THERMAL BEHAVIOUR OF MIXED BLENDED ASHES AERATED CONCRETE

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To my beloved family and friends

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ABSTRACT

This research investigated the used of bottom ash and palm oil fuel ash (POFA) from Tanjung Bin Power Plant and Kahang Palm Oil Mill respectively as sand replacement to produce mixed blended ashes aerated concrete. The goal is to determine characterization and thermal behaviour of the product and to compare the best POFA ratio replacement with existing commercial products. POFA was used as sand replacement at 0%, 10%, 20% and 30% by weight with fixed amount of bottom ash. A small-scale wall structure models was developed to study thermal behaviour of product through conduction and convection mechanism heat transfer for seven sunny days at 24-hour. The result showed that thermal conductivity of P30% achieved 0.48 W/mK, 81% lower than conventional concrete. P30% gave the best insulation result among different POFA ratio replacement with 122 minutes in time lag. As for the comparison with commercial aerated concrete, P30% achieved fastest thermal absorption rate with an hour earlier to reach absorption peak and 50% more in thermal mass. This gave better indoor thermal comfort. P30% also exhibited fastest adiabatic state rate with two hour earlier compared to commercial aerated concrete. Good insulation property also gave better result in lessen Urban Heat Island effect at night. However, the stored heat inside the wall contributed towards hotter indoor temperature compared to commercial aerated concrete. Further study in building design alteration might help in mitigating this drawback such as providing better air circulation with cooling chimney and window.

ABSTRAK

Kajian ini menyiasat penggunaan abu bawah dan abu sisa bahan api minyak sawit (POFA) dari Tanjung Bin Power Plant dan Kahang Palm Oil Mill sebagai pengganti pasir untuk menghasilkan konkrit berudara berasaskan campuran abu. Matlamat kajian adalah untuk menentukan karakter dan sifat termal produk serta nisbah terbaik POFA berbanding produk komersial sedia ada. POFA digunakan sebagai pengganti pasir pada berat 0%, 10%, 20% dan 30% dengan jumlah abu bawah yang tetap. Model struktur dinding berskala kecil telah dibina untuk mengkaji sifat termal produk melalui mekanisma pemindahan haba konduksi dan perolakan selama 7 hari yang panas dalam tempoh 24 jam. Keputusan menunjukkan nilai konduktiviti termal P30% mencapai 0.48 W/mK, 81% kurang daripada nilai konduktiviti konkrit konvensional. P30% memberikan keputusan terbaik penebat bagi POFA berlainan nisbah penggantian dengan masa tangguhan selama 122 minit. Bagi perbandingan dengan konkrit berudara komersial, P30% mencapai kadar penyerapan termal terpantas dengan mencapai puncak penyerapan satu jam lebih awal dan 50% lebih banyak jisim termal. Ini memberikan keselesaan termal dalaman yang lebih baik. P30% juga mempamerkan kadar keadaan adiabatik terpantas dengan dua jam lebih awal berbanding konkrit berudara komersial. Sifat penebat haba yang bagus juga memberikan keputusan yang lebih baik dalam mengurangkan kesan Pulau Haba Bandar di waktu malam. Walau bagaimanapun, haba yang tersimpan di dalam dinding memberikan bacaan suhu dalaman yang lebih panas berbanding konkrit berudara komersial. Kajian lanjut melibatkan pengubahan reka bentuk bangunan mampu membantu dalam mengatasi kelemahan ini seperti menyediakan peredaran udara yang lebih baik melalui cerobong penyejuk dan tingkap.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UHI	-	Urban Heat Island
POFA	-	Palm Oil Fuel Ash
CB	-	Control Bottom Concrete
CS	-	Control Sand Aerated Concrete
Al	-	Aluminium
$Ca(OH)_2$		Calcium Hydorxide
H_2O	-	Water
CaO	-	Calcium Oxide
Al_2O_2	-	Aluminium (II) Oxide
SiO_2	-	Silica
Al_2O_3	-	Aluminium Oxide
Fe_2O_3	-	Ferric Oxide
MgO	-	Magnesium Oxide
K_2O	-	Potassium Oxides
SO_3	-	Sulfur Trioxide
H_2	-	Hydorgen
P0%	-	Aerated Concrete with 0 percent of POFA
P10%	-	Aerated Concrete with 10 percent of POFA
P20%	-	Aerated Concrete with 20 percent of POFA
P30%	-	Aerated Concrete with 30 percent of POFA

LIST OF SYMBOLS

SYMBOL	QUANTITY	UNIT
$\acute{\varepsilon}$	Emissivity	
σ	Stefan-Bolltzmann coefficient (5.67 × 10−8)	$Wm^{-2}K^{-4}$
T_s	Surface Temperature	°C or K
T_a	Ambient Temperature	°C or K
S_r	Solar Radiation	Wm^{-2}
RH	Relative Humidity	%
E	Energy of Radiation	W/m^2
T	Temperature	°C or K
A	Area of the Surface Material	m^2
q_{rad}	Heat of Radiation	W or J/s
q_{conv}	Heat of Convection	W or J/s
q_{cond}	Heat of Conduction	W or J/s
K_{conv}	Convection Heat Transfer Coefficient	$W/ m^2.K$
N_{GR}	Grashof Number	
L	Length in Vertical Planes	m
ρ	Density	kg/m^3
g	Acceleration of Gravity (9.80665)	m/s^2
β	Volumetric Coefficient of Expansion of Fluid	K

$1/(T_{film}) = 1/(T_s+T_a)$

ΔT	│Positive Temperature Different between the Wall and Bulk Fluid│	°C or K
μ	Viscosity	kg/m.s
N_{PR}	Prandtl Number	
C_p	Heat Capacity	J/kg.K
k	Thermal Conductivity	W/m.K
x	Thickness	m
T_o	Outdoor Temperature	°C or K
T_i	Indoor Temperature	°C or K
T_{ao}	Outdoor Ambient Temperature	°C or K
T_{ai}	Indoor Ambient Temperature	°C or K
T_{so}	Outdoor Surface Wall Temperature	°C or K
T_{si}	Indoor Surface Wall Temperature	°C or K
dT_s	Surface Wall Temperature Difference	°C or K

CHAPTER I

INTRODUCTION

1.1 Background of the Study

Building energy efficiency is vital aspect in construction industry as it is related closely with the consumption of energy such as electricity, utilization of natural resource and effect towards climate change. It is undeniable that building con suming huge amount of energy, especially in terms of electricity and cooling utilities to ensure human comfort inside the building, as studied by Gershenfeld, et al. in 2010, where approximately 40% of primary energy is used for buildings in the United States, while more than 70% from this percentage is for electricity generation of buildings. Additionally, several studies on how to consume energy efficiently were made, and one of the focal point is the research on the building material itself.

The goal of research in building material is to find the suitable material that will consume less energy in order to meet the requirement of internal thermal comfort while at the same time avoiding global warming phenomenon such as Urban Heat Island (UHI). The building materials that cause distinctive heat transfer are crucial in mitigating towards controlling the UHI effect. The higher the specific heat, the more resistant the substance is to changes in temperature. Hence, materials with low specific heat will have more influence over the UHI. Heat transfer occurs through conduction, convection and radiation. As the molecules of the structures absorb the radiant energy, the temperature difference that take place will create a molecular motion, which results in the behavior of heat.

Urbanization transformation initiated by human being from agricultural-based rural area to man-made infrastructures without a doubt is the crucial factor behind the significant rise of temperature in urban areas. The impact of buildings materials is one of the main contributors of environment issues in cities related to heat, besides the heat caused by the adsorption of solar radiation by roads and other subsurface materials during daytime.

Urban climate is characterized as hotter, humid, pollution known as Urban Heat Island (UHI). Absorption, re-radiation of heat from surface of built environment, and emission of artificial heat through combustion is one of major effect of Urban Heat Island phenomenon. This elevated temperatures phenomenon associated to developed areas more compared to rural surroundings as high-density urban areas are compacted with excessive tall buildings that experience higher air temperature than its surrounding (heat island) due to the accumulated solar heat from inter-reflection and re-radiation from ground surfaces, building envelopes and wall surfaces (Santamouris, 2013). Building materials seems to escalate the impact towards this phenomenon. Hence, the building materials should be chosen based on human comfort temperature while considering material heat capacity.

Basically, heat transfer occurred in three ways, which are conduction, convection and radiation. The occurrence of heat transferred through wall also influenced by several thermal properties of building materials such as thermal conductivity, thermal resistance and thermal mass. During daytime, solar radiation drives heat through building envelopes while during night time, the stored heat inside the building is being released to environment. These discomfort condition towards people in the building due to thermal balance leads to widely utilization of air conditioner, hence, may rise cost of electricity caused by consumption of energy for cooling purpose and contribute towards carbon emission, which may increase the carbon footprint. Indirectly, this results in increases of peak electricity demand (Santamouris, et al., 2013).

The excess usage of cooling energy to maintain human comfort index leads to higher emissions of oxides group as well as carbon dioxide which is one of greenhouse gases that contribute in global warming. While, the production on an abundance of waste ashes generated from Coal Power Plant and Palm Oil Mill may create possibility of soil pollution due to its heavy metals content while dispose it into landfill. Therefore, instead of creating a waste, these ashes can be used as a new resource for building materials, in this case, as the main ingredients in multiple blended ashes aerated concrete. This prospect is not only can be seen as a resolve towards environmental benefit, but also as a means to mitigate issues regarding human comfort due to building material. By using recycled materials, it will create a better flow, low cost and environmental benefits (Mahlia, et al., 2010).

This study focused on aerated concrete, which is a building material that was considered to mitigate the effect of UHI due to its good thermal properties even without the aid of insulation. In general, aerated concrete consists of quartz-rich sand, hydrated lime, cement and aluminium powder. Aluminium powder was added to produce hydrogen gas when it reacts with calcium hydroxide. The hydrogen gas basically produced a stable air bubbles in slurry form. This production of air bubbles or air voids leads to higher porosity. Aerated concrete absorbed large amounts of radiant energy and slowly releases this thermal energy to the surroundings. It has such advantages as soil saving, energy saving, easy construction, and simple production process (Yang, et al., 2012). Mixed blended ashes aerated concrete is a lightweight concrete with low bulk density ranging of 400-900 kg/m^3, having low thermal conductivity, low shrinkage and high heat resistance. The low density property give reduction of dead load, faster building rate and have a lower haulage cost.

In this study, the approach on material as wall non-load bearing application was identified through its thermal behavior. At the end of the project, it was found that, the developed material was not only good for reducing the heat flux from entering into the building, but it also can be used as the precast wall or panel wall, with lightweight features or as non load bearing construction material.

1.2 Aim and Objectives of the Study

The purpose of the project is to choose the best building wall material from selected materials based on its characteristics and thermal performance. Characterization of the material includes both engineering and thermal properties. This study of product development is expected to help in enhancing the features of environmental friendly framework, energy savings and future construction applications.

As a summary, the following objectives of the study were listed out to meet the aim of study:

(i) To determine characterization of material with different percentage of Palm Oil Fuel Ash (POFA)

(ii) To investigate thermal behavior for materials with different percentage of POFA.

(iii) To analyze thermal behavior of optimum percentage of POFA compared to existing commercial products.

1.3 Scope of the Study

The thermal study was carried out at outdoor environment that was suitable to measure the ambient and surface temperature as well as the humidity. Six set of concretes with difference in thermal and engineering propeties was set up in a small-scale prototype. These prototypes were placed on the parking lot at Universiti Teknologi Malaysia, Skudai. The difference in the surface temperature and heat flux was measured. As for the study of engineering and structure properties, several tests were performed at Structural and Material Laboratory, UTM as well as laboratory at Malaysian Palm Oil Board, Bangi.

The materials utilized in this study were listed as below:

(i) Aerated concrete block with different percentage of POFA (0%, 10%, 20%, 30%) as sand replacement.
(ii) Control sand concrete block.
(iii) Commercial aerated concrete block.
(iv) Red brick.

The measured parameters in this study were stated as below:

(i) Thermal conductivity, k (W/mK).
(ii) Heat flux, q (W/m^2) (conductive and convective heat tranfers).
(iii) Temperature, T (^0C).
(iv) Thermal graphic.
(v) Density, ρ (kg/m^3).
(vi) Percentage of air void (Porosity), %.
(vii) Water absorption, %.

1.4 Significance of the Study

This study was expected to prove the effectiveness of multiple blended ash aerated concrete consists of abundance waste ashes as building material in reducing surface temperature in order to achieve thermal comfort while reducing urban heat island phenomenon. The details of several justification points of this study were as follow:

(i) High heat storage capacity during the day prevents heat from transmitted inside building area while avoiding Urban Heat Island (UHI) phenomenon at night.

(ii) Longer time lag contributing towards better wall insulation with low thermal conductivity.

(iii) Reduction of load for massive structure since it is a lightweight concrete with less dense structure.

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