IOP Conference Series: Earth and Environmental Science

Thermal performance of waste materials as aggregate replacement in asphalt pavement

To cite this article: Salam Ridha Oleiwi Aletba *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **220** 012011

Thermal performance of waste materials as aggregate replacement in asphalt pavement

***Salam Ridha* Oleiwi Aletba**[1], ***Norhidayah* Abdul Hassan**[1,3], ***Eeydzah* Aminudin**[1], ***Ramadhansyah* Putra Jaya**[2], ***Nurul Athma* Mohd Shukry**[1], ***Nordiana* Mashros**[1], ***Md Maniruzzaman* A. Aziz**[1]**,** ***Hasanan* Md. Nor**[1]

[1]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor
[2]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia.
[3]Corresponding author: hnorhidayah@utm.my

Abstract. The high surface temperature of the conventional asphalt pavement due to high solar energy absorption could contribute to the Urban Heat Island (UHI) phenomenon. Concurrent with this phenomenon, rapid urbanization and industrial development have led to a large quantity of waste products available for disposal or recycling. Therefore, this study investigates the thermal performance of selected waste materials that could potentially be used as aggregate in asphalt pavement to combat the problem of increased pavement surface temperature. A number of waste materials were selected for the thermal performance measurement and compared to granite as conventional aggregate. The cylindrical and slab samples of AC14 dense graded asphalt were prepared for the different selected aggregate types. The samples were then measured for solar reflectance using Spectroradiometer. In addition, the surface and internal temperature profiles of the samples were monitored using infrared camera and thermocouples, respectively, in exposed environments. Based on the results, it is possible to use some of the waste materials as an aggregate replacement in order to reduce the UHI impact.

1. Introduction

Conventional pavements, especially the newly constructed asphalt pavements, produce high surface temperatures (up to 65-80 ºC) depending on the climate region and resulting in high near-surface air temperatures [1-7]. The high temperatures of pavements and near-surface air can produce severe negative impacts associated with the urban heat island (UHI) effect in hot climates, including reduced human comfort and health; increased energy use for cooling of buildings and vehicles; impaired air and water quality. In addition, this phenomenon will accelerate pavement deterioration (e.g., rutting and aging of asphalt pavements and possibly thermal cracking) [6–8]. To solve these problems, there is a need to reduce the temperature of the asphalt surface.

Many studies have been conducted around the world through the use of cool pavements as a strategy for mitigating the heat island effect [8–10], to improve the outdoor thermal comfort and the potential of reducing the energy usage. For new asphalt pavements, one of the methods recommended to reduce the UHI effect is through the application of cool paving materials in road construction [11–14]. This research is an attempt to investigate a few industrial wastes as recycled aggregates in asphalt pavement in order to evaluate their potential as cool paving materials. Due to the environmental issues caused by the industrial waste and limited landfill area, this research is very much needed for minimizing the generated waste [15–18].

2. Mix design

2.1 Materials preparation

The asphalt mixtures were prepared and tested according to JKR/SPJ/2008-S4 and ASTM standards. The binder used was 60/70 PEN bitumen with 5.0% of the total weight for each sample. An anti-stripping agent of hydrated lime accounted for 2% of the combined aggregate weight. These materials were used to produce dense graded mixture type with nominal maximum aggregate size of 14 mm. Different aggregate types were used for comparison i.e. granite, garnet (GFA), steel slag (SSA), waste ceramic (WCA) and bottom ash (BAA). Table 1 shows the sieve analysis of the different aggregate types.

Table 1. Materials sieve analysis.

Sieve Size	**% Passing**			**%Retain**				
	Max	Min	Target gradation	Granite	GFA	SSA	WCA	BAA
20	100	100	100	0	-	0	-	-
14	100	90	95	5	-	5	-	-
10	86	76	81	14	-	14	-	-
5	62	50	56	25	-	25	-	-
3.35	54	40	47	9	-	6	-	-
1.18	34	18	26	21	1	-	16	6
0.425	24	12	18	8	8	-	8	8
0.15	14	6	10	8	8	-	8	8
0.075	8	4	6	4	4	-	4	4
Pan				4	4	-	4	4
Total %				100	25	50	40	30

2.1.1 Garnet (GFA)

Garnet sand is a good abrasive, and a common replacement for silica sand in sand blasting. Recently, the use of garnet as the waste spin-off of surface treatment operations remain a major environmental concern worldwide [19, 20]. Basically, the angular fractures and hardness properties of garnets make it useful to be recycled. The garnet used in this study was collected from the shipyard in Pasir Gudang, Johor. It was found that that waste garnet suits to replace the fine aggregate with approximately 20-25% of the total aggregate weight in the selected mix.

2.1.2 Steel Slag (SSA)

Steel slag aggregate (SSA) is a byproduct of the steel production. Steel slag aggregate is very tough due to high iron oxide content and is also angular and porous. The microstructure of the aggregates is reliant on the furnace process [21, 22]. Steel-slag aggregates were collected as a byproduct from a steel company in Pasir Gudang, Johor. In this study, Steel Slag was used as an aggregate replacement with 50% coarse size retained on the sieve of 3.35 mm.

2.1.3 Waste ceramic (WCA)
Waste ceramic tiles increased annually. Previous studies indicated that waste ceramic has been used as aggregate and filler in the asphalt mix [23, 24]. In this study, the 40% was used as fine aggregate and filler which passed 3.35 mm of the total aggregate weight.

2.1.4 Bottom ash (BAA)
Bottom ash is a coarse, granular, incombustible by-product of coal combustion that is collected from the bottom of furnaces. Most bottom ash is produced at coal-fired power plants. The ash particles are lightweight and porous. A million tons of ash are dumped yearly as a by-product [25, 26]. In this study, 30% bottom ash was used as fine aggregate and filler which passed 3.35 mm of the total aggregate through aggregates replacement. The ash was collected from Tanjung Bin Power Plant in Johor.

2.2 Sample Preparation
Five different asphalt mixtures were prepared for comparison. Two sets of samples were produced for the thermal investigations i.e. slab samples with dimension of 300x300x50 mm and Marshall cylindrical samples with dimension of 102 mm diameter and 64 mm height. The aggregate and bitumen were heated prior to mixing and compaction. The mass of each sample prepared is 10 ± 0.2 kg and 1.2 kg for slab and Marshall samples, respectively. The loose mixes were placed in the slab mould and compacted at 100 rolls while the Marshall samples were compacted at 75 blows.

3. Experimental Design
In this study, the thermal behavior was investigated in both laboratory and field. For the field measurement, an infrared thermography image was captured using a thermal imaging camera and analyzed for surface temperature and emissivity of the slab samples. Thermocouples were used to measure the internal temperature of the slab samples when exposed to the sunlight in an open area. Detailed weather conditions i.e. air temperature, wind speed and relative humidity throughout the day were monitored for verification. In addition, a spectral radiometer was used to measure the solar flux and reflectance of the Marshall samples in the laboratory (within controlled surrounding).

3.1 Spectroradiometer
A Spectroradiometer ASD Field Spec Handheld, which is a 512-element photo diode array with a 325-1075 nm wavelength range (UV/VIS/NIR) was used to determine the solar reflectance for each wavelength applied on the surface according to ASTM C 1549-09. Figure 1 shows the test method set up [27].

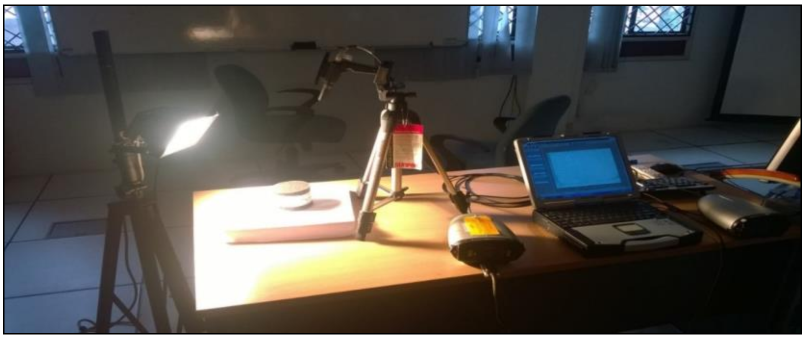


Figure 1. Solar reflectance measurement using Spectroradiometer.

3.2 Infrared Thermography
Heat energy is a part of the electromagnetic spectrum of a material and takes upper portion of the infrared light spectrum that is undetectable to the human eye. The infrared imaging camera utilizes a

special lens designed to capture infrared radiation and then transforms it into an image representing the temperature distribution at the investigated surface. On the other hand, each material emits some form of thermal energy. The radiation direction emitted from the pavement surface goes straight into the space with poor air absorption. By measuring the thermal energy, a material surface could emit to the ratio of black body at the same conditions is called emissivity. The advantage of the thermal camera is it captures in real time the whole surface temperature profile. In this respect, it could be a very effective tool to deploy night time operations. In this study, the thermal camera was used for recording all the superficial temperatures and then the data were analyzed for emissivity of the different paving surfaces. In addition, the thermal camera can be an effective tool in identifying potential thermal segregation for an object [28, 29].

Figure 2 shows the test set-up for the field thermal measurement. The slab samples were exposed to the sunlight exactly at 8:00 am within an open area. The thermocouples were inserted into the sample (at the edge) and connected to data logger type GL220s to monitor the interior temperature at the regular intervals. The samples were monitored, and photos were captured every 30 minutes for 12 hours. The images and data logger readings were analyzed for thermal profile. Figure 3 shows the slab samples and thermal images captured for the different materials used. Figure 4 shows the air temperature, wind speed and relative humidity recorded during the observation with the highest air temperature obtained at 12:30 pm.

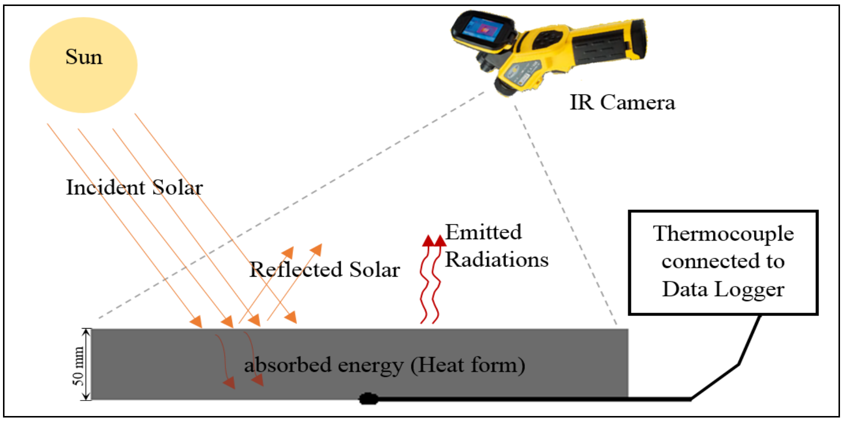
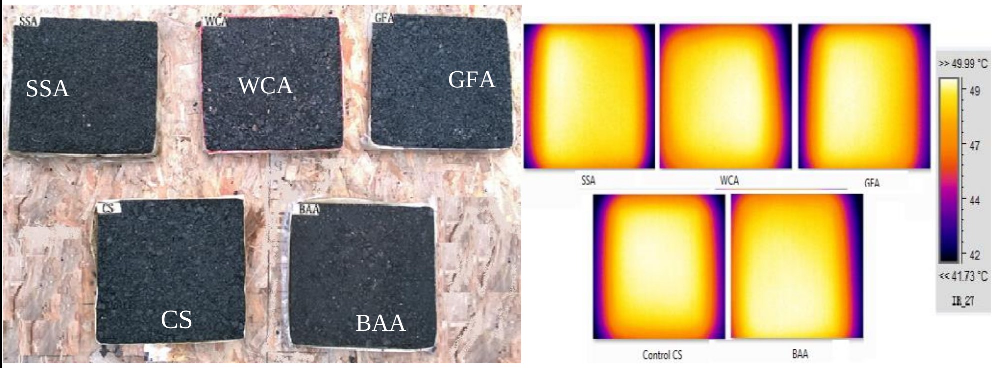
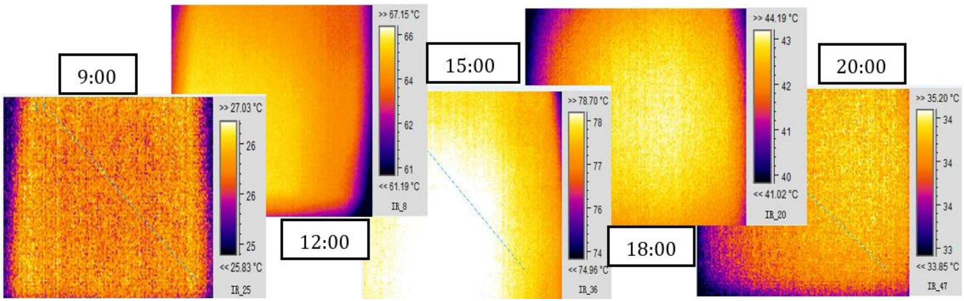


Figure 2. Test method for field measurement.



(a) Slab samples (b) Thermal images captured at 13:00pm



(c) Thermal images captured at various time

Figure 3. Thermal images of the tested samples with time.

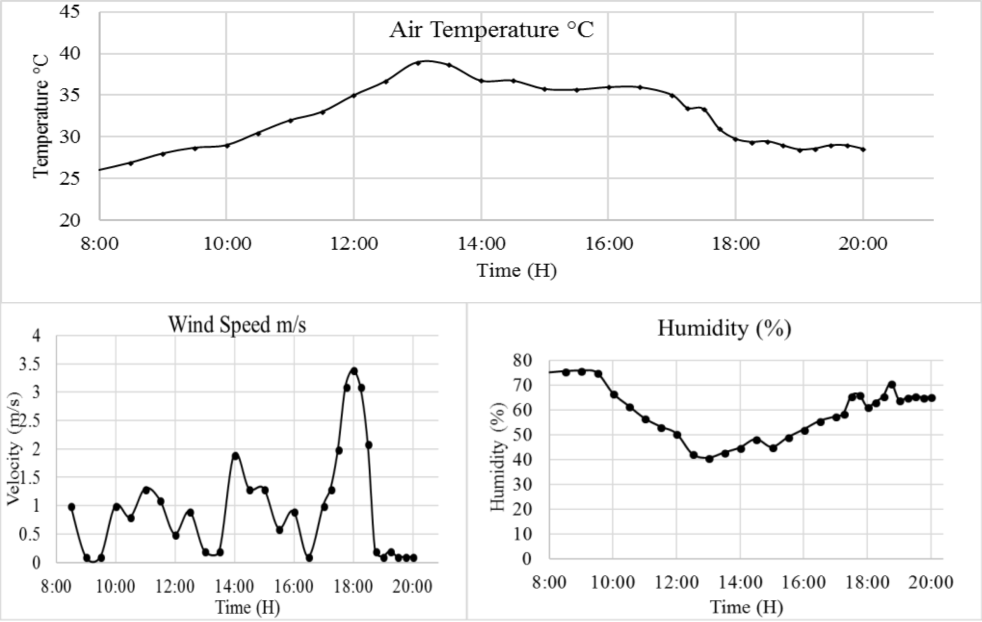


Figure 4. Weather conditions.

4. Results

4.1 Pavement surface solar reflectance

The measurement was conducted on the cylindrical Marshall samples using Spectroradiometer. Figure 5 shows the result of solar reflectance for different mixtures. Based on the results, BAA sample has the highest reflectance followed by WCA and GFA samples for visible light. However, as the wavelength increased to more than 800 nm (near infrared radiation), WCA sample shows greater reflectance than other materials. SSA seems to have the least reflectance and comparable to the control sample with granite aggregate.

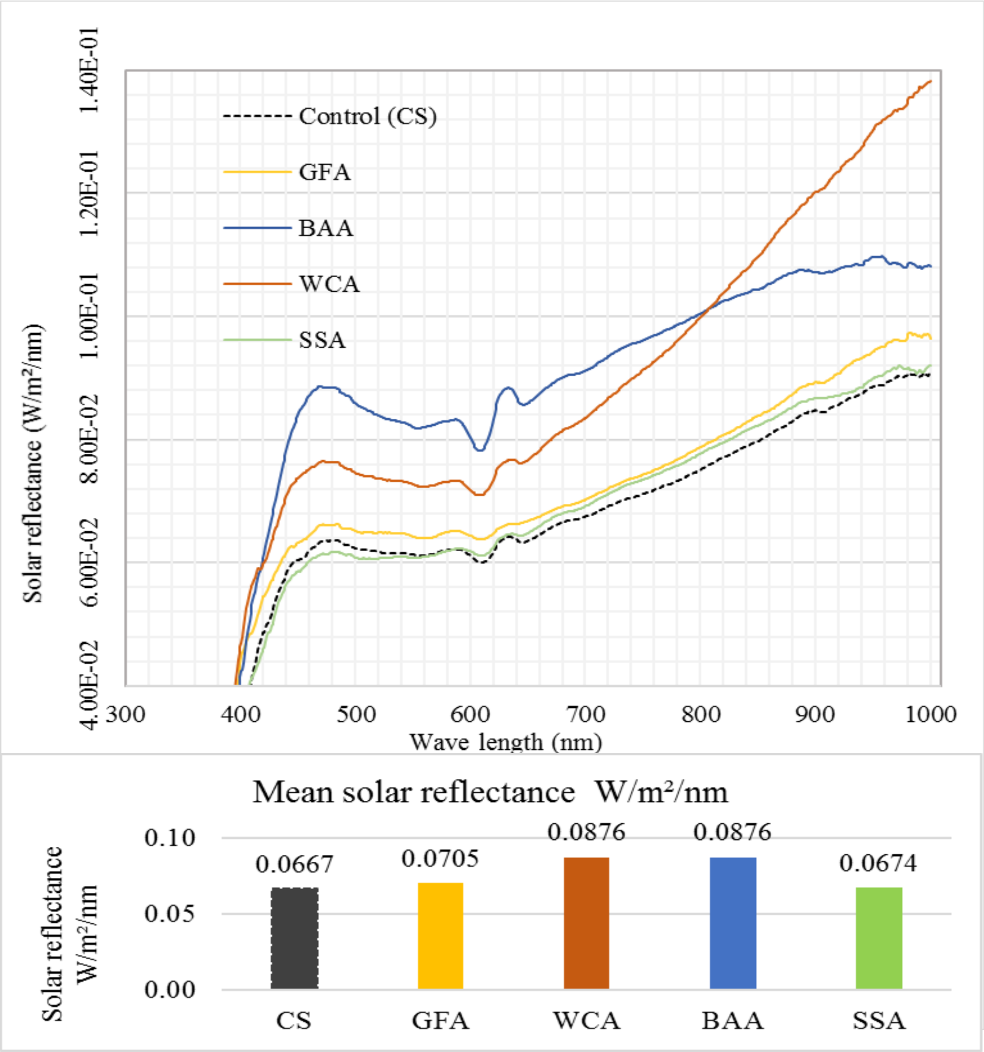


Figure 5. Solar reflectance of the different samples.

4.2 Pavement surface Thermal analysis

4.2.1 Surface Temperature Profile

Figure 6 shows the result of thermal analysis of the surface temperature for the different samples. The air temperature was also plotted in the figure. Generally, the weather temperatures in tropical climate are nearly constant throughout the year. The surface temperature was monitored from 8:00 am until

20:00 pm. Basically, the thermal profile of the pavement surface can be divided into two main gradients which describe the 'gain' and 'release' of the surface temperature.

Based on the analyzed images, the surface temperature starts to increase at 9:30 am and the peak is observed at 15:00 pm, which achieved almost 80°C, before descending sharply as the samples start to release the heat. Even though the surrounding air temperature was recorded to reach the peak at 13:30 pm, the pavement surface temperature continued to heat up and gained more heat from the sunlight. At the peak, BAA and WCA samples have achieved 79.73 and 79.43°C, respectively, followed by CS with SSA and GFA 78.9, 79.03 and 78.07°C, respectively. After 15:30, the air temperature begins to decrease with the increase in wind speed, leading to the reduction of the surface temperatures. It can be seen that samples with BAA, WCA and GFA seem to heat up and release the heat quickly, while others are good at storing the heat energy longer than these materials. In other words, BAA, WCA and GFA can be categorized to have a low specific heat capacity which could potentially shorten the time of the pavement to warm up the surroundings This complements the aforementioned result for solar reflectance where the same materials have high tendency to reflect the solar energy compared to the control samples.

Highest response in terms of releasing temperature was recorded for GFA followed by the BAA, WCA and SSA. The CS demonstrated the least elimination of heat. Mean temperatures of each surface sample are from lowest to highest GFA 52.34°C, BAA 53.32 °C, WCA 53.51 °C, SSA 54.06 °C and CS 55.30 °C.

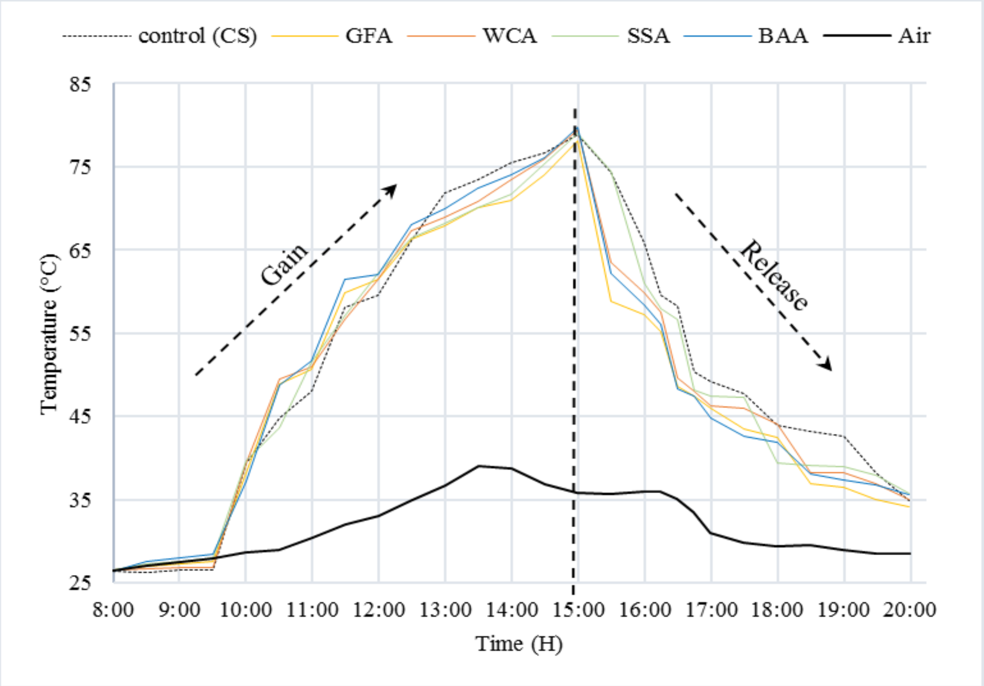


Figure 6. Comparison of different pavement surfaces and air temperatures.

4.2.2 Emissivity

Thermal emissivity plays an important role in determining a material's contribution to UHI, increasing the emissivity reduce UHI impact. In the laboratory, each sample was heated up to certain temperature that can be determined very accurately using a contact thermocouple under known ambient conditions (air temperature and humidity); at the same time, the IR camera indicates the sample temperature by adjusting the emissivity percentage until the temperature reading is synchronous in both IR camera and thermocouple [30]. Figure 7 shows the results obtained for emissivity, where highest emissivity was found both for GFA and BAA at 95%, followed by SSA and WSA. The least emissivity was observed for the control sample with the value of 85%.

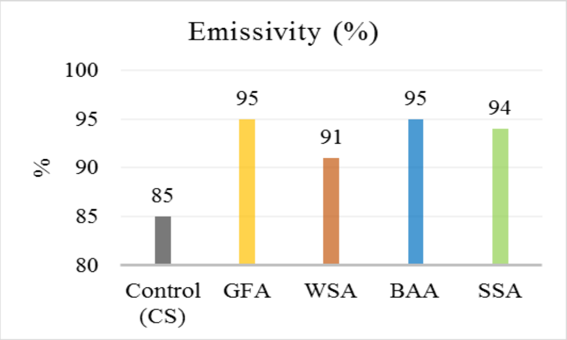


Figure 7. Emissivity for different samples.

4.3 *Interior temperature profile*

Figure 8 shows the interior temperature profile of the asphalt samples made of different potential materials monitored during the day. Generally, the temperature inside the sample was recorded lower than the surface temperature. Based on the figure, initially, the heat begins to transfer differently within the samples with BAA showing the least temperature gain among all up to the peak. However, the heat release behaviour seems comparable between the different materials particularly after 17:00 hrs. The control sample with granite aggregate, CS, gained the highest temperature at peak compared to other samples. Overall, the BAA sample gives the least heat retention among the samples produced, which shows its potential as cool paving material in asphalt pavement.

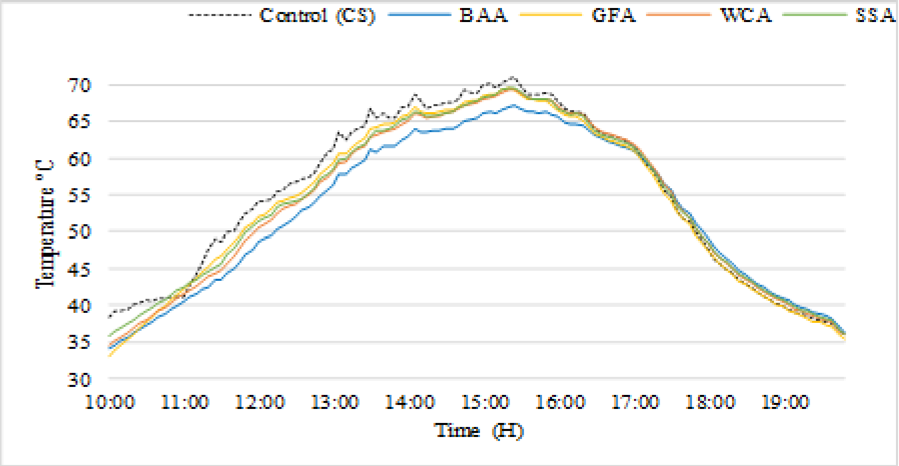


Figure 8. Interior temperature profile of the slab samples.

5. Conclusions

Based on the results, it can be concluded that the use of waste materials in asphalt is able to decrease the surface temperature of asphalt pavement during the day. The results showed BBA has consistently improved the cooling performance of the asphalt with low specific heat capacity compared to other materials including the control samples. In addition, the waste ceramic and garnet were also identified with potential to reflect the solar compared to the control samples. Therefore, consideration should be made on the potential of using them as paving materials in reducing the UHI impact.

6. References

[1] N. Anting *et al.*, “Experimental evaluation of thermal performance of cool pavement material using waste tiles in tropical climate,” *Energy Build.*, vol. 142, pp. 211–219, 2017.

[2] R. S. Benrazavi, K. Binti Dola, N. Ujang, and N. Sadat Benrazavi, “Effect of pavement materials on surface temperatures in tropical environment,” *Sustain. Cities Soc.*, vol. 22, pp. 94–103, 2016.

[3] N. A. Anak Guntor, M. F. Md Din, M. Ponraj, and K. Iwao, “Thermal Performance of Developed Coating Material as Cool Pavement Material for Tropical Regions,” *J. Mater. Civ. Eng.*, vol. 26, no. 4, pp. 755–760, 2014.

[4] M. Pomerantz, H. Akbari, A. Chen, H. Taha, and A. H. Rosenfeld, “Paving materials for heat island mitigation,” no. November, pp. 1–21, 1997.

[5] M. Santamouris, N. Gaitani, A. Spanou, M. Saliari, K. Giannopoulou, and K. Vasilakopoulou, “Using cool paving materials to improve microclimate of urban areas e Design realization and results of the fl isvos project,” *Build. Environ.*, vol. 53, pp. 128–136, 2012.

[6] D. Van Thanh and C. P. Feng, “Study on Marshall and Rutting test of SMA at abnormally high temperature,” *Constr. Build. Mater.*, vol. 47, pp. 1337–1341, 2013.

[7] D. Yinfei, W. Shengyue, and Z. Jian, “Cooling asphalt pavement by a highly oriented heat conduction structure,” vol. 102, pp. 187–196, 2015.

[8] Y. Qin, “A review on the development of cool pavements to mitigate urban heat island effect,” *Renew. Sustain. Energy Rev.*, vol. 52, pp. 445–459, 2015.

[9] E. EPA, “reducing urban heat islands compedium strategies- cool pavements EPA,” 2008.

[10] L. Gartland, *Heat islands: understanding and mitigating heat in urban areas*. 2008.

[11] K. Levine, “Cool Pavements Research and Technology,” no. June 2002, p. 17p, 2011.

[12] A. Mohajerani, J. Bakaric, and T. Jeffrey-Bailey, “The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete,” *J. Environ. Manage.*, vol. 197, pp. 522–538, 2017.

[13] X. Yang, L. Zhao, M. Bruse, and Q. Meng, “Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces,” *Build. Environ.*, vol. 60, pp. 93–104, 2013.

[14] D. Kolokotsa, M. Santamouris, and S. C. Zerefos, “Green and cool roofs ’ urban heat island mitigation potential in European climates for office buildings under free floating conditions,” *Sol. Energy*, vol. 95, pp. 118–130, 2013.

[15] J. Bolden, T. Abu-lebdeh, and E. Fini, “UTILIZATION OF RECYCLED AND WASTE MATERIALS IN VARIOUS CONSTRUCTION APPLICATIONS,” *Am. J. Environ. Sci.*, vol. 9, no. 1, pp. 14–24, 2013.

[16] H. Akbulut and C. Gürer, “Use of aggregates produced from marble quarry waste in asphalt pavements,” *Build. Environ.*, vol. 42, no. 5, pp. 1921–1930, 2007.

[17] D. B. Eme, T. C. Nwofor, and E. S. Umukoro, “Stability of Asphalt Cement Concrete Produced From Waste Plastics As Replacement for Aggregate,” *Int. J. Civ. Eng. Technol.*, vol. 6, no. 5, pp. 976–6308, 2015.

[18] P. S. Kandhal, “Waste materials in hot mix asphalt - an overview,” *Natl. Cent. Asph. Technol.*, no. 1193, pp. 3–16, 1992.

[19] A. Castel, T. Vidal, and R. François, “Bond and cracking properties of self-consolidating concrete,” *Constr. Build. Mater.*, vol. 24, no. 7, pp. 1222–1231, 2010.

[20] H. L. Muttashar, M. A. M. Ariffin, M. N. Hussein, M. W. Hussin, and S. Bin Ishaq, “Self-compacting geopolymer concrete with spend garnet as sand replacement,” *J. Build. Eng.*, vol. 15, no. October, pp. 85–94, 2018.

[21] M. R. Hainin, N. I. M. Yusoff, M. F. Mohammad Sabri, M. A. Abdul Aziz, M. A. Sahul Hameed, and W. Farooq Reshi, “Steel Slag as an Aggregate Replacement in Malaysian Hot Mix Asphalt,” *ISRN Civ. Eng.*, vol. 2012, pp. 1–5, 2012.

[22] W. S. DOT, “Use of Steel Slag Aggregate in Pavements,” 2015, no. November.

[23] R. Muniandy, D. H. Ismail, and S. Hassim, “Performance of recycled ceramic waste as aggregates in hot mix asphalt (HMA),” *J. Mater. Cycles Waste Manag.*, vol. 20, no. 2, pp. 844–849, 2018.

[24] R. Silvestre, E. Medel, A. García, and J. Navas, “Using ceramic wastes from tile industry as a partial substitute of natural aggregates in hot mix asphalt binder courses,” *Constr. Build. Mater.*, vol. 45, pp. 115–122, 2013.

[25] P. Colonna, N. Berloco, V. Ranieri, and S. T. Shuler, “Application of Bottom Ash for Pavement Binder Course,” *Procedia - Soc. Behav. Sci.*, vol. 53, pp. 961–971, 2012.

[26] J. W. Stephen, “Utilization of bottom ash in asphalt mixes,” no. 303, 1999.

[27] ASTM C1549-09, “Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer,” in *ASTM International*, West Conshohocken, PA, 2009.

[28] N. V. F. Å. Silkeborg, “The use of thermal camera for quality assurance of asphalt pavement construction,” no. June, pp. 1–3, 2014.

[29] J. Song, P. Investigator, M. A. C. Investigator, and E. A. C. Investigator, “Use of a Thermal Camera during Asphalt Pavement Construction Department of Construction Management and Engineering Department of Civil Engineering North Dakota State University 1410 14th Avenue North , Fargo Submitted to : North Dakota Department of Trans,” 2009, vol. 1, no. September 2009.

[30] K. Rakrueangdet, N. Nunak, T. Suesut, and E. Sritham, “Emissivity Measurements of Reflective Materials using Infrared Thermography,” *Proc. Int. MultiConference Eng. Comput. Sci.*, vol. I, no. 1, pp. 16–19, 2016.

Acknowledgement

The support provided by Malaysian Ministry of Higher Education (MOHE), Universiti Teknologi Malaysia (UTM) in the form of a research grants number Q.J130000.2522.19H82 and R.J130000.7822.4F867 for this study is very much appreciated.