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MECHANICAL PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETE CONTAINING UNGROUND PALM OIL FUEL ASH AS PARTIAL SAND REPLACEMENT

Escalating quantity of industrial by-products generated, including oil palm shell (OPS) and palm oil fuel ash (POFA) of the palm oil industries, has been a concern to many analysts. They are mostly disposed off as wastes that would heavily impact the environment quality. Therefore, this paper aimed to investigate the possibility of consuming these wastes by using OPS and POFA as replacement materials for fine aggregates in the concrete mixture. The mixtures were prepared by integrating unground palm oil fuel ash of 0%, 10%, and 20% (by weight of sand) to produce lightweight concrete. The experiments observed the mechanical performance of these specimens for 180 curing days. The results show the enhancement of concrete strength relative to the control mixture by using 10% of ash. This is owing to void filling mechanism and product of pozzolanic reaction due to the fine particles of the ash.

Keywords: Oil Palm Shell Lightweight Aggregate; Unground Palm Oil Fuel Ash; Mechanical Performance

1. Introduction

The continuous development in construction industry eventually leads to increase in demand for concrete material. As the quarrying industry encompasses activities such as removal of existing plants and aggregates producing processes which release noise as well as dust, the cleanliness of the surrounding would undeniably be affected. The blasting of rocks during quarrying activity would affect human health and may destroy the landscapes [1]. Continuous aggregate harvesting would result in resource declination and difficulties in obtaining the supply in future. Emergence of new hitches in building trade is possible owing to issues related to aggregates depletion and shortage, constraint of exploring new sources and hiking manufacturing expenses [2]. Disturbance in the river environment, owing to sand harvesting processes, has substantial effects on hydrological and hydrodynamic regimes of river-lake coordination [3]. The mining activities deprive water quality, destroy aquatic life and change the river bed shape [4]. Furthermore, the habitat destruction of the river's flora and fauna also affects the income of people depending on it [5] especially tourism and fisheries industries.

Simultaneously, the local palm oil trade also produces substantial quantity of oil palm biomass at the palm oil extracting mills which then disposed as solid waste thereby, opening the possibility for environmental degradation [6]. Palm oil fruit bunches which are sent from the plantation to the factory are extracted to produce oil using mechanical machines resulting in unwanted palm oil fruit fibres, empty fruit bunches and shells. The shells which obtained by crushing the oil palm kernel during the oil extraction process at the mill are abundantly generated in Southeast Asia [7]. The approximate annual generation of oil palm shell (OPS) in Malaysia is 6.78 MT [8]. The practice of discarding the shells at open areas consume spaces and unhealthy to the surrounding [9,10]. Option of converting the waste as fuel is attractive as it enables the reduction in management of by-product and saves the factory dumping space. However, burning of shells pollutes the environment [11]. The combustion process releases smoke and forms ash [12]. This fine ash which is approximately 5% of the incinerated biomass is unfit for use as plant fertilizer. This agricultural waste is discarded at open field [13] and is known with the name of palm oil fuel ash (POFA). Other than growing consumption of space for dumping that cre-

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ates ecological distress [14], the fine ash also pollutes the air [12] which is unhealthy for the community in the area. Realization on the undesirable impact of these wastes in terms of health and environment cleanliness, research are conducted to explore the potential use of both OPS and POFA in various sectors.

2. Experimental

In this experimental work, sand, water, Ordinary Portland Cement (OPC) and superplasticizer are among the materials used for concrete preparation. Besides that, oil palm shell (OPS) as lightweight aggregates and unground palm oil fuel ash (UPOFA) were incorporated to produce new concrete that can fulfil the standards of requirements. Fine aggregates was locally harvested from the river. Tap water considered in the mixture as it fulfils the requirement for the use in concrete. As an active ingredient, superplasticizer was employed in all mixes. Oil palm shells (OPS) was obtained from a dumping site of a nearby palm oil factory. Since this material is still under investigation as ingredient in such type of concrete, OPS went through a process of cleaning, drying and carefully stored in airtight containers. Unground palm oil fuel ash (UPOFA) waste are collected from the disposal area in the vicinity of one of the palm oil mills in West Malaysia. This material are subjected to process of oven dry at 110 ± 5°C for 24 hours in the faculty's laboratory. After that UPOFA systematically sieved to allow particles passing through 300 μm sieve whereby only these sizes and smaller particles are permitted for the production of concrete specimens. TABLE 1 shows the oxide composition of UPOFA.

TABLE 1

Oxide composition of UPOFA

Oxide Composition	Percentage (%)
Silicon dioxide (SiO_2)	27.45
Aluminium Oxide (Al_2O_3)	1.48
Iron Oxide (Fe_2O_3)	9.39
Magnesium Oxide (MgO)	1.23
Sodium Oxide (Na_2O)	0.07
Potassium Oxide (K_2O)	7.71
Sulphur Trioxide (SO_3)	1.39
Loss on Ignition (LOI)	5.00

A total of three well prepared OPS lightweight aggregate concrete (OPSLWAC) mixes considering diverse percentages of UPOFA to partially replace fine aggregates were used in this experimental work. A Grade 30 concrete functioning as reference specimen was prepared with natural river sand and identified as P-0. The other two mixes of concrete were prepared differently by taking out 10% and 20% by weight of sand and replace it with UPOFA and designated as P-10 and P-20 respectively (TABLE 2). The OPS lightweight aggregates concrete in this research study followed several preparation steps. Firstly, the required mixing ingredients were prepared according to the determined quantity. Then, all these materials were gradually together in a clean concrete mixer. A homogeneous mix were acquired before pouring the concrete into oiled mould. Afterward, the mixes were compacted according to the standard method and then the specimens were covered with wet clothes. After leaving it overnight, the hardened specimen were removed from the mould and immersed in a tank full of tap water for curing purpose.

TABLE 2

Mixing ingredients and proportions of concrete mixtures (kg/m^3)

Mixes	Cement	UPOFA	OPS	Sand	Superplasticizer	Water
P-0	500	0	300	700	5	225
P-10	500	70	300	630	5	225
P-20	500	140	300	560	5	225

3. Results and discussions

Fig. 1 demonstrates the reduction of the concrete's workability with the incorporation of UPOFA as fine aggregates replacement. The mixes containing 0% and 10% UPOFA demonstrated true slump that can be classified as medium range in degree of workability. However, the workability of mix with 20% POFA falls onto low and very low, respectively. Properties of porous and smaller size of UPOFA, unlike natural sand, increases water demand thus producing stiffer mix. The honeycombed internal structure of UPOFA (Fig. 2) contrasted with river sand surface without any visible voids as shown in Fig. 3. The specific gravity of UPOFA was 2.21 indicating that it was smaller than sand with a value of 2.72. Finer aggregates size demands greater mixing water to preserve the workability [15]. Similar trend was also reported in [9,16] when finer material was used to substitute sand partially.

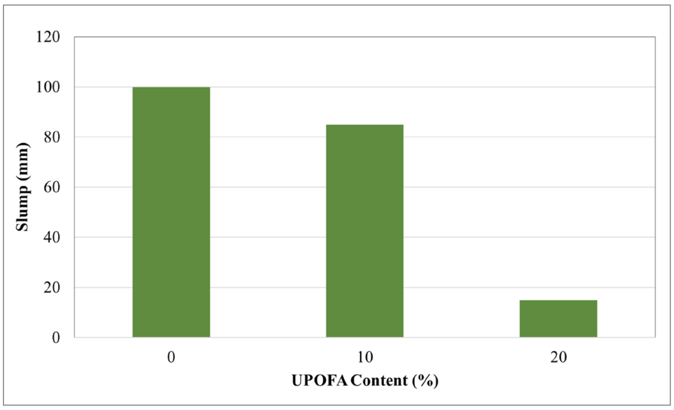

Fig. 1. Slump test result

3.1. Density

Fig. 4 displays the density of UPOFA concrete. All specimens qualified to be characterized as lightweight aggregates concrete. That is proven by the specimens possessing density

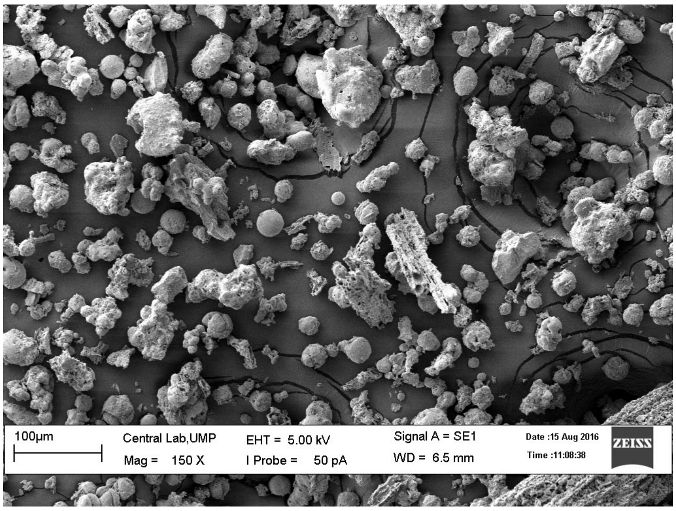

Fig. 2. Porous structure of UPOFA

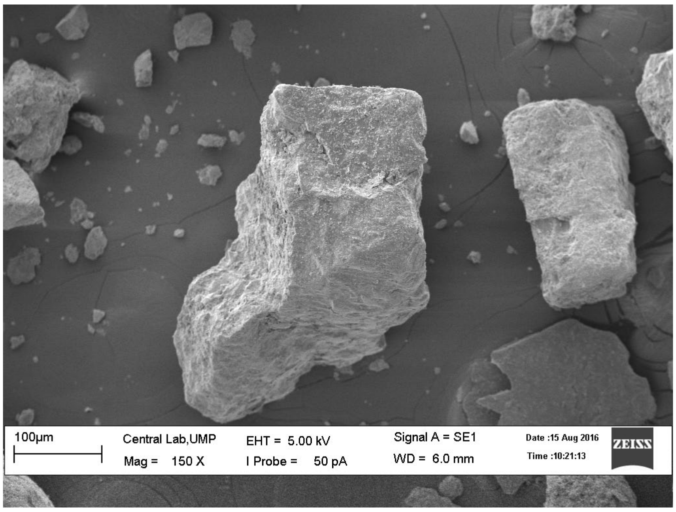

Fig. 3. Solid sand appearance

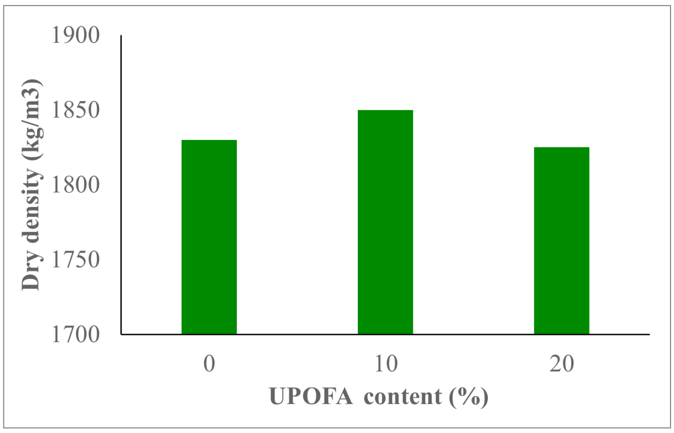

Fig. 4. Dry density of concrete specimens

between 1830 to 1850 kg/m^3. Normally, for the lightweight concrete to fit for structural applications, it has to possess a density between 350 to 1850 kg/m^3 [17]. Integration of 10% of UPOFA as sand replacement increased the density slightly higher than the plain specimen. This is attributed to the compact concrete internal structure as a result of supplementary CSH gel developed by pozzolanic action of fine UPOFA. Incorporating 20% of the same ash has produced concrete with the least density owing to higher content of the ash. Similarly, previous researcher Ahmad Zawawi et al. [9] found that, partial employment of pozzolanic ash as replacement ingredient in concrete results in alike pattern.

3.2. Compressive Strength

The strength of OPSLWAC with different UPOFA replacements are shown in Fig. 5. Amongst all, water cured concrete with 10% UPOFA exhibited the highest strength meeting the targeted Grade 30 concrete. Combination of two factors namely water curing and optimum 10% UPOFA enabled more effective pozzolanic reaction aiding the pores downsizing in the concrete producing firmer and stronger structure. Fig. 6 illustrates the existence of larger amount of Calcium Hydroxide in control specimen which remained unreacted due to absence of pozzolanic ash. In contrast, concrete with 10% UPOFA (Fig. 7) consisted lesser Calcium Hydroxide owing to pozzolanic effect. The effectiveness of fine POFA as mineral admixture in enhancing concrete strength was also stated by Skariah et al., [18].

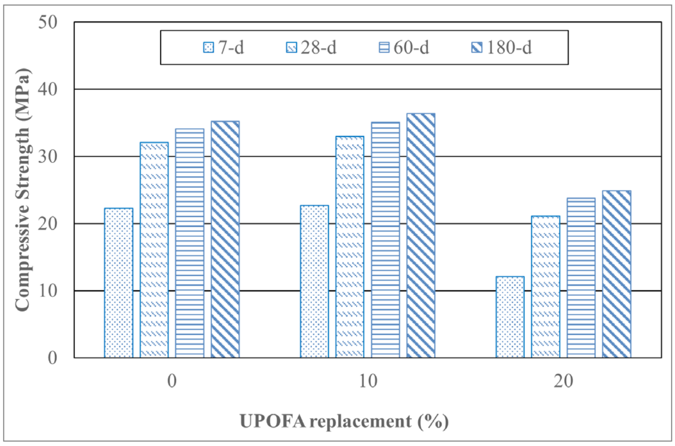

Fig. 5. Compressive strength results

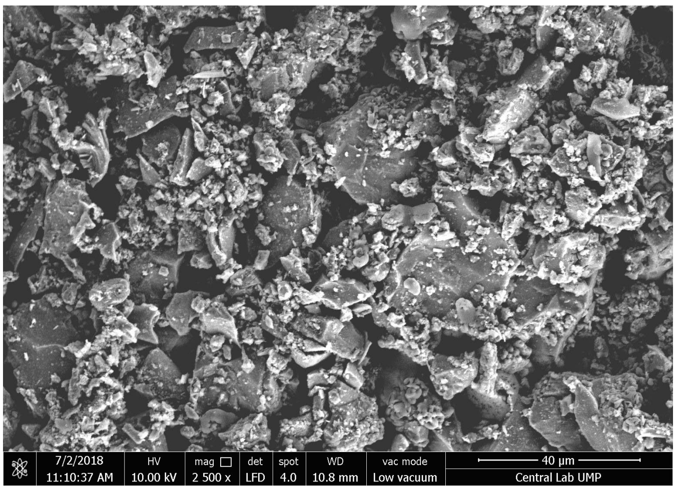

Fig. 6. Higher amount of Calcium Hydroxide in plain concrete

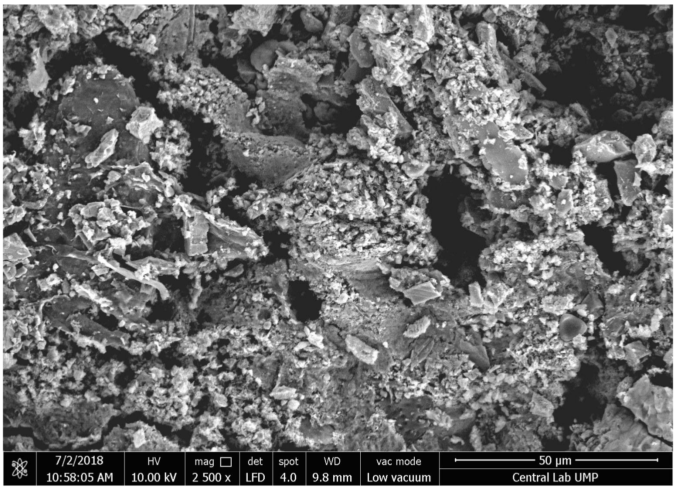

Fig. 7. Lesser Calcium Hydroxide in specimens with 10% UPOFA

However, use of UPOFA in larger amount results in concrete strength declination. UPOFA being finer and porous than sand besides its ability to absorb larger amount of water has reduced the concrete workability. That is noticeable as the initial mixing water was insufficient to coat the larger surface area of ash. As a result, the workability of mix dropped, and furthermore, it was difficult to achieve proper compaction. Subsequently, concrete consisting higher number of pores with inferior bearing ability was produced. On the other hand, the one with the lesser amount of UPOFA enabled higher compaction. Fresh concrete workability influences concrete strength [19]. The concrete strength declination upon the integration of different types of industrial by-products as fine aggregates replacement which exceeds the optimum amount has been observed by Muthusamy et al., [20], Bishta and Ramana [21] and Manoharan et al., [22].

3.3. Splitting tensile strength

Fig. 8 present the splitting tensile strength results of concretes. Results revealed the similar trend patterns as shown in

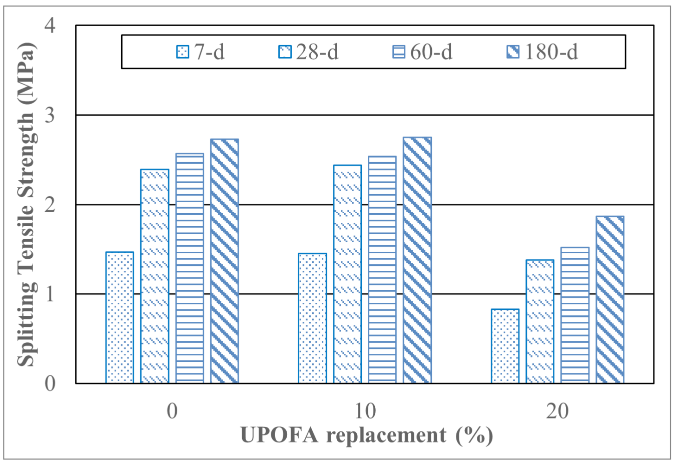

Fig. 8. Splitting tensile strength results

compressive strength. The tensile strength of OPSLWAC containing more than 10% of UPOFA as fine aggregates replacement were lower than the corresponding control specimen. Overall, the data indicated that OPSLWAC specimens containing up to 20% UPOFA are suitable to be used for structural applications. This is in conformation to the requirement in ASTM C330 [23]. As a conclusion, application of water curing and utilization of 10% UPOFA successfully enhances the concrete strength.

3.4. Modulus of elasticity

The modulus of elasticity results are shown in Fig. 9. Incorporation of suitable percentage of UPOFA at 10% produces the stiffest lightweight aggregates concrete. The resistance for elastic deformation of the concrete reduces when 20% of UPOFA were used. This shows that the concrete strength is optimum at 10% of UPOFA and the reduction becomes non-linear from then towards higher amount of UPOFA. Disruption in CSH generation process owing to inadequate moisture supply creates a weaker ITZ and lower stiffness. Likewise, the efficacy of water curing method approach on modulus of elasticity values of concrete was reported by Islam et al., [24].

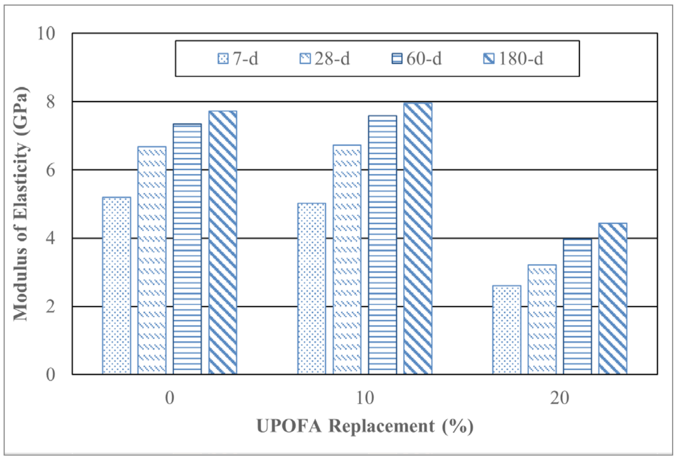

Fig. 9. Modulus of elasticity testing result

4. Conclusion

Considering the current research study, the inclusion of UPOFA in concrete to partially replace fine aggregates, in a controlled amount, enhances the concrete strength. Workability of oil palm shell lightweight aggregate concrete comprising 10% UPOFA is almost similar to control mixture. Water cured OPS lightweight concrete comprising 10% UPOFA improved long-term mechanical strength compare to plain concrete. The continuous water curing technique contributed to the strength development of OPS concrete with UPOFA as it supplies adequate water to form CSH gel through unobstructed cement hydration and pozzolanic reaction of available fine ash.

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