Effect of Curing Regime on Properties of Lightweight Concrete Containing Palm Oil Fuel Ash

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Abstract

Continuous growth in the production of Malaysian palm oil has resulted in higher quantity of palm oil fuel ash disposed as waste thus causing considerable negative impact towards environment. Numerous studies have been conducted by civil engineering researchers particularly, to unearth the potential of this hazardous by-product in order to reduce amount of waste disposed at landfill as well as to produce an environmental friendly construction material. The effort has been rewarded when addition of this waste in production of ordinary concrete and high strength concrete enhance the strength and durability of the new concrete. Recently, attempt has been made to integrate this pozzolanic material as partial cement replacement in aerated concrete which has produced a new type of lightweight concrete known as palm oil fuel ash cement based aerated concrete. The early section of this paper discusses the effect of ash replacement level on the compressive strength of aerated concrete. Then, the discussion centered on laboratory test data related to compressive strength and flexural strength performance of POFA aerated concrete specimens subjected to different curing regimes namely water, wet dry cycle, natural weather and air curing. All the specimens were prepared and tested at 28 days in accordance BS 1881 and ASTM C293-79 to determine compressive strength and flexural strength respectively. Up to 30% by weight of ash replacement, no adverse effect on the strength of aerated concrete was observed. However, integration of 20% POFA as partial cement replacement gave the highest strength of any other replacement level.

Keywords: Palm Oil Fuel Ash, Partial Cement Replacement, POFA Cement Based Aerated Concrete, Compressive Strength, Flexural Strength

1. Introduction

Palm oil fuel ash (POFA), being one of the hazardous waste generated from palm mill that is continuously thrown at landfill, has been identified as one of the agricultural by-product that can be used as replacement material for making concrete product since the end of last century. At the same time, the growing concern towards reducing the environmental pollution created by this disposed waste has attracted researchers from Asian region particularly countries producing palm oil in large amount to explore the potential of this material in concrete production. As a result, it has been found that integration of this agro-waste ash as a partial cement replacement in concrete mix successfully improves the properties of the newly modified normal concrete [1] or high strength concrete [2, 3]. However, no studies have been carried out to add this material as a partial cement substitute in lightweight concrete specifically aerated concrete.

At the same time, the application of aerated concrete is still in the early stage in Malaysia construction industry. These costly imported products fail to capture the attention of contractors from all level to utilize this material in building projects. Therefore, it is seen that production of new agro-cement based aerated concrete would be an alternative construction material for the local builders. In addition, the replacement of cement partially with this ash would be able to reduce cement consumption and being more environmental friendly by reducing the amount of waste ending at landfill. The aim of this paper is to report on strength performance of aerated concrete when POFA is included as a partial cement replacement material. The influence of different curing regime on the development of strength of concrete is also discussed.

2. Experimental programme

2.1Materials

The specimens in this study were produced using several mixing constituents namely ordinary Portland cement (ASTM Type 1), sand passing 600µm, POFA, Aluminium powder type Y250, tap water and superplasticizer conforming to Type F of ASTM C494 – 05a [4]. POFA was collected from palm oil mill owned by Yayasan Pembangunan Johor which is located in the southern part of Johor. The collected ash was oven dried prior to sieving process which is carried out to obtain ashes passing 300µm. Then, it was subjected to grinding process leading to production of fine particles complying with the requirement in ASTM C618 – 05 [5] enabling it to be used as partial cement substitute.

2.2Preparation of test specimen

All the dry ingredients were mixed thoroughly until a uniform mix was obtained. Finally, water was added and mixed quickly within 3 minutes before the mix was poured filling 2/3 of the mould. The mix rise vertically and overflowing the mould as a result of aerating agent that produced bubbles containing hydrogen gas entrapped inside the mix. After the concrete has set around 30 minutes later, the excess concrete were trimmed using flat steel. It was then covered with wet gunny sack to prevent loss of moisture. After 24 hours, the specimens were removed from the moulds and marked for identification before subjected to curing process.

2.3Experiments

At the beginning of this study, the best replacement level of POFA to produce POFA aerated concrete with optimum strength was investigated by developing design mixes with different amount of POFA replacement from 0% to 50%. Having identified the optimum replacement level, the influence of curing regime on compressive strength and flexural strength of POFA aerated concrete were studied using two sets of mixes where the best performing POFA aerated concrete mix and control mix (100% OPC) were produced in the form of cubes (70.6x70.6x70.6mm) and prisms (40x40x160mm) respectively. All specimens were subjected to several types of curing regimes, namely water, natural weather, wet and dry cycle and air curing for 28 days. Finally, all the specimens were tested to determine its compressive and flexural strength in accordance to BS 1881 : Part 116 [6] and ASTM C293-79 [7] respectively.

3. Results and discussion

3.1 Properties of palm oil fuel ash

Considering the chemical composition (Table 1), it can be observed that POFA as a pozzolanic material has higher percentage of SiO_2 of (53.82%) compared to that of OPC i.e. 28.27%. On the other hand, the CaO content is very low for POFA that is around 4.24% which could not contribute towards the early strength development. The total amount of the major components SiO_2, AL_2O_3 and Fe_2O_3 are 64.02%, while LOI value are 10.49%. Based on the chemical composition provided, this agro based material can be classified as Class F pozzolan as prescribed in ASTM C618 - 05 [5].

Since this material is a by-product of combustion process, the chemical composition in this material varies from one to another batch that is collected at a different period of time. Difference in the operating system in the palm oil mills as well as the waste materials that is incinerated to generate electricity for the mill also influence the chemical composition of the ash produced. This fact has been addressed by Abdul Awal and Hussin [8] who reported that quality of POFA varies with the type of materials and the efficiency of burning although the latter has more influence towards the chemical composition of end product formed. This provides explanation as for why the percentage of chemical composition of this pozzolanic ash is differs compared to POFA used by Sumadi [9] Abdul Awal [1], Mat Yahaya [10]; Sata et al [2] and Jasmin [11]. On overall, only a proper complete combustion will produce whitish grey POFA and with lower carbon content.

Since the use of coarser particles would lower the strength of concrete [12], the grinding process that has been carried out manages to increase the fineness of POFA to be higher than OPC. As can be seen in the data presented in Table 1, ground POFA has a very small concentration of particles retained on a sieve of No.325 that is 1.5% as compared OPC that is 5%. Furthermore, the larger value of surface area obtained by POFA indicates that this ash is very much finer than OPC. In overall, application of grinding process able to reduce the size of POFA making it become lighter particle as well as having lower porosity than OPC. Most importantly, the finer POFA produced would be able to have higher pozzolanic reaction rate than coarser POFA which is essential for the concrete strength development.

Table 1. Physical properties and chemical analysis of OPC and palm oil fuel ash

Physical Properties	**OPC**	**POFA**
Specific surface area (m^2/kg)	475	1440
Retained on sieve No.325 (%)	5%	1.5%
Chemical Analysis		
Silicon Dioxide (SiO_2)	28.2	53.82
Aluminium Oxide (AL_2O_3)	4.9	5.66
Ferric Oxide (Fe_2O_3)	2.5	4.54
Calcium Oxide (CaO)	50.4	4.24
Magnesium Oxide (MgO)	3.1	3.19
Sodium Oxide (Na_2O)	0.2	0.1
Potassium Oxide (K_2O)	0.4	4.47
Sulphur Oxide (SO_3)	2.3	2.25
Phosporus Oxide (P_2O_2)	<0.9	3.01
Loss On Ignition (LOI)	2.4	10.49

3.2POFA in aerated concrete at various replacement level

Figure 1 displays the compressive strength of aerated concrete specimens possessing constant density of approximately 900 kg/m^3 that has been produced using various percentage of POFA as partial cement replacement. It can be seen that addition of ash tends to influence the strength exhibited by the concrete material. Not only that, it also can be deduced that the achievement of highest strength gain for aerated concrete integrating POFA as partial cement substitute is possible only when right amount of this pozzolanic material is added. As can be observed, inclusion of POFA up to 30% replacement results in development of material of higher strength than control specimen. Replacement from 10%, 20% and 30% manage to aid towards higher strength that is 104%, 110% and 101% respectively of the OPC aerated concrete. On top of that, the better performance of the blended cement based aerated concrete, the compressive strength exhibited by these specimens that fulfills the requirement for non load bearing application as specified in ASTM C129-85 [13] allows it to be used for the production of non-load-bearing blocks for construction project.

Similar to the findings by Massazza [14], the strength of specimen decreases when too much of POFA that function as partial cement replacement integrated in the concrete mix. Evidently, replacement of 40 and 50% POFA causes the strength of concrete to decrease since the amount of Portland cement was greatly reduced. The lower content of calcium oxide in POFA which is crucial for strength development tends to limit the use of this ash partial cement replacing material. Initially, lower content of calcium oxide reduces the early strength development due the lower amount C-S-H gel produced through hydration process. Then, the smaller amount of lime produced from hydration process is also not sufficient for complete pozzolanic reaction to take place which also lead to the formation of lower amount of secondary C-S-H gel. This provides explanation as for why not all POFA replacement levels could produce aerated concrete having higher strength than control specimen. The inferior performance of aerated concrete consisting too high POFA content compared to plain specimen is due to the formation of lower quantity of total amount of C-S-H gel that is principally responsible for the strength performance of concrete.

This initial stage of study has indicated that, only a certain percentage of POFA could replace OPC to act as partial cement replacement material so that an exclusive combination of blended cement could be produced creating a win-win situation between the two materials finally producing a end product having better properties than the existing one and possess the potential to be used as building material. It is interesting to note that this finding is also in agreement with Abdul Awal and Hussin [8] who becomes the pioneer in integrating POFA as partial cement replacement material in concrete technology as the results of their discovery in producing POFA concrete that possess higher strength and better durability as compared to plain concrete. The creation of another alternative construction material combined with POFA is expected to reduce the quantity of cement to produce aerated concrete as well as able to decrease the quantity of waste material dumped at landfill; which results in more environmentally friendly industry. Conclusively, the second stage of the research has been carried by using specimen consisting 20% POFA as partial cement replacement that exhibit the highest strength were selected for further study and aerated concrete produced using 100% OPC were used for comparison purpose.

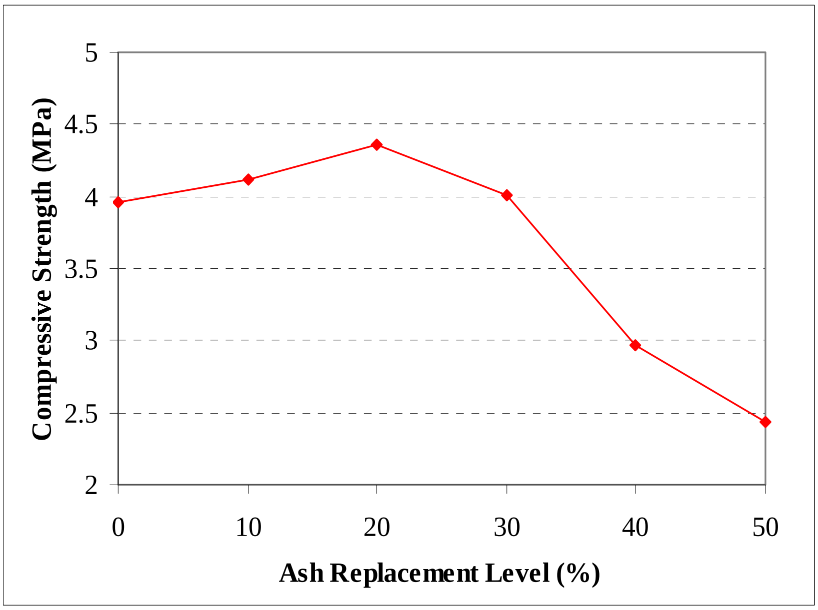

Figure 1. Effect of POFA content on compressive strength of aerated concrete

3.3 Strength and density of aerated concrete under different curing regime

Curing plays a critical role in realizing the full potential of concrete. Absence of adequate moisture would delay the hydration process which in turn affects the strength development of concrete. However, moisture content within the concrete during testing also undoubtedly plays the function in determining the ability of a hardened material to resist load. This has been observed in the outcome of this study which has been presented in Figure 2, 3 and 4 respectively. The results clearly indicate that the density and strength performance of OPC and POFA aerated concrete are influenced by the amount of moisture entrapped in the voids which primarily depend on curing condition applied. The specimen with lowest density due to lesser content of moisture in the material exhibits highest strength compared to the one with higher density, due to the presence of higher amount of moisture in the voids of this lightweight concrete. Most importantly, it is found that the amount of water present throughout the curing periods which depends on the type of curing regime applied, undeniably determines the strength of POFA cement based aerated concrete.

The strength of water cured OPC and POFA specimen is the lowest since the existence of voids in large amount has made it possible for this material to absorb abundant water during water curing process which eventually contributes towards increasing the internal pressure to the cubes, while external force was applied during the testing time. On the other hand, OPC and POFA specimens subject to air curing have exhibited the highest strength as compared to all specimens especially the one that has been immersed in water for longer period namely wet dry cycle and water cured sample. The better performance of air cured specimen is due to absence of moisture in the voids causing no extra internal pressure trying to disrupt the concrete when load is applied making this concrete able to resist larger load than the one containing moisture in it. The better performance of air cured specimen is justifiable since Svanholm [15] has highlighted that the loss of water from aerated concrete exposed to normal atmosphere would lead to strength increment that is usually 40 to 70 percent. Similarly, Popovic [16], Bartlett and Mac Gregor [17], Narayanan and Ramamurthy [18] and Hussin and Abdullah [19] highlighted that the ability of concrete to resist load decreases with the increase in moisture content.

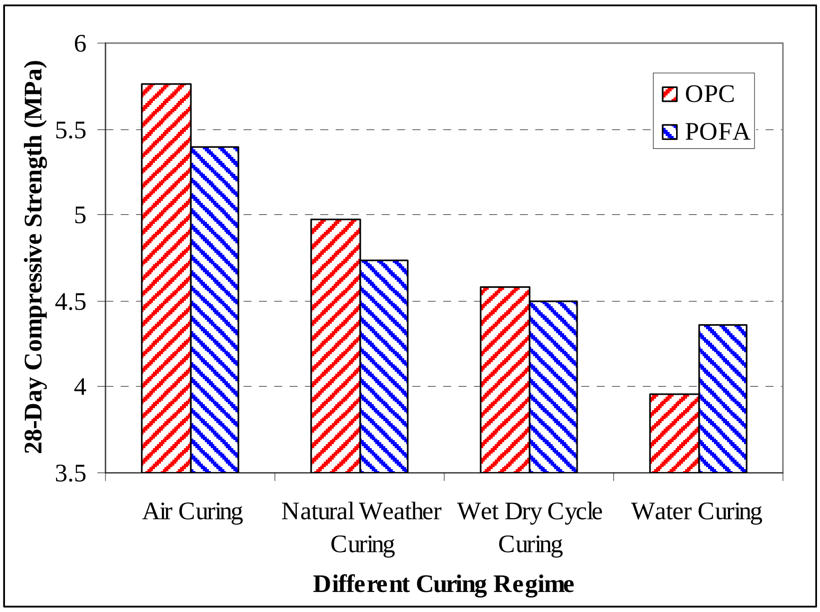

Figure 2. Effect of curing regime on compressive strength of OPC aerated concrete and aerated concrete with 20% POFA at 28 days

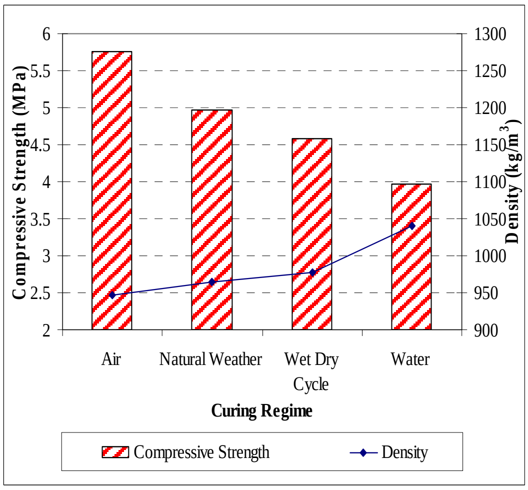

Figure 3. Effect of curing regime on compressive strength and density of OPC aerated concrete at 28 days

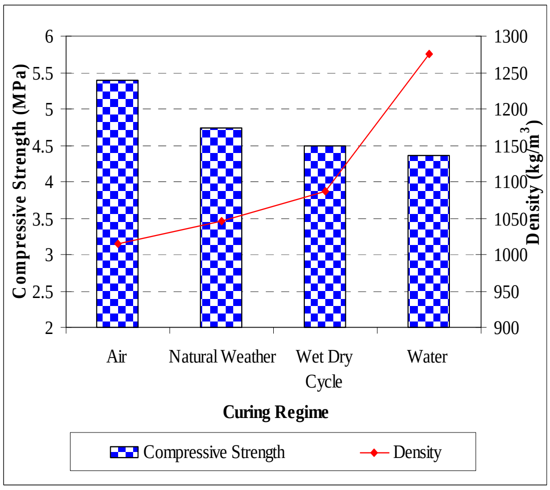

Figure 4. Effect of curing regime on compressive strength and density of POFA aerated concrete at 28 days

3.3.1Compressive strength of POFA aerated concrete

The current findings indicate that POFA specimens did not perform better than OPC aerated concrete in all types of curing except the one subjected to continuous water curing. The constant water curing has allowed for continuous hydration and pozzolanic reaction to take place in POFA aerated concrete eventually leading to better strength achievement than OPC specimen. Formation of secondary calcium silicate hydrate gel as a result of reaction between the pozzolanic ash and lime has contributed towards densification of the microstructure thus enhances the strength of this agro cement based aerated concrete. The importance of constant water curing for first 28 days has been highlighted by Abdul Razak *et al.* [20] who mentioned that the particular approach is crucial for the first 28 days for the hydration and pozzolanic reaction to take place. However, the insufficient moisture throughout the curing process of POFA aerated concrete subjected to air, natural weather and wet dry cycle curing has affected the strength development of the material.

The strength exhibited by POFA aerated concrete subjected to wet dry cycle curing is almost 98% of the control specimen strength. Exposure of the POFA specimen to water for 7 days before left in the air for 7 days with this cycle repeated until the testing day has brought longer period for this specimen to be in the medium conducive for hydration process and pozzolanic reaction to take place thus permitting strength development. However, when the specimens are placed in the air, both processes for strength increment are obstructed as the water inside the cubes evaporates. As in the case of natural weather cured POFA specimen, the frequent change of weather condition undeniably affects the moisture content in the specimen which is essential for the occurrence of hydration and pozzolanic reaction. The reason for this is that the present of wet and dry days alternately causes the water absorbed in the porous specimen during rainy day evaporated when the weather become hot. Eventually, when the relative humidity within capillaries drops below 80%, the hydration of cement virtually ceases [21] and tends to hinder the hydration process which is essential for the occurrence of pozzolanic reaction. This in turn causes lesser amount of C-S-H to be generated compared to OPC leading to lower strength achievement for POFA specimen.

Although air cured POFA aerated concrete do not perform well in comparison to control specimen, this specimen exhibit the highest strength value compared to the specimen subjected to other types of curing. This is possibly because of the influence of lesser moisture content in the specimen as has been discussed earlier. The continuous loss of moisture from the specimen resulting from evaporation process tends to prevent pozzolan to show its binding property. Absence of moisture will cause POFA to remain dormant without reacting with the free lime that has been generated through hydration process during the 7 days initial water curing. As a result, the strength development in POFA aerated concrete solely depends on hydration process that has taken place during early water curing. The larger amount of C-S-H gel produced in OPC concrete during early curing enables it to exhibit higher strength lesser, in contrast to POFA specimen.

On overall, this study has found that pozzolanic aerated concrete are more sensitive to the inadequate curing than OPC aerated concrete. This finding is in line with the statement made by Ramezanianpour and Malhotra [22] and Ozer and Ozkul [23] who mentioned that pozzolanic are more adversely affected by the poor curing conditions than OPC concrete. Water curing for 28 days is essential for POFA aerated concrete in order to promote both hydration and pozzolanic reaction for better strength development of this pozzolanic consisting lightweight concrete. This finding contradicts with the findings of previous researchers Ozer and Ozkul [23] who highlighted that at least an initial 7-day water curing is necessary to expose the pozzolanic activity for pozzolanic cement concretes. However, in the case of aerated concrete this approach may not be applicable to assist the strength development of this porous material.

The cellular structure of aerated concrete is totally different compared to the dense and well-compacted normal concrete. The cellular structure of this highly porous concrete itself though able to absorb a lot of water, cannot retain the moisture absorbed after being left in the open air. The evaporation process that causes the loss of moisture from the aerated concrete pores hinders the pozzolanic reaction. In contrast, the dense structure of normal concrete able to retain water for longer period and eventually able to provide adequate water for pozzolanic reaction. Basically, arguments presented in this discussion clearly illustrate and reinforce that at least 28 days water curing is absolutely necessary, in order to take advantage of the beneficial effects of the pozzolanic activity and pore refinement that assist POFA concrete to perform better than specimen formed of 100% OPC.

3.3.2Flexural strength of POFA aerated concrete

Along with compressive strength, performance of flexural strength for OPC and POFA aerated concrete prism subjected to various curing regime are also looked into. The average values of flexural strength for OPC and POFA specimen subjected to different curing condition namely air, natural weather, wet dry cycle and water curing is illustrated in Figure 5. They exhibit continuous increase in the flexural strength value as curing age become longer although the rate of increment varies. It is observed that the results show the same general trend as for compressive strength under different curing regimes. In addition, the ratio of the flexural strength to compressive strength of POFA aerated concrete, ranges from 0.22 to 0.26. In general, the result obtained is obviously supported by the finding of Narayanan and Ramamurthy [18] who reported that the ratio of flexural strength to compressive strength of aerated concrete is about 0.22 to 0.27.

It is apparent that only water cured POFA specimen is able to produce higher strength compared to control specimen, due to the occurrence of pozzolanic reaction resulting from the constant presence of moisture in the concrete. The distance between the strength curves of OPC and POFA prism exposed to air curing is the largest. It seems that air curing has less favourable effect on the flexural strength development of POFA aerated concrete, as compared to OPC. Explanation on the inability of POFA in contributing to the strength increment of this material when placed in open air has been discussed previously in section 3.3.2. It is also found that the difference between value of POFA and OPC becomes lesser for natural weather and wet dry cycle curing methods, respectively. However, the exposure of the specimen under tropical climate does not allow complete pozzolanic and hydration process since the rain and dry weather comes intervally. However, this curing method is better than air curing since the time for POFA to come in contact with water become much longer than exposing to air inside the laboratory.

Comparing with wet dry cycle curing, the time of exposure to the water is longer since the specimen is immersed in water a week prior to exposure to air for another week and this cycle continues until testing. The controlled environment enables POFA to be involved actively in pozzolanic reaction every time the specimen is placed in water. That eventually reduces the gap between OPC and POFA curves. Nevertheless, application of this type of curing method has allowed the flexural strength between the OPC and POFA curve to be closest since the availability of water throughout the curing period has allowed the hydration and pozzolanic reaction to take place in the blended cement. Not only that, the continued presence of water has enabled POFA to perform better than OPC specimen unlike in other types of curing. Basically, this study has revealed that the flexural strength of aerated concrete is as much affected as by the curing regimes applied, similar to the compressive strength behaviour.

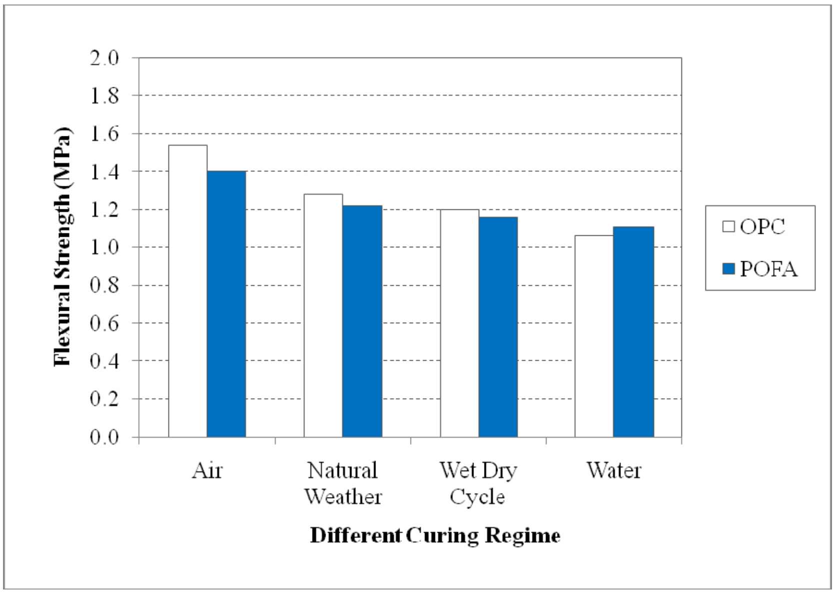

Figure 5. Effect of curing regime on flexural strength of OPC aerated concrete and POFA aerated concrete at 28 days

4. Conclusion

Based on the experimental results and discussion, the following conclusions can be drawn :

a)The density and compressive strength of all specimens depend on the amount of moisture absorbed by this lightweight concrete which is directly influenced by the curing condition applied.

b)POFA aerated concrete is highly sensitive to curing environment, whereby it fails to perform better than OPC aerated concrete in all types of curing except the one subjected to continuous water curing.

c)7 days initial water curing is enough to assist OPC aerated concrete to perform highest strength but this is not applicable for aerated concrete consisting of POFA due to its failure in retaining the absorbed moisture that needs to be used for pozzolanic reaction to take place belatedly.

d)Air cured specimens demonstrated the highest strength because of the absence of moisture in the voids causing no extra internal pressure trying to disrupt the concrete when load is applied making this concrete able to resist larger load than the one containing moisture in it.

e)The flexural strength of POFA aerated concrete subjected to different curing regimes namely air curing, water curing, natural weather curing and wet dry cycle curing, exhibit similar trend of results with compressive strength of this lightweight concrete that has been subjected to similar types of curing method. Flexural strength of air cured specimen is the highest owing to the lesser moisture content in this material while the water cured specimen which contain high amount of moisture in it exhibit the lowest flexural strength. The ratio of the flexural strength to compressive strength of POFA aerated concrete ranges from 0.22 to 0.26.

f)Integration of 20% POFA as partial cement replacement able to produce agro cement based aerated concrete mix with higher strength and lower density compared to OPC aerated concrete, provided continuous water curing is applied.

g)Development of new aerated concrete using local by-product with lower amount of cement compared to the existing one but having enhanced strength and environmental friendly can be an alternative building material contributing for sustainable construction in Malaysia

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