IOP Conference Series: Earth and Environmental Science

Effect of Environmental Exposure on the Cooling Rate of Asphalt Mixtures

To cite this article: I Badruddin *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **682** 012072

4th National Conference on Wind & Earthquake Engineering IOP Publishing
IOP Conf. Series: Earth and Environmental Science **682** (2021) 012072 doi:10.1088/1755-1315/682/1/012072

Effect of Environmental Exposure on the Cooling Rate of Asphalt Mixtures

I Badruddin[1], N Abdul Hassan[1*], M Z H Mahmud[1], S Ismail[2], R Putra Jaya[3], S R Oleiwi Aletba[1] and M R Hainin[3]

[1]Department of Geotechnics and Transportation, School of Civil Engineering, Faculty of Engineering. Universiti Teknologi Malaysia, Johor, Malaysia
[2]Jabatan Kerja Raya Malaysia, Jalan Sultan Salahuddin, 50480 Kuala Lumpur
[3]Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

*Corresponding author: hnorhidayah@utm.my

Abstract. Temperature is one of the major factors that affect the compactability and mechanical performance of asphalt pavement. Therefore, the cooling rate variability of asphalt due to various surrounding conditions and aggregate surface areas is crucial to achieving proper compaction. This study focused on the effect of environmental exposure on the cooling rate and available time for compaction of the asphalt mixtures (AC10 and AC14). Several factors, such as base and ambient temperatures, daytime and nighttime, solar flux, and wind speed, were considered in the evaluation of the cooling curve. A few loose samples were prepared and grouped as covered (with canvas) and uncovered during the monitoring process. The time and temperature of both samples were monitored during the day and night, starting after the mixing process and ending at 80 °C. Results reveal that the cooling rate of asphalt mixtures is undoubtedly affected by the surrounding factors. The use of canvas and coarse aggregate gradation could retain the heat and minimize the wind and solar flux effects, thus increasing the available time for compaction or lengthening the cooling time. In addition, the cooling rate tends to increase during nighttime compared with daytime exposure.

1. Introduction

Temperature variations during the paving works of hot mix asphalt, HMA can affect the final asphalt performance. Difference in wind speed and air temperature will affect the compaction process and cooling rate of asphalt mixture [1-2]. This can be evaluated through the analysis of cooling rate and time available for compaction, TAC. The cooling rate refers to the rate of change of the asphalt's temperature which is proportional to the difference between asphalt and ambient temperatures. In general, heat moves from warmer to cooler place until both achieve equivalent temperature. Pavement temperature is directly related to the surrounding air temperature, wind speed, relative humidity, solar radiation and cloud cover [3,5,6]. During the paving works, the temperature of HMA brought to the field for paving is generally around 160°C with the bitumen in a liquid state, making it easily coats the aggregate particles and workable for compaction [7]. The top pavement layer is normally exposed to greater temperature fluctuations than the layers below the surface [8]. Hotter air temperatures will remove heat from the mat at a slower rate, increasing the time available for compaction [9]. It is also important to find out the projected wind speed for the day of paving. Under windy condition, the temperature of HMA will cool faster than the normal condition. The higher the wind speed the quicker the HMA will cool. Any precipitation also can reduce the temperature of the HMA, which can cause difficulties in achieving the required compaction level [10]. Other than that, the base or ground temperature is also critical in cooling the asphalt mat during the road works. These factors have created unfavourable construction conditions for HMA paving where TAC can be the major aspect to be observed. Specifications that have been made by the local authority are generally at the tolerable limits of delivery and laying compaction temperature. This study focuses on the evaluation of the cooling rate and TAC of asphalt mixture under different material characteristics and environmental conditions. Environmental effects such as air temperature, daytime and night-time condition, and wind speed were considered during the monitoring. The asphalt mix of AC10 and AC14 (dense graded type) were prepared in according to the Malaysian Public Works Department Specification (JKR/SPJ/2008-S4) [4].

2. Materials and Methods

2.1. Samples Preparation

Bitumen with penetration grade 60/70 was used as mentioned in the Malaysian Public Works Department (JKR/SPJ/2008-S4) specification. The properties of materials used in this study are shown in Table 1. Crushed granite aggregate was collected from Hanson Quarry Company to prepare AC10 and AC14 asphalt mixtures following the Malaysian Public Works Department Specification (JKR/SPJ/2008-S4) [6]. Table 2 shows the detailed aggregate gradations of AC10 and AC14. The optimum bitumen content was determined using the Marshall mix design with 5.6% and 4.9% for AC10 and AC14, respectively. Several loose samples were prepared for the investigation, wherein each sample weight was approximately 5 kg for each container.

Table 1. Physical properties of materials

Materials	Physical Properties	
Coarse Aggregate	Bulk Specific Gravity	2.695
	Water Absorption	0.620%
	Aggregate Impact Value	14.4%
Fine Aggregate	Bulk Specific Gravity	2.633
	Water Absorption	1.051%
60/70 PEN	Specific gravity at 25°C	1.030
	Penetration Test at 25°C	60.9 dmm
	Viscosity at 135°C	0.5 Pa˙s

Table 2. Aggregate gradations and OBC for AC10 and AC14

Sieve size (mm)	AC14 percentage passing (%)		AC10 percentage passing (%)	
	Limit	Average	Limit	Average
20	100	100	-	-
14	90-100	95	100	100
10	76-86	81	90-100	95
5	50-62	56	58-72	65
3.35	40-54	47	48-64	56
1.18	18-34	26	22-40	31
0.425	12-24	18	12-26	19
0.15	6-14	10	6-14	10
0.075	4-8	6	4-8	6
Nominal Agg. Size (NMAS)	14 mm		10 mm	
Optimum Binder Content (OBC)	4.9%		5.6%	

2.2. Monitoring of Cooling Curves and TAC

The monitoring process for the asphalt mixture was conducted to determine the cooling rate of the sample. The samples were placed in the open-air near a building during daytime and night-time (solar flux effect) to simulate the road construction conducted during the day and night (Figure 1). Several environmental factors, such as wind speed and surrounding temperature, including covered (with canvas) and uncovered conditions of the exposed samples, were considered. Canvas was used to cover the asphalt loose sample after loading in the truck to avoid heat dissipation during transportation and queuing. The wind speed was measured using an anemometer. The surface and internal temperatures of the loose samples were monitored using the thermal imaging camera and thermocouples, respectively [17]. The TAC was measured starting from the initial exposure until it reaches 80 °C, which is the cessation temperature as specified in the JKR specification. These data were recorded at the time interval of 1 min. Figure 2 shows the example of infrared images of the surface temperature captured during the monitoring. The area highlighted in red refers to the highest temperature of the material and the blue is the coolest area. The cooling rate was analyzed at the interval of 10 min measurement based on the collected data.

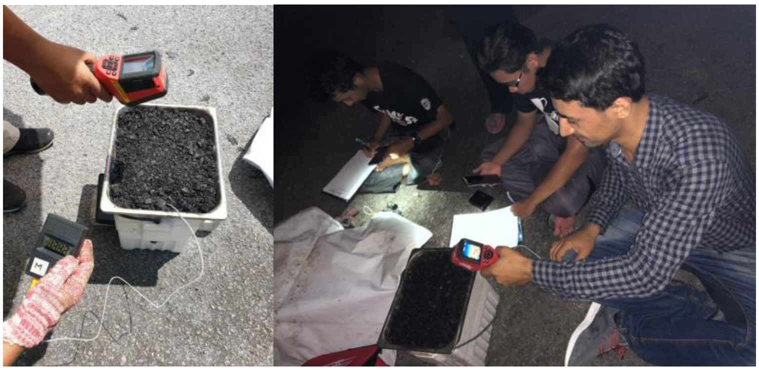

(a) (b)

Figure 1. Monitoring during (a) daytime (b) night-time

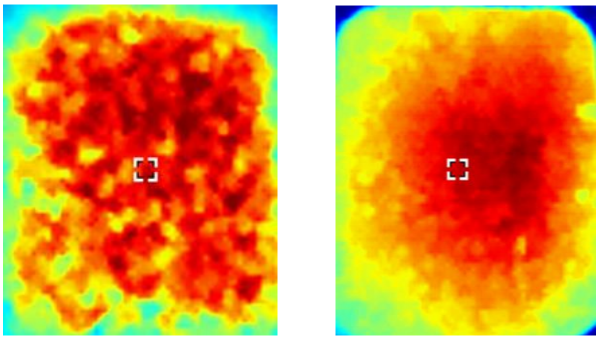

(a) (b)

Figure 2. Infrared images during the monitoring (a) initial stage, (b) after exposure to surrounding

3. Results and discussion

3.1. Surrounding Conditions

Figure 3 shows the plot of the surrounding temperature and wind speed measured during the temperature monitoring. Three specific times were chosen for the temperature monitoring: morning, afternoon, and evening. This condition aims to simulate the construction works undertaken at various times throughout the day and night. The data verify that the highest temperature of the surrounding was observed in the afternoon despite strong wind speed. The cooler condition was observed in the evening than the other specified times. This finding shows that paving works undertaken in the afternoon could help in reducing the cooling rate of the loose asphalt mixture even under wind conditions.

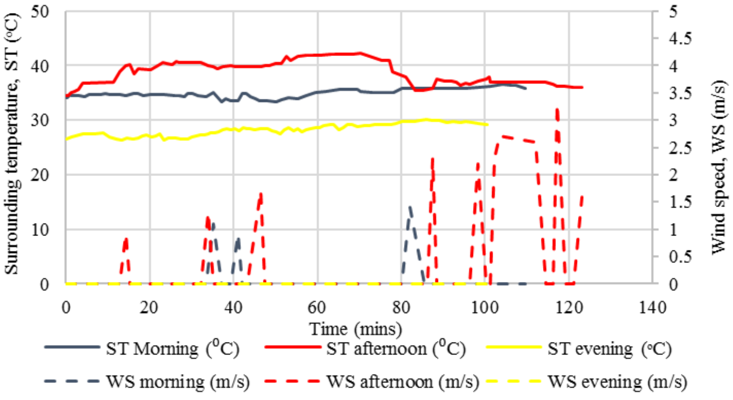
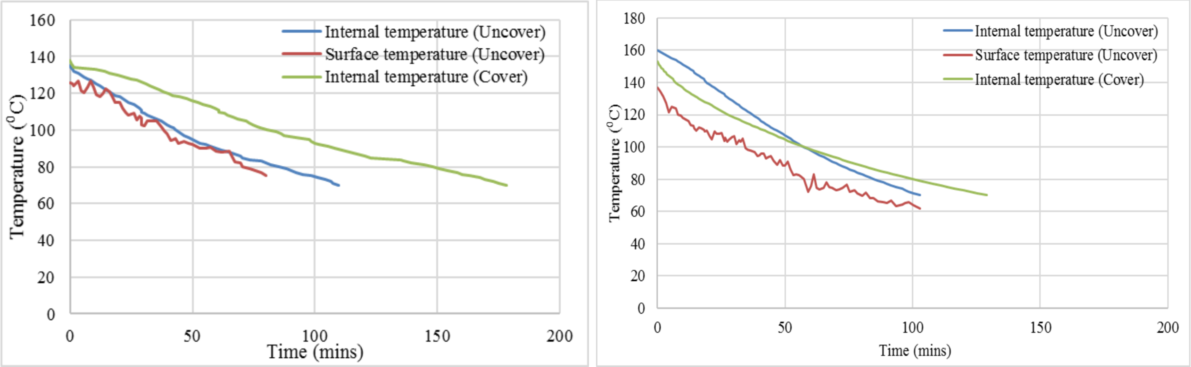


Figure 3. Surrounding temperature and wind speed during monitoring

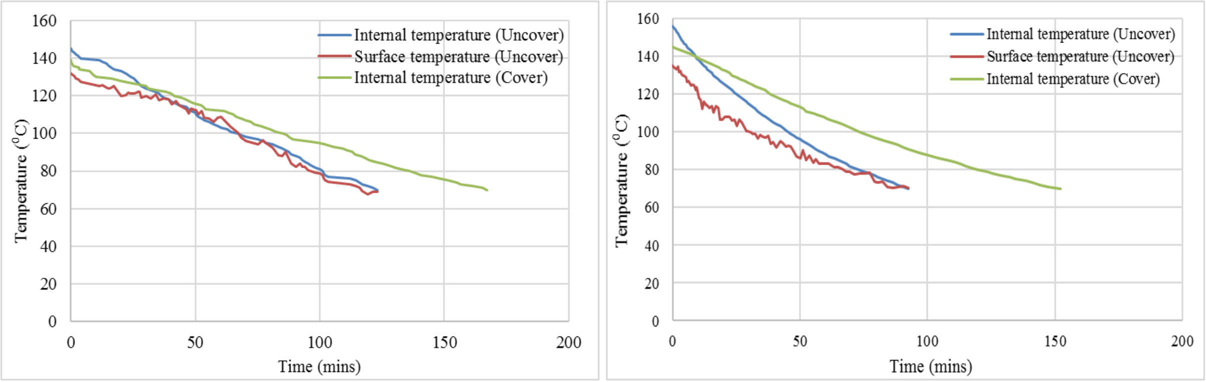
3.2. Cooling Curves and TAC

Figures 4-6 show the cooling curves for AC14 and AC10 monitored in the morning, afternoon, and evening starting at 9 am, 2 pm, and 8 pm, respectively. The cooling curves are presented for the surface and internal temperatures of the uncovered sample. Only the internal temperature was measured for the covered samples to prevent from opening the canvas. The results of TAC for different conditions and mixtures are summarized in Table 3. The results for all conditions showed ranges for the TAC from 46 min to 148 min, with the highest TAC obtained for the covered samples of AC14. The cooling curves of the internal temperature are generally higher than those of the surface temperature based on the plotted graph. Covering the samples lengthened the TAC, which could improve the road construction works during laying and compaction as commonly practiced. Samples monitored in the morning and afternoon show that AC14 retains heat longer than the AC10, particularly for the covered samples. Covering the samples with canvas helped sustain the heat or TAC substantially longer than the uncovered samples of more than 2 h. This condition is due to the trapped heat underneath the canvas, which lowered the thermal diffusivity rate in achieving the thermal equilibrium. The reduction in the TAC of the AC10 mix could be due to the high surface area of the fine aggregate particles exposed to the surrounding for the equilibrium heat transfer. The presence of solar flux during the day monitoring was also found to enhance the potential of heat retention. Although the concentration of solar flux was higher in the afternoon than that in the morning session, the presence of wind affected the cooling curves of the uncovered samples, particularly the surface temperature. Previous studies also stated that the cooling curve of the HMA is considerably affected by the environmental factors, such as air temperature, solar radiation, and wind velocity, thus influencing the final TAC [9, 18]. In comparison to the day monitoring, the evening session demonstrated some fluctuations in the cooling curves, wherein AC10 provides slightly higher TAC than the AC14 with the highest TAC obtained for the covered samples at 119 min.



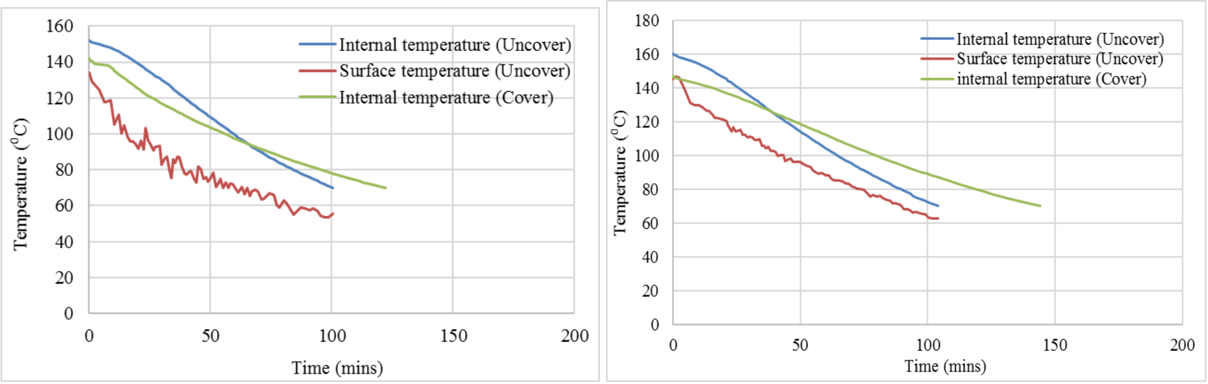
(a) (b)

Figure 4. Cooling curves for (a) AC14 and (b) AC10 (morning)



(a) (b)

Figure 5. Cooling curves for (a) AC14 and (b) AC10 (afternoon)



(a) (b)

Figure 6. Cooling curves for (a) AC14 and (b) AC10 (evening)

Table 3. TAC measurements for different mixes

Exposure Time/Mix type	**TAC (minutes)**	
	AC14	**AC10**
Morning		
Internal temperature (uncover)	86	85
Surface temperature (uncover)	70	58
Internal temperature (cover)	148	100
Afternoon		
Internal temperature (uncover)	101	74
Surface temperature (uncover)	96	67
Internal temperature (cover)	136	120
Evening		
Internal temperature (uncover)	84	90
Surface temperature (uncover)	46	74
Internal temperature (cover)	96	119

3.3. Cooling Rate

The cooling rate was analyzed at an interval of 10 min throughout the temperature monitoring. The results of AC14 and AC10 are plotted in Figures. 7, 8, and 9 for samples monitored in the morning, afternoon, and evening, respectively. The cooling rate value was obtained from the gradient of the cooling curve data as shown in the aforementioned figures. The figure shows that the cooling rate of the AC10 mixture is higher than that of the AC14 mixture for the plotted data of 2 h. This finding verifies the obtained results for the cooling curves, particularly those samples monitored in the morning and afternoon. The trend observed for AC10 shows that the highest cooling rate occurs at the beginning of the exposure for approximately 2 °C/min, and then the rate reduces to approximately 0.5 °C/min after 2 h. The uncovered samples have a higher gradient in heat loss at most of the time interval compared with that in the covered samples, particularly those samples monitored in the evening. The covered samples tend to have low cooling rates due to heat retained by the canvas. The canvas avoids heat dissipation, and wind effects acted on the sample and minimized the heat transfer to the surrounding. The highest drop in the temperature achieves almost 3 °C/min for the AC14 sample during exposure of the first 10 min. Samples exposed to the surrounding in the afternoon have the lowest cooling rate, particularly for AC14, due to high solar flux and surrounding temperature.

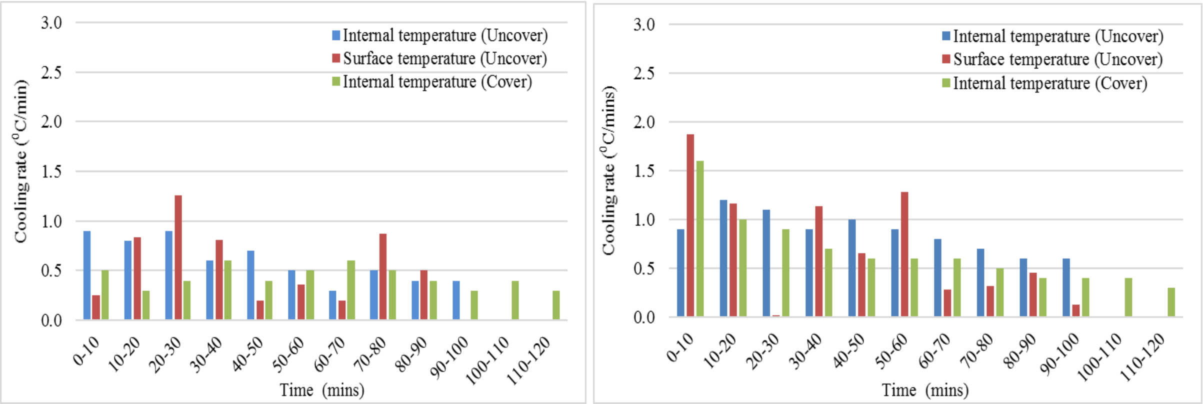


Figure 7. Cooling rate for AC14 and AC10 (morning)

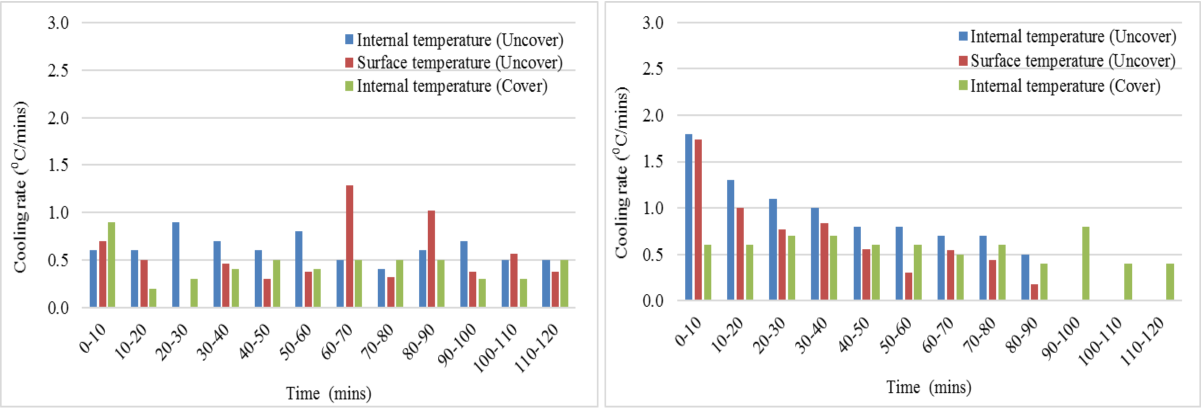


Figure 8. Cooling rate for AC14 and (afternoon)

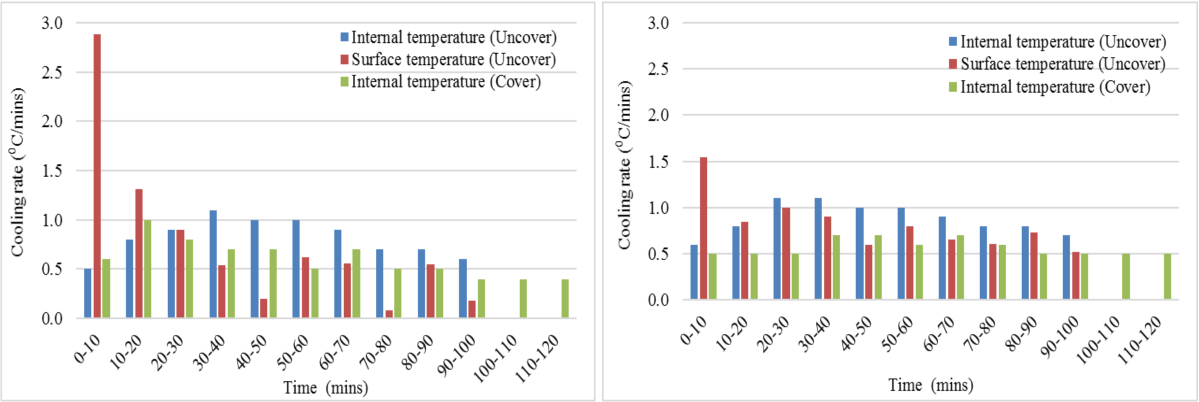


Figure 9. Cooling rate for AC14 and AC10 (evening)

4. Conclusion

The results of this study reveal that covered samples have lower cooling rates than uncovered samples, thus increasing the TAC of HMA. In addition, a significant difference in total cooling time is observed between daytime and night-time samples. Daytime samples have higher TAC of HMA than night-time samples due to the presence of solar flux, which affects the base and ambient temperatures, particularly for the AC14 mixture. The minimal solar flux during night-time resulted in high cooling rates, thus lowering the TAC. Moreover, a significant difference is found between the cooling rate and TAC measured for AC14 and AC10. This finding indicates that asphalt mixture with different aggregate gradations affects the cooling rate and TAC. AC14 with coarse aggregate gradation tends to have a lower cooling rate than AC10 due to the minimal surface area of the loose mix exposed to the surrounding. Overall, the cooling rate of HMA is majorly affected by the environmental factors and the aggregate gradation.

References

[1] R. H. Ramadhan and H. I. A. Wahhab. "Temperature variation of flexible and rigid pavements in Eastern Saudi Arabia." Building and Environment 32.4 (1997): 367-373.

[2] T. P. Lin, Y. F. Ho and Y. S. Huang. "Seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan." Building and Environment 42.12 (2007): 4124-4131.

[3] G. Qian, Z. He, H. Yu, X. Gong, & J Sun. "Research on the affecting factors and characteristic of asphalt mixture temperature field during compaction." Construction and Building Materials 257 (2020): 119509.

[4] H. Wardati, N. S. F. Mustapa, A. K. Arshad, E. Shaffie & Noh N. I. F. M. "Wind Speed Effect on the Time Available for Compaction of Warm Mix Asphalt (WMA)." Key Engineering Materials. Vol. 846. (2020) Trans Tech Publications Ltd.

[5] Q. Yinghong, & J. E. Hiller. "Modeling temperature distribution in rigid pavement slabs: impact of air temperature." Construction and building materials 25.9 (2011): 3753-3761.

[6] Malaysian Public Works Department. Standard Specification for Road Works Section 4: Flexible Pavement. 2008. JKR/SPJ/2008-S4: Kuala Lumpur.

[7] M. L. Bueno, J. Luong, U Viñuela, F. Terán, and S. E. Paje. "Pavement temperature influence on close proximity tire/road noise." Applied Acoustics 72.11 (2011): 829-835.

[8] A.K. Schindler, J.M. Ruiz, R.O. Rasmussen, , G.K. Chang, and L.G. Wathne. Concrete Pavement Temperature Prediction and Case Studies with the FHWA HIPERPAV Models. Cement and Concrete Composites. 26(5) (2004) 463-471.

[9] W. Hashim, M.R. Hainin, N.N. Ismail, N.I.M. Yusoff, M.E. Abdullah, & N.A. Hassan. "Evaluating the cooling rate of hot mix asphalt in tropical climate". Jurnal Teknologi. 78(4) (2016): 97-104.

[10] C. Yavuzturk and K. Khaled. Assessment of temperature fluctuations in asphalt pavements due to thermal environmental conditions using a two-dimensional transient finite difference

approach. No. MPC-02-136. United States. Dept. of Transportation. Research and Special Programs Administration, (2002.

[11] Y. Qin, J. E. Hiller, and D. Meng. "Linearity between pavement thermophysical properties and surface temperatures." Journal of Materials in Civil Engineering 31.11 (2019): 04019262.

[12] X. Shi, Y. Rew, E. Ivers, , C. S. Shon, E. M. Stenger, & P. Park. "Effects of thermally modified asphalt concrete on pavement temperature." International Journal of Pavement Engineering 20.6 (2019): 669-681.

[13] A. Hermansson. "Simulation model for calculating pavement temperatures including maximum temperature." Transportation Research Record 1699.1 (2000): 134-141.

[14] F. L. Roberts, P.S. Kandhal, E.R. Brown, D.Y. Lee, and T.W. Kennedy. Hot Mix Asphalt Materials, Mixture Design, and Construction. National Asphalt Paving Association Education Foundation. (1996). Lanham, MD.

[15] S. Ismail, N.A. Hassan, H. Yaacob, M. R. Hainin, Ros Ismail, C., Mohamed, A., & Satar, M. K. I. M.. Properties of dense-graded asphalt mixture compacted at different temperatures. IOP Conference Series Earth and Environmental Science, 220(1), (2019) 012010.

[16] P. Mieczkowski, and B. Budziński. "The Influence of Water on the Heat Loss of Hot Mix Asphalt." Applied Sciences 9.9 (2019): 1747.

[17] S. R. O. Aletba, N. A. Hassan, E. Aminudin, R. P. Jaya , N. A. M. Shukry, N. Mashros, M. M. A. Aziz & H. M. Nor. "Thermal performance of waste materials as aggregate replacement in asphalt pavement." IOP Conference Series Earth and Environmental Science 220.1 (2019): 012011.

[18] Y. Gao, R.X. Wang, and W.B. Yu. “Effective Compactible Time of Asphalt Pavement.” Advanced Materials Research 255–260 (2011): 3156–60.

Acknowledgment

This work was supported by Malaysian Ministry of Higher Education (MOHE) and the Universiti Teknologi Malaysia (UTM) in the form of a research grant number R.J130000.7851.5F169.