Energy and Buildings 142 (2017) 211–219

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

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

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ARTICLE INFO

Article history:
Received 24 November 2016
Received in revised form 5 March 2017
Accepted 6 March 2017
Available online 7 March 2017

Keywords:
Waste tile
Urban heat island
Surface temperature
Cool pavement
Solar reflectance
Thermal performance

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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http://dx.doi.org/10.1016/j.enbuild.2017.03.016
0378-7788/

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