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Compressive Strength and Density of Oil Palm Shell Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash under Different Curing Regime

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Abstract**:** *Efforts to reduce quantity of oil palm shell and palm oil fuel ash from being disposed as environmental polluting waste has result in innovation of oil palm shell lightweight aggregate concrete containing palm oil fuel ash as partial cement replacement. The current investigation looks into the effect of curing methods on density and compressive strength performance of this newly modified lightweight concrete. Plain concrete consist of 100% OPC were used as control specimen and another one is produced by integrating 20% ground palm oil fuel ash by weight of cement. The specimens were produced in form of cubes (100mmx100mmx100mm) and subjected to different curing method up to 60 days. Four types of curing method were applied namely continuous water curing, sprayed curing, air curing and natural weather curing. Compressive strength test were conducted in accordance to BS EN 12390-3 at 7, 28 and 60 days. The results reveal that strength development of oil palm shell lightweight aggregate containing palm oil fuel ash depends on the frequency of water supplied during curing age. Continuous water curing is the most suitable type of curing as it promotes better hydration process and pozzolanic reaction in the concrete mix. Formation of larger amount of C-S-H gel makes the concrete internal structure denser and able to sustain larger load compared to plain concrete.*

Keywords: *compressive strength, oil palm shell lightweight aggregate concrete, palm oil fuel ash, partial cement replacement, different curing regime*

1. Introduction

Palm oil industry in Malaysia is one of the incomes generating trade which continue to flourish throughout the years offering prosperous economy of the country. Being one of the largest palm oil producers in the world, the industry generates increasing quantity of solid wastes which requires proper management. Yacob et al. [1] reported that palm oil mills in Malaysia generated about 56.7 million tonnes of solid waste in 2004 and the quantity will keep on arising. Annually, over 4 million tonnes of oil palm shell (OPS) [2] and 4 million tonnes of palm oil fuel ash (POFA) were generated [3]. In practice, both wastes were disposed at open area within the vicinity of palm oil mill. Dumping of these wastes is an easy way to solve the problem temporarily, but this method would demand for more valuable land to be provided for this purpose and also arising more environmental problems. On top of that, the environmental regulation becomes more stringent causing the waste disposal cost becoming increasingly expensive [4]. In view of the rising production of these solid wastes and also considering the issue of sustainable construction as well as establishment of cleaner environment, the use of these solid wastes in production of materials are highly desirable.

In relation to those issues, the abundantly available oil palm shell has inspired researchers [5, 6] in attempting to produce more environmental friendly concrete by using this by-product as one of the mixing ingredient. Being hard and does not deteriorate easily inside hardened concrete, makes oil palm shell suitable to be used as lightweight aggregate. Continuous researches has led to innovation of oil palm shell lightweight aggregate concrete having a wide range of strength [7, 8, 9, 10] suitable for various application in construction.

As for palm oil fuel ash, after this material has been discovered as a good pozzolanic material at the end of 20^{th} century, it has been used as partial cement replacement to produce normal concrete [11], lightweight concrete [12], high strength concrete [13] up to high performance concrete [14]. However, these materials have not been combined together to produce concrete until recently, Muthusamy and Azimah [15] manage to upgrade the existing oil palm shell lightweight aggregate concrete to be more environmental friendly by integrating palm oil fuel ash as partial cement replacement. Early findings reveal that incorporation of ground palm oil fuel ash at suitable percentage successfully enhances the strength to be higher than plain concrete. However, using too much of POFA would have adverse effect on strength development. The performance of this lightweight aggregate concrete in different type of curing regimes is unknown. Thus, this paper addresses the effect of curing method on density and compressive strength development of oil palm shell lightweight aggregate concrete containing palm oil fuel ash. The information on the suitability of curing method for better strength performance of this lightweight aggregate concrete is therefore beneficial for future application of this material.

2. Experimental Programme

The material used for concrete preparation in this experimental study consist of ordinary Portland cement (OPC), local river sand, supplied tap water, superplasticizer, oil palm shell and palm oil fuel ash. Both oil palm shell and palm oil fuel ash were obtained from a local palm oil mill. The oil palm shell was ensured clean from debris. The raw palm oil fuel ash were oven dried and then sieved before subjected to grinding process to produce fine ash fulfilling the specification in ASTM C618-12 [16] enabling it to be used as partial cement replacement material. This pozzolanic ash is categorised as Class C in accordance to ASTM C618-12 [16].

Two types of oil palm shell lightweight aggregate concrete mixes have been used. The reference mix is plain oil palm shell lightweight aggregate concrete prepared using 100% OPC. The second mix is produced by partially replacing the cement with 20% palm oil fuel ash by weight of cement. The mix proportion used to produce oil palm shell lightweight aggregate concrete containing palm oil fuel ash is presented in Table 1. All mixes were casted in form of cubes (100x100x100mm), and then covered with wet gunny sack before demoulded the next day. After that, the specimens were placed in different curing conditions namely continuous water curing, sprayed curing (water spray 3 times / day), natural weather curing (under the open sky) and air curing (inside the laboratory) as illustrated in Fig.1 to 4. The specimens were left in each curing condition until the testing date. The compressive strength test was conducted in accordance to BS EN 12390 – 3 [17] at 7, 28 and 60 days. The density of specimens was measured following the guideline in ASTM567M – 14 [18]

TABLE I Mix Proportion of 1 m^3 Oil Palm Shell Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash

Details	kg/m^3
Cement	400
Palm oil fuel ash	100
Sand	870
Oil palm shell	360
Water	225
Superplasticiser	4

Fig. 1: Continuous water curing

Fig. 2: Sprayed curing

Fig. 3: Air curing (inside laboratory)

Fig. 4: Natural weather curing (under the open sky)

3. Results and Discussion

3.1. Density

The density of the concrete specimen subjected to different types of curing regime until the age of 28 days are shown in Fig. 5. Evidently, density of the concrete specimens is influenced by types curing method applied and also inclusion of palm oil fuel ash in the concrete mix. It is observed that use of POFA as partial cement replacement increases the concrete density. Inclusion of POFA in concrete mixture has caused occurrence of pozzolanic reaction which consume the $Ca(OH)_2$ by-product of hydration process thus producing secondary C-S-H gel. As a result, concrete containing POFA consist larger amount of C-S-H gel that cause concrete densification thus assisting to be higher density than control specimen. This fact has been highlighted by Zhang et al. [19] who stated that the fine pozzolanic material can increase the packing density of the cement matrix thus creating less permeable structure with higher density. As a result, better strength and durability characteristic were obtained.

Comparing the performance of specimen from different curing medium, water cured specimens exhibit the highest density, followed by sprayed curing, air curing and natural weather specimens respectively. Water curing maintains a suitably moist environment for the developments of hydration products that is used during pozzolanic reaction that takes place throughout the curing period. Production of larger amount of C-S-H gel which fills in the existing pores increases the denseness of microstructure in concrete leading to higher density. The hydration products extend from the surfaces of cement grains, and the volume of pores decreases due to proper curing [20]. Water curing is also the best curing for OPS LWAC with POFA as it requires continuously presence of water for pozzolanic reaction to takes place. In the case of specimens subjected to sprayed curing, the water was not supplied continuously as water curing. However, there is still available moisture for hydration process and pozzolanic reaction to takes place as the specimens was watered three times a day.

Air cured specimens' falls in the third place. Evidently, concrete cured under air curing only depended on the concrete moisture itself for hydration process. Insufficient moisture will retard the hydration process as well as pozzolanic reaction and reduce of C-S-H gel formed which will reduce the concrete density. Concrete with the least density value is the one placed outside the laboratory under the open sky exposed to the direct sunlight and rain. The occurrence of extreme hot weather during the period whereby this experimental work conducted causes the specimens suffered excessive evaporation thus caused rapid moisture loss from fresh concrete. When water from concrete evaporates, it leaves voids inside the concrete element creating capillaries which lead to porous concrete and resulted in lower concrete density. This is supported by Kodur [21] who state that the density or mass of concrete decreases with increasing temperature due to loss of moisture. The absence of sufficient moisture in the concrete retards the hydration process and the effective bonding of particles. The weak bond resulted in concrete volume not so closely packed thus resulted in low density concrete. Despite varies value obtained, the mean dry densities of all specimens ranged from 1600 to 1843 kg/m^3 which can be classified as lightweight concrete.

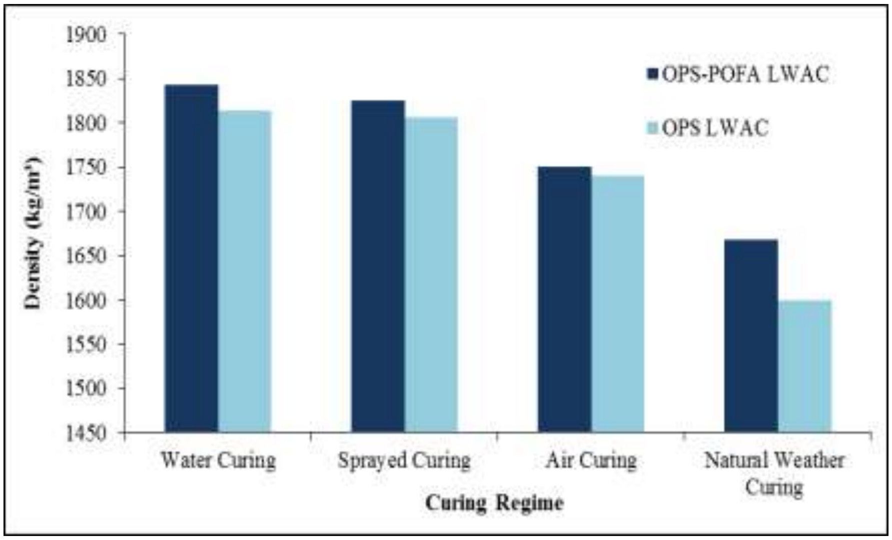

Fig. 5: Density of specimens subjected to different curing regimes at 28 days

3.2. Compressive Strength

From the result illustrated in Fig. 6, the compressive strength performance of OPS lightweight aggregate concrete containing POFA is influenced by curing method applied. Continuous supply of water during curing period for concrete containing POFA promotes excellent strength achievement compared to all other specimens. Keeping the specimen completely submerged in the water prevents loss of moisture that can happen through evaporation of moisture from the concrete surface. The continuous presence of water allows better hydration process and pozzolanic reaction to occur resulting in formation of larger total amount of C-S-H gel filling in the voids which eventually increase concrete strength. The effectiveness of water curing in assisting concrete containing palm oil fuel ash to exhibit higher strength than control specimen has been reported by researcher elsewhere [22, 23]. Other than water curing, sprayed curing also can be used since this method has increased the frequency of exposure for POFA specimen to water supply which is 3 times per day throughout the curing age. This has provided longer period for this specimen to be in the medium conducive for production of C-S-H gel enabling better strength development in comparison to air cured and natural weather cured specimen.

Application of air curing for concrete containing palm oil fuel ash should be avoided as it fails to promote the concrete strength to be higher than plain concrete. Since the strength development is very much dependent on the availability of moisture for hydration process or pozzolanic reaction to take place, concrete specimen containing POFA failed to maintain it leads throughout the curing period. The strength developments slowed when the water inside the cubes evaporates as the absence of water obstruct the pozzolanic reaction to produce secondary C-S-H gel. The significant role of moisture for strength development of OPS LWAC with POFA has been highlighted in ASTM C618-12 [16] stating that pozzolanic material will chemically react with calcium hydroxide with the presence of moisture to form compounds possessing cement properties. The poor performance of concrete containing palm oil fuel ash compared to plain concrete upon subjected to air curing method has been reported by other researchers [22, 24]. In this investigation, specimens' subjected to natural weather demonstrates the lowest value of strength. Due to extreme hot weather at the early curing age has caused excessive water evaporation from the concrete which disrupted the hydration process. According to Mannan et al. [25], at higher temperatures, the rate of cement hydration is negatively affected the hydration process leading to poor strength development. As a result, pozzolanic reaction is interrupted due to two factors that is availability of calcium hydroxide in lower amount due slow rate of hydration process and absence of moisture.

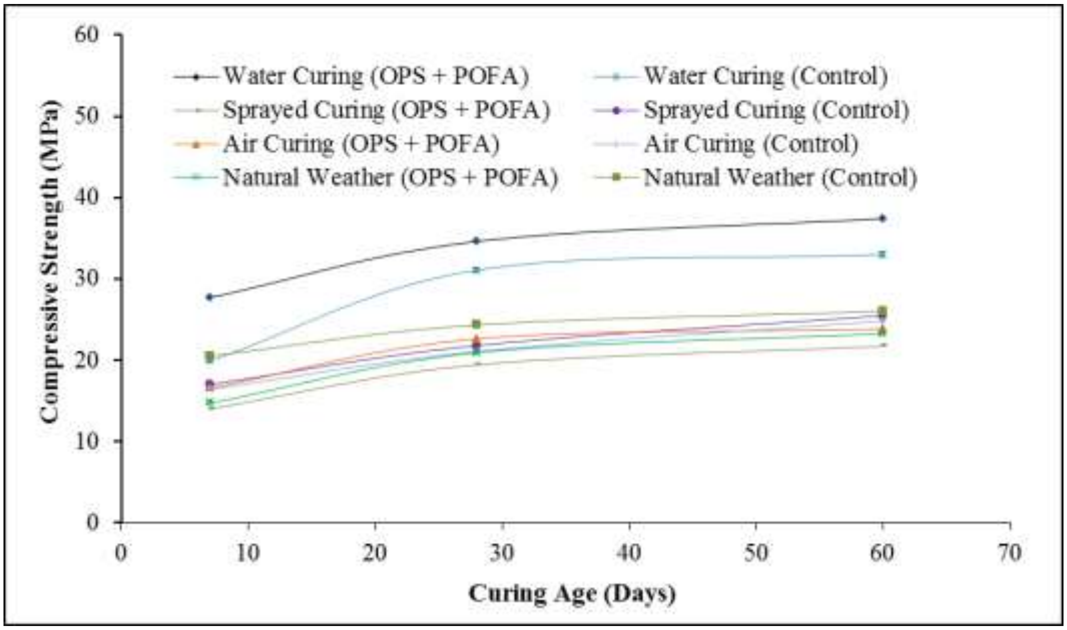

Fig. 6: Compressive strength of specimens subjected to different curing regimes up to 60 days

4. Conclusion

Water curing is the most suitable method to ensure excellent strength performance of oil palm shell lightweight aggregate concrete. On the other hand, air curing is not recommended since it fails to assist better strength achievement of concrete containing palm oil fuel ash. Success in incorporating POFA as partial cement replacement is expected to produce a more affordable lightweight aggregate concrete, reduces environmental problems and become a profit contributing means to the palm oil industry in future.

5. Acknowledgement

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