavement (M4) was found to be less desirable because the lowering surface temperature was not much significant when compared to the models of M1, M2,

Table 8
Results of least significant difference.

Samples		Results of investigated period		
		Daily	Diurnal	Peak
M1	M2	Not Significant	Not Significant	Not Significant
	M3	Not Significant	Not Significant	Not Significant
	M4	Not Significant	Not Significant	Significant
	M5	Significant	Significant	Significant
M2	M1	Not Significant	Not Significant	Not Significant
	M3	Not Significant	Not Significant	Not Significant
	M4	Not Significant	Not Significant	Significant
	M5	Significant	Significant	Significant
M3	M1	Not Significant	Not Significant	Not Significant
	M2	Not Significant	Not Significant	Not Significant
	M4	Not Significant	Not Significant	Significant
	M5	Significant	Significant	Significant
M4	M1	Not Significant	Not Significant	Significant
	M2	Not Significant	Not Significant	Significant
	M3	Not Significant	Not Significant	Significant
	M5	Significant	Significant	Significant
M5	M1	Significant	Significant	Significant
	M2	Significant	Significant	Significant
	M3	Significant	Significant	Significant
	M4	Significant	Significant	Significant

and M3. This is mainly caused due to the difference in their thermal performance especially on each of the tile materials, Full Body Porcelain (M1), Monoporosa (M3) and Porcelain Glaze (M4).

Relationship between surface reflectance and surface temperature of tested samples

As demonstrated in Table 3, the model M1 exhibit the lowest mean of surface temperature value when compared to other coated samples. This is because the coating material like the full body porcelain has the highest reflectance value at the visible light region, since 50% of the total sun's energy occurs in the visible light region, and 45% of sun's energy occurs in the near infrared region [24]. Thus, by comparing all the optimized model, the coating materials that contain full body porcelain materials promote much lower surface temperature. However, based on the statistical analysis, the results had showed that the temperature differences among the optimized model M1, M2 and M3 are not significant to each other. There are not much difference on the surface temperature between these three optimized models.

On the other hand, although all the studied types of tile coatings are characterized with higher solar reflectance, M2, M3, and M4 stay warmer during nocturnal period compared to M1. This is specifically due to the higher amount of solar radiation been absorbed instead of reflected during the daytime. Thus, higher amount of sensible heat released to the atmosphere during nocturnal period. Among tiles-coated pavement, this study had demonstrated how M1 stays coolest particularly during all the experimental period compared to M2, M3, and M4. As a results, a linear relation was found between the mean surface temperature and the solar reflectance of the coating materials where the increasing of the solar reflectance on the surface pavements could help to decrease their surface temperature as well as reduced the amount of sensible heat released to the atmosphere.

High reflective and albedo material provide more cooler surface compared to the low albedo surface. In this study, model M1, M2 and M3 has the highest surface reflectivity value, for both of near infrared and visible region compared to model M4. Thus, these three models give the highest surface temperature reduction compared with model M4. High reflectivity surface will reduce the amount heat to be absorbed from solar radiation and thus could maintain the surface temperature of the asphalt model at low level.

4. Conclusion

Three types of tiles were used and it was found that these tiles – coating pavement material can significantly reduce the surface temperature by providing higher solar reflectance to the conventional asphalt pavement. The thermal performance of the tile-coated pavement was also found to be better than the conventional asphalt pavement (uncoated). The presence of tiles as coating materials improved the thermal performance of conventional pavement (uncoated).

In comparison, M1 (Full Body Porcelain) showed the best results in terms of thermal performance and it is able to obtain the highest surface temperature reduction (6.4 °C) when compared to other tiles-coated pavements (M2, M3, and M4). The reflectance of the coating materials seem was the main factor that determining the potential of the coating materials to reduce the surface temperature of asphalt pavement. The result obtained shows that all the optimized model M1, M2 and M3 provide the highest surface reflectance compared to model M4.

As conclusion, high reflectivity of the pavement surface will maintain it at the low temperature. Throughout this study, the different aspects of thermal performance exhibited by the models were considered and it can be concluded that Full Body Porcelain tile (M1) is the most promising coating material that can be used on the asphalt pavement to mitigate the adverse effects of heat island phenomenon.

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