
PROPERTIES OF PALM OIL FUEL ASH CEMENT BASED AERATED CONCRETE PANEL SUBJECTED TO DIFFERENT CURING REGIMES

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Abstract : Palm oil fuel ash (POFA) being disposed as profitless waste by palm oil mills throughout Malaysia has inspired researchers from Universiti Teknologi Malaysia to integrate this material in lightweight concrete production. This paper presents results on strength of aerated concrete containing POFA at various replacement levels and its application as non-load bearing wall after subjected to different curing regimes. Cubes of (70.6x70.6x70.6mm) containing 10, 20, 30, 40 and 50 percent ash replacement levels were cast and tested for compression following the procedures in BS 1881 : Part 116. Mix with 20% POFA which exhibit superior strength than any other replacement level was used to prepare panel of 540x250x25mm. The specimens were subjected to curing regimes namely; water, air, natural weather and wet dry cycle curing before the 28 days compressive strength of panels was evaluated in accordance to ASTM E72-05. This study proved that air cured panel performs better than panel subjected to other types of curing.

Keywords: Palm Oil Fuel Ash; Partial Cement Replacement; Aerated Concrete; Compressive Strength; Curing Regimes

1.0 Introduction

Palm oil industry is one of the sectors famously chosen to be developed commercially in several tropical countries located in Asian region. Malaysia is one of those countries that has been given attention in developing this agricultural-based industry since previous century and able to become the largest producer of palm oil. Basiron and Simeh (2005) reported that Malaysia, the current number one palm oil producer is forecast to maintain its lead position over the next one and the half decades producing 18 million tones or 42% of the world palm oil in 2020. It is predicted that the quantity of palm oil fuel ash (POFA), a profitless by-product generated by palm oil mill will increase as the production of palm oil continue to grow over the year. Therefore, it is anticipated that the success in discovering the utilization of this material in any type of material making process would be able to reduce quantity of waste thrown and assist palm oil industry to be more ecological friendly sector.

Glancing through the history of this material introduced in construction area, it has been Malaysian researcher who managed to prove that this material possesses

pozzolanic properties (Abu, 1990). Abdul Awal and Hussin (1997) have proved that this waste could be used as partial cement replacement in concrete for production of stronger and more durable construction material. Succeeding the findings, more researchers have integrated POFA as one of mixing ingredient in the mix to produce new type of concrete such as high-strength concrete (Sata *et al*, 2004; Budiea *et al*, 2008) and lightweight concrete (Mat Yahaya, 2003). This paper presents the results on the strength performance of aerated concrete produced using POFA as partial cement replacement at different level. Then, the discussion in this paper is focused on the strength performance of POFA cement based aerated concrete panel after subjected to different curing regimes.

2.0 Materials And Experimental Programme

2.1 Raw Materials

In the present study, POFA used was collected from a palm oil mill located in the area of Bukit Lawang, Johor. The ashes were dried in the oven at the temperature of $110^{\circ}\text{C} \pm 5$ for 24 hours before sieving through 300 μm sieve. Then, it was ground using a modified Los Angeles abrasion test machine until the fine particles produced able to fulfill the fineness requirement in ASTM C618 - 05 (2005). This is because it has been stated in ASTM C618 - 05 (2005) that, for a material to be used as a mineral admixture in concrete, maximum amount of pozzolanic material that can be retained when sieved wet on 45 μm sieve is 34%. The detail chemical composition analysis of POFA used in this study is listed in Table 1.

Table 1 : Chemical Constituents (%) Of OPC and Palm Oil Fuel Ash (POFA)

Chemical Constituents	OPC	POFA
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
Phosphorus Oxide (P_2O_5)	<0.9	3.01
Loss On Ignition (LOI)	2.4	10.49

A single batch of Ordinary Portland Cement (OPC) complies with the Type 1 Portland Cement as in ASTM C150 - 92 (1992) was used in this experiment. The chemical constituent of OPC obtained from the manufacturing company known as HOLCIM Sdn Bhd is illustrated in Table 1. Fine aggregate passing 600 μm sieve was used throughout this study. Aluminium powder was also integrated in the mix to function as a gas foaming agent. A small percentage of superplasticizer classed as type F high range water reducing admixture according to ASTM 494 - 05a (2005) was included in preparing aerated concrete in order to decrease water content. Tap water has been used throughout the experimental work.

2.2 Experimental Programme

During the early stage, the best percentage of POFA to be used as partial cement replacement material were determined. This is done by incorporating ash into aerated concrete mix as a direct replacement for ordinary Portland cement on weight basis. A control specimen was formed using 100% OPC known as OPC aerated concrete and five mixes of OPC/POFA consisting POFA from the range of 10% until 50% were cast in the cubes of 70.6x70.6x70.6mm. The specimens were water cured for 28 days before subjected to compressive strength test that was conducted in accordance to BS1881: Part 116 (1983). Aerated concrete mix containing 20% POFA that exhibit the highest strength that were selected for further experimental work- was also subjected to microstructure study using Scanning Electron Microscopy (SEM) method.

At the second stage, the panel specimens with the size of (540x250x25 mm) were cast using POFA cement based aerated concrete mix which consist two types of binder that is 80% OPC and 20% of POFA. All specimens were left in the mould and covered with wet gunny sack for 24 hours before demoulded. Later, they were subjected to initial water curing for seven days prior to placing in other types of curing in order to study the effect of curing regime towards the compressive strength performance of panel. The specimens were subjected to different types of curing namely water, wet dry cycle, natural weather and air curing for 28 days.

Panel specimens were tested using DARTEC Universal Testing Machine. All the specimens were tested in the vertical position. A leveling ruler was used to ensure the proper leveling of the panel. The deformation of the specimen was studied through measurement of stroke of panel with the increment of load which was done by placing LVDT on each side of specimen. LVDT was fixed at both sides of the specimen to record the deflection of the panel during compression. The compression tests were conducted at the age of 28 days in accordance to ASTM E72 - 05 (2005).

The specimen was placed in the loading frame in the correct position so that the end conditions were as described above. The specimens used were painted white so that the crack pattern could be observed easily as illustrated in Figure 1. The LVDTs were placed at the proper locations. The instruments were checked and adjusted properly as presented in Figure 2 before applying the load. The load was applied gradually and without shock at a constant rate of 0.5 kN/s until the specimens fails. During the

loading, the specimen was being observed for any physical changes, especially the cracking. The specimen was loaded until it fails and the maximum load was recorded. Finally, the performance of POFA cement based aerated concrete specimen were compared with commercial boards available in the local market.

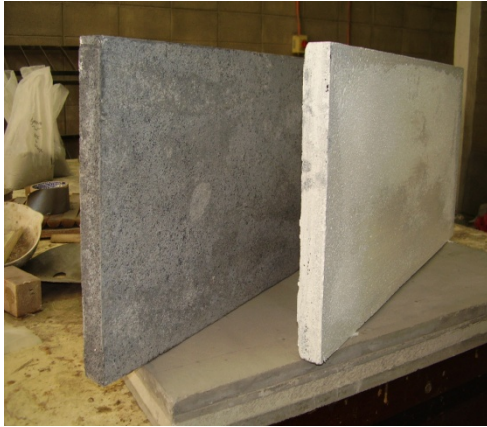


Figure 1 : Panel before and after being painted

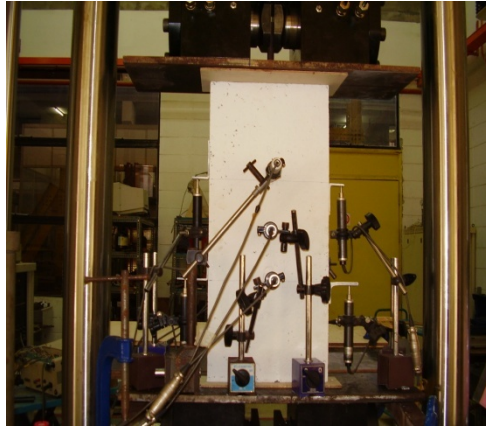


Figure 2 : Panel ready for testing

3.0 Results And Discussion

3.1 Chemical Composition of POFA

Originally at dumping site behind the palm oil mill, POFA particle is grayish. Discussing on the chemical composition aspect, it was found that this agro based material can be classified as Class F pozzolan, according to the standard specified in ASTM C618-05a (2005). Table 1 clearly displays the chemical analysis of OPC and POFA. In general, this material as a pozzolanic material has higher content of silica and lower lime content as compared to OPC. The carbon content of this currently collected material is nearly 42% lower than POFA used by Abdul Awal and Hussin (1996) whom collected this material from the same source. The application of improved technology in palm oil production system in this era of information technology, assisted with enhanced knowledge on factors affecting properties of by-product generation has enabled the creation of waste with lower carbon content.

3.2 Superiority of POFA in Aerated Concrete

3.2.1 Effect of POFA Content

One of the early researchers in the area of POFA concrete technology, Abdul Awal (1998) has proven that integration of POFA as partial cement replacement able to increase the strength of normal concrete. Then attempts made to incorporate this ash in lightweight concrete production become fruitful when it was discovered that

POFA can be used as partial cement substitute to produce aerated concrete known as POFA cement based aerated concrete. Based on the results obtained from this study as shown in Figure 3, it can be observed that inclusion of POFA up to 30% as partial cement replacement able to produce aerated concrete of similar strength with control specimen consisting 100% OPC. However, too much of POFA content in the mix tend to decrease the strength of the concrete significantly due to the lower cement content that disturbs the hydration process within the aerated concrete matrix. This finding proves that replacement of 20% POFA is the best replacement level since it successfully increases the strength of aerated concrete to be the highest as compared to any other specimen.

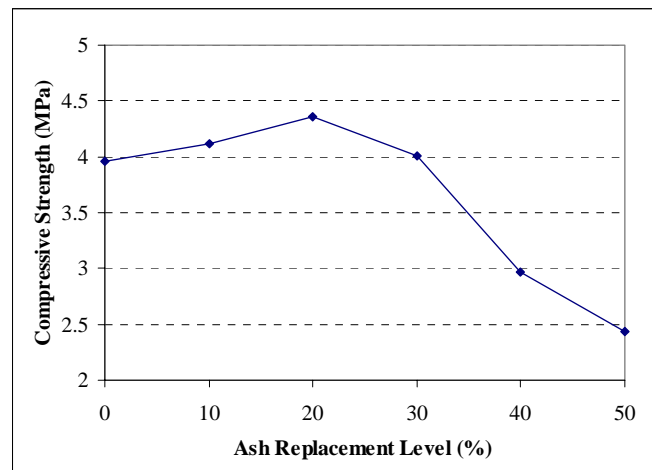


Figure 3 : Effect of POFA content on compressive strength of aerated concrete

3.2.2 Microstructure Study

The influence of POFA towards densification of internal structure of aerated concrete can be clearly seen in the photographic image of Figure 4 and Figure 5 taken on the sample of both types of aerated concrete at the age of 28 days using Scanning Electron Microscopy method. It is interesting to note that microstructure of POFA cement based aerated concrete is denser in comparison to OPC specimen. This is because the occurrence of hydration process followed by pozzolanic reaction in the blend of POFA aerated concrete mix which consist more silica and less CaO than Portland cement alone has lead towards production of more C-S-H gel that fills in the existing pores as compared to OPC aerated concrete.

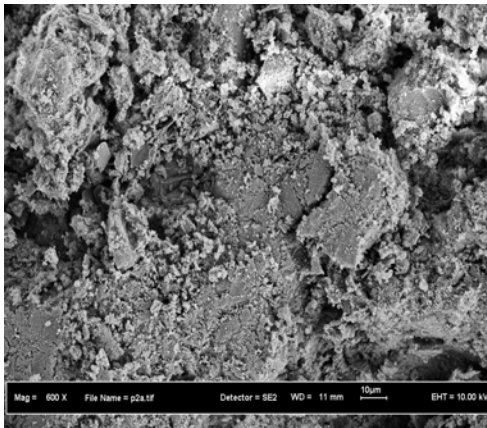


Figure 4 : Aerated concrete with POFA at the magnification of 600x

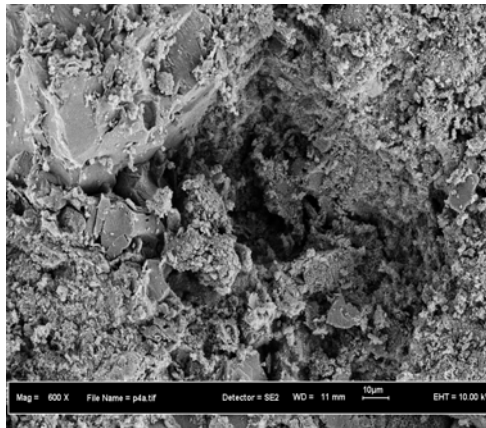


Figure 5 : Aerated concrete without POFA at the magnification of 600x

The presence of higher amount C-S-H gel in aerated concrete formed using 20% POFA in contrast to OPC aerated concrete can be clearly seen in Figures 6 and 7. The presence of crowded form of tiny cotton shaped C-S-H products in POFA aerated concrete mix as compared to OPC aerated concrete which has a large number of hexagonal crystals clearly proves that the integration of POFA absolutely affect the microstructure of aerated concrete. Moreover, the formation of dense structure as a result of the crowded C-S-H produced in this agro blended cement based aerated concrete proves the occurrence of pozzolanic reaction which responsible to increase the strength of this environmental friendly concrete.

Since Escalante-Garcia and Sharp (2004) has highlighted that C-S-H gel is principally responsible for the mechanical properties of the hydrated cement, therefore it is justifiable for POFA cement based aerated concrete to possess higher strength than OPC aerated concrete. In addition, Calcium hydroxide that tends to form large crystals with a distinctive hexagonal prism (Tashiro and Urushima, 1987) was also found present in the microstructure when few hexagonal crystals have been captured in micrograph. Existence of lime indicates that the strength of this concrete will continue to increase once these crystals are transformed into additional C-S-H due to presence of POFA playing the function in promoting the pozzolanic reaction which is essential to increase the strength and durability of the hardened aerated concrete.

On the other hand, image of OPC aerated concrete illustrated in Figure 7 is far different from POFA sample whereby large numbers of hexagonal crystals were present with some of it overlapping each other. This fact has been explained by Diamond (1976) whom stated that at the early stage, appearance of calcium hydroxide is in a form of thin hexagonal plated but as the deposits of CH grow massive it loses their hexagonal outline and invade and encapsulate other regions of the paste containing gel and other

constituents. Besides that, high amount of CaO in OPC aerated concrete causes the excessive production of calcium hydroxide unlike POFA cement based aerated concrete.

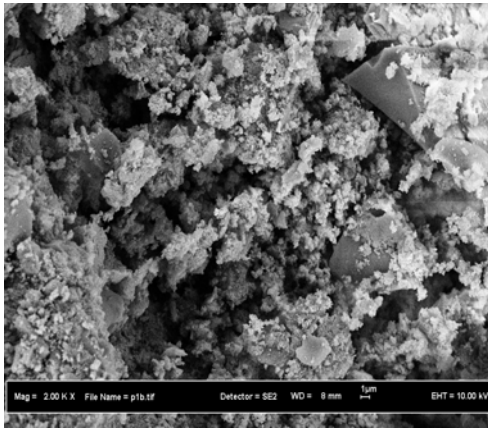


Figure 6 : POFA aerated concrete at the magnification of 2000x

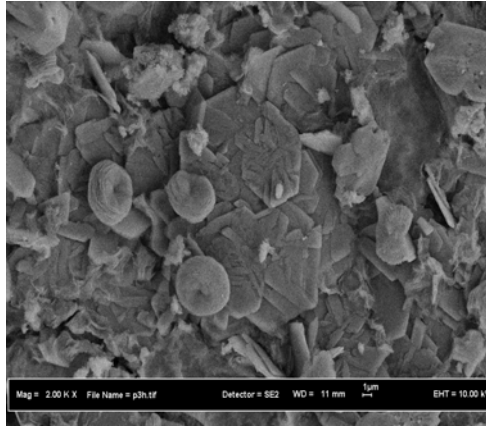


Figure 7: OPC aerated concrete at the magnification of 2000x

POFA aerated concrete possess lower percentage of CaO due to integration of POFA as partial cement replacement also because of pozzolanic reaction that works to convert CaOH becoming C-S-H gel. Basically, incorporation of POFA as partial cement substitute plays vital role in contributing towards densification of microstructure of this lightweight concrete eventually increasing the strength of this POFA cement based aerated concrete. Conclusively, this discovery is aligned with finding of Manmohan and Mehta (1981) who stated that additions of pozzolanic and cementitious admixtures to ordinary Portland cement were instrumental in causing pore refinement or transformation of large pores into fine pores.

3.3 Performance of POFA Cement Based Aerated Concrete

3.3.1 Compressive Strength of Panel

This section presents the results on density and compressive strength of the whole unit of wall panel tested at the age of 28 days. Discussing on the density of specimens studied, Figure 8 clearly shows that application of different type of curing influence the density of the panel. It is evident that water cured specimen was the heaviest whereby the average of weight is about 4.213 kg with the density of 1248 kg/m³ due to continuous contact of the specimen with water which enables water absorb into the specimen. Natural weather samples falls behind as less heavy specimen due to lesser contact with water as compared to water cured sample since the frequent rain usually followed by hot weather which is influenced by tropical climate. Wet dry cycle specimens seems to be lighter than natural weather cured sample due to shorter period of time where the sample is subjected to water curing for seven days before placed in the air for seven days and this continues. Air cured specimen on the other hand, is the

lightest since it is kept in a room and does not have chance to come in contact with water throughout the curing period.

As for the compressive strength performance, illustration in Figure 9 proves that method of curing applied towards POFA cement based aerated concrete mix undeniably influence the strength development of the specimen. Of all samples, air cured specimen exhibits the highest strength. Natural weather specimen performs better than wet dry cycle panel and water cured specimen gives the lowest strength value. The excellent performance of air cured specimen is justified by Svanholm (1983) who highlighted that reduction in moisture content would lead to strength increment of about 40 to 70%.

In general, the overall strength performance of the specimens is influenced by the moisture content in it whereby increment in moisture content of the panel lead to reduction in the strength exhibited. Similar fact has been highlighted by Narayanan and Ramamurthy (2000b) whom mentioned that increase in moisture content of aerated concrete will cause decrease in its compressive strength. The result in this study proves on the importance of selecting curing method for optimum strength performance of POFA cement based aerated concrete. On overall, these findings is aligned with statement made by Narayanan and Ramamurthy (2000b) who stated that method of curing influence the physical and mechanical properties of aerated concrete.

Generally, all specimens investigated able to fulfill the strength requirement as stated in ASTM C129-85 (1990) which mentions the strength requirement for non-load bearing units is 3.45 MPa at the age of 28 days. On overall, panel subjected to all types of curing up to 28 days is suitable to be used in non-load bearing applications, mainly as internal wall panels or partitions. It can be concluded that air curing method not only able to assist towards highest strength development of hardened agro cement based aerated concrete panel being the lightest product as compared to specimens subjected to other types of curing method but also practical for commercial production due to its easy and cheap curing technique.

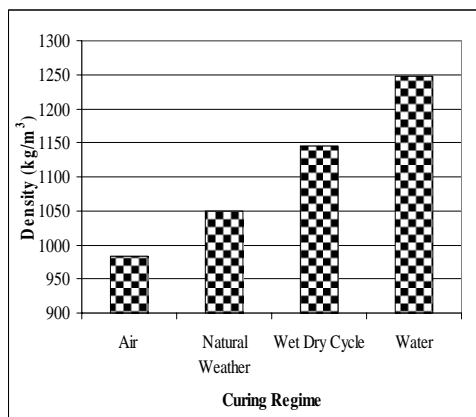


Figure 8: Density of panels subjected to different curing at 28 days

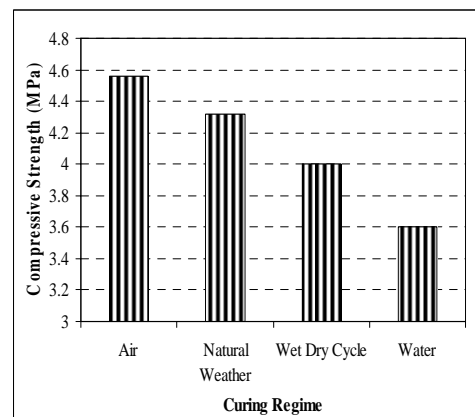


Figure 9: Compressive strength of panels subjected to different curing at 28 days

3.3.2 Failure Pattern of The Panel

The observation on the failure pattern of the panels shows that there are some similarities in the failure more depending on the curing type. It was observed, panel subjected to air, natural weather and wet dry cycle curing failed due to sudden horizontal crack occurrence in the middle of the specimens as presented in Figure 10. Those specimens did not show any crack prior to the sudden failure. On the other hand, water cured panel exhibited different form of failure whereby fine cracks occur at the lower part of the specimen prior to sudden crushing failure both for specimen at the age of 28 days as shown in Figure 11.

Basically, the failure pattern of the panel seems to be influenced by amount of moisture present inside the specimen. Earlier, Narayanan and Ramamurthy (2000a) highlighted that water content is one of the factor that influence the strength of concrete. It seems the presence of water not only influence the strength performance of POFA cement based aerated concrete but also its failure pattern. Conclusively, it can be summarized that failure pattern of panel also depends on type of curing applied which is largely influenced by the amount of water present during testing period.

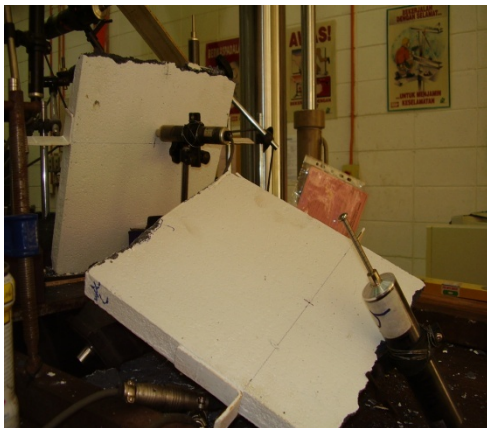


Figure 10: Horizontal crack failure



Figure 11: Crushing failure at lower part

3.3.3 Panel Stroke

The reduction in the height of the panel during the loading was also observed during the compressive strength test for all specimens. The results presented in Table 2 and Figures 12 illustrate the relationship between stroke and loading rate of all specimens at 28 days. On overall, the stroke of every panel in this test increases gradually when the loading was increased and it becomes considerable higher when the loading exceeds 2 kN. Water cured panel displays the highest stroke with 1.24 mm, followed by natural weather specimen exhibiting value of stroke of 0.29 mm, then wet dry cycle panel displaying stroke of 0.26 mm and air cured specimen presenting lowest stroke that is 0.16 mm.

Discussing on the panel performance, it was found that water cured panel possess the lowest strength of 18 kN and the stroke observed during the failure was 4.57 mm. Wet dry cycle specimen seems to exhibit good compressive strength whereby it fails at 3.14 mm at the maximum load of 24 kN. As for natural weather specimen, the panel exhibited higher compressive strength when it fails at the load of 26 kN with the stroke observed was 2.5 mm at the time of failure. Finally, air cured specimen exhibited highest strength with the ability to sustain higher load than any other panel before failure at 28 kN with the stroke as low as 2.13 mm.

Studying the performance of all these panels, it can be deduced that deformation for specimen possessing lower strength such as water cured specimen is bigger as compared to panel with higher strength namely air, natural

Table 2 : Load (kN) vs Stroke(mm) of Panel Subjected To Different Curing Regime

Load (kN)	Air	Natural Weather	Wet Dry Cycle	Water
0	0.00	0.00	0.00	0.00
2	0.16	0.26	0.29	1.24
4	0.23	0.36	0.46	1.89
6	0.34	0.45	0.62	2.33
8	0.44	0.56	0.76	2.77
10	0.54	0.67	0.9	3.22
12	0.64	0.75	1.02	3.57
14	0.74	0.89	1.19	3.82
16	0.87	1.01	1.45	4.22
18	1.02	1.23	1.81	4.57
20	1.22	1.43	2.16	
22	1.43	1.78	2.65	
24	1.69	2.13	3.14	
26	1.95	2.5		
28	2.13			

weather and wet dry cycle cured. Moreover, the pattern of deformation when same load was applied during the early stage of loading were identical to the pattern of stroke exhibited at the final stage of panels failure whereby air curing seems to have smaller

stroke throughout the loading period as compared to the other panels.. Water cured panel on the other hand, possess biggest stroke than other specimens.

It was found that, the water content in the specimen also influence the deformation of panel under loading whereby, water cured specimen having high water content due to curing under saturated condition not only exhibited biggest stroke than other specimens but also lowest compressive strength. On the other hand, air cured panel having lowest water content not only exhibited highest compressive strength but also lowest stroke. Wet dry cycle specimen happens to perform better in terms of higher compressive strength and lower stroke than water cured panel. This is because the limited exposure of wet dry cycle panel in water curing which is only for seven days before placed in dry area for another seven days and this cycle continued until the time of testing. As for natural weather specimen which was placed outdoor and exposed to rain and sunny day throughout the curing period was not capable in retaining much water because of evaporation process that occurs due to hot weather resulting in better strength with smaller stroke than wet dry cycle specimen.

It was observed that water content in the panel during testing definitely influence the strength and deformation performance of the panel. Observation on the stroke during the early loading stage could assist for early prediction regarding the panel performance in terms of compressive strength whether it is going to be higher or lower than other specimens. As a conclusion in this section, curing regime does not only influence the strength development of aerated concrete panel but also the deformation of the specimen under constant increasing load as well.

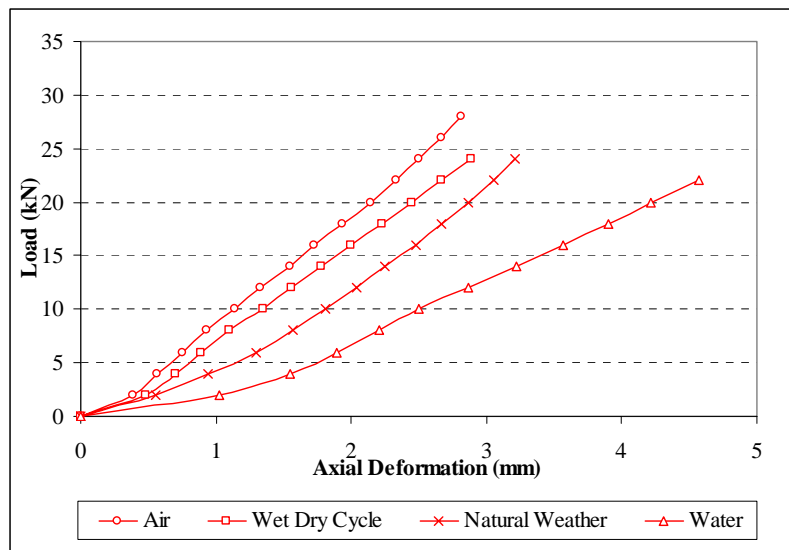


Figure 12 : Panels Subjected To Various Curing Regimes At 28 days

3.4 Comparison of POFA Cement Based Aerated Concrete With Commercial Board

Figure 13 shows the compressive strength performance of POFA cement based aerated concrete panel in comparison to existing commercial board that is widely used nowadays. It is evident that aerated concrete performs better in terms of compressive strength than gypsum board. However, the failure mode of the commercial board is alike to the air cured POFA panels. During the testing, the specimens never indicated any cracks on the surface. It just failed at the maximum load with the sudden formation of horizontal crack in the middle of the specimens. Discussing on the effect of load towards deformation of the specimens, it was observed that the reduction in the height of gypsum board is far higher compared to POFA panel for a constant load as illustrated in Figure 14. In other words, POFA cement based aerated concrete panel is more superior in terms of compressive strength as compared to other existing product already available in Malaysian market.

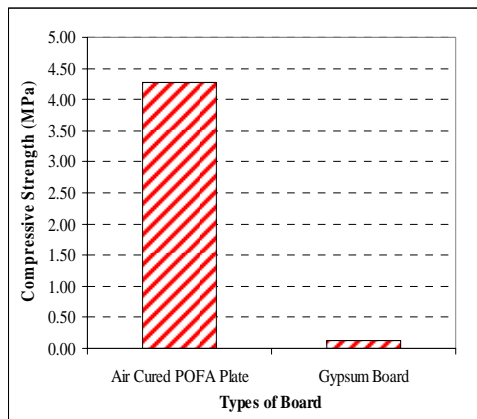


Figure 13 : Compressive strength of air cured POFA aerated concrete panel compared to commercial product

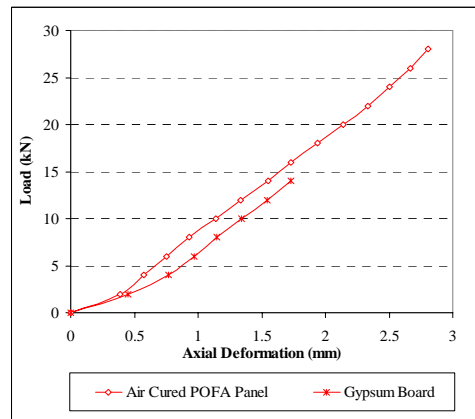


Figure 14 : Relationship between loading and stroke of air cured POFA panel compared to commercial product

4.0 Conclusions

The building industry has the maximum potential for the utilization of POFA, an abundantly produced by palm oil industry in this county for production of composite material known as POFA cement based aerated concrete panel. Base on the experimental results and discussion, the following conclusions can be drawn.

- Replacement of POFA up to 30% able to produce aerated concrete exhibiting equivalent strength with aerated concrete containing 100% OPC.
- The maximum strength for aerated concrete containing POFA occurred at the replacement level of 20 percent.

- c) Integration of 20% POFA alters the microstructure of aerated concrete making it to be denser than the plain aerated concrete.
- d) Curing regime definitely influences the strength performance including the type of failure and deformation of POFA aerated concrete panel.
- e) Curing of panel in 100% saturated condition such as water curing lead to lower strength development and exhibit very high deformation under the continuous load increment as compared to other curing that minimize the contact of water with the specimen throughout the curing age. Air curing is the best method for higher strength performance with lesser deformation when load is applied.
- f) Deformation of panel tends to become higher under constant load as the strength become lower.

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References

- Abdul Awal, A.S.M. and Hussin, M.W. (1996) Properties of fresh and hardened concrete containing palm oil fuel ash. *Proceedings of the 3rd Asia-Pacific Conference On Structural Engineering and Construction*. Johor Bahru, Malaysia.
- Abdul Awal, A.S.M. and M.W. Hussin (1997) Some aspects of durability performances of concrete incorporating palm oil fuel ash. *Proceedings of the 5th International Conference on Structural Failure Durability and Retrofitting*, Singapore.
- Abdul Awal, A.S.M. (1998) *A Study of Strength and Durability Performances of Concrete Containing Palm Oil Fuel Ash*. Ph.D Thesis. Universiti Teknologi Malaysia, Malaysia, 242 pp.
- Abu, Z. (1990) *The Pozzolanicity of Some Agricultural Fly Ash and Their Use In Cement Mortar and Concrete*. Master Thesis. Universiti Teknologi Malaysia, Malaysia, 216pp.
- ASTM C129-85 (1990). Standard Specification for Non-Load Bearing Concrete Masonry Units. Annual Book Of ASTM Standards, American Society for Testing and Materials

- ASTM Designation C 150 - 92 (1992). Standard Specification for Portland Cement. Annual Book of ASTM Standards, American Society for Testing and Materials
- ASTM C494-05a (2005). Standard Specification for Chemical Admixtures for Concrete. Annual Book of ASTM Standards, American Society for Testing and Materials
- ASTM C 618-05 (2005). Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. Annual Book of ASTM Standards American Society for Testing and Materials
- ASTM E72-05 (2005). Standard Test Methods of Conducting Strength Tests of Panels for Building Construction. Annual Book of ASTM Standards, American Society for Testing and Materials
- Basiron, Y. and Simeh, M.A. (2005) Vision 2020 – the palm oil phenomenon. *Oil Palm Industry Economic Journal*, 5 (2): 1-10.
- British Standard Institution. Testing Concrete. Method For Determination of Compressive Strength of Concrete Cubes. London, BS 1881: Part 116. 1983.
- Budiea, A.M.B, El-Gelany, M.A.I, Hussin, M.W. (2008) Durability of high strength pofa concrete. *Proceedings of the International Conference on Science And Technology Applications in Industry and Education*, UiTM Permatang Pauh, Malaysia.
- Diamond, S. (1976) Cement paste microstructure – an overview at several levels. *Proceedings of a Conference On Hydraulic Cement Pastes : Their Structure and Properties*, University of Sheffield, UK
- Escalante-Garcia, J.I. and Sharp, J.H. (2004) The chemical composition and microstructure of hydration products in blended cements, *Cement and Concrete Composite*. 26: 967-976.
- Sata, V., C. Jaturapitakkul and Kiattikomol, K. (2004) Utilization of palm oil fuel ash in high-strength concrete. *Journal of Materials in Civil Engineering*, 16: 623-628.
- Svanholm, G. (1983). Influence of Water Content on Properties. *Proceedings of The RILEM International Symposium On Autoclaved Aerated Concrete*. Amsterdam, The Netherlands: Vol. 6: 119 - 129.
- Tashiro, C. and Urushima, H. (1987) Microstructure and strength of C₃S cement paste cured at hydrostatic pressure of 450 kg/cm². *Proceedings of the First International Congress On Pore Structure and Construction Materials Properties*, Versailles, France, 57-60.
- Manmohan, D. and Mehta, P.K. (1981) Influence of pozzolanic, slag and chemical admixtures on pore size distribution and permeability of hardened cement pastes, *Cement, Concrete and Aggregates*, 3: 63-67
- Mat Yahaya, F (2003) *Pengaruh Abu Terbang Kelapa Sawit Terhadap Kekuatan Mampatan Dan Ketahananlasakan Konkrit Berudara* Master Thesis. Universiti Teknologi Malaysia. Malaysia, 145 pp.

- Narayanan, N. and Ramamurthy, K. (2000a) Microstructural investigations on aerated concrete: *Cement and Concrete Research*, 22: 457-464
- Narayanan, N. and Ramamurthy, K. (2000b) Structure and properties of aerated concrete: a review. *Cement and Concrete Composite*, 22: 321-329.