PALM OIL SHELL AGGREGATE AS COOL PAVEMENT BY REPLACING FINE AGGREGATE

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A thesis submitted in fulfillment of the requirement for the award of the Degree of Master of Civil Engineering

Faculty of Civil and Environmental Engineering
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DEDICATION

This thesis is dedicated for my beloved and lovely person in my life, my mother and my auntie, Mdm. Rosnah Binti Abdul Majid and Mdm. Jamaliah Binti Abdul Majid, My beloved brothers Azrul Azlan and Azril Azli and to all my friends.
ACKNOWLEDGEMENT

In the name of Allah S.W.T. the Most Gracious and the Most Merciful

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ABSTRACT

Urban Heat Island (UHI) phenomenon is due to ever increasing environment temperature in cities compared to the adjacent non-urbanized areas. One of the major contributors to UHI is asphalt pavement because of its tendency to absorb high amount of heat due to its dark color. Cool pavement is known as a paving material that can reduce surface temperature due to its ability to reflect more solar energy, enhance water evaporation and being altered to be less heat absorbent. Palm Oil Shell Aggregate (POSA) is the material that is identified as having a potential to be the cool pavement due to the presence of Near Infrared Region (NIR) reflective component and void after POSA is replaced in asphalt pavement. Therefore, the study is aimed to apply POSA material as the new cool pavement technology. The investigation involves both physical and chemical properties of POSA, physical performance of asphalt pavement and thermal performance of pavement surface temperature. Various percentage of POSA as fine aggregate replacement which are 10% (P10), 20% (P20), 30% (P30), 40% (P40) and 50% (P50) were mixed into asphalt pavement for subsequent experiment and compared with control sample (CS). The result demonstrated POSA’s particle density value at 1.6mg/m³ and specific gravity value of 1.6, fulfil the minimum requirement by AASHTO which is 1.0. The X-Ray Fluorescence (XRF) analysis showed the chemical element content in POSA are SiO₂ (46.41wt%), Fe₂O₃ (34.01wt%), Al₂O₃ (7.74wt%) and TiO₂ (0.22wt%). Thus, these pure elements of POSA are considered high in NIR reflective agent. All tested samples met the minimum requirement for Marshall stability test. All modified pavement exhibits different performances thus the least susceptibility for modified mixture in resilient modulus is P10 sample. Furthermore, results for dynamic creep show P10, P20 and P30 are recommended for heavily trafficked roads. However, P40 and P50 are more suitable in lightly trafficked road. Thermal performance showed the P50 sample obtaining highest surface temperature reduction of up to 3.29°C compared to CS during peak periods. Statistical analysis showed the ANOVA mean surface temperature indicates a significant reduction of pavement surface temperature due to increased amount of POSA as fine aggregate replacement. Overall finding concludes that P10, P20, P30, P40 and P50 as having a good potential to be used as cool material for paving based on its thermal performance on trafficked road. Thus, the material could be used to mitigate UHI and develop a new idea for cool pavement technology.
ABSTRAK

Fenomena Pulau Haba Bandar (UHI) adalah disebabkan oleh peningkatan suhu persekitaran yang tinggi di kawasan bandar berbanding dengan kawasan pinggir bandar. Turapan asfalt merupakan antara penyumbang terbesar kepada UHI kerana keupayaannya untuk menyerap haba yang tinggi disebabkan faktor fizikal warna yang gelap. Turapan sejuk dikenali sebagai bahan penurap yang boleh mengurangkan suhu permukaan kerana keupayaannya untuk memantulkan lebih banyak tenaga suria, meningkatkan proses penyejatan dan di tambah baik untuk kekal sejuk. Tempurung kelapa sawit sebagai agregat (POSA) adalah bahan yang telah dikenal pasti mempunyai potensi untuk turapan sejuk kerana kehadiran komponen pemantulan, Wilayah Inframerah Terhampir (NIR) dan kehadiran liang rongga selepas POSA digantikan dengan turapan asfalt. Oleh itu, kajian ini memberi tumpuan kepada teknologi baru tentang turapan sejuk dan prestasi terma. Kajian yang dilaksanakan termasuk sifat fizikal dan kimia POSA, prestasi fizikal turapan asfalt dan prestasi terma suhu permukaan turapan. Peratusan POSA yang berbeza sebagai pengganti agregat halus telah digunakan untuk eksperimen iaitu 10% (P10), 20% (P20), 30% (P30), 40% (P40) dan 50% (P50) dan dibandingkan dengan sampel terkawal (CS). Hasil menunjukkan nilai ketumpatan zarah POSA adalah 1.6mg / m³ dan nilai graviti spesifik adalah 1.6 yang telah memenuhi peruntukan minima AASHTO iaitu 1.0. Analisis X-Ray Fluorescence (XRF) menunjukkan unsur kimia yang terdapat dalam POSA adalah SiO₂ (46.41wt%), Fe₂O₃ (34.01wt%), Al₂O₃ (7.74wt%) dan TiO² (0.22%). Oleh itu, unsur-unsur tulen POSA ini dianggap berada pada tahap yang tinggi sebagai ejen pantulan NIR. Semua sampel yang diuji mencapai keperluan minimum untuk ujian kestabilan Marshall. Kesemua sampel turapan mempamerkan prestasi yang berlainan, dengan itu campuran yang boleh diterima dalam modulus berdaya tahan adalah campuran sampel P10. Tambahlah pula, keputusan untuk rayapan dinamik yang ditunjukkan P10, P20 dan P30 disyorkan untuk jalan raya yang banyak trafik. Walau bagaimanapun, P40 dan P50 boleh digunakan di jalan yang mempunyai trafik ringan. Prestasi terma menunjukkan sampel P50 menghasilkan pengurangan suhu permukaan yang paling tinggi iaitu sehingga 3.29°C berbanding CS semasa waktu puncak. Analisis statistik ANOVA menunjukkan suhu permukaan mengalami pengurangan suhu yang signifikan. Ini adalah disebabkan oleh peningkatan jumlah POSA sebagai pengganti agregat halus di dalam sample turapan. Secara keseluruhan, kajian mendapat bahawa P10, P20, P30, P40 dan P50 masing-masing mempunyai potensi yang baik untuk digunakan sebagai bahan sejuk dalam turapan berdasarkan prestasi haba dan beban trafik. Oleh itu, bahan tersebut boleh digunakan untuk mengurangkan UHI dan mengembangkan idea baru dalam teknologi turapan sejuk.
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<td>UHI</td>
<td>Urban Heat Island</td>
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<tr>
<td>POSA</td>
<td>Palm Oil Shell Aggregate</td>
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<tr>
<td>NIR</td>
<td>Near Infrared Region</td>
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<tr>
<td>XRF</td>
<td>X-Ray Fluorescence</td>
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<tr>
<td>SiO₂</td>
<td>Silica Dioxide</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>Iron Trioxide</td>
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<tr>
<td>Al₂O₃</td>
<td>Aluminium Trioxide</td>
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<tr>
<td>TiO₂</td>
<td>Titanium Dioxide</td>
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<td>K₂O</td>
<td>Potassium Oxide</td>
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<tr>
<td>MgO</td>
<td>Magnesium Oxide</td>
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<td>CaO</td>
<td>Calcium Oxide</td>
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<tr>
<td>Cl</td>
<td>Chloride</td>
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<td>ZnO</td>
<td>Zinc Oxide</td>
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<tr>
<td>SO₃</td>
<td>Sulphur Trioxide</td>
</tr>
<tr>
<td>Mg/m³</td>
<td>milligram per meter cubic</td>
</tr>
<tr>
<td>Wt%</td>
<td>weighted percentage</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Assessment</td>
</tr>
<tr>
<td>Mm</td>
<td>millimetre</td>
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<tr>
<td>µm</td>
<td>micro meter</td>
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<tr>
<td>PEN</td>
<td>Penetration</td>
</tr>
<tr>
<td>PWD</td>
<td>Public Works Department</td>
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<tr>
<td>HMA</td>
<td>Hot Mix Asphalt</td>
</tr>
<tr>
<td>MS</td>
<td>Malaysia Standard</td>
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<tr>
<td>BS</td>
<td>British Standard</td>
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<tr>
<td>ASTM</td>
<td>American Society for Testing Material</td>
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<tr>
<td>AASHTO</td>
<td>American Association and Transportation Official</td>
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<tr>
<td>AC14</td>
<td>Asphaltic Concrete 14</td>
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<tr>
<td>MPOC</td>
<td>Malaysia Palm Oil Council</td>
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</table>
K-Value = Thermal Conductivity
R-Value = Thermal Resistance
U-Value = Thermal Transmittance
LVDT = Linear Variable Differential Transducers
KPa = Kilo Pascal
MPa = Mega Pascal
VFB = Void Filled Bitumen
VMA = Void Mineral Aggregate
OBC = Optimum Bitumen Content
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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Human tends to live in urban areas. Day after day, the population in urban areas are increasing because of economic factors, good amenities and life getting better. Therefore, it is not surprising that the negative impacts related to urbanization are also increasing throughout the years. According to statistics made by Statistic Research Section in Australia, it is estimated that the world’s population will reach 23.8 billion people by year 2200 (Tuckwell & Koziol, 1993). Urbanized areas are directly impacted from the increase of temperature. One of the impacts is Urban Heat Island (UHI).

Urban heat island is defined as a phenomenon when the temperature in urban areas is significantly higher than its surrounding rural areas (Qin, 2015a). This phenomenon of Urban Heat Island (UHI) is mainly due to built environment such as construction industry and the concentration of human activities which are commonly referred as urbanization phenomenon. The elements which lead to the occurrence of heat island include weather, geographical location, time and day, season, types of the city and function of that city (Voogt, 2015). The warming effect from urban heat island at some area such as cities was a case of localized climate change and global warming.
(EPA, 2008). There are several methods to mitigate UHI effect such as planting trees, utilisation of light colour material, green roof and cool pavement technologies.

Cool pavements is a pavement which is either having a more reflective surface than traditional pavements, better evaporative cooling properties or other methods that allow the paved surface to remain cooler than traditional pavements (Rymer & Levine, 2011). Cool pavement is a pavement which used a material that can reflect the heat to be compared with conventional asphalt pavement which absorbed more heat. The technology of cool pavement has been introduced as the mitigation measure to this problem. Cool pavement is designed to reduce the surface temperature of the existing asphalt pavement. Various studies performed (by Anting et al., 2015; Anting et al., 2014; Gunthor, et al., 2014) are the first attempt to apply this solution in Malaysia, by using waste tile as cool pavement.

The waste tile application as the cool-pavement material can reduce about 4.4 °C compared to conventional asphalt surface temperature (Anting et al., 2014). Nowadays, researchers are drawn towards using waste material for further research in order to maximise and utilize the usually wasted material in their field for example in construction and water treatment, which can perhaps reduce environmental problem. Malaysian government are promoting green technology for corporate company via Malaysia Green Technology Corporation who certifies all products, equipment or system as green technology whether it is produced or used by the company (Ng et al., 2011).

Palm oil refining industry in Malaysia covers 4.49 million hectares of land and produces 17.73 million tonnes of palm oil (MPOC, 2016). As the industry becomes bigger and broader, a significant amount of oil palm waste is generated, causing problem of biomass waste overload, resulting in disposal difficulties and escalates the operating cost (Awalludin et al., 2015). Palm oil shell aggregate (POSA) has been utilized in research field as a replacement for construction materials such as brick and concrete (Johnson et al., 2011; Kadir et al., 2013; Liu et al., 2014), energy and solid fuel (Asadullah et al., 2014; Bazargan et al., 2014; Dit, 2005) and wastewater treatment (Okoroigwe et al., 2014).
Road surfacing is another application that can potentially gain benefit from using POSA as fine aggregate. It is recommended for heavily trafficked road, POSA can replace aggregate of stone dust and bitumen in 10% blend with asphaltic concrete (Okoroigwe et al., 2014). Therefore, the POSA was applied into pavement mix as a cool material in order to develop cool pavement technology. Besides that, the utilization of POSA waste will be diversified and help to overcome the environmental problem.

1.2 Problem Statement

Studies to reduce the UHI effect have started since a few decades ago and it is found that the implementation of cool pavement is one of the preventive solutions. Many researchers have discussed about the albedo effect on the surface of material. Previous researchers studied on the coatings, painting, tile manufacturing and design properties, with least attention to the pavement materials. On the other hand, pavement is one of the main contributors to the UHI phenomenon. About 20 - 39 % of the land surface in the city around the world are covered by asphalt pavement (Akbari, 2005). Conventional pavement made from dark colour asphalt and not contain reflective heat element hence can absorb huge amount of heat energy that can increase the pavement surface temperature. Stored heat by the pavement significantly increases the ambient temperature of the city because pavement act as a heat storage due to its dark coloured properties (Asaeda et al., 1996). Normal aggregate not contain reflective element which can reflect the heat that cause high temperature on the pavement surface.

Malaysia is the one of the world largest palm oil exporter which account to 39% of world palm oil production (MPOC, 2017a). Palm oil industries produce five types of waste from palm oil tree such as oil palm fronds, empty fruit bunch (EFB), oil palm trunks, oil palm fibre and oil palm shells (Yusoff, 2012). Similarly, countries producing and exporting palm oil faced a problem in handling the waste. The increase in production of palm oil in Southeast Asia, leads to pollution, greenhouse gas emissions and land conversion, as well as increased the operating cost (Awalludin et al., 2015; Saswattecha et al., 2015). It is imperative that, to reduce the environmental problem owing to palm oil industries, palm oil shell has a potential to be utilized in new industry. Previous study by Okoroigwe et al., (2014) stated that palm oil shell has
a potential to be used as partial replacement of aggregate in road constructions. The review from previous study shows that none of the researcher are focused on thermal performance of asphalt pavement for partial replacement fine aggregate with POSA. Therefore, this research is to study the thermal performance of the modified pavement when the mixtures are mixed with palm oil shell as fine aggregate and develop a new cool material to overcome the rise in temperature which is one of the UHI impact.

1.3 Objective of Study

The aim of this study is to evaluate the potential of palm oil shell aggregate for the application as cool pavement material. The objectives of this study are as follows:

i. To characterize the physical and chemical properties of treated palm oil shell aggregate.
ii. To determine the mechanical properties of cool pavement material using palm oil shell as fine aggregate replacement.
iii. To investigate the thermal performance of developed cool pavement materials using palm oil shell as fine aggregate replacement.

1.4 Scope of Study

Scope of study was then determined to increase the effectiveness of this research. These scopes are mainly focus on the potential of thermal performance on asphaltic concrete by using palm oil shell aggregate (POSA) as partial replacement of fine aggregate as cool pavement. Furthermore, the raw material was obtained and collected at local palm oil process factory and was prepared through several steps such as washing, drying, crushing and sieving. The physical and chemical properties of the POSA were determined. Various tests were conducted such that for physical properties, particle density and water absorption test are carried out, and soundness of fine aggregate by using magnesium sulphate. On chemical properties condition, the mineralogy identification of the produced sample material was investigated by means
of X-Ray Fluorescence (XRF) to obtain chemical composition of the material. The recorded test result was taken from an average of three tests sample.

In this study, to obtain a good proportion of the mixture by laboratory test, the Marshall design was calculated to determine the mixing ratio of aggregate and Optimum Bitumen Content to produce a high quality and good mixture for casting. This study uses Hot Mix Asphalt (HMA) as a type of mixture. The gradation limit for asphaltic concrete purposely selected from JKR/SPJ/2008 specification for Malaysian road work (JKR, 2008). The grading for nominal maximum aggregate size is 14mm. Low, medium and high traffic scenarios were selected for road traffic level. In the mix design, Penetration Grade (PEN) 80/100 as specified in Public Works Department (PWD) was selected as binder. The pavement mix material using POSA as replacement in the form of fine aggregate with the size passing 1.18mm until 75µm followed JKR specification. The pavement mix can act as cooling and reflecting material. Furthermore, to evaluate the physical performance of the asphaltic concrete after replacing POSA as fine aggregate, several tests were carried out such as Marshall test, indirect tensile resilient modulus test, dynamic creep and bulk specific gravity and porosity test. From the experiment rutting, fatigue, and maximum load was further explored.

Equally important to observe after palm oil shell aggregate (POSA) was added in the mix is the thermal performance of asphaltic concrete. The thermal performance was evaluated by using the following tests: initially thermal conductivity (K-value) test was conducted for every sample and after that, surface temperature was recorded by using data logger and thermocouple by assessing 18 samples with different percentage of POSA added which are 10%, 20%, 30%, 40% and 50%. The surface temperature then was measured for 20 days consecutively. The surface temperature of asphalt pavement was measured at Peak period for Daily period. The result of surface temperature was analysed statistically by using IBM SPSS. Table 1.1 shows the designation of Percentage POSA replacement.
Table 1.1: Samples for Percentage of POSA Replacement

<table>
<thead>
<tr>
<th>Samples</th>
<th>Percentage of POSA Replacement in Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>P0</td>
<td>0%</td>
</tr>
<tr>
<td>P10</td>
<td>10%</td>
</tr>
<tr>
<td>P20</td>
<td>20%</td>
</tr>
<tr>
<td>P30</td>
<td>30%</td>
</tr>
<tr>
<td>P40</td>
<td>40%</td>
</tr>
<tr>
<td>P50</td>
<td>50%</td>
</tr>
</tbody>
</table>

1.5 Significance of Study

The technology of cool pavement has been introduced as the countermeasure of this problem. Cool pavement has been designed to reduce the surface temperature of the existing asphalt pavement. The developed materials can reduce the surface temperature of the asphalt pavement by about 1 °C to 5 °C. The evaluation on the thermal performance of tested pavement will give the beneficial result on the temperature pattern in Malaysia. Since this technology can increase the solar reflectance of the pavement, it can help reduce the urban heat island in the city. As pavement occupies about 35% of the urban area, there is a high possibility of reducing UHI effect. In addition, the significance of this study may generate a new product from waste material such as POSA and it can contribute as environment solution product. Furthermore, this research will produce an innovative product that can possibly lower construction cost.

As a part of this mitigation plan, the exploration of cool pavement technology is possibly the best solution for an immediate effect of the problem. Therefore, this study will be conducted to evaluate the application of palm oil shell aggregate materials as an option and will be the latest. Palm oil shells aggregate are usually higher in composite materials (e.g. SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$ and TiO$_2$) that could reflect all heat energy from outside. Furthermore, the manufacturers are always having problem with the waste material produced from their processes. This could enhance the recycling of the waste material, which can be used into making other valuable
products. All concepts and cooling aspects should be suitable for any type of pavement materials.

1.6 Thesis Outline

This thesis consists of 7 chapters whereas Chapter 1 discusses on the background of the study, including problem statement and objective of research. Besides that, this chapter explained the scopes of the study followed by the significance of the research.

Chapter 2 generally presents the literature review of the introduction of UHI phenomenon such as the effect of UHI and countermeasure for this problem. After that, the pavement development and introduction to cool pavement technology were thoroughly discussed. Then, the material used for this research which is wasted POSA from palm oil industry were explained in detail. Furthermore, this chapter also provides the details on understanding heat transfer and thermal properties which is related to this research.

Chapter 3 depicted the material preparation, experimental set up and data collecting method in detail. This chapter explains the selection and preparation of cool agent material specimen which is POSA, by following Marshall method and other standards. All the tests conducted are explained in detail in this chapter.

Chapter 4 discussed the analysis for the objective 1 based on the result obtained from the experiments. This chapter were divided into two objectives which are to evaluate the physical properties of POSA and to analyse the chemical characteristic of POSA as cool agent material.

Chapter 5 explicated the analysis for objective 2. The physical performance and experimental data of asphaltic concrete for both control and modified samples were collected, discussed and thoroughly analysed in this chapter.

Chapter 6 discussed the analysis for objective 3. The results for thermal performance of control and modified samples were explained in this chapter. All the data collected on site are thoroughly elaborated in this chapter. The main objective of this research is determined in this chapter.
Lastly, Chapter 7 justifies the concluding remark of this research and determine whether the objectives of this research were achieved or not. Future recommendation is also represented in this chapter.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The most vital manifestation of the urban climate is Urban Heat Island (UHI) and it has been the subject of various researches. Many researchers are interested to study this problem because the phenomenon is complex and it varies significantly based on a daily or seasonal factors. The urban cool island was introduced by Luke Howard in his study The Climate of London (1818) (Erell et al., 2011). Pavement is one of the main contributors to urban heat island because of the physical characteristic that is dark in colour, whereby study shows that pavement can absorb high amount of sunlight heat and attain high temperature.

An overall literature review was carried out on environmental pollution associated with Palm Oil Shell. Many references were collected and reviewed regarding recycling wastes into different types of building materials. The literature was then narrowed down to a modest review concerning asphaltic concrete and a wide range of wastes was successfully incorporated into this study by previous researchers together with the associated advantages and disadvantages.


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