INFLUENCE OF PALM OIL FUEL ASH (POFA) TOWARDS THE PERFORMANCE OF KERNELRAZZO CONCRETE

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by

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DEDICATION

I dedicate this dissertation to almighty Allah, my lovely wife and children Bldr. (Mrs.) Oluwatoyin E. Olanrewaju, Halimat Yetunde, Abdulzahir Folarin, Maryam Abimbola, Zainab Ifeoluwa and Genimat Bolanle for their advice, patience, support, sacrifices, and prayers during this long journey. And to my beloved family and friends for their continuous encouragement and unconditional support to me, may Allah provide them strength and health.

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LIST OF SYMBOLS

Al_2O_3	Aluminium oxide
C_3S	Tricalcium silicate
$Ca(OH)_2$	Calcium hydroxide
Ca+	Calcium ion
Ca_3SiO_5	Tricalcium silicate
CaO	Calcium oxide
C-S-H	Calcium silicate hydrate
Fe_2O_3	Iron III oxide
J/kg.K	Joule per kilogramme Kelvin (Material specific heat capacity)
J/kg.K	Joule per kilogramme Kelvin (Material specific heat capacity)
K2O	Potassium oxide
kg/m^3	Kilogramme per cubic metre (Material density)
$kJ/K.m^2$	Kilojoule per Kelvin square meter (Daily effective thermal inertia, floor area)
m^2 /kg	Metre square per kilogramme (Blain fineness)
m^2/m^2	Meter square per meter square (Surface area, Floor area)
m^2/s	Meter square per second (Thermal diffusivity)
MgO	Magnesium oxide
MPa	Mega Pascal
Na_2O	Nitrogen dioxide
Ø	Diameter
SiO_2	Silicon dioxide
SO	Sulphur 0xide

SO_3	Sulphur trioxide
W/m.K	Watts pr meter Kelvin (Thermal Conductivities)
μm	Micrometers (micron)

LIST OF ABBREVIATIONS

ASTM	American standard test method
BS	British standard
PKSC	Palm kernel shell concrete
POFA	Palm oil fuel ash
LWAC	Lightweight aggregate concrete
OPC	Ordinary Portland cement
UPV	Ultrasonic pulse velocity
PPOF	Palm kernel shell POFA
SEM	Scanning electron microscopy
TEM	Transmission Electron Microscopy
SPM	Scanning Probe Microscopy

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PENGARUH ABU BAHAN BAKAR KELAPA SAWIT (POFA) TERHADAP PRESTASI KONKRIT KERNELRAZZO

ABSTRAK

Penggunaan tempurung isirong sawit (PKS) dan abu bahan api minyak sawit (POFA) sebagai alternatif kepada bahan konvensional untuk pembinaan adalah wajar untuk menggalakkan pembangunan mampan. Konkrit Kernelrazzo adalah gabungan penggantian separa atau keseluruhan tempurung inti sawit (PKS) dengan kepingan marmar dalam beberapa tahap teraso dengan simen, POFA, habuk kuari dan air. Penyelidikan ini mengkaji perkadaran dan kekuatan campuran antara tempurung isirong sawit (PKS) yang diganti sebahagian dengan kepingan marmar dan simen di mana kandungan granit konkrit kernelrazzo digantikan dengan 0%, 10%, 20%, 30%, 40% dan 50% kulit inti sawit dan 100%, 90%, 80%, 70%, 60% dan 50% kepingan marmar untuk peringkat satu, masing-masing. Spesimen konkrit Kernelrazzo nisbah campuran PKMC0100, PKMC1090, PKMC2080, PKMC3070, PKMC4060 dan PKMC5050 telah dihasilkan dan diawetkan masing-masing selama 3 hari, 7 hari, 14 hari dan 28 hari. Tujuan peringkat kedua kajian ini adalah untuk mengoptimumkan abu bahan api minyak sawit dan simen konkrit kernelrazzo yang dihasilkan dengan perkadaran campuran berbeza POFA masing-masing 0, 5, 10, 15, 20 dan 25% dan campuran (terdiri daripada 33 % habuk kuari). Ujian yang dilakukan pada konkrit kernelrazzo ialah ketumpatan kering, kekuatan mampatan, kekuatan lentur, kekuatan tegangan membelah, halaju nadi ultrasonik, keliangan, pengecutan pengeringan, ujian rintangan hentaman, sifat terma, dan SEM. Telah didedahkan bahawa ketumpatan spesimen konkrit kernelrazzo semuanya kurang daripada 2000 kg/m^3, yang membayangkan bahawa konkrit kernelrazzo memenuhi keperluan konkrit ringan untuk digunakan. Kekuatan mampatan bagi spesimen konkrit kernelrazzo bancuhan optimum PKMC2080 pada pengawetan 28 hari ialah 26.46 MPa iaitu 16.10% hingga 51.02% lebih baik daripada konkrit bancuhan PKMC yang lain. Kekuatan mampatan spesimen konkrit kernelrazzo PFCM1090 yang dioptimumkan pada pengawetan 28 hari ialah 24.94 MPa yang juga 9.02% hingga 33.48% lebih baik daripada konkrit campuran kernelrazzo PFCM yang lain. Ia juga didedahkan oleh sifat terma bahawa ia bergantung kepada ketumpatan konkrit kernelrazzo dan analisis SEM menyimpulkan bahawa terdapat ikatan yang baik antara cengkerang isirong sawit, abu bahan api minyak sawit dan konkrit kernelrazzo. Jubin lantai konkrit kernelrazzo mencapai kekuatan lenturan 4.67MPa dan berat 6kg/m^2 dan mengesyorkan PFCM1090 untuk digunakan oleh pengamal pembinaan untuk pengeluaran jubin lantai konkrit kernelrazzo.

INFLUENCE OF PALM OIL FUEL ASH (POFA) TOWARDS THE PERFORMANCE OF KERNELRAZZO CONCRETE

ABSTRACT

The utilization of palm kernel shells (PKS) and palm oil fuel ash (POFA) as alternative to conventional materials for construction is desirable to promote sustainable development. Kernelrazzo concrete is a combination of partial or total replacement of palm kernel shell (PKS) with marble chippings in some extent of terrazzo with cement, POFA, quarry dust and water. This research examined the mix proportion and strength between partially replaced palm kernel shell (PKS) with marble chippings and cement wherein the granite content of the kernelrazzo concrete was replaced by 0%, 10%, 20%, 30%, 40% and 50% of palm kernel shell and 100%, 90%, 80%, 70%, 60% and 50% of marble chippings for stage one, respectively. Kernelrazzo concrete specimens of mix ratios PKMC0100, PKMC1090, PKMC2080, PKMC3070, PKMC4060 and PKMC5050 were produced and cured for 3 days, 7 days, 14 days, and 28 days respectively. The purpose of this second stage of this study was to optimize the palm oil fuel ash and cement of kernelrazzo concrete produced with different mix proportions of POFA of 0, 5, 10, 15, 20 and 25%, respectively and mix (consisting of 33% quarry dust). The tests performed on the kernelrazzo concrete are dry density, compressive strength, flexural strength, splitting tensile strength, ultrasonic pulse velocity, porosity, drying shrinkage, impact resistance test, thermal properties, and SEM. It was revealed that the densities of the kernelrazzo concrete specimens were all less than 2000 kg/m^3, which implies that the kernelrazzo concrete satisfied the requirement of lightweight concrete for use. The compressive strength of the optimum mix PKMC2080 kernelrazzo concrete

specimens at 28-day of curing was 26.46 MPa which was 16.10% to 51.02% better than the other PKMC mixes concrete. The compressive strength of the optimized PFCM1090 kernelrazzo concrete specimens at 28-day of curing was 24.94 MPa which was also 9.02% to 33.48% better than the other PFCM mixes kernelrazzo concrete. It was also revealed by the thermal properties that it depends on density of kernelrazzo concrete and SEM analysis concluded that there was a good bond between the palm kernel shells, palm oil fuel ash and the kernelrazzo concrete. The kernelrazzo concrete floor tiles achieved flexural strength of 4.67MPa and weighed 6kg/m^2 and recommends PFCM1090 for use by construction practitioners for kernelrazzo concrete floor tiles production.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

A building is a mechanism that are designed and built for human habitation and safety. Schools, hospitals, mosques, churches, industrial and commercial buildings, public buildings, domes, silos, housing estates, etc. are examples of buildings (Michael Lin Yew Chew, 2017). Kernelrazzo concrete is a lightweight concrete which comprises of palm kernel shell, marble chippings, quarry dust, palm oil fuel ash cement and water to reduce the cost of construction, reduce environmental pollution and it was initiated by Ayangade et al. (2004) without considering durability. Construction protection from environmental deterioration caused by moisture, temperature, air movement, radiation, chemical and biological attack, or natural calamities like fire or flood, must be one of a building's primary purposes (Michael Lin Yew Chew, 2017). The mechanical and durability characteristics are the two major areas that guiding the activity of any concrete throughout its service life. This kernelrazzo concrete is classified as lightweight concrete based on its compressive strength.

The employment of complex design, newly introduce building materials such as kernelrazzo concrete to reduce the cost of flooring, and contemporary construction technology has undergone a great and progressive revolution in modern building (Rashudul, 2018). The quality and rich history of a house function in the built environment is to have an impact on its social, commercial, and cultural attraction. In addition, it needs to include interior occupancy criteria and basic comfort parameters. Examining the relationship between the value and quality of the built environment in relation to human health, society, the economy, and the environment (Carmona, 2019).

One of a building's fundamental structural components, the floor serves as the base for conveying and supporting live loads (weight of pieces of furniture and occupants of the building). It is where many the building's tenants' official and informal activities take place. As a result, it is the most crucial component of a structure since it gives its occupants a place to work, cook, and have fun. This component must also be preserved to prevent deterioration, wear, and aesthetic failure. As a result, to provide engineering and cost-effective solutions to the current challenge of high cost of flooring material, it is important to assess and view the design requirements within the context of the building materials' strength, mechanical capabilities, and durability for sustainability of local source construction materials. This is especially true in a world where research is currently concentrated on the sourcing and the creation of alternative materials for construction.

The grade of kernelrazzo concrete mixture is produced with locally available materials of palm kernel shell and palm oil fuel ash which was obtained from the agricultural waste product. The constituents for mix proportions are ordinary Portland cement (OPC), quarry dust, marble chippings, palm kernel shell (PKS) and water. Palm oil fuel ash (POFA) is partially substituted for cement as a pozzolanic material. The mix proportion for the research was in the range of 20MPa and 30MPa. The details of mix proportions have been provided on optimization I, II and III respectively. The durability aspects are evaluated by conducting laboratory test on salt crystallization test.

Among the most important and basic human necessities has traditionally been recognised as housing and the term "housing" refers to more than just a place to live. It includes not only the physical building but also the environmental infrastructure, charitable deeds, and other welfare activity that greatly aids in leading a good life. Sustainable residential development necessitates a steady information between the rising housing demand and the effective utilization of materials and resources such as newly introduced waste to wealth like agricultural and industrial waste materials such palm oil fuel ash and palm kernel shell to reduce the price of flooring while also lowering environmental pollution (Al-Aidrous et al., 2022).

Globally, and particularly in developing nations, there is a housing crisis because of rising demand for residential buildings (Ebekozien et al., 2017). In addition, the construction industry generates a lot of waste and uses a lot of resources (Mazenan et al., 2017). To reduce the effect of environmental pollution, to lower the cost of materials used in concreting, roofing, flooring, and other construction projects by substituting locally accessible materials for standard ones, research is ongoing in this area like this study. This continues the present trend of employing resources that the local environment can afford to create alternatives to conventional materials.

There are several locally accessible pozzolana materials that have been found to be suitable, including palm oil fuel ash, rice husk, corncob, sawdust, pineapple fibre, eggshells, and bamboo leaf ash as replacements for cement, and palm kernel shells as an alternative to the traditional coarse aggregates (gravel, granite, stone, marble, etc).

Mazenan et al. (2017) claimed that the manufacturing of Portland cement results in the significant contribution to global warming caused by the release of CO_2

and other gases and its high cost which is affecting the low income earners to own a house gives the room to extend the research work on alternative building elements include palm oil fuel ash and palm kernel shell were incorporated into the construction industry to generate income to the farmers, government, palm oil industries, to reduce environmental pollution and health hazard within the community.

Palm kernel shell (PKS) and palm oil fuel ash (POFA) are agricultural by-product that are common in Africa and Asia countries. Palm oil fuel ash (POFA) is obtained from the burning of palm oil trash for the purpose of generating electricity in power plants has special qualities as pozzolanic material useful as a binder or supplementary and as partial replacement of a cement, POFA is a localized responsive material with strong pozzolanic inclinations, and which shows adequate micro-filling capabilities (Khasib & Nik Daud, 2020). The lignocellular characteristics of palm kernel shell (PKS) is a substance produced from biologically generated green waste, have been extensively documented (Ikumapayi & Akinlabi, 2018).

The sourcing, development, and use of alternative, non-conventional local construction materials, including the potential use of some indigenous building materials, has been one of the suggestions at the forefront of various proposals focusing on lowering the costs of conventional building materials. Numerous proposals have been made because of the need for cheap housing systems that use local building materials for nation's rural and urban populations and other developing nations (Attah et al., 2020; Kumar et al., 2017; Maraveas, 2020; Mokhtar et al., 2021; Sa'ad et al., 2021; Verma & Shrivastava, 2019).

1.2 Problem statement

According to British Standard (BS 8110-1, 1997), aggregates that do not meet British Standard may be used in concrete if there is sufficient data on the properties of concrete made from them. In his book on building sustainability, Szafranko (2019) suggested that the durability of what is being built be improved to reduce environmental impact. Even though much research has been conducted on the use of palm oil fuel ash as a partial replacement for cement in concrete. However, previous studies on the use of palm kernel shell (PKS) as coarse aggregate and palm oil fuel ash (POFA) as pozzolan have not considered the durability aspects thus a study of the physical and chemical properties of the palm oil fuel ash is very necessary as a condition for its acceptability. Before PKS and POFA concrete can be effectively used in building construction, it is reasonable that its durability properties are studied.

To improve on the performance of marble chippings and ordinary Portland cement concrete, some basic parameters describing its performance characteristics must be developed for a material to be effectively used in housing or building construction in general, many researchers have used industrial and agro-allied waste as coarse aggregates and mineral admixtures to substitute partially or completely marble chippings and cement in kernelrazzo concrete production. The most used mineral admixtures are fly ash (FA) and granulated blast furnace slag GBFS; however, these pozzolans are not easily available in Africa, so research into the use of agricultural waste materials that are locally available and affordable must be expanded.

High and rising cost of construction materials, which has significantly hampered the development of housing and other infrastructure facilities in developing nations, there is a need to take into the use of less expensive but more durable and locally accessible materials, which lowers the overall cost of construction for sustainable development (Bredenoord, 2017; Manandhar et al., 2019; Patel & Patel, 2021).

The global warming problem is greatly increased by the construction industry and the concrete-making industry is responsible for emission of carbon dioxide (CO_2) emissions per year, though Portland cement is the "culprit" (PC). Indeed, PC production is both energy-intensive and environmentally damaging because, in addition to oxygen (O_2) and dust emissions, 1 tonne of cement production requires 1.5 to 2.4 tonnes of non-renewable non-metallic minerals (limestone and clay), which are primarily extracted from quarries (Khozin et al., 2020). One tone of carbon dioxide (CO_2) is released into the atmosphere by the cement production industry alone when one tone of cement is produced (Abdulameer, 2015). The alternatives to cement used in construction not only enhance the properties of concrete but also save money, reduce construction expenses, and are more environmentally friendly (Abdulameer, 2015). Reduced cement consumption has a favourable effect by lowering carbon dioxide levels (CO_2).

Sulphate attack has long been blamed for concrete deterioration in a wide range of structures. Sulphate attack in concrete is known to occur when sulphate solutions, either from a constituent of the concrete such as aggregate or from external sources such as groundwater, react with the cement hydrates present in the hardened cement paste to form products that can occupy more volume than the reactants. Soils (particularly in arid regions), groundwater, fertilisers, seawater, industrial chemicals and wastes, and fertilisers are the primary sources of these salts.

Sulphate attack deteriorates concrete by destabilising the cement paste and causing expansive effects that result in cracking, disintegration of the concrete, efflorescence, mass loss, and compressive strength loss. Sodium, potassium, calcium, and magnesium sulphates are among the aggressive compounds, and the sulphate attack is generally attributed to the reaction of sulphate ions with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. It needs to evaluate the effects of sulphate ions on kernelrazzo concrete.

This study suggest solution to the following questions by determining the influence of palm oil fuel ash (POFA), palm kernel shell (PKS) content, and examine the compressive strength, flexural strength, splitting tensile strength, ultrasonic pulse velocity, porosity, water absorption, thermal properties, and impact load resistance of kernelrazzo concrete floor tiles. This research investigated the influence of palm oil fuel ash (POFA) on the performance of kernelrazzo concrete, effect of sulphate on kernelrazzo concrete mass loss and compressive strength loss; therefore, sulphate attack deteriorates concrete by destabilising the cement paste and causing expansive effects that lead to cracking, expansion, losing strength, and disintegration concrete component. Sodium, potassium, calcium, and magnesium sulphates are among the aggressive compounds.

The most common type of failure kernelrazzo concrete floor tile is cracking, which is usually caused by the structural system that supports the kernelrazzo concrete topping rather than the material itself. The bonding agents used in kernelrazzo concrete can deteriorate when exposed to alkalis or acids. Because aggregates are frequently quarrying dust, marble chippings, which is calcium carbonate, strong acid can also cause aggregate deterioration.

Therefore, to solve this gap, kernelrazzo concrete can be effectively used in building construction, it is reasonable that its durability properties are studied to avoid, cracking, major or minor home accidents or environmental hazards, because of sub-standard building materials and components. Due to the dearth of literature on the influence palm oil fuel ash (POFA) on the performance of kernelrazzo concrete, this research has provided answers to the following questions:

(i) What happened to the mechanical and durability features of the kernelrazzo concrete if palm kernel shell (PKS) and palm oil fuel ash (POFA) are replaced in part of mix proportion with marble chippings and cement?

(ii) What was the impact on the mechanical and durability properties of kernelrazzo concrete floors of partial substitution of palm kernel shell and palm oil fuel ash?

(iii) What are the effects of varying exposure periods and concentrations of magnesium sulphate on the mass loss and compressive strength loss of kernelrazzo concrete?

(iv) What was the rate of water absorption, porosity, and impact resistance on the durability properties of kernelrazzo concrete?

(v) What was the relationship between mechanical, durability and thermal functions to avoid cracking and spalling of kernelrazzo concrete?

This study investigates the influence of palm oil fuel ash (POFA) on the performance of kernelrazzo concrete up to 180 days

1.3 Aim and objectives of the research

The aim of this study is to influence of palm oil fuel ash (POFA) on the performance of kernelrazzo concrete with a view to enhancing its effective utilization.

The specific objectives of the study are:

i. To develop a rational/ideal mix design procedure for kernelrazzo concrete floors that comprise a combination of PKS and POFA components.

ii. To study the impact on the mechanical and durability properties of kernelrazzo concrete floors of partial substitution of palm kernel shell and palm oil fuel ash.

iii. To examine the effects of exposure periods and concentrations of magnesium sulphate on the mechanical properties of kernelrazzo concrete floor tiles.

iv. To examine the rate of water absorption, porosity, and impact resistance on the durability properties of kernelrazzo concrete floors.

v. To investigate the behaviour of the newly designed kernelrazzo concrete floors and to evaluate its strength correlations between mechanical, durability and thermal properties.

1.4 Significance of the research

The worldwide economic recession and the current high cost of conventional building materials have been identified as the major causes of shortage of decent housing. As the demand for decent and affordable housing continues to grow in the country there has been a call for the development of locally available raw materials into building industries that will meet the current challenges and the primary aim of this research is to promote the utilization of those unassuming natural building materials, especially for affordable housing for middle-income and low-income earners that can afford conventional tiles, terrazzo, and marble floor finishes. Considerable efforts are being taken worldwide to improve the strength and durability performances of concrete. The use of pozzolanic and cementitious materials such as fly ash, rice husk ash, silica fume, natural pozzolans and granulated blast-furnace slag has been found a beneficial technique of enhancing the plasticity and workability of fresh concrete; achieving lower heat of hydration, lower thermal shrinkage, reduced permeability, improved resistance to sulphate and other chemically aggressive agents, lower cost and increased long term strength of hardened concrete (Amran, Debbarma, et al., 2021; Geetha & Selvakumar, 2019; Sherin et al., 2023).

Many studies have been carried out on POFA most of which focused on its mechanical properties, while limited work has been carried out on its durability. The durability of concrete is a real challenge because potential sources of degradation are numerous, as observed from effects of sulphate attack, acid attack and corrosion of reinforcing steel embedded in concrete; freeze-thaw damage, abrasion, and mechanical loads. External sulphate attack on cement-based materials has been a key durability issue and a subject of extensive investigation for many decades Sulphate attack on concrete causes strength loss, expansion, surface spalling, mass loss, and eventually disintegration (Atahan & Arslan, 2016; Huang et al., 2021; Kanaan et al., 2023; K. Liu et al., 2015; Maes & De Belie, 2017) because concrete deterioration due to sulphate attack is the second major durability problem of concrete, after reinforcement corrosion. The quests for affordable housing, resource depletion of non-renewable building materials and global pollution among others have necessitated this research work. Exploiting the availability of palm kernel shell and palm oil fuel ash agricultural waste materials, not only maximizes its use, but also helps to preserve natural resources, reduce environmental pollution, and maintain ecological balance. Therefore, this study was set out to investigate the durability of palm kernel shell and palm oil fuel ash concrete exposed to various sulphate concentrations over a period. Moreover, the scarcity and trade bottleneck experienced through the importation of marble chippings used in producing terrazzo will be withdrawn.

1.5 Scope of the research

The scope of this study was optimization of palm kernel shell, optimization palm oil fuel ash and development of kernelrazzo POFA concrete floor tiles. It was done on kernelrazzo concrete floors tiles, and it focused mainly on the influence of palm oil fuel ash (POFA) on the performance of kernelrazzo concrete.

Kernelrazzo concrete was produced by the controlled mixing, palm kernel shell, quarry dust, and marble chippings and partially replaced with palm kernel shell at 0%, 10%, 20%, 30%, 40% and 50%, quarry dust at 33% , palm oil fuel ash (POFA) of 0%, 5%, 10%, 15%, 20%, and 25% replacement, 100%, 95%, 90%, 85%, 80% and 75% cement respectively mass for the prescribed mixes concrete mix design of Department of Environment (DoE) where their compressive strengths were verified. The materials for the control are cement, marble chippings, granite/quarry/stone dust and water.

1.6 Layout of the research

To cover the entire research, six chapters were written. The first chapter provided an overview of this study, provided background information, and clarified the issue that this research aimed to address. Additionally, this chapter provided insight into the significance, scope, and goals of the research.

In Chapter 2, the invention of kernelrazzo concrete as lightweight concrete was emphasized after a critical examination of previous studies on lightweight concrete and the effects of palm kernel shell (PKS) and palm oil fuel ash (POFA) in partial replacement of marble chippings and cement respectively when used to produce kernelrazzo concrete. It provided information about the components and the physical, mechanical, and durability characteristics of kernelrazzo concrete. The effects of PKS and POFA integration on the structural, mechanical, and durability characteristics of kernelrazzo concrete were also discussed. Chapter 2 also discussed kernelrazzo concrete floors attempts and their characteristics.

The qualities of the ingredients, the mixing process, and the tests that were done on the kernelrazzo concrete cubes, beams and cylindrical for compressive strength, flexural strength, splitting tensile strength, porosity, water absorption mixtures were all covered in Chapter 3. Furthermore, Chapter 3 described how to test the newly created kernelrazzo concrete and kernelrazzo concrete POFA floor tiles.

The results of all experiments done on kernelrazzo concrete cubes, beams, cylindrical members and kernelrazzo concrete floor tiles mixtures were given in Chapter 4 along with a full results and explanation in details for the findings. The ideal and optimum mix with PKS and POFA replacement level was developed in this chapter and used to create the newly designed kernelrazzo concrete floor tiles.

In Chapter 5, the performance of the newly designed kernelrazzo concrete floor tiles was thoroughly discussed along with the results of the tests that was done on it.

Chapter 6 outlined the research's findings and that further study to be done for better understanding of the influence of palm oil fuel ash (POFA) on the performance of kernelrazzo concrete floor tiles.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter contains a review of the major concepts outlined the conceptual framework in this study. The feasibility of replacing palm oil fuel ash with cement and marble chippings with palm kernel shells to produce kernelrazzo concrete was investigated. Apart from the high and rising cost of construction materials, which has hampered the development of shelter and other infrastructural facilities in developing countries, there is a need for engineering consideration on the use of less expensive and locally available materials, which leads to an overall reduction in construction costs for sustainable development.

The satisfactory design of a building structure to meet the appropriate design requirements necessitates a thorough understanding of the strength and mechanical properties of the building materials to be used in its construction. Inappropriate material selection will eventually lead to failure. The term "materials selection" refers not only to the selection of generic names for materials (steel, concrete, timber, bricks, etc.), but also to their specific type, composition, and/or performance criteria.

In cement industries, continuous attempts are being made to reduce the cost of production of Portland cement, to reduce the consumption of raw materials, to protect the environment; and to enhance the quality of cement. One way is to use certain low-cost materials for partial replacement of Portland cement clinker. Low-cost materials used are industrial and agricultural by-products. Mixture of Portland cement and the palm oil fuel ash are known as blended cements or composite cements. Blended cements are hydraulic binders in which a part of Portland cement is replaced by other hydraulic or non-hydraulic materials. Their general behaviour is quite like that of Portland cement since they hardened when mixed with water and form the same hydration products. The most common ingredients that are blended with Portland cement clinkers are latent hydraulic component (blast furnace slag), or a pozzolanic component such as pozzolana, fly ash, rice husk ash, condensed silica fume, burnt clay or filler component such as limestone and other waste materials (Amran, Debbarma, et al., 2021; Geetha & Selvakumar, 2019; Sherin et al., 2023). During the hydration of Portland cement, $Ca(OH)_2$ is obtained as one of the hydration products, which is responsible for deterioration of concrete.

However, when certain pozzolanic materials containing amorphous silica are added to Portland cement during hydration, it reacts with lime, producing an additional amount of calcium silicate hydrate (C-S-H), the main cementing component. Pozzolanic materials have a lower $Ca(OH)_2$ content and a higher C-S-H content. Thus, adding a good quality pozzolanic material in appropriate amounts during the hydration of Portland cement improves the cementing quality. There is a continuous search for alternative supplementary materials, which may have hydraulic and pozzolanic properties. This is especially important in developing countries where power and high-quality raw materials are scarce. The annual production of palm oil in Malaysia which constitute 29% of global palm oil output (Jalani et al., 2016; Kahar et al., 2018) and in 2021, it was reported that about 18,116,354 million metric tons of crude palm oil (CPO) produced in Malaysia (Malaysian Palm Oil Board, 2021).

The American Concrete Institute (ACI 318R, 1995) defines concrete as a mixture of Portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without admixtures. (ASTM C125, 2015) defines

Portland cement concrete is defined as a mix of Portland cement, water, coarse and fine aggregates, and admixtures proportioned to form a plastic mass that can be cast, placed, or moulded into forms that will harden to a solid mass. From these explanations, four main components of concrete that are recognized in a bid to produce the modern concrete that will meet desired properties in making and service are Portland cement, water, aggregates (both fine and coarse) and admixtures (mineral or chemical). Admixture is defined as a material other than hydraulic cement, aggregate, or water used as a concrete ingredient and added to concrete before or during mixing to modify its properties and the addition of chemical and mineral admixtures, as well as other aggregates, improves workability, flow ability, compressive strength, and segregation resistance (Frhaan et al., 2020). Most researchers have confirmed that the use of chemical and mineral admixtures gives better fresh and hardened of the concrete (Al-Hadithi & Hilal, 2016; Faraj et al., 2020; Frhaan et al., 2020; Mohammed et al., 2019).

Most soil contains sulphates in the form of calcium, ammonium, sodium, magnesium, and potassium ions; however, the most abundant naturally occurring sulphates in ground water are sodium (Na_2SO_4), magnesium ($MgSO_4$), and calcium ($CaSO_4$). Sulphate can also be found in fertilisers and industrial effluents, such as ammonium sulphate (Beesigamukama et al., 2020; Kandil et al., 2017; Mohd Udaiyappan et al., 2017). According to (Joshaghani, 2018; C. lin Zhang et al., 2021) posited that concrete deterioration due to sulphate attack is the second major durability problem after reinforcement corrosion. Sulphate attack on concrete causes strength loss, expansion, surface spalling, mass loss, and eventually disintegration (Atahan & Arslan, 2016; Huang et al., 2021; Kanaan et al., 2023; Liu et al., 2015; Maes & De Belie, 2017). A pozzolan is a siliceous or siliceous and aluminous material that has little or no cementitious value in itself but will chemically react with calcium hydroxide at ordinary temperatures when finely divided and in the presence of moisture to form compounds with cementitious properties (ASTM C 618, 2014). Pozzolans in concrete help to strengthen the concrete by continuing to react for many years, making it harder and more durable during its service life. Pozzolans also help to increase the density and decrease the permeability of concrete, making it more resistant to deterioration and swelling caused by various exposure conditions.

The incessant generation of solid waste materials represents serious environmental problems; hence, some industrial by-products and wastes are attracting research attention, because of their high silica and alumina content for use as additives in Portland cements. The hydrated phases formed during pozzolanic reaction frequently improve concrete performance (A. Ash et al., 2018; Lemonis et al., 2015; G. Zhang et al., 2023). The use of pozzolanic waste materials in concrete production is a worldwide practise. In addition, because of the need for more sustainable cementing products, research into the pozzolanic activity of cement replacement materials is becoming increasingly important (Cao et al., 2022; E. Harrison et al., 2020; V. M. John et al., 2019; Juenger & Siddique, 2015; Scrivener et al., 2018).

In further attempts to source locally available materials as pozzolans, efforts are being increased in the use of agricultural waste materials, with encouraging results reported by many researchers. Some of the pozzolans that are derived from agricultural wastes include banana leaves ash, corn cob ash, millet husk ash, groundnut husk ash, periwinkle shell, eggshell ash, bamboo leaf ash, saw dust ash

(Adedokun & Oluremi, 2021; Fapohunda et al., 2021; H. Nguyen et al., 2019; Oluwaseun Olatunji et al., 2022; Raheem & Ikotun, 2020).

In recent years, new research has focused on the use of agricultural solid wastes as pozzolans in the production of blended mortars and concrete (Aprianti et al., 2015; Aprianti S, 2017; Paul et al., 2020; Ren et al., 2021; Vishwakarma & Ramachandran, 2018). In fact, because of the chemical reactivity of the ashes with the portlandite generated during the cement hydration reaction, the addition of ashes from the combustion of agricultural solid waste to concrete is now a common practise. Some of these agricultural wastes such as rice husk ash, coconut pith, sawdust ash, cork granules, wheat straw ash, sugarcane bagasse ash and sugarcane straw ash, bamboo leaves ash are being tested for mortar and concrete production (Abu-Jdayil et al., 2019; Juenger et al., 2019).

There are many industrial by-products which are practically considered to be waste that when mixed in an appropriate quantities and proportions with Portland cement, improves the properties of the cement, some of such materials are blast furnace slag, fly ash and silica fume. These materials also known as mineral admixtures improve hydraulic or pozzolanic in nature (Sobol et al., 2017; D. Zhang et al., 2020). Apart from industrial by-products, pozzolanic ashes obtained from agricultural industries, such as rice husk ash and sugarcane bagasse ash, are already in use in the construction industry in the form of blended cements, also known as composite cements, which are obtained when these materials are mixed with Portland cement (Aprianti S, 2017; G. Athira & Bahurudeen, 2022; V. S. Athira et al., 2021; Charitha et al., 2021; Jittin & Bahurudeen, 2022; Moayedi et al., 2019; Torres de Sande et al., 2021).

A general discussion on kernelrazzo concrete was reviewed. The chapter highlighted issues related to natural materials such as palm kernel shell and palm oil fuel ash in terms of properties. The problem associated with the mechanical and durability properties of kernelrazzo concrete were outlined. An overview of marble chippings and quarry dust, its constituent and its properties were presented. Additionally, a review of previous research efforts on kernelrazzo concrete was highlighted and the gaps in knowledge has been identified. Finally, an overview of the potentials of kernelrazzo concrete POFA tiles as a sustainable development in kernelrazzo concrete flooring and design, as well as a discussion of the benefits and drawbacks of kernelrazzo flooring was presented.

A review on the appearance of kernelrazzo concrete floors was presented and discussed in this chapter. Cement, aggregate, timber, steel, bricks, sand, and other building materials are in great demand. Researchers have recently investigated the possibility of employing agricultural waste in the form of ashes as one of the components in concrete. Palm oil fuel ash (POFA), which has pozzolanic properties due to its high silica concentration, is one of the most frequently produced agricultural wastes in Asian and African countries. The constituents of kernelrazzo concrete, factors influencing the durability and other qualities of the kernelrazzo concrete floor tiles were discussed.

The ability of a material to withstand a quick, severe force or shock is known as impact resistance, which affects the design and choice of many test types. Impact resistance is determined by measuring the coefficient of restitution by dropping a steel ball from a fixed height onto the test specimen and measuring the height of rebound. It is calculated by dividing the relative velocity of departure by the relative velocity of approach. Impact resistance is measured as the amount of energy (typically expressed in Joules, J) that a standard specimen must absorb before it will break under a standard impact (ISO10545-2, 2018). It has to do with how impact-resistant packaging materials are. The amount of force necessary to cause the specimen to fracture, the quantity of blows necessary to cause a particular level of distress (during a series of impacts), the size of the damage (such as crater size or perforation), or the size and velocity of spall after the specimen has been subjected to a surface blast loading are some of the criteria used to determine the material's resistance. Impact resistance helps to assist in controlling the formation of cracks by redistributing the stresses induced in the kernelrazzo concrete and helped to guide against wear and tear of kernelrazzo concrete.

2.2 Concept of kernelrazzo concrete

Kernelrazzo concrete (KC) is a form of lightweight concrete which comprised of palm kernel shell, marble chippings, quarry dust, cement, and palm oil fuel ash. Ayangade et al. (2004) initiated kernelrazzo concrete as another new material, and it was produced by mixing palm kernel shell with quarry dust, Portland cement, and granite. Therefore, kernelrazzo concrete is a variant of terrazzo floor finish in which marble chippings have been partially or wholly replaced by palm kernel shells (Arowojolu et al., 2019; Olusola & Babafemi, 2015; Yalley, 2018). However, it may more appropriately be termed kernelrazzo since the gap has been discovered and worked on, it is palm kernel shell (PKS) and palm oil fuel ash (POFA) that is used in producing the kernelrazzo concrete floor tiles.

Cement, marble chips, quarry dust, palm oil fuel ash (POFA), and palm kernel shells are the key components employed for this review and study effort. Other aspects reviewed were the consequence of aggressive condition on the durability and strength of kernelrazzo concrete. Furthermore, the incorporation of lightweight materials in the production of concrete as coarse materials and their effect on the mechanical, durability, thermal and functionality properties were also presented and discussed. At the end of the chapter, summary was made on the existing gap and the forecasted challenges that may hinder the onsite application of kernelrazzo concrete floor finishes. Concrete is a combine building substance largely made of cement, gravel, and water. There are numerous formulas with a wide range of characteristics. The construction industry's most popular material is concrete (Oyejobi et al., 2020). This is produced using a combination of water, chemical admixtures, fine and coarse aggregate, and binding materials. This is thought to be the least expensive and most easily obtainable substance with a strong resistance to water that can be created quickly when it is fresh. The universality of its components makes concrete simplicity possible practically anyplace (Maghfouri et al., 2018). The aggregate typically consists of a hard material like gravel or crushed rocks like limestone or granite and a soft material like sand. The aggregate is bound together by the cement, most frequently Portland cement, including other cementitious materials such as fly ash and slag cement.

From the above definition, four main constituents of concrete are identified in a bit to produce modern concrete that will meet desired properties in making and service, and these are Portland cement, water, materials (soft and hard), and admixtures (mineral or chemical).

2.3 Constituent materials for kernelrazzo concrete

The materials used to produce kernelrazzo concrete are primarily four in number. Binder, aggregate, and water are the materials (Ayangade et al., 2004). In some cases, admixtures such as plasticisers are added to these basic ingredients to enhance the workability. To reduce the heat of hydration and to improve the mechanical properties, SCMs such as fly ash, silica fume, rice husk ash, GGBFS and metakaolin can also been used (Guo et al., 2020; Kim et al., 2022; Ma et al., 2022; Ming & Cao, 2020; Qin et al., 2022; Sasanipour et al., 2021; Vafaei et al., 2021; H. Wang et al., 2021; J. Wang & Huang, 2023). Concrete can be made in a variety of ways by adjusting the ratios of the key components listed below. The resulting product can be customised to its application with varied strength, density, and chemical and thermal resistance qualities by doing this or by replacing the additive and material phases. Due to more rigorous environmental regulations, recycled materials are increasingly being used as ingredients in concrete. The mix design is determined by the type of structure being built, the mixing, delivery, and placement methods for the concrete, as well as how the structure will be assembled.

2.4 Properties of kernelrazzo concrete floors

The characteristics of a concrete floor made of kernelrazzo will be enumerated and thoroughly explained in the parts that follow. These are the characteristics of freshly hardened kernelrazzo concrete flooring.

2.4.1 Drying shrinkage

When concrete is stored in unsaturated air, drying shrinkage refers to the removal of moisture from the material (Neville, 2004). Prisms of 75 x 75 x 280 mm are utilised to calculate drying shrinkage. Readings of drying shrinkage were taken in accordance with (BS ISO 1920-8, 2009). To simulate the actual conditions that the finished product will experience, the shrinkage specimens were left outside under cover. The drying shrinkage readings for the kernelrazzo concrete samples were taken up to 180 days following the first reading after de-moulding.

Studies by H. K. Kim et al. (2012) demonstrate a considerable difference in the shrinkage strain of concretes manufactured with various types of coarse aggregate. This difference was detected at a consistent concrete mix proportion. This phenomenon most likely results from the fluctuating elasticity modulus derived from the various aggregate types.

Drying shrinkage tests were performed on lightweight materials for the production of PKSC by (Lau et al., 2018) and compared with standard concrete after 7, 28, 56, and 90 days. The creep and shrinkage results of palm kernel shell concrete (PKSC), appreciated as the percentage content of palm kernel shell rose with the concrete age (Olayinka & Ewaen, 2020). However, PKSC demonstrated a higher drying shrinkage rate.

2.4.2 Density

ACI 213R (2003; ACI Committee 213 (2014); ASTM C331 (2005); BS 812:2 (1995)express the fresh concrete's minimal weight density as a purpose of mixing ratios, air contents, water demand, particle density, and moisture content of the lightweight aggregate. Density of lightweight material as a function of many parameters which include aggregate density, water, air, moisture content as well as mix design, nonetheless, the density of one lightweight material may be greater than the density of alternative lightweight natural and synthetic materials, therefore, there are differences in densities of different lightweight materials as examined by (Aslam, Shafigh, et al., 2017).

The minimum density of a lightweight concrete as specified by ASTM C330/C330M (2009) and ASTM C1113 (1999) is 1680kg/m^3 when 100% lightweight aggregate is used, and the maximum density should not exceed 1840kg/m^3. The aggregates' grading, moisture content, mix proportions, cement content, water-to-binder ratio, chemical admixtures, and other factors are all important, are additional factors that affect concrete density in addition to aggregate density. Along with the material, other factors include the compaction technique, the curing environment, etc (Neville, 2004)**.**

Table 2.1 below shows the densities of lightweight aggregate concrete with their corresponding compressive and tensile strength at 28 days. It also classified lightweight aggregate concrete according to usage and their corresponding densities, strength and thermal conductivity as shown in table 2.2 below.

Table 2.1 Lightweight concrete properties according to (ASTM C330/C330M, 2000).

Average 28 days Max. density kg/m^3	Average 28 days min. splitting tensile strength (MPa)	Average 28 days min. compressive strength (MPa)
1840	2.3	28
1760	2.1	21
1680	2.1	17

Table 2.2 Lightweight aggregate concrete classified according to use and physical properties.

Class of Lightweight Aggregate Concrete	Type of Lightweight Aggregate Used in Concrete	Typical Range of Lightweight Concrete Density (kg/m^3) Structural grade	Typical Range of Compressive Strength (MPa)	Typical Range of Thermal Conductivities (W/m.K)
Structural	Structural LWA C330	1440 – 1840 at equilibrium	>17	Not specified in C330
Structural/	Either structural	720 – 1440 at	3.4 – 17	C332 from 1.05