Energy and Buildings 158 (2018) 172–180

Contents lists available at ScienceDirect

Energy and Buildings

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

# Optimizing of near infrared region reflectance of mix-waste tile aggregate as coating material for cool pavement with surface temperature measurement

Nickholas Anting [a,*], Mohd Fadhil Md Din [b], Kenzo Iwao [c], Mohanadoss Ponraj [d], Alvin John Lim Meng Siang [e], Lee Yee Yong [f], Joewono Prasetijo [e]

[a] Jamilus Research Center, Department of Structural and Material Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
[b] Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Environmental Sustainability, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[c] Department of Environmental Engineering, Nagoya Institute of Technology, Nagoya, Japan
[d] Centre for Sustainable Technology and Environment, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
[e] Smart Driving Research Center, Department of Infrastructure and Geomatic Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
[f] Jamilus Research Center, Department of Building and Construction Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

ARTICLE INFO

*Article history:*
Received 15 August 2017
Received in revised form 1 October 2017
Accepted 1 October 2017
Available online 4 October 2017

*Keywords:*
Waste tiles
Design of experiment
Urban heat island
Cool pavement
Surface temperature
Near infrared region reflectance

ABSTRACT

The heat generated from dark color asphalt, which is low in surface reflectance mainly contributes to the environmental problem called as urban heat island. Low reflectance at high energy wavelength of sunlight, such as visible light and infrared region will cause the pavement to have high surface temperature, due to high energy absorption from solar radiation. This paper presents the optimization result of cool pavement coating material based on selected tiles aggregate to achieve high near infrared region (NIR) reflectance. Three types of waste tiles were used in this study which are Full Body Porcelain (FBP), Monoporosa (MP) and Porcelain Glaze (PG). All the tiles were prepared in the form of aggregates. A linear model was formed as a function of mix tiles fraction and the analysis of ANOVA suggest that the linear term used for this model is significant. Diagnostics of the model was evaluated using box-cox plot, normal plot of residuals and optimized to predict the mix of the different type of tiles to produce the highest surface NIR reflectance value. The first solution suggests that 100% of MP tile can provide NIR reflectance of 0.53, whereas the second solution suggest that the combination of 50% FBP and 50% of MP tile aggregates could give NIR reflectance value of about 0.51. Experimental work on measuring surface temperature found that optimized samples, M1 and M2 with high NIR reflectance could significantly reduce surface temperature of asphalt pavement at range of 4.1 °C–9.6 °C. In conclusion, the results of optimization is reliable and this method able to provide significant information on optimizing mix of tiles material as to achieve high NIR reflectance value for coating materials of cool-pavement.


## 1. Introduction

Rapid development in modern cities creates significant impact to our environment, directly or indirectly. Modernization involves with the alteration of natural environment, from green natural surface to concrete jungle. Improper planning and design of the cities, e.g. (a) materials selection; and (b) building layout, directly affects the thermal condition in the cities, which is known as urban heat island (UHI) phenomena, a term used to describe the heating phenomenon in the urban areas. UHI is an environmental problem that is identified as a heating process in urban areas, that causing overall temperature at urban area higher compared to its surrounding rural areas [1–3]. A study in countries with four seasons all over the world shows that the daytime average air temperature in urban area is 5.6 °C higher than its surrounding areas [4]. Thermal discomfort, high energy consumption for increasing in cooling demand, and air pollution have been listed as several direct effects of UHI [5–8].

The surface reflectance or albedo of construction material plays important roles that significantly affects the existence of UHI [9]. Usually, the albedo of materials is correlated with the colour of surface materials. Most of the light colour materials have high

* Corresponding author.

https://doi.org/10.1016/j.enbuild.2017.10.001
0378-7788/

**Table 1**
16 sets of run condition by the mix design model.

| Run | Materials Composition (%) | | |
|---|---|---|---|
| | Full Body Porcelain | Monoporosa | Porcelain Glaze |
| 1 | 0.00 | 100.00 | 0.00 |
| 2 | 16.67 | 16.67 | 66.67 |
| 3 | 0.00 | 100.00 | 0.00 |
| 4 | 66.67 | 33.33 | 0.00 |
| 5 | 16.67 | 66.67 | 16.67 |
| 6 | 50.00 | 0.00 | 50.00 |
| 7 | 100.00 | 0.00 | 0.00 |
| 8 | 50.00 | 50.00 | 0.00 |
| 9 | 100.00 | 0.00 | 0.00 |
| 10 | 0.00 | 50.00 | 50.00 |
| 11 | 0.00 | 50.00 | 50.00 |
| 12 | 0.00 | 0.00 | 100.00 |
| 13 | 66.67 | 16.67 | 16.67 |
| 14 | 33.33 | 33.33 | 33.33 |
| 15 | 0.00 | 0.00 | 100.00 |
| 16 | 50.00 | 0.00 | 50.00 |

| Component | Name | Units | Low actual | High actual | Low coded | High coded |
|---|---|---|---|---|---|---|
| A | Full Body Porcelain | % | 0.00 | 100.00 | 0.00 | 1.00 |
| B | Monoporosa | % | 0.00 | 100.00 | 0.00 | 1.00 |
| C | Porcelain Glaze | % | 0.00 | 100.00 | 0.00 | 1.00 |

| Response | Name | Units | Analysis | Minimum | Maximum | Ratio |
|---|---|---|---|---|---|---|
| Y1 | NIR Reflectance | None | Polynomial | 0.35 | 0.55 | 1.57143 |

Study type: Mixture.
Design type: D-Optimal.
Design model: Quadratic.
Runs: 16.

surface reflectance value. In developed urban cities, most of the construction materials are made from low albedo surface materials, thus creating low albedo canopy areas compared to the rural area that is mostly covered with light and green colour surfaces [10]. In addition, downtown urban areas could absorb and store twice the amount of heat when compared to its surrounding areas during daytime [11,12]. A study conducted in [13] reported that the changes of outdoor air temperatures both for daytime and nocturnal is albedo. Thus, the improvement of outdoor air temperature could be done by increasing the albedo of buildings and others construction materials such as road, external infrastructures, etc [7,14].

Asphalt pavements are usually dark in colour and cover significant percentage of urban surfaces and their thermal characteristic plays dominant role in UHI formation [15–17]. During daytime, source of sunlight energy, heated the pavement surface that contributed to the heating phenomenon of the air near to the surface. Furthermore, the incoming solar radiation is absorbed and stored as heat energy by the subsurface of the pavement and it is re-released at night [18–20]. Many studies shows that this urban structures caused surface temperature and overall air temperature to increase, both during daytime and at night [21,22]. Normally, conventional pavements are made of impervious asphalt materials, which has solar reflectance values ranging from 4%–45% [23] and peak surface temperature range from 48 °C–67 °C during summer [24]. Cool-pavement is one of a promising alternative technology that can potentially minimizing the effects of UHI. One important feature of cool-pavement is it has low surface temperature, which is due to its ability to reflect high amount of incoming solar energy. This mechanism significantly reduce the amount of heat released by the pavement into the atmosphere [25]. Thus, many research that are related with application of high reflectivity materials as coating for cool-pavement technology has gained lot of interest [26–30]. Some study shows that by increasing surface reflectance of asphalt pavement using heat reflective coating, could reduce its surface temperature up to 9 °C in a hot season [31–33]. Potential material that could be used for cool-pavement coating material should consist of high solar heat reflectance compound. As mentioned by [34], the presence of crystalline minerals, such as quartz could significantly increase solar reflectance of any flat surface. Study in [35] reported that pure $SiO_2$ has contribute to 89.4% of NIR reflectance of material surface.

This study focuses in the determination of optimal mix composition of cool-pavement materials that derived from three types of wasted tiles, which are Full Body Porcelain (FBP), Monoporosa (MP) and Porcelain Glaze (PG). Study in [34] shows the presence of NIR reflective compound in thus selected tiles, such as silica dioxide ($SiO_2$), titanium dioxide ($TiO_2$) and aluminium trioxide ($Al_2O_3$). Thus, the optimization is performed based on near infrared region reflectance value as the respond factor. The outcome of this study is to obtain the optimal amount each of the types of wasted tile, by percentage, that could achieve the maximum NIR reflectance value. Final part of this study is to evaluate the tested samples with optimal performance of high NIR reflectance based on its surface temperature. This is to confirm that by increasing NIR reflectance of asphalt surface will reduce its surface temperature, thus make it applicable for cool pavement material.

## 2. Methodology

### 2.1. Materials preparation

The materials used for making coating materials consisted of three types of wasted tiles (to be mixed together) with epoxy, as binder. The three types of wasted tiles that have been selected as the main material used in the study for the newly developed cool-pavement materials, were (a) Full body Porcelain; (b) Monoporosa; and (c) Porcelain glaze. The wasted tile materials were supplied by Malaysian Mosaic Berhad (MMB), Malaysia and the Coalcut epoxy resin that was provided by Nichireki Co. Ltd., Malaysia was selected