Properties of oil palm shell lightweight aggregate concrete containing fly ash as partial cement replacement

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Abstract. In Malaysia, the growing palm oil business and increasing energy consumption that pushes more coals supply for power generation at power plants generates by-products. A large amount of oil palm shell from palm oil mills and fly ash from coal power plant still disposed as waste. At the same time, the expanding cement and granite industry to cater the construction industry need also causes environmental degradation that requires solution. Thus, incorporation of the industrial solid wastes as alternative mixing ingredient in production of zero granite concrete production is seen as one of the viable approach to reduce waste thrown at landfill. The present research investigates the mechanical performance of palm oil waste lightweight aggregate concrete containing fly ash as supplementary cementitious material. Five concrete mixes were prepared by varying the quantity of fly ash added that is 0%, 10%, 20%, 30% and 40% by the weight of cement. All specimens were air cured until the testing age. Then, the specimens were tested to determine compressive strength and flexural strength up to 28 days. The finding shows that integration of fly ash up to 30% produces concrete that has the potential to be used for structural application. Conclusively, approach of integrating fly ash in lightweight aggregate concrete would reduce cement consumption and fly ash disposal.

1. Introduction
The increasing building construction to cater the need of growing population has increased the demand of cement, which used in concrete as construction material. Cement industry releases huge amount CO2 gases posing negative impact to the environment. Amongst other industry, cement-producing industry has been continuously top in the list of CO2 emitters [1]. The cement industry has always...
Contribute towards the greatest CO$_2$ discharge sources with 900 kg CO$_2$ released with every 1000 kg of cement production [2]. This gas mostly released during the calcination process at the factory. The large amount of CO$_2$ emissions has put a great burden over environment such as global warming and rising in sea level. Global warming results in climate change which poses negative impact to the green environment and wildlife’s. Therefore, incorporating pozzolanic ash generated as industrial by-product as supplementary cement replacement material during concrete production would reduce the consumption of cement in building industry. Among the existing pozzolanic materials is fly ash which has huge potential to be used to partially replace cement in concrete production. Fly ash is formed as a result of pulverized coal burning in a coal-fired boiler which exist is in the form of fine-grained, powdery particulate material carried off in the flue gas and usually collected from the flue gas [3]. Increasing quantity of fly ash from the power plants causes it to be dumped at landfill. According to [4], there is huge quantity of FA remains unutilized and disposed as waste. However, utilization of fly ash in concrete would enhance the concrete properties in terms of compressive strength, durability and thermal properties [5, 6]. In order to promote sustainable construction, the new special modern concretes that developed for certain application, should also be investigated its performance upon the use of fly ash as supplementary cementitious material.

At the same time, the global palm oil production is projected to increase with Malaysia being one of the largest world palm oil producers. Besides obtaining the precious oil, palm oil mill also generates high amount of solid waste. Oil palm shell (OPS) is a waste product of oil palm milling process at the factory. About 4MT of oil palm shell is produced annually [7]. Dumping of oil palm shell causes environmental pollution [8] and consumes larger area for dumping purpose, which can be utilized for better use. As the palm oil waste is available in large amount, it is seen that there is good potential in utilizing oil palm shell in the production of concrete. Thus, the main objective of this research is to investigate the effect of fly ash as partial cement replacement in oil palm shell lightweight aggregate concrete towards workability and mechanical properties. The mechanical properties of oil palm shell lightweight aggregate concrete with various percentage of fly ash were compared with the control specimen. Apart from providing information on these concrete, the utilization of fly ash as cement replacement in lightweight aggregate concrete mixture would decreases both energy and CO$_2$ emitted during production and at the same time, solve the landfill problem.

2. Experimental Work

2.1 Materials

Two types of binder namely ordinary Portland cement and fly ash were used in this research work. Fly ash in Figure 1 was obtained from a local power plant located in West Malaysia. Supplied tap water was used for concrete preparation work. The fine aggregate is used in this study is natural river sand. Oil palm shell (OPS) was used as the replacement of coarse aggregate to produce lightweight aggregate concrete in this research. Oil palm shell (OPS) is obtained from palm oil mill in Gambang in the state of Pahang, West Malaysia as illustrated in Figure 2. At the laboratory, the oil palm shells were oven dried before soaked in water for 24 hours. Then, the OPS was placed on the net of size 6mm until it reached SSD condition.
2.2 Sample preparation and testing
Total of five mixes containing various percentage of fly ash as partial cement replacement were prepared and tested. The control specimen of Grade 25 was produced using 100% ordinary Portland cement. Other mixes consist a range of fly ash replaced from 10%, 20%, 30% and 40% by weight of cement. Accurately measured mixing ingredients were mixed uniformly before placed in the mould. After compacting process, the samples were covered with wet gunny before demoulded after 24 hours. After the hardened specimens removed from the molds, the specimens were air cured by placing it on the shelf in the laboratory. The curing process continues until the mechanical properties testing date. Figure 3 illustrates the concrete specimens’ preparation process. In this experimental work, all testing conducted to determine the properties of concrete is in accordance to existing standards. In order to determine the effect of fly ash on concrete workability, slump test was conducted on the freshly prepared mixed following the procedures in BS EN 12350-2 [9]. The compressive strength test and flexural strength were conducted in accordance to BS EN 12390-3: [10] and BS EN 12390-5[11]. The water absorption test was carried following the procedures in BS 1881: Part 122 [12].

Table 1. Details of 1m³ concrete mixes

| Mixes (%) | Cement (kg/m³) | Sand (kg/m³) | Oil Palm Shell (kg/m³) | Fly Ash (kg/m³) | SP (kg/m³) | w/c ratio |
|-----------|----------------|--------------|-----------------------|----------------|------------|-----------|
| MFA0      | 500            | 700          | 300                   | 0              | 175        | 0.35      |
| MFA10     | 450            | 700          | 300                   | 50             | 175        | 0.35      |
| MFA20     | 400            | 700          | 300                   | 100            | 175        | 0.35      |
| MFA30     | 350            | 700          | 300                   | 150            | 175        | 0.35      |
| MFA40     | 300            | 700          | 300                   | 200            | 175        | 0.35      |
3. Results and discussion

3.1 Workability

Figure 4 illustrated the result of workability that obtains from the slump test. Evidently, the workability of OPS concrete mix increases as larger percentage of FA was added as partial cement replacement. This is due to the difference in physical properties of fly ash which is larger size than ordinary Portland cement. Larger particle sizes have smaller surface thus needing less water in mixing. Researcher [13] reported a similar observation on the concrete workability when fly ash was replaced by 0 to 50% as partial cement replacement.

![Figure 3. Concrete mixing.](image)

![Figure 4. Effect of fly ash content on concrete workability.](image)
3.2 Mechanical properties
As illustrated in Figure 5, and Figure 6, the inclusion of fly ash as mixing ingredient affects the strength of oil palm shell lightweight aggregate concrete. Generally, the concrete strength increases as curing age become longer owing to on-going hydration process. It seems that the presence of fly ash results in concrete strength reduction. The compressive strength decreased gradually as larger amount of fly ash added as partial cement replacement from 10% to 40% by weight of cement. The trend presented in compressive strength and flexural strength at all curing ages are similar to each other. Past researcher [14] have reported similar observation. The strength reduction is probably due to absence of moisture during curing period which in inhibits the pozzolanic reaction by fly ash. This lowers the amount binding gel produced as compared to control specimen, which solely depends on hydration process for strength increment. The importance of water in assisting strength development of concrete containing pozzolanic ash as partial cement replacement is stated in [15]. However, concrete containing fly ash up to 30% is suitable for structural application purpose. The suitability of lightweight aggregate concrete with strength equal or more than 17MPa for structural application is highlighted in [16].

![Figure 5. Compressive strength test result.](image)

![Figure 6. Flexural strength results.](image)
3.3 Water absorption
Water absorption of oil palm shell lightweight aggregate containing a different percentage of FA is presented in Fig. 7. On overall, use fly ash as partial cement replacement increases the concrete water absorption. Control specimens exhibit the lowest water absorption compared to other specimens. As the water absorption of specimens containing fly ash in this experimental work is in the range of 0.7 to 2.5%, therefore the specimens is classed as high quality concrete. According to [15], concrete with water absorption below 10% is high quality concrete.

![Water absorption test result](image)

**Figure 7.** Water absorption test result.

4. Conclusion
The present research founds that air cured oil palm shell lightweight aggregate concrete exhibit strength reduction with the increment of fly ash content as partial cement replacement. However, oil palm shell lightweight aggregate concrete containing 30% fly ash has the potential to be used for structural application. It is recommended that further research is conducted to investigate the performance of this lightweight concrete consisting fly ash in water curing and moist curing condition. The influence of nano-fly ash as partial cement replacement towards mechanical properties of OPS lightweight concrete is also another area that remains for future exploration. Use of fly ash as partial cement replacement in concrete would reduce the consumption of less environmental friendly cement and decrease the quantity of fly ash thrown as waste.

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