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Thermal Behaviour of Cool-Pavement Materials Development using Palm Oil Shell Aggregate

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ABSTRACT

Cool-pavement technology has emerged as a potential solution to environmental issues posed by the urban heat island phenomenon, with surface temperature acting as a vital parameter in the evaluation of its thermal performance. This study focuses on the thermal performance results of modified asphalt concrete mix, wherein palm oil shell (POS) serves as a replacement for fine aggregate. Modified asphalt samples prepared using the Marshall Mix Design, with varying degrees of fine aggregate substitution (0%, 10%, 20%, 30%, 40%, and 50%), underwent a 24-hour continuous surface temperature measurement over a span of 20 days, under real-world tropical climate conditions. The findings demonstrated that sample P5, comprising 50% fine aggregate substitution, exhibited the highest reduction in surface temperature when compared to control sample P0, registering a significant decrease of up to 3.29°C during the period of peak solar intensity. ANOVA test-based statistical analyses confirmed significantly lower temperatures for all test samples, barring sample P1 (10% aggregate replacement), relative to the control sample. The results highlight the efficacy of POS as a fine aggregate substitute in asphalt concrete, significantly lowering asphalt pavement surface temperature, thereby endorsing the potential use of POS-modified asphalt in cool-pavement applications.

1. Introduction

Urbanization is one of the processes that been experienced by most of developing and developed countries in the world, parallel to the economic and population growth in megacities. Without proper planning at early stage, it can significantly affect environmental condition, thus reducing quality of life for human being. Urban heat island (UHI) has been listed is one of major environmental problem that been experienced by most of megacities in 21st century [1-3]. UHI is defined as phenomena where average air temperature in the urban area is much higher compared with its surrounding rural

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area. As reported in some research, cities that has been affected by UHI having overall ambient temperature range from 2.0 – 5.6°C higher than its surrounding rural area and found to be increased from year by year [4-6]. There are various of factors that cause the formation of UHI in the city, such as a) improper city planning; b) lack of vegetation to promote evaporation; and c) most of city build-up covered with material with low albedo surface. Phenomenal of UHI cause serious impacts on economy and societies, such as increasing energy consumption, thermal discomfort, degradation of human health quality, and increase intensity of air pollution in the cities [7-9]. Since then, there are much research have been conducted to study on the potential mitigation measures and solution of minimizing the effects of UHI. There are various of aspect has been explore and proposing innovative mitigation technologies, such as cool-pavement, green roof, modification of building envelope and reservation of green park [10-15].

Pavement has covers significant percentage of urban surface, which is up to 45% of the total land in cities area. Most of researchers found that the heating mechanism by low albedo or surface reflectance of asphalt material for pavement has contribute significant role in formation of UHI [16,17]. Conventional asphalt pavement usually dark in colour and has low albedo value, range from 0.04 – 0.45. This will cause the asphalt pavement absorbs huge amount of energy from solar radiation, which then turn into heat that resulting to high surface temperature of the pavement. During hot clear sunny day, surface temperature of asphalt pavement can achieve very high temperature, range from 48°C to 67°C [16,18].

Cool-pavement has been identified as part of mitigation technology for combating urban heat island, and numerous of research have reported convincing result that applying this technology could significantly reduce the asphalt surface temperature, thus helping to reduce amount of heat emitted by the pavement into atmosphere. Theoretically, there are two main important parameters that contribute of the cooling mechanism by cool-pavement; a) increase pavement surface's albedo; and b) increase pavement's permeability which promote cooling effect through evaporation process [16,19,20]. An experimental finding reported by Qin *et al.,* (2018) found that a water-retaining paver block that has low albedo, range of 0.10 – 0.15, have surface temperature that significantly lower than conventional pavement, in the range of 2°C - 10°C on hot summer day due to evaporation process [21]. Meanwhile, increasing albedo or surface reflectance of the pavement will reduce amount of heat to be absorbed, thus reducing its surface temperature and quantity of heat to be re-radiated into the ambient. Albedo of the asphalt pavement can be increased by a) applying surface coating material; and b) inclusion of high near infrared region (NIR) into the mix material [12,22-24]. Crystalline mineral pigment such as quartz or silica dioxide (SiO_2), titanium dioxide (TiO_2), aluminium trioxide (Al_2O_3) and iron trioxide (Fe_2O_3) are mix of compound that could increase the NIR reflectance of material's surface. Pure SiO_2 could reflecting up to 89.4% of heat from solar radiation [22]. There are more advance formulation of cool-pigment that derived from those listed mineral pigment, which currently apply for roof [25,26].

Therefore, this study was conducted to explore the potential of applying palm oil shell (POS) to be recycled and reused as fine aggregate in asphaltic concrete mixture. POS is a hard protective layer of the palm kernel. Previous study on the investigation of chemical composition have found that NIR reflective pigment, such as SiO_2, Al_2O_3 and Fe_2O_3 has presence in the POS material [11,27]. The tested sample of asphaltic concretes were mixed with varies composition of POS as fine aggregate replacement. Series of experimental work of measuring surface temperature of tested samples at actual weather condition were performed to evaluate their thermal performance. Further statistical analysis was conducted to determine the level of significant of obtained data from the experiment. Thus, the findings reported in this study could provide significant information to apply palm oil shell as fine aggregate replacement in asphaltic concrete that able to reduce the surface temperature of the pavement, which potentially be part of mitigation technology of urban heat island phenomenon.

2. Experimental Methodology
2.1 Sample Preparation

The palm oil shell (abbreviated as POS) for this research was obtained from Malaysian's local company, that is located at Johor, Malaysia. Initially, the POS material, in the bulk form was washed repeatedly for several time to remove dirt, dust or any impurities and free from deleterious material. After that, the POS material was air-dried naturally under the sunlight for 24-hours, and then, the material was crushed into fine grain size in between 0.05mm to 2mm. The crushed POS material was oven dry for approximately 24-hours at temperature of 110°C±5°C. After drying process, then crushed POS material was sieved to obtain POS fine aggregate with the size between 0.075mm to 1.18mm. Finally, once again, the prepared POS fine aggregate was washed using clean water to remove dust, which then enhance the bonding strength of its surface with the asphalt binder.

The procedure for Marshall mix design is in accordance to Public Work Department of Malaysia [28] employed to design hot mix asphalt (HMA). A total of 18 HMA samples were prepared, with 3 samples for each mix design were prepared for the purpose of testing and experiments. Table 1 shows the samples for percentage of POS replacement and denoted as samples P0 to P5. The POS percentage are varies to investigate its effects towards temperature reduction in asphalt. Meanwhile, Figure 1 shows the laboratory work to prepare the asphalt samples.

Table 1
Asphalt samples with POS materials as aggregate replacement by weight of total aggregate

Samples	% of POS replacement by weight of aggregate
P0	0%
P1	10%
P2	20%
P3	30%
P4	40%
P5	50%

(a) (b)

(c)

(d)

(e)

(f)

Fig. 1. Preparation of asphalt samples (a) samples heating using oven (b) mould to prepare the samples (c) sample mixing (d) moulding the samples (e) compaction and (f) ready samples for testing

2.2 Experimental Work

All the tested samples, together with control sample, with an average size of 110mm diameter and 68.9mm height, each, were further prepared before measuring its surface temperature. The sides surface of the tested samples was cover with polystyrene to ensure that the heat only flow in one direction and enter through opening surface on top of the sample. The experiment was conducted on the rooftop of Advance Highway Engineering Laboratory, Universiti Tun Hussein Onn Malaysia (Batu Pahat, Johor, Malaysia). The location of samples is positioned away from any shades and the samples were exposed directly to sunlight in the open space. Setting up of the experiment is shown in Figure 2.

Fig. 2. Experimental setup at site

Thermocouple sensors will be installed in each mix sample for measured the pavement surface temperature. The experiment was conducted for 24 hours period for 20 consecutive days starting from 12 Jan 2017 – 1 Feb 2017, under actual surrounding ambient of tropical climate by considering rain falls several times during the experimental period. Surface temperature of the pavement samples were recorded every 5 minutes using Graphtec 220 data logger that connected with thermocouple type T. Meanwhile, the solar intensity and ambient temperature was measured using Radio Globale Pyranometer that connected to the Babuc data logger.

3. Analysis and Discussion

3.1 Surface Temperature Behaviour of Tested Samples

Surface temperature measurement was carried out to investigate the thermal performance of the control and modified asphaltic concrete samples. The surface temperature profile for 24 hours period of each tested pavement mixture is shown in Figure 3. The surface temperature data of the pavement samples were measured continuously for 20 days. The collected data reflecting both sunny and rainy days, where it is presenting the weather condition in tropical climate. Three asphalt pavement samples were used for each mixture to measure the surface temperature to obtain an average. The experimental period for 24-hour measurement is divided into four sub-periods which is daily, nocturnal, diurnal, and peak started from 08:00 to 19:00; 22:00 to 05:00; 00:00 to 00:00, and 12:00 to 15:00 [16,19,30]. In this study, the data of surface temperature from each pavement were collected during daily and peak period.

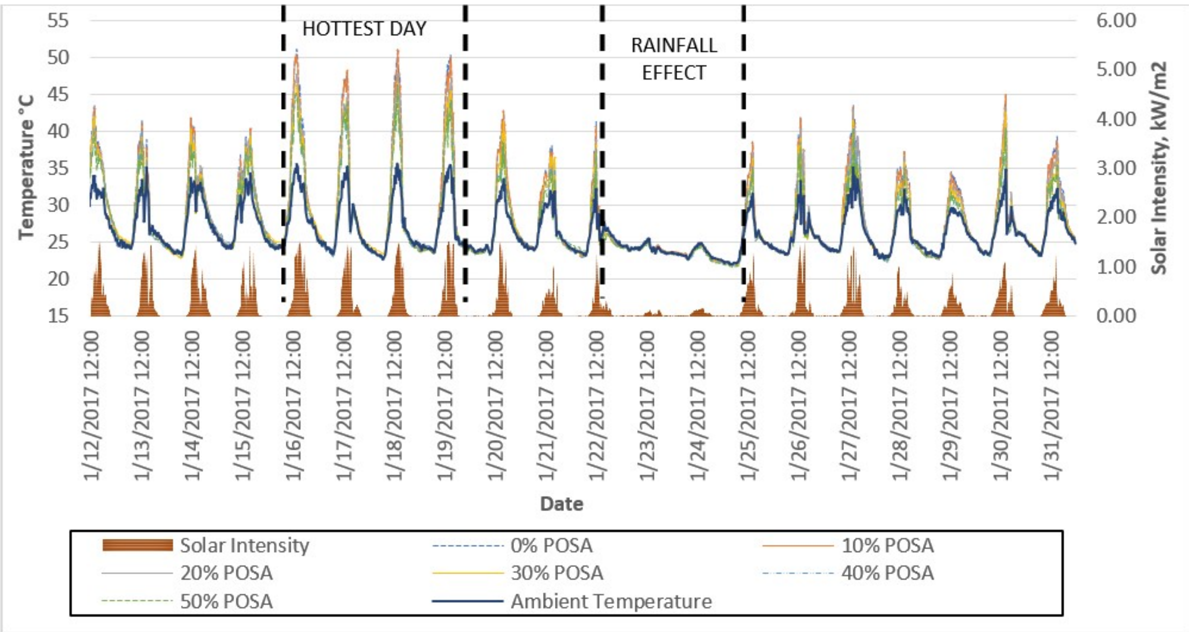

Fig. 3. Surface temperature profile of tested samples

At the peak period of 12.00 to 15.00 or during afternoon, the graph in Figure 3 shows that the surface temperature of control sample is higher compared with modified samples. However, surface temperature of the control sample recorded could have achieved up to 50.0°C in this period during a sunny day. During daytime in between 08.00 to 19.00, all tested pavement samples indicate higher surface temperature compared with ambient temperature.

The natural event of rainfall and turbid seem significantly affect the surface temperature of tested pavement samples. As demonstrated from the graph, data of solar intensity shows the presence of cloud is noticed on 12th January 2017 until 15th January 2017, 22nd January 2017 and 1st February 2017. The most adverse weather condition was recorded from 23rd January 2017 until 25th January 2017 directly affecting the maximum surface temperature achieved by the tested samples. The maximum surface temperature of the samples instantly dropped into 24°C at the peak hour period.

As shown from the graph Figure 3, due to cloud and rain on 24th Jan 2017 the maximum surface temperature recorded by controlled sample was found significantly lower at 24°C as compared to the hot and sunny day on 17th Jan 2017 where the temperature can rise to 50°C. Based on the previous study, the researchers stated the conventional pavement surface temperature measurement can be in the range between 48°C to 67°C [31,32]. The asphaltic concrete will remain low in temperature when there is less amount of heat generated by the pavement surface due to the presence of cloud which block the solar radiation, therefore less radiation energy would be received by the pavement surface [16]. Table 2. depicted the mean surface temperature and difference mean surface temperature of control and modified samples.

As tabulated in Table 2, the difference of mean surface temperature between controlled and modified pavement mixture are high during peak hour. The presence of 50% POS as cool material in asphaltic concrete by replacing fine aggregate could reduce the mean surface temperature of asphaltic concrete sample by 3.29°C during peak period instead of 1.95°C for daily period. The result shows that POS as cool material could reduce the surface temperature of conventional surface pavement because of NIR reflectivity, due to the presence of Al_2O_3 [11,22].

Table 2
Mean surface temperature and difference of mean surface temperature of tested sample

Period	Mean Surface temperature (°C)					
	P0	P1	P2	P3	P4	P5
Daily	32.1	31.8	31.1	30.6	30.3	30.1
Peak	37.0	36.6	35.4	34.5	34.0	33.7
	Difference of mean Surface temperature between P0 and P1 – P5 (°C)					
Daily	0	0.25	0.95	1.44	1.78	1.95
Peak	0	0.44	1.66	2.52	3.00	3.29
	% Reduction					
Daily	0	0.78	2.96	4.49	5.54	6.07
Peak	0	1.2	4.49	6.81	8.11	8.90

3.2 Thermal Performance of the POS as Aggregate Replacement in Asphalt Pavement

In Table 3, it summarises that the highest mean surface temperature recorded for peak period is 37.0°C were obtained from control sample. Furthermore, the lowest mean surface temperature recorded for peak period are from 50% of POS sample where the temperature was 33.0°C. The mean temperature difference between pavement samples 50% and 0% is almost 90%. The mean temperature between modified samples was reduced by 1°C when the content of POS is increased in the mixture. As shown, the samples for 30% and 40% have small difference for mean surface temperature which is 0.4°C.

Table 3
Descriptive statistics of surface temperature for peak period

Sample	Min	Max	Mean	Std. Error	Std. Deviation	Variance
P0	24.0	51.1	37.0	0.42	6.8	46.6
P1	24.0	50.8	36.6	0.41	6.6	43.7
P2	23.9	47.7	35.4	0.37	5.9	35.1
P3	23.7	46.4	34.5	0.35	5.7	32.0
P4	23.7	46.3	34.0	0.34	5.4	29.5
P5	23.6	45.9	33.7	0.33	5.4	28.9

Replacement certain percentage of asphalt's aggregate with POS materials shows reduction of overall surface temperature of asphalt during peak solar intensity period. This is due to the presence of chemical component in POS that act as a cool agent in asphaltic concrete. This can be supported by the finding of high quantity of SiO_2, Fe_2O_3, and Al_2O_3 which is the main component of NIR element to reflect the solar energy [20]. After all, the mean surface temperature is showing the reduction of the pavement surface temperature due to the increasing amount of POS as replacement of fine aggregate.

The analysis of variance (ANOVA) was performed to determine the significance of test temperature on pavement surface samples. The one-way ANOVA test described that if the significant value is less than 0.05 ($p<0.05$), it indicates the statistically significant difference between the means. Henceforth, when the significant value is bigger than 0.05 ($p>0.05$) it shows the mean does not have any significant difference between the group [36,37]. As summarises in Table 4, the mean surface temperature of between each sample during peak solar intensity period are significant, since the computed value of p-value is less than 0.05. This is to support the statement that there is a significant difference on pavement surface temperature in each type 0%, 10%, 20%, 30%, 40% and 50% of POS sample during peak period.

Table 4
ANOVA result of surface temperature at peak solar intensity period

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2425.826	5	485.165	13.488	0.000
Within Groups	55898.164	1554	35.971		
Total	58323.990	1559			

4. Conclusions

Palm oil shell aggregate were used as fine aggregate replacement in asphaltic concrete, and it was found that this cool material can significantly reduce the surface temperature by offering reflectivity to the asphalt pavement. Thermal performance of the modified pavement with POS replacement was founded to be more efficient than the control sample (conventional asphaltic concrete). The best outcome in term of thermal performance is by replacing fine aggregate with 50% of POS. It is because 50% replacement can obtain the most eminent surface temperature reduction which is at temperature 3.3°C rather than other amount of percentage replacement (10%, 20%, 30% and 40%).

Introducing the POS as aggregate replacement materials into the asphalt mix increase amount of void, which then increase the porosity of the modified asphaltic samples. Presence of void significantly reduce the asphalt surface temperature when it filled with water. The cooling effect is promoted by the evapotranspiration process - the movement of liquid water from asphalt void to the atmosphere. It is proved by the experimental work that modified asphalt with POS delayed the surface temperature achieved highest peak temperature after rainfall event.

Statistical analysis by using ANOVA test for surface temperature has been conducted. Based on the analysis, mean surface temperature for peak period are significant where $p<0.05$, given this point indicates the null hypothesis (H0) is rejected. The results show a significant difference on pavement surface temperature in each type 0%, 10%, 20%, 30%, 40% and 50% of POS sample results at daily period and peak period. It can be concluded, the proportion of each control and modified sample of POS replacement has a significant effect on the surface temperature difference.

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References
[1] Yang, Jiachuan, Zhi-Hua Wang, Kamil E. Kaloush, and Heather Dylla. "Effect of pavement thermal properties on mitigating urban heat islands: A multi-scale modeling case study in Phoenix." *Building and Environment* 108 (2016): 110-121. https://doi.org/10.1016/j.buildenv.2016.08.021

[2] Rizwan, Ahmed Memon, Leung YC Dennis, and L. I. U. Chunho. "A review on the generation, determination and mitigation of Urban Heat Island." *Journal of environmental sciences* 20, no. 1 (2008): 120-128. https://doi.org/10.1016/S1001-0742(08)60019-4

[3] Sun, Ranhao, Yihe Lü, Xiaojun Yang, and Liding Chen. "Understanding the variability of urban heat islands from local background climate and urbanization." *Journal of cleaner production* 208 (2019): 743-752. https://doi.org/10.1016/j.jclepro.2018.10.178

[4] Synnefa, Afroditi, Mat Santamouris, and I. J. S. E. Livada. "A study of the thermal performance of reflective coatings for the urban environment." *Solar Energy* 80, no. 8 (2006): 968-981. https://doi.org/10.1016/j.solener.2005.08.005

[5] Rizvi, Shahnilla Haider, Khan Alam, and Muhammad Jawed Iqbal. "Spatio-temporal variations in urban heat island and its interaction with heat wave." *Journal of Atmospheric and Solar-Terrestrial Physics* 185 (2019): 50-57. https://doi.org/10.1016/j.jastp.2019.02.001

[6] Levermore, Geoff, John Parkinson, Kwanho Lee, Patrick Laycock, and Sarah Lindley. "The increasing trend of the urban heat island intensity." *Urban climate* 24 (2018): 360-368. https://doi.org/10.1016/j.uclim.2017.02.004
[7] Theophilou, M. K., and D. Serghides. "Estimating the characteristics of the Urban Heat Island Effect in Nicosia, Cyprus, using multiyear urban and rural climatic data and analysis." *Energy and Buildings* 108 (2015): 137-144. https://doi.org/10.1016/j.enbuild.2015.08.034
[8] Anting, Nickholas, Mohd Fadhil Md Din, Kenzo Iwao, Mohanadoss Ponraj, Alvin John Lim Meng Siang, Lee Yee Yong, and Joewono Prasetijo. "Optimizing of near infrared region reflectance of mix-waste tile aggregate as coating material for cool pavement with surface temperature measurement." *Energy and Buildings* 158 (2018): 172-180. https://doi.org/10.1016/j.enbuild.2017.10.001
[9] Lee, Yee Yong, Mohd Fadhil Md Din, Zainura Zainon Noor, Kenzo Iwao, Shazwin Mat Taib, Lakhveer Singh, Nur Hafizah Abd Khalid, Nickholas Anting, and Eeydzah Aminudin. "Surrogate human sensor for human skin surface temperature measurement in evaluating the impacts of thermal behaviour at outdoor environment." *Measurement* 118 (2018): 61-72. https://doi.org/10.1016/j.measurement.2018.01.010
[10] Santamouris, Mattheos, Shamila Haddad, Maria Saliari, Konstantina Vasilakopoulou, Afroditi Synnefa, Riccardo Paolini, Giulia Ulpiani, Samira Garshasbi, and Francesco Fiorito. "On the energy impact of urban heat island in Sydney: Climate and energy potential of mitigation technologies." *Energy and Buildings* 166 (2018): 154-164. https://doi.org/10.1016/j.enbuild.2018.02.007
[11] Anuar, M. A. M., N. Anting, S. Shahidan, Y. Y. Lee, MF Md Din, F. S. Khalid, and W. M. H. W. Nazri. "Preliminary evaluation of physical and chemical characterization of waste palm oil shell as cool material replaced in asphaltic concrete as fine aggregate." In *IOP Conference Series: Materials Science and Engineering*, vol. 271, no. 1, p. 012054. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/271/1/012054
[12] Anting, Nickholas, Mohd Fadhil Md Din, Mohanadoss Ponraj, Karlvin Jungan, Shazwin Mat Taib, Kenzo Iwao, Shreeshivadasan Chelliapan, and Naoki Ubukata. "Physical and chemical characterization of wasted tiles as coating materials for pavement surface temperature reduction." *Malaysian Journal of Civil Engineering* 26, no. 3 (2014).
[13] Kandya, Anurag, and Manju Mohan. "Mitigating the Urban Heat Island effect through building envelope modifications." *Energy and Buildings* 164 (2018): 266-277. https://doi.org/10.1016/j.enbuild.2018.01.014
[14] Kolokotsa, Dionysia–Denia, Gerassimos Giannariakis, Kostas Gobakis, Giannis Giannarakis, Afroditi Synnefa, and Mat Santamouris. "Cool roofs and cool pavements application in Acharnes, Greece." *Sustainable Cities and Society* 37 (2018): 466-474. https://doi.org/10.1016/j.scs.2017.11.035
[15] Nastran, Mojca, Milan Kobal, and Klemen Eler. "Urban heat islands in relation to green land use in European cities." *Urban Forestry & Urban Greening* 37 (2019): 33-41. https://doi.org/10.1016/j.ufug.2018.01.008
[16] Anting, Nickholas, Mohd Fadhil Md Din, Kenzo Iwao, Mohanadoss Ponraj, Karlvin Jungan, Lee Yee Yong, and Alvin John Lim Meng Siang. "Experimental evaluation of thermal performance of cool pavement material using waste tiles in tropical climate." *Energy and Buildings* 142 (2017): 211-219. https://doi.org/10.1016/j.enbuild.2017.03.016
[17] Gilbert, Haley E., Pablo J. Rosado, George Ban-Weiss, John T. Harvey, Hui Li, Benjamin H. Mandel, Dev Millstein, Arash Mohegh, Arash Saboori, and Ronnen M. Levinson. "Energy and environmental consequences of a cool pavement campaign." *Energy and buildings* 157 (2017): 53-77. https://doi.org/10.1016/j.enbuild.2017.03.051
[18] Gaitani, Niki, Giouli Mihalakakou, and Mattheos Santamouris. "On the use of bioclimatic architecture principles in order to improve thermal comfort conditions in outdoor spaces." *Building and environment* 42, no. 1 (2007): 317-324. https://doi.org/10.1016/j.buildenv.2005.08.018
[19] Synnefa, Afroditi, Theoni Karlessi, Niki Gaitani, Mat Santamouris, D. N. Assimakopoulos, and C. Papakatsikas. "Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate." *Building and Environment* 46, no. 1 (2011): 38-44. https://doi.org/10.1016/j.buildenv.2010.06.014
[20] Anak Guntor, Nickholas Anting, Mohd Fadhil Md Din, Mohanadoss Ponraj, and Kenzo Iwao. "Thermal performance of developed coating material as cool pavement material for tropical regions." *Journal of Materials in Civil Engineering* 26, no. 4 (2014): 755-760. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000859
[21] Qin, Yinghong, Yuhui He, Jacob E. Hiller, and Guoxiong Mei. "A new water-retaining paver block for reducing runoff and cooling pavement." *Journal of Cleaner Production* 199 (2018): 948-956. https://doi.org/10.1016/j.jclepro.2018.07.250
[22] Thongkanluang, T., N. Chirakanphaisarn, and P. Limsuwan. "Preparation of NIR reflective brown pigment." *Procedia Engineering* 32 (2012): 895-901. https://doi.org/10.1016/j.proeng.2012.02.029
[23] Shiao, Ming Liang, Jennifer A. Sharp, and Gregory F. Jacobs. "Roofing granules with high solar reflectance, roofing materials with high solar reflectance, and the process of making the same." U.S. Patent 8,394,498, issued March 12, 2013.
[24] Puesan, Carlos-Wilbert Peña, and Joan-Lluis Zamora Mestre. "Technical evaluation of an improved paint coating with NIR pigments designed to reduce thermal discomfort caused by incident solar radiation: Application in the Caribbean area." *Energy Procedia* 115 (2017): 463-479. https://doi.org/10.1016/j.egypro.2017.05.043

[25] Meenakshi, Paraman, and Muthiah Selvaraj. "Bismuth titanate as an infrared reflective pigment for cool roof coating." *Solar Energy Materials and Solar Cells* 174 (2018): 530-537. https://doi.org/10.1016/j.solmat.2017.09.048

[26] Sameera, S., P. Prabhakar Rao, S. Divya, Athira KV Raj, and TR Aju Thara. "High IR reflecting BiVO4-CaMoO4 based yellow pigments for cool roof applications." *Energy and buildings* 154 (2017): 491-498. https://doi.org/10.1016/j.enbuild.2017.08.089

[27] Nwaobakata, C., and J. C. Agunwamba. "Effect of palm kernel shells ash as filler on the mechanical properties of hot mix asphalt." *Archives of Applied Science Research* 6, no. 5 (2014): 42-49.

[28] Raya, Jabatan Kerja. "Standard Specification For Road Work, Section 4: Flexible Pavement Jkr." *Spj* (2008): S4.

[29] AASHTO T245, T245 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, in: Stand. Specif. Transp. Mater. Method Sampl. Test., 24th ed., American Association of State Highway and Transportation Official, Washington, DC, 1993: p. T245.

[30] Santamouris, M. "Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions." *Science of the Total Environment* 512 (2015): 582-598. https://doi.org/10.1016/j.scitotenv.2015.01.060

[31] Doulos, Lambros, Mattheo Santamouris, and I. Livada. "Passive cooling of outdoor urban spaces. The role of materials." *Solar energy* 77, no. 2 (2004): 231-249. https://doi.org/10.1016/j.solener.2004.04.005

[32] Pomerantz, Melvin. "Durability and visibility benefits of cooler reflective pavements." (2000)..

[33] Pomerantz, Melvin. "The effect of pavements' temperatures on air temperatures in large cities." (2000).

[34] Santamouris, Matheos, Nikos Papanikolaou, Iro Livada, Ioannis Koronakis, Chrysa Georgakis, Athanasios Argiriou, and D. N. Assimakopoulos. "On the impact of urban climate on the energy consumption of buildings." *Solar energy* 70, no. 3 (2001): 201-216. https://doi.org/10.1016/S0038-092X(00)00095-5

[35] Garth, Andrew. "Analysing data using SPSS (A practical guide for those unfortunate enough to have to actually do it.)." (2008).

[36] Leech, Nancy L., Karen C. Barrett, and George A. Morgan. *IBM SPSS for intermediate statistics: Use and interpretation*. Routledge, 2014.

[37] Utah, Rahim. "IBM SPSS Statistic For Window." *Pejabat Teknologi Maklumat* (2013).