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Effect of mixing ingredient on compressive strength of oil palm shell lightweight aggregate concrete containing palm oil fuel ash

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Abstract

The increasingly generated oil palm shell (OPS) and palm oil fuel ash (POFA) which is a by-product of Malaysian palm oil mills annually, has lead towards the effort of integrating palm oil fuel ash as mineral admixture in lightweight aggregate concrete which produced using 100% oil palm shell as lightweight aggregate. This paper addresses the compressive strength of this oil palm shell lightweight aggregate concrete upon usage of different ash replacement level, water cement ratio, superplasticiser, sand and cement content. At the early state of investigation, cubes of (100x100x100mm) containing various replacement level of ash were produced and tested for it compressive strength. Then, the 20% replacement levels of POFA which give the highest compressive strength value were used for further experimental work. Experimental work to investigate the effect of water content, percentage of superplasticiser, sand content and amount of cement used were conducted using two types of mixes. Plain oil palm shell lightweight aggregate concrete (0% POFA) as reference specimen, and oil palm shell lightweight aggregate containing 20% palm oil fuel ash (20% POFA) were prepared in form of cubes. All the specimens were subjected to water curing until the testing date. The compressive strength test was conducted following the procedures in BSEN 12390 – 3 at 28 days. Integration of 20% POFA in oil palm shell lightweight aggregate concrete leads to production of a greener lightweight aggregate concrete product with optimum strength. Inclusion too much of water should be avoided as it diminishes the concrete compressive strength. Only right formulation of palm oil fuel ash, water, superplasticizer, sand and cement content would be able to produce oil palm shell lightweight aggregate concrete containing palm oil fuel ash exhibiting optimum strength.

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Keywords: oil palm shell, lightweight aggregate concrete ; palm oil fuel ash ; mixing ingredient ; compressive strength

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1. Introduction

As one of the major palm oil producers in the world, Malaysia produces bountiful amount of waste namely, palm oil fuel ash and oil palm shell from the palm oil mill. Over 6.89 million tonnes of oil palm shell [1] and 4 million tonnes of palm oil fuel ash [2] are generated annually in Malaysia. The thrown oil palm shell is left to rot in huge mounds that ultimately cause pollution [3]. Opening up new landfills for disposal of this solid waste that takes long time to biodegrade seems to be less economic for the palm oil mill management and also less environmental friendly. Palm oil fuel ash which is unsuitable to be used as fertilizer was dumped as waste behind the mill or landfill. Being light, this ash is easy to be blown by the wind and spread to other place thus causing air pollution. Prolonged exposure to this polluted air may cause respiratory illness for the workers of the mill. According to [4], the disposal of palm oil fuel ash causes negative effect on the health and comfort of the community. Continuous dumping of these wastes at the landfill would pose more severe environmental problems in terms of pollution of ground water source as well as unsightly view.

With the aim to reduce amount of waste disposed to the environment and also decrease amount of natural resources from being harvested to be used in concrete production, researchers attempt to explore the potential of these palm oil industry by-products to be used in concrete industry. As a result, both wastes were found to have the potential to be used as a mixing ingredient in concrete. The discovery of palm oil fuel ash as a potential supplementary cementitious material [5] together with increased awareness on negative impact posed by greenhouse gases emission by cement manufacturing, has initiated many researches in concrete area. This led to production of many types of concrete containing palm oil fuel ash such as ordinary concrete [5], aerated concrete [6], high strength concrete [7] and high volume ash concrete [8] were produced. Classification of oil palm shell as lightweight aggregate material [9] and realization in preserving natural granite aggregate resources that has been used in concrete industry has opened a new area in lightweight aggregate concrete research. The abundantly available oil palm shell locally has led to utilisation of this waste material as lightweight aggregate in production of oil palm shell lightweight aggregate concrete (OPS LWAC) of varies strength [10, 11, 12] for various application.

Availability of both wastes locally, has initiated efforts to combine these materials in concrete production. Incorporation of palm oil fuel ash as partial cement replacement in oil palm shell lightweight aggregate concrete successfully enhances the compressive strength of concrete [13]. However, there are many other properties of this new lightweight concrete remains to be investigated. Thus, this paper discusses the influence of mixing ingredients to the compressive strength of oil palm shell lightweight aggregate concrete containing palm oil fuel ash.

2. Experimental Methods

2.1. Materials

Materials used in this experimental work consist of ordinary Portland cement, sand, oil palm shell (OPS), palm oil fuel ash (POFA), superplasticizer and water. Ordinary Portland cement conforming to MS 522: Part 1 [14] for Portland cement specification from single source was used as binder. Air dried local river sand was used as fine aggregate. Both palm oil fuel ash (POFA) and oil palm shell (OPS) used was collected from a local palm oil mill located in Gambang, in the state of Pahang, West Malaysia as shown Fig.1 and 2 respectively. The collected ashes were oven-dried for 24 hours before sieved passing 300μm sieve. Then, it was subjected to grinding process to produce finer ash particle that comply with the requirement in ASTM C618–12 [15]. The BET surface area of ground POFA is 2.5443 m^2/g indicating it is finer than cement with the surface area value of 1.2967m^2/g. Based on the chemical composition of POFA, the ash is classified as class C pozzolana in accordance with ASTM C618– 12 [15]. OPS collected were sieved using 10 mm sieve and then washed thoroughly to remove dirt. OPS were then air-dried until it turns into saturated surface dry (SSD) condition. After drying process, the OPS were crushed using jaw crusher in order to obtain smaller particle. The crushed oil palm shells were sieved with a 5mm sieve to remove smaller particles. Only OPS aggregates retained in this sieve were used as coarse aggregate. Superplasticizer classified as Type A according to ASTM 494 -05 [16] was also employed in all concrete mix to improve workability of concrete. Tap water were used for concrete preparation work and curing purpose.


Figure 1. Oil palm shell at the palm oil mill


Figure 2. Palm oil fuel ash at the palm oil mill

2.2. Specimens Preparation and Testing

The experimental programmed is divided in two stages. Experimental work in the first stage focus on determining the optimum POFA content that should be integrated as partial cement replacement for better strength development of OPS LWAC concrete. OPS LWAC concrete used in this research consists of 100% processed oil palm shell functioning as lightweight aggregate material and no granite aggregate is used. Six types of mixes consisting of POFA as partial cement replacement ranging from 0% to 50% were prepared. Amount of POFA added in the mix was by weight of ordinary Portland cement. All the specimens were cast in form of cubes and then water cured for 28 days. The effect of POFA on concrete workability has also been investigated through slump test following the procedures in BS EN 12350 : 2 [17]. The compressive strength test was conducted on the specimens in accordance with BS12390:3 [18] at 28 days. Scanning Electron Microscopy has also been used to investigate the internal structure of the concrete specimens.

In the second stage of investigation, only two types of mixes were used. The control specimen (P-0) of grade 30 also known as plain OPS LWAC was prepared using trial mix method similar to the approach used by previous researcher [19], to design lightweight aggregate concrete mix . The mix proportion of Plain OPS LWAC (P-0) that consists of 100% OPC as binder is shown in Table 1. OPS LWAC containing POFA was prepared by integrating 20% of POFA by weight of cementitious materials. The second stage investigates the effect of water cement ratio, percentage of superplasticizer used, amount of sand and cement used towards compressive strength of concrete. The influence of water content to the concrete mix was investigated by varying the water cement ratio from 0.45, 0.50 and 0.55. The effect of admixture content was investigated by varying the superplasticizer content from 0.6, 0.8 and 1.0%. To investigate the effect of sand content towards compressive strength of OPS LWAC, sand content of 670, 770 and 870 kg/m^3 was used. The effect of cement content was also investigated by varying the amount of cement content from 400, 450 and 500 kg/m^3. All the specimens were cast in form of cube (100x100x100)mm and the placed in water curing for 28 days, Then, the compressive strength of the specimens were determined through compressive strength test in accordance with BS12390:3 [18].

Table 1. Mix proportion of oil palm shell lightweight aggregate concrete

Material	kg/m^3
Cement	500
Palm oil fuel ash	0
Sand	870
Oil palm shell	360
Water	225
Superplasticizer	5

3. Results and Discussion

3.1. Effect of Palm Oil Fuel Ash Content

Amount of POFA added do influence the workability of fresh concrete as can be observed in Figure 3. The slump values of OPS LWAC with different percentage of POFA mixtures were measured between 80 and 110 cm. Slump with POFA replacement between 10 to 30% produces true slump with a medium degree of workability. Concrete mix containing 50% POFA as partial cement replacement results in the driest mix but provides the highest slump result. However, the concrete segregation is inherently due to porous particle of POFA as compared with OPC, which essentially results in a larger absorption of water when utilising of more than optimum amount that in turn causes concrete segregation. The result of BET surface area conducted shows that the total volume of pores for POFA is two times higher than OPC (0.002822 cm^3/g) with 0.005405 cm^3/g). Dry mixture essentially leads to low cohesion which in turn causes the slump to collapse. The same dry mixture was also developed in the concrete mixture with 40 % replacement by POFA. The best slump is best exhibited by 30% cement replacement by POFA with 100 mm slump followed by 20% replacement. Therefore, the suitable percentage of POFA to be integrated to produce OPS LWAC with POFA with better workability is between 20% to 30% replacement.

In term of strength, a suitable combination of POFA content produces concrete with enhanced strength as illustrated in Figure 4. Replacement of POFA in OPS LWAC from 10% to 30% resulted in strength higher than plain OPS LWAC. However, OPS LWAC reached their maximum strength at the replacement level of 20%. The increase in strength of OPS LWAC with POFA could be attributed by the filling effect of the fine ash and also the pozzolanic reaction that improves the bond between the hydrated cement matrix and the aggregates. During pozzolanic reaction, calcium hydroxide ($Ca(OH)_2$) generated from the hydration process reacts with silica in POFA forming secondary calcium silicate hydrate gel (C–S–H) gel that which fills up the voids between cement and aggregates generates a stronger bond between the paste and the aggregate creating a higher strength. Figure 5 illustrates the SEM microstructure of specimen containing 20% POFA which consist large amount C-S-H gel type I and type IV in comparison to plain specimen (Figure 6) which has lesser amount of C-S-H gel and unreacted calcium hydroxide in form of hexagonal shape. Concrete containing ash replacement level of more than 30% produces lower strength than plain concrete owing to the lesser amount of total C-S-H gel produced. Lower cement content causes lesser hydration process in the concrete resulting in generation of lower amount of calcium hydroxide to be used pozzolanic reaction for formation of secondary C-S-H gel. The adverse effect to the concrete strength upon using too much of palm oil fuel ash as partial cement replacement has been reported by other researchers [20, 21].

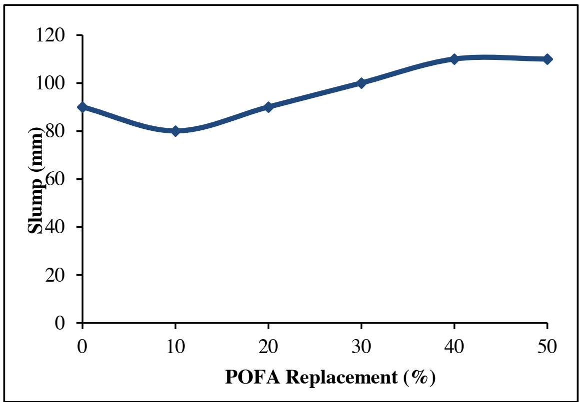

Figure 3 . Effect of POFA content on workability of OPS LWAC concrete

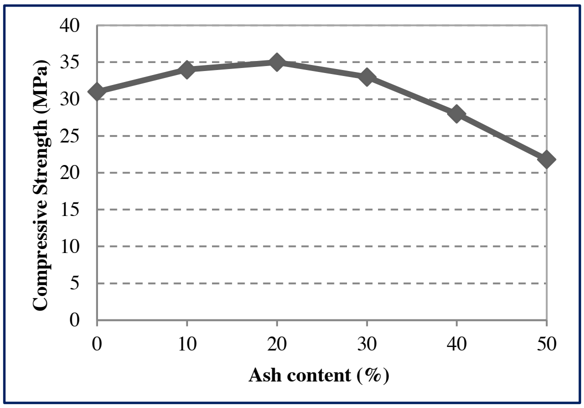

Figure 4 . Compressive strength of OPS LWAC concrete with different POFA content

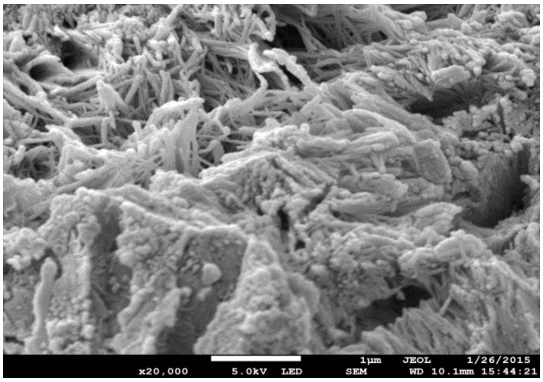

Figure 5. SEM microstructure of concrete with POFA (20% POFA)

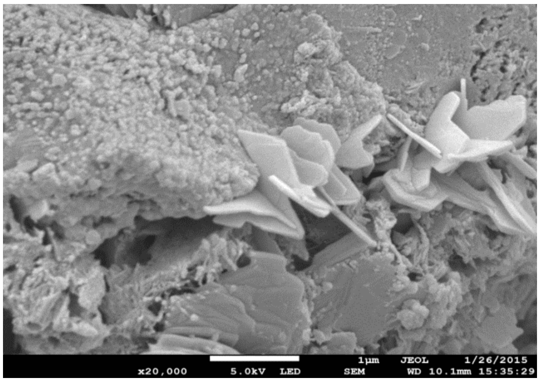

Figure 6. SEM microstructure of plain concrete (0% POFA)

3.2. Effect of Other Mixing Ingredients

As can be observed in Figure 7, 8, 9 and 10, the amount of mixing ingredient used has on effect the compressive strength of OPS lightweight aggregate concrete specimens. Looking at the effect of water cement ratio, both types of concrete mixes exhibit similarity in the pattern of strength achievement upon variation in water content used as illustrated in Figure 7. The least strength was attributed by water-cement ratio of 0.35. The reduction in strength OPS LWAC containing POFA is due to the insufficient water for occurrence of better hydration and pozzolanic reaction. In addition, less water usage in concrete reduced the workability causing improper compaction work. The presence of voids due to improper compaction also contributes to reduction of concrete strength. However, adding high amount of water causes the concrete to bleed excessively due to segregation of the sand and aggregate components from the cement paste leaving a cement sand paste layer on top of the surface of concrete. Other than that, the hydrated water which is not completely consumed during the hydration process will result in microscopic pores that affect the final strength of the concrete. Compressive strength was observed to be highest at 0.45 water-cement ratio. Inclusion of adequate amount of water assist towards occurrence of better hydration process and pozzolanic reaction resulting in formation of larger amount of C-S-H gel making the concrete structure denser and stronger. As for influence of superplasticizer, both concrete mixes in Figure 8 exhibit increment in the strength value as the percentage of superplasticizer used become larger. This presumably attributed to the role of water reducing admixtures that disperse the cement particles in concrete preventing difficulties during mixing work and better hydration process. This leads to proper concrete compaction and hence, improves concrete strength. The role of water reducing admixture has been well elaborated by [22] who highlighted that the absorption of substances from water reducing admixtures on cement particles, would give negative charges that causes the particles repulse each other thus resulting in workable concrete mix. The highest compressive strength was denoted by 1.0% of superplasticizer content which is the optimum amount to be utilised in OPS LWAC.

The compressive strength performance of OPS LWAC with POFA increases with the increment in the quantity of sand and cement as shown in Figure 9 and 10 respectively. The strength of these types of concretes increases 20 to 50% for every 100 kg/m^3 additional of sand up to 870 kg/m^3. Mix with sand content of 670 kg /m^3 shows the least strength compared to higher amount of sand. Low amount of sand leads to segregation and bleeding of concrete. Adding larger quantity of sand makes the concrete denser and stronger. However, the highest amount of sand content that can be utilized in OPS LWAC is 870 kg/m^3. Adding sand beyond 870 kg/m^3 would result in concrete with higher dry density more than 1850kg/m^3 causing it cannot be considered as lightweight aggregate concrete. Apart from that, excessive amount of sand used causes high consumption of cement in concrete [23]. Optimum amount of sand with fairly even size distribution tends to fill up the voids in concrete making it denser and possess higher strength. Adding larger amount of cement increases hydration process that produces larger amount of C-S-H gel filling in the existing voids of concrete internal structure thus enhancing the concrete strength. It is interesting to note in OPS LWAC containing POFA, the higher quantity of calcium hydroxide which is a by-product of hydration process are used during pozzolanic reaction by POFA for generation of secondary C-S-H gel that contributes towards densification of microstructure resulting in enhanced concrete strength. On the other hand, lower quantity of cement in concrete reduces the binding capacity between concrete particles finally leading to failure in achieving the targeted strength. Overall, it can be concluded that combination of suitable amount of mixing ingredient would be able to produce OPS LWAC with the targeted strength.

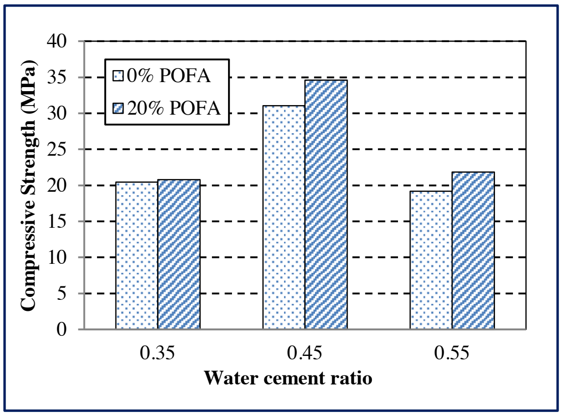

Figure 7 : Strength of concrete with different water-cement ratio

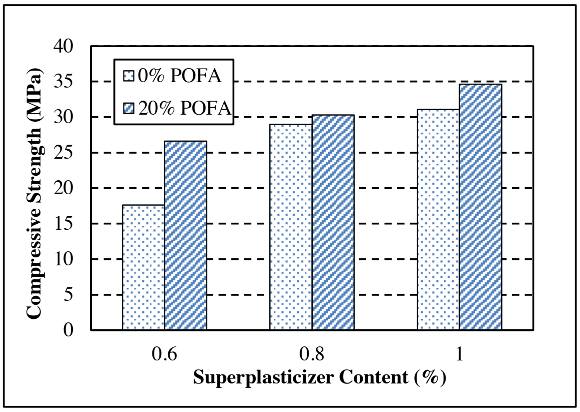

Figure 8. Strength of concrete with various content of superplasticizer

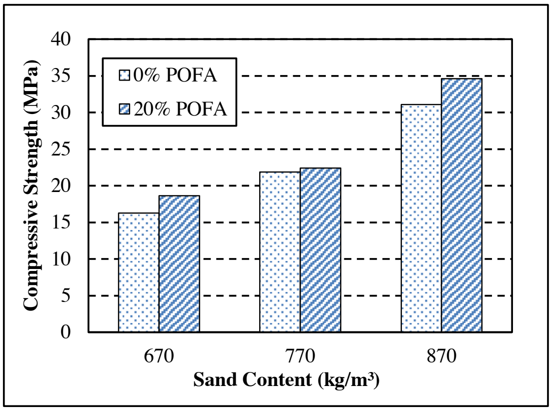

Figure 9. Strength of concrete containing different sand content

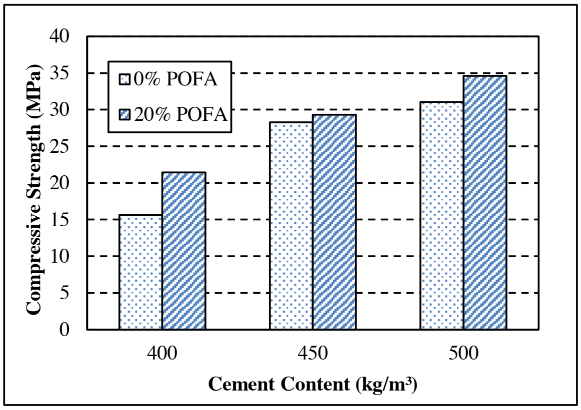

Figure 10. Strength of concrete containing different cement content

4. Conclusion

The use of POFA and 100% OPS in concrete would be able to reduce amount of solid waste disposed by oil palm industry to the environment. It is possible to utilize POFA as a supplementary cementing material in OPS LWAC with optimum POFA content of 20%. PO.FA content of higher than 30% may adversely affect the strength and properties of OPS LWAC. The suitable amount of water cement ratio, superplasticizer, sand and cement contents to be produce oil palm shell lightweight aggregate concrete containing POFA are 0.45, 1.0% , 870 and 500 kg/m^3 .

Acknowledgements

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