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Utilization and Upcycling of Palm Oil Fuel Ash for Use as Eco-Friendly Partial Cement Replacement in Kernelrazzo Concrete

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Abstract
The aim of this research report is to provide the results of a study on the utilization and upcycling of using palm oil fuel ash as an environmentally friendly partial replacement for cement in kernelrazzo concrete created by combining cement, quarry dust, and palm kernel shell in place of some marble chips, according to the Department of Environment's (DoE) design technique. This study project's only option for reducing the self-weight or dead load of the kernelrazzo concrete and lowering construction costs is to employ palm oil fuel ash, which is easily accessible as a partial cement alternative. In this investigation, the coarse aggregates were palm kernel shell and marble chips, and the fine aggregates were quarry dust. Six different concrete mixtures were generated for 5%, 10%, 15%, 20% and 25% of the binder weight of POFA was employed to partially replace cement. The research work's contribution to knowledge by raising awareness of the potential applications of agro-waste materials, preventing epidemics and other related diseases that could be caused by waste palm kernel shells, providing a source of income, and lowering the potential financial losses that could arise from early failure of kernelrazzo concrete. The results of the workability test indicated that the workability of fresh kernelrazzo concrete decreased as POFA addition to the kernelrazzo concrete increased. With this findings, it is advised to utilize palm oil fuel as in place as partial cement alternative for kernelrazzo concrete and for creating lightweight concrete with the use of 10% POFA, 90% Cement, 20% PKS and 80% marble chippings. The substitution of POFA for OPC has numerous economic advantages while also assisting in the reduction of environmental pollution.

Keywords: Palm oil fuel ash, Palm kernel shell, Cement, Compressive strength, Flexural strength

Introduction
In the pursuit of an affordable housing system that uses local building materials for the rural and urban populations of Nigeria and other developing nations, several proposals have been made to reduce the cost of conventional building materials. One of the most prominent of these proposals is the sourcing, development, and use of alternative, non-conventional local construction materials, such as the potential use of some agricultural wastes like rice husk, coconut shells, periwinkle, and residues as construction materials (Attah et al., 2020; Kumar et al., 2017; Maraveas, 2020; Mokhtar et al., 2021; Sa'ad et al., 2021; Verma and Shrivastava, 2019). Palm oil fuel ash (POFA) is an agricultural waste and industrial by-product that is obtained as a result of the incineration of palm oil wastes due to electrical generation in power plants which has unique properties 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 and Nik Daud, 2020). In order to combat climate change and pollution brought on by inefficient waste management, sustainability has gained significant traction in recent years. The cement industry, one of the primary producers of building materials, contributes significantly to social and economic advancement while also posing a significant problem due to its high energy and natural resource consumption and greenhouse gas emissions. Mazenan et al. (2017) reported

that the production of Portland cement results in the emission of a substantial amount of CO_2 and other gases causing a contribution to global warming 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 materials such as palm kernel shell and palm oil fuel ash 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. One of the basic components of concrete, cement is one of the most widely used commodities worldwide (Us Geological Survey, 2017). Environmentally speaking, the manufacture of 1 tonne of cement results in the direct generation of approximately 1 tonne of CO_2 (Mineral Products Association, 2007; Fact Sheet 18 Part, 2007). As a result, 7–10% of the world's total CO_2 emissions are attributable to the manufacturing of cement, compared to 2.8% from the aviation sector, which is three times lower (Andrew, 2019; Malaysia NC3 BUR, 2018; UNFCCC, 2018). Apart from the consideration of the high and increasing cost of construction materials which has greatly hindered the development of shelter and other infrastructural facilities in developing countries, which thus arises the need for construction consideration on the use of cheaper but durable and locally available materials which leads to an overall reduction in construction cost for sustainable development **(**Bredenoord, 2017; Manandhar et al., 2019; Patel and Patel, 2021). The increasing demand of cement is a cause of concern that leads to the utilization of supplementary cementitious materials in cement industry and high-cost marble finish products which make it difficult to buy for the poor people or low-income earners and the cost of construction is too high for low-income and middle-income earners.

To reduce the cost of marble in terrazzo flooring finish, the most expensive constituent material which is marble chippings could be replaced with locally available palm kernel shell materials. Therefore, to solve the gap, the combination of palm kernel shell (PKS), palm oil fuel ash (POFA), quarry dust and marble chippings are the main components examined in this study where the PKS and POFA will be used to investigate important effects on the mechanical and durability properties of kernelrazzo concrete. Quarry dust is a commercial by-product that results from the first stage of crushing rocks, and it is an industrial by-product with rising demand in construction and it is dumped in enormous quantities at crusher plants and quarry sites (Birch and Datson, 2008.; Sridharan et al., 2006). Palm kernel shell (PKS) can be used as a partial replacement to marble chippings (MC) either fully or to some extent in terrazzo floor finish to produced kernelrazzo (Arowojolu et al., 2019; Olusola and Babafemi, 2015; Yalley, 2018). In Africa, millions of tonnes of waste are produced every year. It's been proposed to be used as an alternative substitute for cement replace in most countries through research and development.

Materials and methods

Palm kernel shells, palm oil fuel ash, marble chippings and quarry dust were sourced locally from Nigeria as shown in Figures 1, 2, 3, and 4. Type I Portland Cement from Penang Island was the cement employed in the current investigation. The cement used in the mixing was Ordinary Portland Cement (OPC) Type 1 which meets the (ASTM C150/C150M-12; MS EN 197-1:2014, 1995). Cement has a specific gravity of 3.15. Table 1 provides specifics on the cement's and POFA chemical make-up that was employed in this study.

Figure 1: Palm kernel shell

Figure 2: Palm oil fuel ash

Figure 3: Granite

Figure 4: Quarry dust

Table 1: Chemical composition of POFA and OPC

Item No	Chemical compound	POFA (%)	Portland Cement (%)
1.	Silicon dioxide (SiO_2)	59.3	21.28
2.	Aluminum oxide (Al_2O_3)	4.1	5.60
3.	Calcium oxide (CaO)	8.9	64.68
4.	Potassium oxide (K_2O)	-	0.39
5.	Sodium oxide (Na_2O)	0.2	0.40
6.	Iron oxide (Fe_2O_3)	6.4	3.36
7.	Magnesium oxide (MgO)	2.7	2.06
8.	Sulphur oxide	2.6	2.14
9.	LOI	10	-

Table 2 shows the proportions of POFA concrete mix using cement type 1 to produce kernelrazzo concrete. Where POFC = palm oil fuel ash, C = cement, PKS = palm kernel shell and MC = marble chippings. POFC-0100 represent 0% POFA and 100% Cement.

Table 2: Proportions of POFA concrete mix using cement type 1 kernelrazzo concrete.

Item No	Composition with POFA replacement	Binding Agents (kg)		Coarse aggregate (kg)		Quarry dust (kg)	Water (kg)
		Cement	POFA	PKS	MC		
POFC0100	0	6.05	0.00	3.36	13.43	8.27	3.02
POFC0595	5	5.75	0.30	3.36	13.43	8.27	3.02
POFC1090	10	5.44	0.60	3.36	13.43	8.27	3.02
POFC1585	15	5.14	0.91	3.36	13.43	8.27	3.02
POFC2080	20	4.84	1.21	3.36	13.43	8.27	3.02
POFC2575	25	4.54	1.51	3.36	13.43	8.27	3.02

Workability and slump tests

According to Abram's law, higher strengths and lower w/c values are indicated by the water to cement ratio (w/c), which determines the strength of a concrete mix (A. Ash et al., 2018), a water to cement ratio (w/c) of 0.5 was used for the mixes to achieve a good balance of workability and strength. Curing is the procedure adopted for promoting hydration of cement and consists of a measure of reducing temperature and moisture movement from and into the concrete drops below 80% (Neville, 2004) and curing is designed primarily to keep the concrete moist by preventing loss of moisture from it during the period in which it is gaining strength (Raheem A.A., 2013). Curing can be accomplished by keeping the concrete part as damp or as nearly saturated as is practical until the hydration products dramatically diminish the water-filled gaps or spaces (H. M. Hamada et al., 2019; Jokhio et al., 2020; Oluwasola et al., 2020). According to the dimensions specifications of (BS EN 12390-1:2012; BS EN 12390-4:2019), cube moulds for compressive testing were 100mm x 100mm x 100mm met (BS EN 12390-3:2009), beam moulds are 40 x 40 x 160mm for flexural strength, while cylinder moulds for splitting tensile strength testing were 100mm in diameter and 200mm in height. The cube-making process adhered to (BS EN 12390-2, 2003). Beams met (ASTM C78-18, 2018; ASTM C293-16, 2016; BS EN 12390-5:2009) and cylinders met (BS EN 12390-4:2019) requirements. The specimens were placed in the moulds for 24 hours, after which they were removed, marked, and tested in accordance with (BS EN 12390-2, 2003) at temperatures of 20 °C2. Up to 28 days were needed to cure the samples. A steady load was applied at a rate of 10% after the initial load of 0.60.2N/mm^2, which, in accordance with (BS EN 12390-4:2019), does not exceed 30% of the failure load, until no more loads could be maintained. Testing for compression was done after 7 and 28 days.

The slump test was carried out in accordance with (BS 1881-102:1983; BS EN 12350-2:2009). Slump test is useful for defining high and medium workability together with the consistency of the fresh concrete (ASTM C143/C143M-03, 2003). The types and qualities of the elements in concrete, for example, as well as other variables, affect the slump test results. The high-water demand of POFA, which can be mitigated by admixtures, is the cause of the decreased workability of POFA concrete with increasing replacement. Any cementitious material's workability or "consistence," which is mostly based on how wet the concrete is, is one of its fundamental properties. This is known as a slump.

Table 3 shows the slump readings for POFA blends with the percentage replacement levels of ordinary Portland cement Type 1 with water cement ratio of 0.5. The 80% marble chippings, 20% PKS with 100% cement and 0% POFA replacement, also referred to as the control which was taken as the point of reference from which all performance was measured.

Table 3: Slump readings for POFA mixes.

Item No	Mix samples	Binder mix proportion (%) and w/c 0.5		Coarse aggregates (%)		Slump value (mm)
		POFA	CEMENT	PKS	MC	
1	POFC 0100	0	100	20	80	170
2	POFC 0595	5	95	20	80	110
3	POFC 1090	10	90	20	80	100
4	POFC 1585	15	85	20	80	90
5	POFC 2080	20	80	20	80	35
6	POFC 2575	25	75	20	80	15

The slumps of POFA replaced mixes at various replacement levels are depicted Figure 5. In general, the slump is higher the wetter the concrete is. Although slump is frequently regarded as a measure of water content, it is more accurately understood as a consistency indicator. When concrete is delivered to a job site, consistency refers to how fluid the freshly mixed material is. Although it might be challenging to measure, concrete is said to be workable when it can be evenly and quickly compacted. The high surface area of the palm oil fuel ash is the main reason for the rise in the water demand of concrete containing POFA, which rises with increasing levels of POFA (Ash et al., 2018).

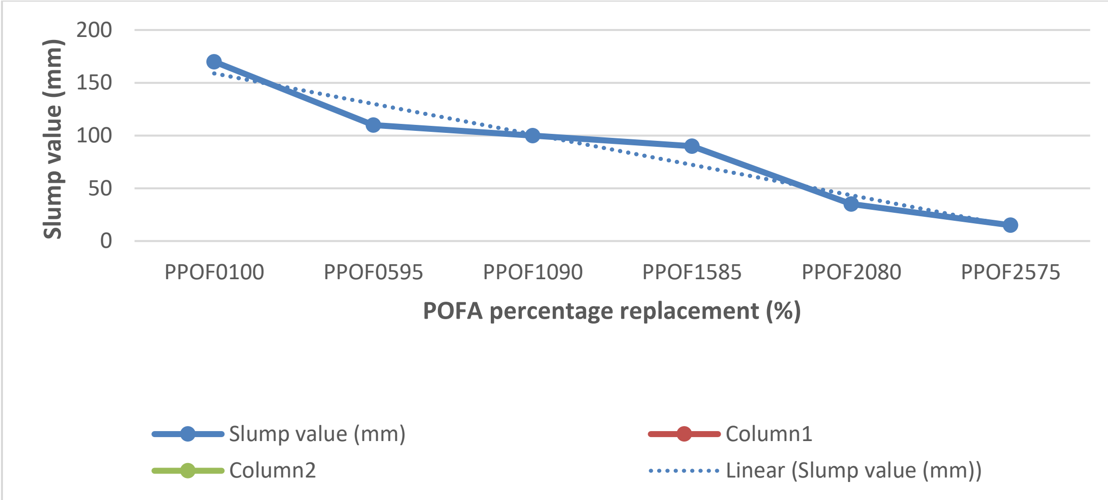

Figure 5: Development of slump of POFA blends against percentage replacement (mm)

Results and Discussion

Effect of POFA on compressive strength

The effect of POFA replacement levels on the compressive strength of concrete is illustrated in Table 4 and Figure 6 respectively. For mixes in samples POFC-0100, -0595, -1090, -1585, -2080 and -2575, the compressive strength rises with increasing POFA replacement levels. Mixes with a 10% replacement level of cement by POFA (POFC-1090) showed higher compressive strengths than those exhibited by their correspondent mixes at all ages except control POFC-0100 which has no POFA substance. Mehta (2004) was cited by (Hamada et al., 2021; Hamada, et al., 2018b; Hamada et al., 2020) that concrete containing supplementary cementing materials (SCMs), such as POFA and FA, has a positive effect on reducing water evaporation and drying shrinkage. However, the utilization of high-volume UPOFA in concrete can reduce drying shrinkage and thus improve the concrete's durability with time (Hamada et al., 2020). At 3, 4, 7, and 28 days, the compressive strength test was performed in accordance with (BS EN 12390-3:2002). The finding shows that integration of 10% palm oil fuel ash contributes to the enhancement of palm kernel shell lightweight aggregate concrete properties (Wan Ahmad et al., 2020). There was a successful report in using POFA as partial replacement in kernelrazzo concrete production would reduce quantity of ash disposed as waste and save the consumption of cement (Hamada et al. 2018). Table 4 shows compressive strength for the POFA kernelrazzo concrete mixes (N/mm^2).

Table 4: Compressive strength for the POFA kernelrazzo concrete mixes (N/mm^2)

Series	Mix	Curing Days			
		3	7	14	28
A	POFC 0100	19.24	24.05	26.29	30.26
B	POFC 0595	16.03	19.42	20.46	22.69
C	POFC 1090	17.32	20.71	22.45	24.94
D	POFC 1585	15.26	17.53	18.98	20.33
E	POFC 2080	14.56	15.46	17.55	18.63
F	POFC F2575	12.65	13.43	15.42	16.59

Effect of POFA splitting tensile strength

Palm oil fuel ash (POFA) is often used in concrete owing to its substantial enhancements of the mechanical and durability properties of kernelrazzo concrete and its environmental benefits. The resistance to the

splitting tensile stress was determined for all the kernelrazzo concrete mixes conducted in this study at various ages. The splitting tensile strength was taken at the ages of 3, 7, 14, and 28 days. The effect of POFA replacement, and age of sample was discussed thoroughly earlier. Also, the influence of the sample's compressive strength on the splitting tensile strength will be addressed in future.
Table 5 shows the effect of increasing palm oil fuel ash POFA replacement level on the tensile splitting strength kernelrazzo concrete inclusion of POFA. It analysed splitting tensile strength and POFA showed higher tensile strength values, the splitting tensile strength of POFA concrete increased when 0–10% POFA was added, and it decreased when the amount of POFA was greater than 20% (Alsubari et al., 2014, 2017, 2018; Amran et al., 2021; Tambichik et al., 2018). According to the study, the addition of 20% POFA improved the tensile strength of the concrete (Mohammadhosseini et al., 2016, 2018). It was concluded by Muthusamy et al. (2018) that over-inclusion of POFA is not advised because it would increase water demand, which will decrease workability and strength. The least splitting tensile strength values are in samples POFC-2575 at 7 and 14 days respectively.

Table 5: Splitting tensile strength for the POFA kernelrazzo concrete mixes (N/mm^2)

Series	Mix	Curing Days			
		3	7	14	28
A	POFC 0100	2.35	2.41	2.48	2.65
B	POFC 0595	2.13	2.21	2.29	2.43
C	POFC 1090	2.22	2.29	2.41	2.52
D	POFC 1585	1.99	2.13	2.19	2.33
E	POFC 2080	1.88	2.02	2.12	2.25
F	POFC 2575	1.72	1.84	1.97	2.15

Effect of POFA on flexural strength

Flexural strength is one of the most essential, valuable hardened properties of concrete and it is a measure to resist failure in the bending of an unreinforced concrete. Flexural strength of a concrete is nearly between 10% and 20% of the compressive strength of concrete (Dash et al. 2016). There is limited number of studies on the effect of palm oil ash (POFA) inclusion in concrete production on its flexural strength. (Saffuan et al., 2017) findings indicate that as more POFA is added, the workability of the concrete decreases. It could be noticed that the flexural strength of kernelrazzo concrete was increased as the curing age increases by the introduction of supplementary and pozzolana additive of palm oil fuel ash.
Table 6 show the effect of increasing POFA levels on the flexural strength of kernelrazzo concrete. Flexural strengths exhibited by the POFA kernelrazzo concrete mixes followed the same trend shown when determining the tensile splitting strengths. The flexural strength of concrete at the early age of 3, 7, 14 and 28 days were assessed using ASTM C78-16. A varying proportion of POFA concentrations were used to generate 12 beams specimens measuring 40 mm by 40 mm by 160 mm to evaluate the breaking point of the beams.

Table 6: Flexural strength for the POFA kernelrazzo concrete mixes (N/mm^2)

Series	Mix	Curing Days			
		3	7	14	28
A	POFC 0100	3.98	4.65	4.75	5.56
B	POFC 0595	3.35	3.76	3.89	3.96
C	POFC 1090	3.76	4.15	4.29	4.67
D	POFC 1585	2.57	2.75	2.93	3.15
E	POFC 2080	2.39	2.46	2.65	2.83
F	POFC 2575	2.15	2.21	2.42	2.61

Conclusion

The palm oil sector, which is extensively utilized in countries in Asia and Africa, produces the waste product known as palm oil fuel ash (POFA). Thus, it is effective to use palm oil fuel ash as a binder in the manufacturing of kernelrazzo concrete and other lightweight concrete for applications requiring low to moderate strength. To evaluate compressive, splitting tensile, and flexural strengths, kernelrazzo concrete specimens were made using a standard Portland cement Type 1, quarry dust, palm kernel shell, and marble chips. This kernelrazzo concrete production technique employs a water cement ratio of 0.5. At the curing age of 28 days, the concrete's compressive strength of the kernelrazzo concrete for 0%, 5%, 10%, 15%, 20% and 25% replacements were 30.26N/mm^2, 22.69N/mm^2, 24.94N/mm^2, and 20.33N/mm^2 and 18.63 N/mm^2 and 16.59 N/mm^2. Considering the results, it is advised to utilize palm oil fuel as in place as partial cement alternative for kernelrazzo concrete and for creating lightweight concrete with the use of 10% POFA, 90% Cement, 20% PKS and 80% marble chippings.

Recommendation

The latter age strength of pozzolanic concrete is related to the reaction of SiO_2 in the POFA with free lime $Ca(OH)_2$ over time to generate calcium silicate hydrate. According to (Bapat, 2013; Shetty, 2005), the hydration of cement is what causes the early age strength, and POFA fill in voids and contribute to the strength gain of calcium silicate hydrate (C-S-H). Based on laboratory tests, the following suggestions were made in this study:

i. The findings of compression, tensile splitting, and flexural strength tests have been correctly tabulated. According to the analysis that has been done, the 10% POFA increase with 24.94MPa has the highest average ultimate stress. This indicates that the compressive strength of the concrete made using blended cement was improved by POFA characteristics.
ii. The results of a slump test indicate that adding more palm oil fuel ash (POFA) to kernelrazzo concrete will result in a reduced slump value. Less workability is expressed by a lower slump value. The concrete slump value for this investigation has been impacted by the POFA and admixture properties.
iii. The substitution of palm oil fuel ash (POFA) for ordinary Portland cement (OPC) has numerous economic advantages while also assisting in the reduction of pollution.

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