INVESTIGATION OF GREEN FOAMED CONCRETE INCORPORATING PALM OIL FUEL ASH AND EGGSHELL ASH AS PARTIAL CEMENT REPLACEMENT

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DEDICATION

I would like to dedicate this work to my parents Rafique Ahmed and Badarunisa, my wife Arifa, and my cousins Mansoor Ul Haque and Tahir, without their support, this work would not have completed in time.

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ABSTRACT

The tendency of concrete to absorb heat, high thermal conductivity and self-weight due to its high density, and its extensive use has given rise to Urban Heat Island (UHI). Therefore, this study was carried out to provide a solution to these limitations by developing innovative lightweight green foamed concrete (GFC) of 1800 kg/m^3 density incorporating Palm Oil Fuel Ash (POFA) ranging from 20% to 35% and Eggshell Ash (ESA) from 5% to 15% as partial cement replacement. The effect of partial replacement on the workability was determined by J-ring test, mechanical properties such as, compressive and tensile strengths as well as modulus of elasticity and thermal performance of GFC was determined by thermal conductivity and surface temperature. Based upon the results, it was observed that the combined utilization of POFA and ESA reduced the workability slightly but enhanced the mechanical properties of GFC such that it can be used for structural applications. It was also observed that 25P5E, a total 30% cement replacement, was the optimum mix at which the maximum compressive and higher tensile strength, though up to 40% cement replacement can be done without any loss in strength. With the addition of POFA, the colour of specimens became blackish, thus due to albedo effect, these samples recorded higher surface temperature, though the surface temperature reduced slightly with the increment of ESA content. The inclusion of POFA and ESA in GFC reduced the thermal conductivity value. The combined utilization of POFA and ESA in the development of GFC contributes not only to reduction of dependency on cement for manufacturing of concrete but also towards the development of sustainable buildings which reduce the use of natural resources while at the same time provide beneficial mean for utilization of waste materials instead of disposing in landfills which causes scarcity of land and environmental issues.

ABSTRAK

Konkrit cenderung untuk menyerap dan mengalirkan haba serta **mempunyai** ketumpatan yang tinggi. Konkrit di dalam kawasan bandar menyebabkan wujudnya Pulau Haba Bandar (*urban heat island* - UHI). Justeru itu, kajian inovasi terhadap konkrit ringan berbusa hijau (*green foamed concrete* - GFC) pada ketumpatan 1800 kg/m^3 yang menggabungkan abu terbang kelapa sawit (POFA) dari 20% hingga 35% dan abu kulit telur (ESA) dari 5% hingga 15% sebagai bahan gantian separa pengganti simen. Kesan penggantian separa simen pada kebolehkerjaan konkrit telah ditentukan melalui ujian J-ring. Manakala, sifat-sifat mekanikal seperti kekuatan mampatan, kekuatan tegangan, modulus keanjalan dan prestasi terma yang ditentukan oleh daya pengaliran terma dan suhu permukaan. Berdasarkan hasil kajian, diperhatikan bahawa penggunaan gabungan POFA dan ESA mengurangkan kebolehkerjaan dan meningkatkan sifat-sifat mekanikal GFC yang dapat diaplikasikan pada struktur binaan. Campuran 25P5E, iaitu penggantian simen sebanyak 30%, merupakan campuran yang optimum berdasarkan nilai kekuatan tegangan mampatan yang lebih tinggi. Manakala, penambahan POFA telah menyebabkan warna sampel menjadi hitam dan suhu permukaan lebih tinggi disebabkan kesan albedo dan apabila berlaku penambahan kandungan ESA, seterusnya sampel menunjukkan suhu permukaan berkurangan. Ia juga mengurangkan daya pengaliran terma apabila berlaku penambahan kuantiti POFA dan ESA dalam GFC. Campuran POFA dan ESA telah memberi manfaat dalam pembangunan GFC yang bukan hanya mengurangkan kebergantungan pada penghasilan simen malah memberi manfaat terhadap pembangunan yang lestari yang dapat mengurangkan penggunaan sumber asli. Lanjutan dari itu, ia dapat menyumbang manfaat terhadap bahan buangan sisa pepejal dengan mengurangkan kawasan pelupusan dan seterusnya melestarikan alam sekitar.

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LIST OF ABBREVIATIONS

Al_2O_3	-	Aluminum trioxide
ASTM	-	American Standard Test Method
BCA	-	British Cement Association
BS	-	British Standard
CaO	-	Calcium oxide (lime)
$Ca(OH)_2$	-	Calcium hydroxide
CO_2	-	Carbon dioxide
C-S-H	-	Calcium silicate hydrate
ESA	-	Eggshells ash
Fe_2O_3	-	Ferric oxide (iron)
FKAAS	-	Faculty of Civil and Environmental Engineering
GFC	-	Green foamed concrete
K_2O	-	Potassium oxide
LOI	-	Loss of Ignition
MgO	-	Magnesium oxide
MPa	-	Mega Pascal
Na_2O	-	Sodium oxide
OPC	-	Ordinary Portland cement
POFA	-	Palm oil fuel ash
PSD	-	Particle size distribution
SCM	-	Supplementary cementitious materials
SEM	-	Scanning electron microscope
S_g	-	Specific gravity
SSA	-	Specific surface area

SiO_2	-	Silicon dioxide (silica)
SO_3	-	Sulfur trioxide (sulfuric anhydride)
UHI	-	Urban heat intensity
UTHM	-	Universiti Tun Hussein Onn Malaysia
w/b	-	Water – Binder
w/c	-	Water – Cement
XRF	-	X-Ray fluorescence

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CHAPTER 1

INTRODUCTION

1.1 Background

Concrete, being an artificial building material, has revolutionized the way that the human beings have been building the structures. Due to its flexibility and durability, its popularity has kept on increasing over the years. Concrete is an artificial composite whose ingredients are cement, aggregates and water (Jin & Chen, 2013). Its long life, fire-resistance and low maintenance are the reasons that has increased the use all over the world. But one of the main problem that concrete has is, its low strength-to-weight ratio. Normal weight concrete's density varies from 2200 to 2600 kg/cm^3 (Rafi *et al.*, 2014) and this high density adds self-weight to the structure. By reducing the density of concrete, it will become economical construction and will help in reducing the cost of transportation, handling and constructability. One way to make concrete reduce its self-weight is to make it lighter by introducing light-weight aggregates and foaming agent. Light-weight concrete is an innovative concrete in which a foaming agent is used to introduce air bubbles in such a way that the volume of the mixture is increased. This introduction of air bubbles significantly reduces self-weight. The light-weight concrete can be made up to 87% lighter as compared to the normal concrete and its density typically ranges from 300 to 1840 kg/cm^3 (Mohamad *et al.*, 2015).

Foamed concrete is an innovative concrete which can be produced on construction site by mixing cement, sand, water and a stable foaming agent. Due to its reduced self-weight, excellent thermal insulation and self-compacting and levelling nature, foamed concrete has attracted many in the construction industry for various applications. With the ever-growing focus towards improving the sustainability of buildings, the demand for lightweight materials has increased, allowing foam concrete to present itself as a suitable as well as reliable material for sustainability. Due to this, many countries have started utilizing foamed concrete in the development and of precast blocks in construction (Jones, Ozlutas & Zheng, 2016). Besides having low density, foamed concrete over the years has shown excellent performance in thermal and acoustic insulation.

With the gradual increase in temperatures across the world due to the global warming and urban heat island (UHI) effect, the utilization of foamed concrete panels as thermal insulating element in the building is not only an innovative concept but also, it's relevant. The UHI is a phenomenon observed in metropolitan areas, where the average urban temperatures are slightly warmer than adjacent rural areas. High thermal energy of the buildings and paving materials is the main factor for the development of UHI in metropolitan cities nowadays, which subsequently increases near surface temperatures because of their increased thermal energy content. The ambient temperature in the cities is approximately 2^{o}C hotter than the surrounding rural areas. Meanwhile, in the highly densely populated areas are warmer up to 7^{o}C than their adjacent rural areas (Shahmohamadi *et al.*, 2011). This rise in temperature can occur during the daytime as well as in the night-time. During the daytime concrete (walls and roof slabs) and asphalt will absorb solar energy while at night time release the heat. Hence, it causes temperature difference between urban cities and its surrounding rural area (Bristow, Blackie & Brown, 2012).

1.2 Problem statement

Due to its high density, the normal weight concrete indirectly increases the permanent load of the building in the form of self-weight as well as its thermal conductivity. The thermal conductivity of 2240 kg/m^3 has been reported to be 1.3 W/mK (Soebarto, 2009). Being thermal conducive, the concrete surfaces absorb heat from the sun in the form of solar radiation instead of reflecting it, which causes the surface temperatures and ambient temperatures to increase.

Malaysia, a tropical country that lies on the equatorial region, receives more heat as its climate remains mostly warm and humid throughout the year. According to the previous research (Elsayed, 2012), the intensity of UHI in Kuala Lumpur is varied from 3.9 to 5.5°C. This UHI effect is influenced by the concentrations of infrastructures that are built using concrete and its tendency to absorb heat.
Apart from this, concrete is known to have carbon footprint, due to its main ingredient cement. With the rapid urbanization, the demand for cement has been on the rise. But during the production of cement, the cement industry releases CO_2 emissions which account to 7% of the global CO_2 emissions (Benhelal *et al.*, 2013). Nowadays, to reduce the dependency of cement, researchers have focused on the utilization of supplementary cementitious materials especially waste by-products as partial replacement of cement.

The utilization of agricultural wastes as cement replacement is an innovative way to reduce the production of cement as well as produce green concrete. With the rapid urbanization and industrialization, generation of waste materials has increased significantly, and disposal of such waste has become an environmental catastrophe. Malaysia is one of the largest palm oil producers and exporters in the world, generates approximately 4 million tonnes of a waste product known as Palm Oil Fuel Ash (POFA) annually (Zamri & Muthusamy, 2016; Sooraj, 2013). This hazardous material is usually sent to be disposed at landfills without any commercial gains.

Another, major agricultural waste which is produced in large quantity is eggshells. In 2012, 9.35 billion eggs were consumed in Malaysia according to Malaysia Veterinary Department and estimated to increase over the years with an increase of 400 million per year. Eggs are a cheap source of nutrition and eggshells are waste product of eggs which ultimately end up in landfills without proper treatment, causing significant environmental pollution. With continuous disposal of waste materials, Malaysia is facing severe environmental issue regarding landfilling. The number of landfills has increased exponentially from 49 in 1998 to 161 in just 4 years (Yu, Ing & Choo, 2017).

By reducing the density of concrete, it will become economical construction, and can solve the self-weight and the high heat transfer problems. The foamed concrete is an ideal solution for these limitations of normal weight concrete, and with the utilization of agricultural wastes such as POFA and Eggshell Ash (ESA) as partial cement replacement a green foamed concrete can be developed. POFA has been used as an additive in foamed concrete of 1000 kg/m^3 density, it has shown that it reduces the thermal conductivity slightly as compared to the controlled specimen (Ganesan *et al.*, 2015). Incorporation of POFA and ESA in green foamed concrete will not only partially replace the cement content but also have thermal insulation properties which is the need of the hour in urban cities due to UHI effect.

1.3 Aim and objectives of study

This innovative experimental study aims to develop an 1800 kg/m^3 green foamed concrete incorporating agricultural wastes (POFA and ESA) as partial cement replacement and improve its thermal performance. Therefore, the objectives of this research study are:

1. To determine the physical and chemical properties of POFA and ESA.
2. To investigate the fresh state properties, mechanical properties and micro-structural analysis of green foamed concrete.
3. To obtain the optimum mix of green foamed concrete incorporating POFA and ESA.
4. To identify the thermal performance in terms of surface temperature and thermal conductivity of green foamed concrete.

1.4 Scope of the study

The study was conducted to develop green foamed concrete by incorporating agricultural wastes such as POFA and ESA. Since the green foamed concrete is intended to be used as structural light-weight concrete, therefore, trial mix was conducted to determine the suitable target density. Through the initial mix trials, it was determined that 1800 kg/m^3 can achieve significant strength which is the minimum required for structural light-weight concrete, therefore, the dry density of 1800 kg/m^3 was targeted for the green foamed concrete.

The utilization of cementitious materials and their possible effects and reactions during the chemical action can be better understood if the physical and chemical properties of the cementitious materials are known. Therefore, physical properties such as the specific gravity and particle size analysis while chemical analysis using X-Ray Fluorescence (XRF) were determined. The mechanical properties were determined of green foamed concrete incorporating ESA as partial cement replacement. From previous studies, it has been determined that POFA can be used up to 20% in lightweight concrete, therefore, in this research 20% to 35% POFA while 5% to 15% ESA content by weight of cement was used. 1800 kg/m^3 dry density was targeted for the green foamed concrete for this experimental study.

The J-ring test was employed to determine the effect of POFA and ESA on the flowability (workability) of fresh green concrete. Eighty-four (84) Cubes, having dimension of 100 x 100 x 100 mm, were cast (42 cubes each for 7 days and 28 days strength) for determining the compressive strength. Forty-two (42) cylindrical samples of 200 x 100 mm dimension were utilized for determining the splitting tensile strength as well as the modulus of elasticity of green foamed concrete. The micro-structural analysis was conducted by scanning electron microscopy (SEM) of crushed sample collected after compressive strength testing to study the effect of POFA and ESA on the concrete on a micro-structural level.

Forty-two (42) panel specimens, of 300 x 300 x 50 mm dimension, were used to conduct the thermal conductivity test. The surface temperature and the ambient temperature were measured to understand the effect of intensity of solar radiation on the green foamed concrete. Based upon the compressive, tensile and thermal performance the optimum mix containing POFA and ESA in green foamed concrete was determined.

1.5 Significance of study

In this day and age of global warming, the society faces critical challenges and the demand for energy saving materials in the construction industry is increasing. To reduce the use of energy and enhancing the comfortability of indoor environments, proper building materials are to be selected which can perform as thermal insulation (Ganesan *et al.*, 2015) and heat transfer through the material. The UHI effect causes significant increase in the temperature in the urban areas. Excellent thermal insulating properties makes foamed concrete, a potential substitute to normal weight concrete to counteract the raise in temperatures in the cities due to UHI. This research focuses on the development of green foamed concrete, having cement partially replaced by waste products, reduce the heat transfer and as such counteract the UHI which is increasing difference in temperature between the urban and its adjacent rural areas.

Cement is an important constituent of concrete and is widely used across the world. Although with all its benefits and advantages, the production of cement has some negative impacts on the environment. The production of cement is one of the sources of emission of CO_2, contributing to approximately 6% of the global emission of CO_2 (Zhang *et al.*, 2014). Considering this emission of CO_2, this research aims at partially substituting cement with waste products, which also cause environmental problems due to their disposal and scarcity of land. The partial supplement of cement will help in reducing the production of cement and ultimately reduce the emission of CO_2, while also contribute towards the reduction of ESA and POFA's negative impact on the environment and provide a beneficial means instead of disposing in landfills. It will be able to provide useful information and exposure in the thermal properties of green foamed concrete since the data and statistic in this field is still limited. In addition, this study can help in providing idea and vision to other researchers or engineers in potential application of green foamed concrete.

This research output will also contribute towards sustainability of available material resources and environmental protection through natural materials reduction in usage. The pool of knowledge created in this area will serve as further references for other researchers through publications, conferences and seminars.

1.6 Thesis layout

This thesis covers the experimental study conducted in six (06) chapters. Chapter one provides a brief background related to this study and problems faced. The chapter also presents aim and objectives, scope, significance of study and layout of report.

Chapter two discusses about light-weight foamed concrete and its advantages over normal weight concrete, utilization of supplementary cementitious materials which include POFA and ESA, and the innovative idea of green foamed concrete containing POFA and ESA rises from the environmental issues caused by the production of cement and the UHI effect in urban areas.

Chapter three illustrates the research flowchart associated to this experimental work involved in this experimental study. It contains the materials used and their preparation, detailed mix proportions, mixing procedures, curing as well as various tests regarding this study are discussed.

Chapter four presents the results obtained and is analysed to provide discussion of the results. The physical and chemical properties of POFA and ESA are discussed. While the effect of partial cement replacement by utilizing POFA and ESA on the fresh and hardened state properties of green foamed concrete is also discussed. The thermal performance is also discussed of green foamed concrete.

Chapter five concludes based upon the results obtained and provides recommendations for further research related to the development of green foamed concrete incorporating POFA and ESA.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents brief background related to this research study. The innovative idea of green foamed concrete containing POFA and ESA rises from the environmental issues caused by the production of cement and the UHI effect in urban areas. Foamed concrete, per previous studies, have excellent thermal properties, while POFA and ESA can be used as supplementary cementitious materials to minimize the use and production of cement ultimately tackling the emission of CO_2 issue and produce green foamed concrete.

2.2 Concrete

Concrete is unarguably, the most important and useful material, as it is considered as the backbone of any country's infrastructure. It is one of the widely preferred construction material in the world. It has vast application, ranging from making roads to building skyscrapers, from use in construction of dams to nuclear structures. Due to its flexibility, durability, versatility and sustainability, popularity of concrete has kept on increasing over the years. Concrete's long life, fire-resistance and low maintenance are the reasons that has increased the use all over the world. The durability aspect and strength characteristics of concrete is significantly influenced by the constituents and the proportions of mix (Gambhir, 2013).

Concrete is made up of four basic ingredients: water, cement, fine and coarse aggregate (Jin & Chen, 2013). The use of concrete has improved the way our structures are built and have better durability and life-cycle, but it has also brought some disadvantages and some serious impacts on the environment. With demand of concrete increasing day by day ever since its inception, the production of cement also increases. During the production of cement significant CO_2 gas is released which negatively impacts the environment by contributing to the global warming. Due to high density of normal weight concrete which ranges from 2200 to 2600 kg/cm^3, concrete has self-weight making the it uneconomical structural material. It is also due to the high density of concrete, that it has high thermal conductivity value, absorbing more solar radiation contributing to UHI.

2.3 Limitations of normal weight concrete

Although concrete is second most consumed substance on in the world, it has some disadvantages. One of the main disadvantages is its low strength-to-weight ratio. Density of concrete ranges from 2200 to 2600 kg/cm^3 (Rafi *et al.*, 2014) and this high density adds self-weight to the structure. The increased self-weight in concrete is attributed to the existence of coarse aggregates. The self-weight in the form of dead load puts permanent stress on the building. The foundations of the building have to consider the self-weight of structural and non-structural components built using concrete, thus increasing the constructional cost.

The high thermal conductivity value of normal weight concrete is also considered as a limitation of concrete, as the thermal conductivity is the property of a material which allows heat from hot region to cold, in this case, from exterior to the interior of the building, which causes thermal discomfort. Along with high thermal conductivity, the concrete has the tendency to absorb and store the heat energy from solar radiation and then release it back into the atmosphere. This causes the rise in urban temperatures and gives birth to UHI effect. The extensive use of concrete in the construction of concentrated infrastructures which has relatively increased the temperatures of the urban areas than the surrounding rural areas.

Another limitation of normal weight concrete is due to its main ingredient, cement. The manufacturing of cement is the leading CO_2 producing industries of the world. While each constituent of concrete has its own importance, cement plays a

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