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PHYSICAL AND CHEMICAL CHARACTERIZATION OF WASTED TILES AS COATING MATERIALS FOR PAVEMENT SURFACE TEMPERATURE REDUCTION

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Abstract: Urban heat island (UHI) is the phenomenon that temperatures in urban area reach a relatively higher value than its surroundings areas due to urbanisation. Pavement is one of the urban fabrics that contribute to UHI, due to its ability to absorb high amount of heat from solar radiation. In the tile production process, cracked or broken tile bodies are not accepted as commercial products and they are too impure to be reused and is usually discarded as unsold waste. This scenario could possibly lead to environmental problems. This study focuses on three types of wasted tiles (Full Body Porcelain, Monoporosa, Glazed Porcelain) from a chosen tile industrial factory, as coating materials for pavement surface. The main purpose of this study is to obtain specific information regarding the significance characterization of three types of wasted tiles as coating materials on pavement surface. The title characterization showed that Full Body Porcelain contains the highest bulk density value of 1366.699 kg/m^3 and highest particle density of 2580 kg/m^3, whereas Monoporosa has the highest porosity value of (56.8%) and Monoporosa posses the highest amount of void content (56.85%) between the aggregate particles. The X-Ray Fluorescence study shows that Full Body Porcelain contains the highest amount of SiO_2 (66.50 wt%), when compared to other two wasted tiles used during this study. As a conclusion these three types of wasted tiles have the potential and promising UHI mitigation benefits to be considered as coating materials for the pavement surface.

Keywords: *Wasted tiles; physical properties; chemical composition*

1.0 Introduction

One of major contributions to the urban heat island (UHI) phenomenon where warmer air temperature in urban area compared to a rural area is the properties of urban material composition that used in the urban developments. These properties affect whether the sun's energy is reflected, emitted, and absorbed (Gui *et al.*, 2007). Thus, most of the urban materials are relatively promoting solar heat absorption instead of reflectance, reduced evaporation due to their impermeability and generate higher heat storage and temperatures (Barnes *et al.*, 2001).

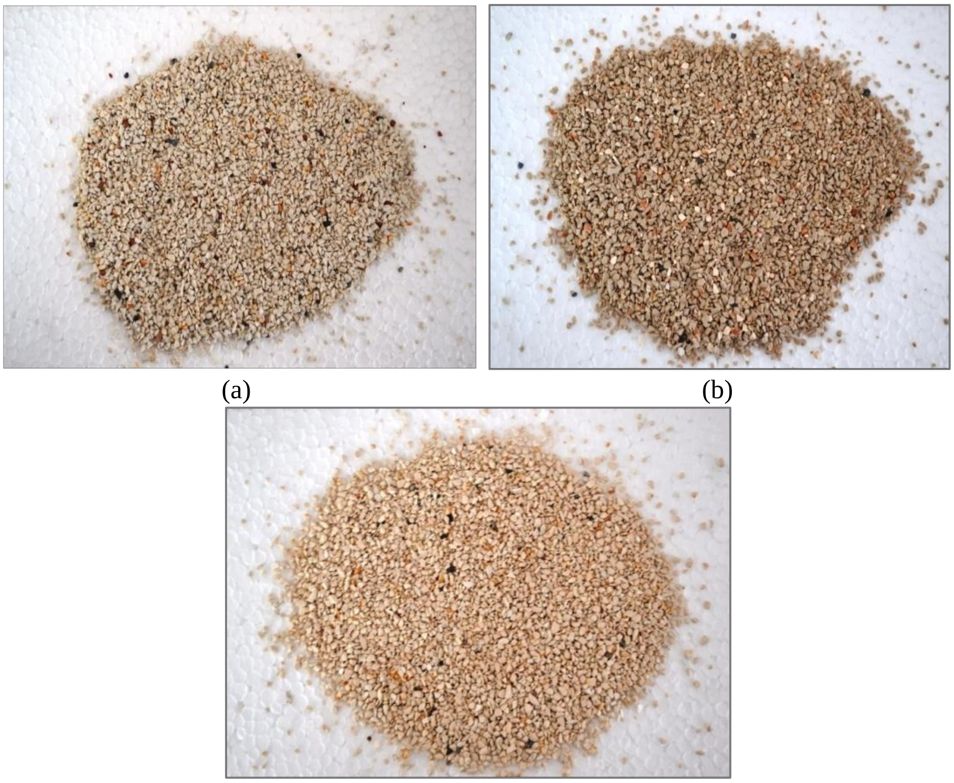
Pavement structure covers significance percentage of city skin surface, about 29 to 45% of the urban land used. An impermeable pavement surface has the tendency to absorb a massive amount of solar radiation due to its material does not encourage evaporation to occur. This condition generates the pavement surface temperature significantly higher than that of overlying atmosphere. The presence of higher amount of void content within material particles could be able to avoid creating the coating surface to be impervious condition. Thus, in permeable pavements, water passes to the asphalt pavement through the coating materials. Therefore, by using porous materials for the pavement construction, which creates water exchange between the ground surface and the deep soil layer, and subsequently allows evaporation, may be one of the most promising methods to moderate the thermal conditions of the pavement surface (Asaeda *et al*., 2000). The condition of higher porosity in coating materials in tropical country is very useful because in warm and humid climates where availability of rain water helps to keep the materials in higher moisture contents. Higher moisture contents and increased watering may keep the surface of the coating materials cooler (Yamagata, 2008).

Besides, a conventional or typical pavement is commonly made of dark colour asphalt, which is low solar reflectance or albedo (0.04 to 0.45) and absorbed large amount of heat from solar radiation during the day. Instead, the incoming solar radiation heated the surface of the asphalt has caused high surface temperature of asphalt pavement during daytime, which can reached up to 48 to 67 °C (Gaitani *et al*., 2007; Menon *et al.*, 2010). Advanced materials and surfaces, known as cool pavements, have been developed and 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). Mineral particles, such as quartz, may have high solar heat reflectance as describes by Shiao *et al*. (2013). Based on previous study, silicon oxide (SiO_2) has a high reflectivity pigment where this pigment is suitable to become the materials for cool pavement (Lavat *et al*., 2009). Another study shows that pure SiO_2 which is 100 wt%, has 89.4% of solar reflectance (Thongkanluang *et al.*, 2012). 52 percent of total solar radiation is composed of infrared (NIR) which can be felt as heat and the remaining 5 percent and 43 percent are ultraviolet (UV) rays and visible light, respectively (ASTM Standard G173, 2003).

This study aims at presenting the characterization and evaluation of three types of wasted tiles (Full Body Porcelain, Monoporosa, and Glazed Porcelain) according to its physical properties and chemical composition.

2.0 Experimental

The wasted tiles were collected from a tiles industry company, Malaysian Mosaic Berhad (MMB), which is located at Kluang, Johor. It is an established global Malaysian company that manufacturing three types of tiles products. As can be seen in Figure 1, they are Full Body Porcelain, Glazed Porcelain, and Monoporosa.



(a) (b) (c)

Figure 1: Wasted tiles of (a) Full Body Porcelain, (b) Glazed Porcelain and (c) Monoporosa

2.1 *Preparation of Tile Materials*

A sufficient amount of three types of wasted tiles materials were collected from the factory and stored separately in three containers. The materials were washed in order to remove dirt, dust or any impurities and dried in a lab-scale oven at 110ºC. Then, the tile materials were crushed to a fine-size. Finally, all crushed tile materials were sieved to obtain the particle sizes of 60µm. Figure 2 shows the flow of tile materials preparation.

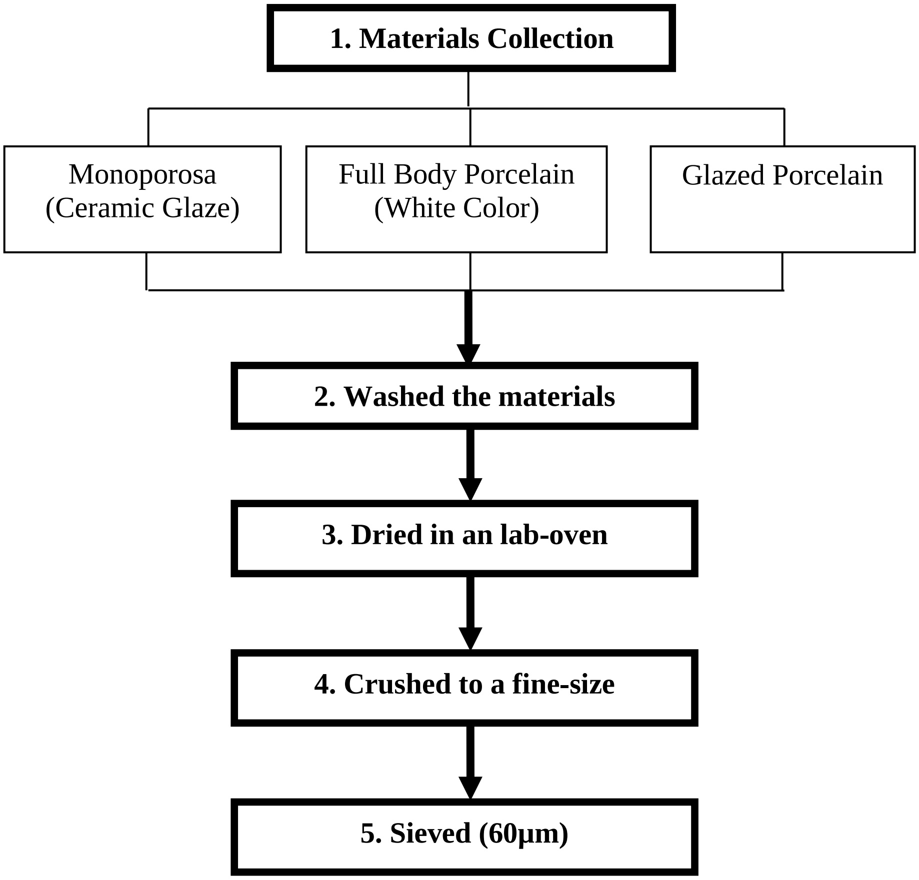


Figure 2: Preparation of Tiles Materials

2.2 Physical Characterization of Wasted Tiles Materials

In this study, physical characterization covers three measurements which are bulk and particle density, specific gravity and porosity. However among all of the measurements, porosity is the significant end result to presume which wasted tiles can perform better in reducing surface temperature of pavement as coating material.

2.2.1 Bulk Density

Bulk density is defined as the mass of a unit volume of bulk aggregate materials, where the volume is include both of individual particle volume and volume of voids between the particles. In general, a lower bulk density indicates the more looser and porous of the materials (Huq *et al.*, 2013). In order to determine the bulk density for each of the wasted tiles aggregate, the experiment was conducted and calculated in accordance with the procedures in ASTM C29 standard. The experiments were performed in triplicate and average values of bulk density were used for discussion.

2.2.2 Particle Density

The experiment of particle density was performed by using Small Pyknometer method based on BS CODE 1377 - Part 2. This apparatus and experiment procedures involve with several stage in order to obtain the value of particle density for each of the tile aggregate materials. The final value of particle density for each of the tile aggregate material is averaged from three replicated samples and should not more than 0.03 Mg/m^3 and the particle density value must be nearest 0.01 Mg/m^3.

2.2.3 Specific Gravity and Porosity

Specific gravity of any materials is defined as the ratio of its density to the density of water. In this sub-section, bulk and particle specific gravity was determined by using formulation of Eqn. 1. Finally, the results of specific gravity were used to obtain the porosity of the materials, present the amount or fraction of void content of tile aggregate material for given volume. The relationship between specific gravity and porosity of tested tiles material can be seen in Eqn. 2 (Martin *et al.*., 2013).

$$SG_{bulk/particle} = \frac{\rho_{bulk/particle}}{\rho_{water}} \quad (1)$$

$$Porosity, \eta = \frac{SG_{particle} - SG_{bulk}}{SG_{particle}} \quad (2)$$

where $SG_{bulk/particle}$ = Bulk or particle specific gravity of tile aggregate, $\rho_{bulk/particle}$ = Bulk or particle density of the tile aggregate (kg/m^3), and ρ_{water} = density of water, 1000 kg/m^3.

2.3 Chemical Characterization of Wasted Tiles Materials

This section outlines an instrumentation of X-Ray Fluorescence (XRF) analysis was used to find out the chemical compound or element in tile materials and its composition. It is an elemental analysis technique with a unique capability to determine major elements of a material highly accurately. The weight percentage (wt%) of each element that exist in each particular material were compared to the result of previous study by Thongkanluang et al. as shown in Table 1. The comparison significantly helps to predict which wasted tiles has the better degree of NIR solar reflectivity and thus contributes in reducing surface temperature of pavement as coating material.

Table 1: NIR solar reflectance values in the wavelength range from 780-2100 nm

Sample	*Solar Reflectance (%)*
Fe_2O_3	26.3
Sb_2O_3	84.8
SiO_2	89.4
Al_2O_3	98.1
TiO_2	96.0

(Source: Thongkanluang *et al*. 2012)

Each of detected elements is in 100% pure state. The sample of Full Body Porcelain, Monoporosa, and Glazed Porcelain tiles were crushed into fine powder form as shown in Figure 3. The powders were compressed in a mold to obtain the sample in a form of thin disk with a diameter of 2.7cm and thickness of 4mm. tile were sent to laboratory in Universiti Tun Hussein Onn Malaysia (UTHM), Johor, for XRF analysis.

Figure 3: Samples of X-Ray Fluorescence (XRF) analysis

3.0 Results and Discussion

3.1 Physical characterization results of the wasted tiles

The results of the bulk density and particle density of selected tiles obtained from the experimental work are shown in Table 2.

Table 2: Bulk density, particle density, specific gravity, and porosity of the selected tiles

Tiles Materials	*Full Body Porcelain (FBP)*	*Monoporosa*	*Glazed Porcelain (GP)*
Bulk Density (kg/m³)	1366.7	1042.67	1248
Bulk Specific Gravity	1.37	1.04	1.25
Particle Density (kg/m³)	2580	2416	2458
Particle Specific Gravity	2.58	2.42	2.46
Porosity (%)	47.0	56.8	49.2

As shown in Table 2, results proved that the material of Full Body Porcelain has the highest value of bulk density, which is measured up to 1366.699 kg/m^3, then followed by 1247.995 kg/m^3 for Glazed Porcelain, and the lowest is Monoporosa with 1042.669 kg/m^3. The same pattern can be seen at the particle density of the wasted tiles materials result, which presents Full Body Porcelain as the highest particle density, 2580 kg/m^3, followed by Glazed Porcelain with density of 2458 kg/m^3 and the lowest density is Monoporosa with the value of density of 2416 kg/m^3. From the comparison of the result above, particle density of tile materials is much higher than its bulk density. It shows that the presence of pores or voids could reduce the density of a material. Besides, the comparison of particle density values among three individual materials were not much differ. It is theoretically due to the texture and structure does not affect particle density (Huq *et al*., 2013). Meanwhile, there are quite large gaps of bulk density values among individual materials. It reflects the materials have different amount of pores. As mentioned earlier, the more looser and porous of the materials will have lower bulk densities. Therefore, it can be presumed that Monoporosa has more amounts of pores compared to Full Body Porcelain and Glazed Porcelain.

Furthermore, Table 2 shows the calculated values of porosity for each of the tiles aggregate which were obtained by using Eqn. 2. From the calculations, it is noted that the Monoporosa has the highest value of porosity (56.8%), while Full Body Porcelain (47.0%) shows the lowest value of porosity. The porosity of tile aggregate is one of the important aspects for coating surface as it is related with the hydraulic conductivity of the materials. It determines the amount of void content which encourages infiltration from the top surfaces. By referring to the results in Table 2, Monoporosa has high amount of void content between the aggregate particles. It signify to that 56.85% is the percentage empty space which could be possibly occupied water and air, while the rest, 43.2%, is the percentage for Monoporosa aggregate particles. For both of Full Body Porcelain and Porcelain Glaze tile materials, their structure are to be found denser and less void compared to Monoporosa. More than half of Full Body Porcelain and Porcelain Glaze tile materials volume is consisted of solid particles, 53% and 50.8% respectively.

From this part of study, it can be concluded that the presence of higher amount of void content within Monoporosa material particles is undoubtedly useful and significant in providing the coating surface to be more pervious condition. This condition promotes evaporation which subsequently contributes to a lower surface temperature.

3.2 X-Ray Fluorescence (XRF) Characterization of Wasted Tiles

This sub-section discusses the major pure elements which present in Full Body Porcelain, Monoporosa, and Glazed Porcelain. The result of XRF analysis for the chemical compound for each of wasted tiles is shown in Table 3.

Table 3: XRF results of wasted tiles

Compound	*Composition (wt %)*		
	Full Body Porcelain	*Monoporosa*	*Glazed Porcelain*
SiO_2	66.50	63.70	65.70
Al_2O_3	19.70	20.00	18.90
CaO	3.70	6.94	3.91
K_2O	3.09	2.87	3.57
Na_2O	3.13	2.63	3.83
Fe_2O_3	1.81	1.53	1.96
MgO	0.61	0.64	0.63
TiO_2	0.63	0.60	0.61
ZrO_2	0.39	0.56	0.43
ZnO	0.13	0.20	0.15

As can be seen in Table 3, generally each of tile materials have highest amount the silica oxide (SiO_2) compound compared to other elements compound. The composition of SiO_2 which presents in each tile materials are more 60 wt% and the weight percentage is dominantly higher than the other 9 elements compound. In the previous study of Thongkanluang *et al.*., 2012, the NIR solar reflectance values for pure of Sb_2O_3, SiO_2, Al_2O_3, and TiO_2 are 84.8, 89.4, 98.1, and 96.0, respectively. Therefore, these pure elements are considered high NIR reflective compound. Subsequently, this can be presumed that each of tile materials has the potential to perform high NIR solar reflectance due the presence of high amount of SiO_2. However, there is also possibility that other element compounds might contributes to NIR solar reflectance such as

Aluminium oxide (Al_2O_3) whereas the element compound presents in all tile materials and shown nearly 20 wt% of its presence. Similar to XRD results, it shows Full Body Porcelain has the highest amount of SiO_2 (66.50 wt%). This shows Full Body Porcelain could perform higher NIR solar reflectance compared to Monoporosa and Glazed Porcelain which possibly promotes lower surface temperature.

4.0 Conclusion

This study has been carried out to evaluate the physical and chemical properties of three types of wasted tiles which possibly contribute to the reduction of pavement surface temperature as coating materials. Findings show that Monoporosa has high amount of void content between the aggregate particles. For both of Full Body Porcelain and Porcelain Glaze tile materials, their structure are to be found denser and less void compare with Monoporosa. However, more than half of Full Body Porcelain and Porcelain Glaze tile materials volume is consisted of solid particles, 53% and 50.8% respectively. From physical characterization analysis, it could possibly relates that the presence of higher amount of void content within material particles contribute towards lower pavement surface temperatures through evaporation process. Moreover, the condition of higher porosity in coating materials in tropical country is very useful because in warm and humid climates where availability of rain water helps to keep the materials in higher moisture contents and cooler at once. Meanwhile, it can be also concluded that Full Body Porcelain (FBP) tile material has the highest amount of quartz (SiO_2) element compared to Glazed Porcelain and Monoporosa. The existence SiO_2 element in a material encourages high amount of the solar reflectance of NIR part in the solar spectrum. Other elements including Sb_2O_3, SiO_2, Al_2O_3, and TiO_2 are also possibly contributed to the NIR reflectance. Nevertheless, based on the findings, these three types of wasted tiles in general have the potential and promising UHI mitigation benefits as coating materials of pavement surface.

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