Investigation on Properties of Concrete with Palm Oil Fuel Ash as Cement Replacement

Deepak T.J., Albarra Elsayed., Noor Hassan, Chakravarthy. N, Siow Yun Tong, Mithun B.M.

Abstract: Pozzolanic materials in concrete works are increasing, and are expected to continuously increase in the years ahead because of technological advancement and the desire for sustainable development. This study presents some experimental results on the behavior of Palm Oil Fuel Ash (POFA) in concrete. Specimens containing 5, 15, 25, 35 and 45% POFA were prepared at constant water-cement ratios of 0.5 with superplasticizer content of 0.5% with cement. Workability in terms of slump and strength properties were studied, and compared with control specimen. The Study discovered that the workability of POFA concrete was quite satisfactory in the expected range, while the compressive, tensile and flexural strengths increased with POFA replacement up to 25%, 15% and 15%. Consequently the general optimum strength for all variable hardening tests was found at 15% POFA replacement.

Index Terms: Pozzolanic Material, Palm Oil Fuel Ash, Replacement, Superplasticizer, and Workability

1 INTRODUCTION

The oil palm is a tall-stemmed tree which belongs to palm family Palmea. The countries in the equatorial belt that cultivate oil palm are Benin Republic, Colombia, Ecuador, Nigeria, Zaire, Malaysia and Indonesia of which Malaysia is the largest producer of palm oil and palm oil products. It has been estimated that the total solid waste generated by this industry in some two hundred palm oil mills in the country has amounted to about ten million tons a year. These by-products are commonly used as fuel in the boiler of palm oil mills and become ash. The ash, popularly known as palm oil fuel ash or POFA is a waste material the disposal of which poses enormous environmental pollution. This ash is simply disposed of without any commercial return. It has been identified that POFA has good pozzolanic properties that can be used as a cement substitute in mortar and concrete mixes [10]. The use of supplementary cementing materials, like fly ash in concrete has attracted attention over the past decades. Apart from industrial waste, ashes from agricultural origin like rice husk, coconut husk, corn cob, peanut shell etc have been identified as supplementary cementing materials in many parts of the world. It improves the durability, reduces cost due to less use of cement. It will also be beneficial for the environment with respect to reducing the waste disposal volume of landfills [13]. POFA is an agro-waste ash from which palm oil residue, such as palm fiber and shells, are burnt at temperatures of about 800^0C –1000^0C to produce steam for electricity generation in biomass thermal power plants.

- *Deepak T.J1., Deputy Dean, School of Civil Engineering, University of East London, Linton University College, Malaysia, PH-0126352464. E-mail: deepak_tj@gmail.com*
- *Albarra Elsayed, Noor Hassan, Chakravarthy. N, Siow Yun Tong, School of Civil Engineering, University of East London, Linton University College, Malaysia*
- *Mithun B. M., National Institute of Technology, Karnataka, India.*

In Thailand, more than 100,000 tons of POFA are produced every year, and this amount increases every year because palm oil is one of the major raw materials used in the production of bio-diesel [14]. According to [1] it is estimated that million tons of its waste will be produced yearly and the Malaysian Government need to allocate more dump area for disposal in the form of land-fills. Through use of the waste material considering public concerns and research efforts, the waste materials have the potential to be used as construction materials to replace conventional Ordinary Portland cement (OPC) or at least to be used together with it. [2] said that the compressive strength of POFA in different replacement levels and also compared with control mixtures and other types of pozzolans with 15% replacement of OPC, namely quarry dust and fly ash. The results shows that concrete with 15% replacement gave the highest compressive strength and only series of concrete using fly ash surpass the strength of palm oil fuel ash concrete. Nevertheless, by adding palm oil fuel ash into the concrete mixture, it gave the compressive strength up to 45MPa at 28 days of curing.

2 EXPERIMENTAL PROGRAM

2.1 Materials Used

Cement

Portland cement is made by heating a finely divided mixture of clay or shale and chalk or limestone in a kiln at a temperature-around 1500^0 C, such that chemical combination occurs between them. Ordinary Portland cement is the cement best suited for general concreting purposes. It is the lowest priced cement and combines a reasonable rate of hardening with moderate heat output.

Coarse aggregate

The coarse aggregate was air dried to obtain saturated surface dry condition to ensure that water cement ratio was affected. Few characteristics of aggregate that affect the workability and bond between concrete matrixes are shape, texture, gradation and moisture content. In this study crushed aggregates from quarry with the nominal size 10 mm in accordance to [5] were used.

Fine aggregate

Sand is commonly known as Fine aggregate and should comply with coarse, medium, or fine grading needs. The fine aggregate was saturated under surface dry conditions to ensure the water cement ratio is not affected. The oven dry sand will then be sieved sand passing through the 600μm sieve before it was stored in an airtight container from atmospheric humidity.

Water

The chemical reaction between water and cement is very significant to achieve a cementing property. Hydration is the chemical reaction between the compounds of cement and water yield products that achieve the cementing property after hardening. Therefore it is necessary to that the water used is not polluted or contain any substance that may affect the reaction between the two components, so tap water will be used in this study.

Palm Oil Fuel Ash (POFA)

Palm oil fuel ash is the byproduct of burnt palm oil husk and palm oil shell in the boiler of palm oil mill. In this study, POFA have been collected from Sime Darby Plantations palm oil processing factory from Kilang Kelapa Sawit Mills, Negeri Sembilan. The ash was found at the shaft of the tower where all the fine ashes are trapped when escaping from the burning chamber of the boiler. Among the available ashes, only the grayish ash will be sorted out and collected. Firstly, the dried ashes will be sieved through a 300μm sieve in order to remove bigger size of ash particles and impurities. Secondly, only the fine ashes passing through 300μm will be used

Superplasticizer

Type of Superplasticizer is used for this project is Rheobuild100. The purpose of Superplasticizer is to affect the fresh concrete properties by increasing the workability in concrete. The Superplasticizer is applied as a constant by 0.5% of total cement.

2.3 Mix Design

The mix design method in this research is comprehended based on the Department of Environmental (DOE) United Kingdom. Selecting the best proportions of cement, fine and coarse aggregate and water to produce concrete having specified properties is a primary problem in designing concrete mix. Hence, the design mix is very essential in achieving the design characteristic strength. Table 1and 2 shows the mix proportions for compressive, tensile, flexural strength.

Table 1: Mix Proportions for cylinder

Quantities	Cement (Kg/m^3)	Water (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	POFA (Kg/m^3)
Per 1 m^3	450.00	225.00	682	1023	-
Control 0.00173 m^3	0.779	0.389	1.179	1.769	-
5% POFA 0.00173 m^3	0.740	0.389	1.179	1.769	0.039
15 % POFA 0.00173 m^3	0.662	0.389	1.179	1.769	0.117
25 % POFA 0.00173 m^3	0.584	0.389	1.179	1.769	0.195
35 % POFA 0.00173 m^3	0.506	0.389	1.179	1.769	0.273
45%POFA 0.00173m^3	0.428	0.389	1.179	1.769	0.351

Table 2: Mix Proportions for Flexural Strength

Quantities	Cement (Kg/m^3)	Fine Aggregate	Water (Kg/m^3)	Coarse Aggregate (Kg/m^3)	POFA (Kg/m^3)
Per 1 m^3	450.00	225.00	682	1023	-
Control =0.00363 m^3	1.634	0.817	2.476	3.713	-
5% POFA 0.00173 m^3	1.552	0.817	2.476	3.713	0.082
15 % POFA 0.00173 m^3	1.389	0.817	2.476	3.713	0.245
25 % POFA 0.00173 m^3	1.226	0.817	2.476	3.713	0.409
35 % POFA 0.00173 m^3	1.062	0.817	2.476	3.713	0.572
45%POFA 0.00173m^3	0.899	0.817	2.476	3.713	0.735

3 Results and Discussion

3.1 Slump Test

Fresh concrete is defined as workable when the concrete can be transported, placed, compacted and finished easily and without segregation, slump tests were conducted for concrete and 5%, 15%, 25%, 35%,and 45% POFA replaced cement to determine the workability. For this study 3 batches of concrete were tested on the workability before the fresh concrete specimens were casted in the moulds. The result for the average slump and all POFA replacements were shown below in Table 3.

Table 3: Slump test

Composition with POFA replacement	Batch No	Slump (mm)	Average slump (mm)
0%	1	61.50	60.43
	2	60.00	
	3	59.80	
5%	1	66.00	66.33
	2	68.00	
	3	65.00	
15%	1	71.00	71.33
	2	72.50	
	3	70.50	
25%	1	80.00	81.00
	2	82.00	
	3	81.00	
35%	1	88.00	88.33
	2	86.00	
	3	91.00	
45%	1	107.00	104.00
	2	100.00	
	3	105.00	

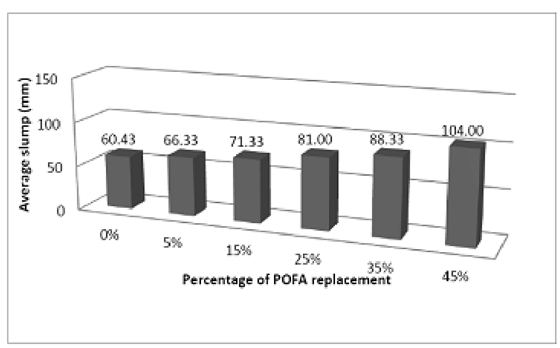

Figure 1: Results of Slump Test

From figure and table 3 above, the results of average slump verses percentage of palm oil fuel ash were plotted in a bar chart to show the comparison between the control 0% and the replacements of 5%, 15%,25%, 35%, and 45% palm oil fuel ash in concrete. The results shows the slump improved for all concrete specimens increase from 0% control to 45% palm oil fuel ash replacement. It is evident that the average slump increased by 5.9mm, 10.9mm, 20.57mm, 27.9mm, and 43.57mm for 5%, 15%, 25%, 35%, and 45% palm oil fuel ash respectively. Based on this research slump containing 45% POFA found to have the highest workability

3.2 Compaction Factor Test
Compacting factor test for testing fresh concrete. For this study, also 3 batches of concrete were tested on the workability before the fresh concrete specimens were casted in the moulds. The results of average compacting ware shown in table 4.

Table 4 Compacting Factor test results

Composition With POFA Replacement	Batch No	compacting factor	Average compacting factor
0%	1	0.93	0.93
	2	0.94	
	3	0.92	
5%	1	0.94	0.93
	2	0.93	
	3	0.93	
15%	1	0.94	0.94
	2	0.92	
	3	0.95	
25%	1	0.95	0.95
	2	0.94	
	3	0.95	
35%	1	0.96	0.96
	2	0.96	
	3	0.95	
45%	1	0.91	0.97
	2	0.91	
	3	0.92	

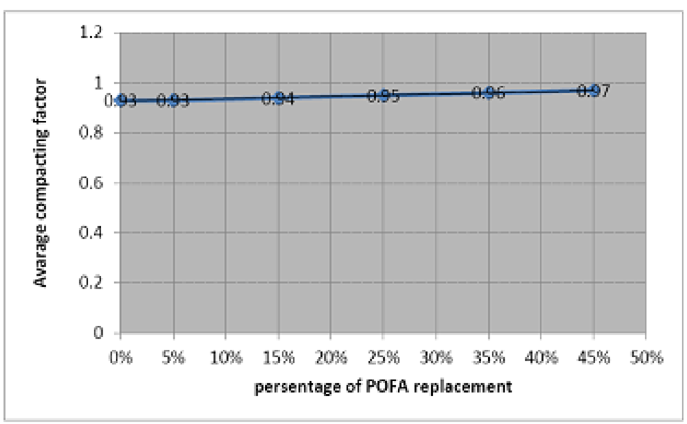

Figure 2 Average compacting factor verses percentages of POFA replacement

The results obtained from compacting factor test, it can be correlated to slump results. It can also be seen that the percentage of POFA concrete shows the higher degree of compacting factor which is more than OPC concrete. For all the percentage replacement of 5% to 35% POFA concrete, except the last percentage 45% represented lower workability which is less than OPC concrete. The control 0% compacting factor is lowest compared to the percentage of POFA up to 35%. Concrete containing 35% of palm oil fuel ash represented highest value of compacting factor comparing to POFA percentage. While the 45% POFA indicating the lowest workability. The increased of workability is due to the w/c ratio and also the effect of superplasticizer.

3.3 Compressive Strength
The most valuable property in concrete is the concrete compressive strength because it gives the overall definition of the quality concrete strength that relates to the hydrated cement paste. Basically, the specimens were being tests for three selected curing periods of 7, 14, 28 days, detail test results are shown in table 5.

Table 5: Compressive strength of concrete specimens at 7, 14, and 28 days of curing.

Concrete composition with	Average compressive strength		
POFA replacement	7day	14days	28days
0%	23.03	31.1	37.04
5%	24.36	31.46	37.55
15%	23.45	30.79	38.8
25%	22.89	29.99	37.07
35%	12.76	19.98	23.55
45%	8.04	12.64	16.86

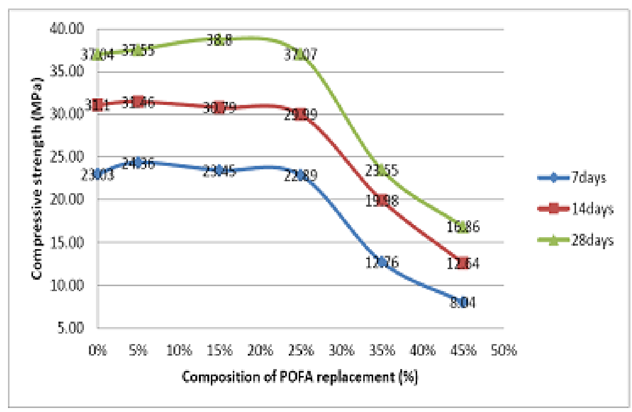

Figure 3: Average compressive strength verses curing days of concrete specimens

The average test results of the compressive strength in their specified curing periods of 7, 14 and 28 days and percentage replacement of CS were summarized as shown in Table 5. Similarly, the results were also presented in graphical form in Figure 3. From the figure it is evident that the higher compressive strength was achieved when using OPC replacement with 15% POFA at the age of 28 days with a higher compressive strength of 38.8 MPa. It can also be seen that the 15% percentage of POFA produce higher strength more than OPC concrete.

3.4 Flexural Strength
Flexural strength can be described as the capacity of a beam or even a slab of concrete to resist failure due to bending. This flexural strength is also known as *Modulus of Rupture*. The effect of concrete with various percentage of POFA on flexural strength is shown on table 6. The flexural strength was tested on 7, 14 and 28 days of curing. The results showed that the flexural strength of the concrete increased as the percentage of the POFA increased in the mix ratio. It was observed that

the concrete flexural strength of the beam specimens increases with increasing age.

Table 6: Flexural strength of concrete specimens at 7, 14, and 28 days of curing

Concrete composition with	Average flexural strength		
POFA replacement	7day	14days	28days
0%	2.01	2.98	3.7
5%	2.02	3.09	3.97
15%	1.96	2.82	4.31
25%	1.78	2.52	3.68
35%	1.21	1.53	2.03
45%	0.85	1.12	1.55

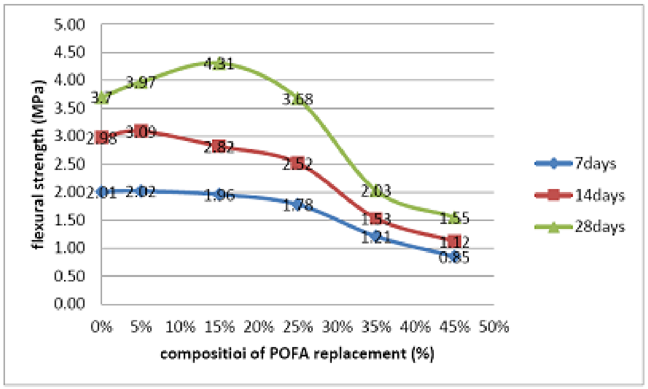

Figure 4: Average flexural strength verses curing days of concrete specimens

Figure 4, shows a graphical representation of reduction in flexural strength for different POFA percentage. The results showed that the flexural strength of the concrete increased as the percentage of the POFA increased in the mix ratio. It was observed that the concrete flexural strength of the beam specimens increases with increasing age.

3.4 Tensile Strength

The split tensile strength of the concrete specimens was determined at 7, 14 and 28 days following [7]

Table 7: Tensile strength of concrete specimens at 7, 14, and 28 days of curing

Concrete composition with POFA replacement	Average Tensile strength		
	7day	14days	28days
0%	1.15	1.31	1.78
5%	1.18	1.32	1.81
15%	1.1	1.21	1.91
25%	0.91	1.03	1.70
35%	0.59	0.84	1.12
45%	0.38	0.6	0.8

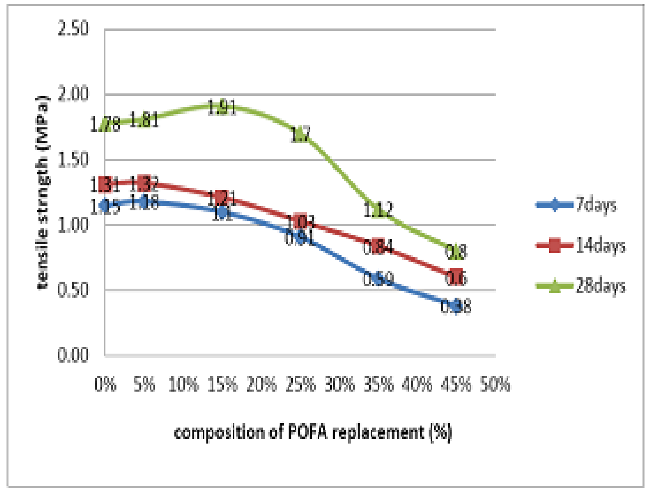

Figure 5: Tensile strengths variation with different percentages of POFA

The average test results of the split tensile strength in their specified curing periods of 7, 14 and 28 days and percentage replacement of POFA were summarized as shown in Table 7. Similarly, the results were also presented in graphical form shown in Figure 5. The results showed that the tensile strength of the concrete increased as the percentage of the POFA increased in the mixes. It was observed that the concrete tensile strength of the cylindrical specimens increases with increasing age.

4 Conclusions

Extensive experimentation was carried out on control concrete with POFA replacement from 0 - 45% cement replacement were prepared with constant water – binder ratio of 0.5. For all mixes, workability, compressive strength, flexural strength and tensile strength were determined at 7, 14 and 28 days. The following conclusions can be derived from the investigation:

1. When superplasticizer is added to POFA concrete, there is improvement in workability. Therefore the effect of the superplasticizer also increases the workability of POFA concrete.
2. The effect of superplasticizer on concrete exhibits a higher value for slump compared to the slump of OPC concrete. Also the result of the compacting factor can be correlated to the slump. The higher percentage of replacement exhibited higher workability. Hence POFA has higher workability when superplasticizer is added.
3. The results showed that the ultimate compressive strength of concrete could be improved by using up to 25 % of POFA to replace Portland cement in the concrete mix.
4. Compressive strength of POFA shows its optimum compressive strength is when the cement is replaced with 15% POFA giving a higher compressive strength than OPC.
5. Consuming POFA as cementing materials in construction industry will reduce the environmental problems associated without disposing it in landfill.
6. The flexural strength of POFA is slightly higher than that of OPC by replacing cement with 15% POFA. Similar to flexural strength, the tensile strength of concrete containing POFA develops in the similar way.

REFERENCES

[1] Abdul, A., A.S.M.andHussin M. W. (1997)Strength, Modulus Of Elasticity And Shrinkage Behaviour Of POFA Concrete', Malaysian Journal of Civil Engineering 21(2),pp.125-134.

[2] Ahmad, M. H., Omar, R. C., Malek, M. A., Noor, N. M. and Thiruselvam,S. (2008) 'Compressive Strength of Palm Oil Fuel Ash Concrete', ICCBT 2008, A (27), pp. 297-30.

[3] BS 1881-103: (1993) "Testing concrete: Method for determination of compaction factor.

[4] BS EN 12350-2: (2000) "Testing fresh concrete Part 2: Slump test," European Committee for Standardization.

[5] BS 882: (1992), Specification for aggregates from natural sources for concrete, British Standard Institution.

[6] BS 1881-Part 118, (1983), testing concrete: Method for determination of flexural strength, British Standard Institution.

[7] BS EN 12390-7 (2009), Testing hardened concrete Part 7: Density of hardened concrete, European Committee for Standardization.

[8] BS EN 12390-3: (2009), testing hardened concrete part 3.Compressive strength of test specimens, European Committee for Standardization.

[9] BS 1881: Part 3 (1970), Testing concrete: Methods of making and curing test specimens.

[10] Sata, V., Jaturapitakkul C. and Chaiyanunt R. (2010)' Compressive Strength and Heat Evolution of Concretes Containing Palm Oil Fuel Ash', Journal of Materials in Civil Engineering, 22(10),pp.1033-1038.

[11] Sata, V., Jaturapitakkul C. and Kiattikomol K., (2007)' Influence of Pozzolan from Various By-productMaterials on Mechanical Properties of High-strength Concrete', Construction and Building Materials, 21(7),pp.1589-1598.

[12] Neville, A. M. (2005) 'Properties of Concrete'. 4TH Edition, Longman Group Ltd,pp, 844.

[13] Tangchirapat, W., Jaturapitakkul, C., Chindaprasirt, P. (2009) 'Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete', Construction and Building Materials, 23 (7), pp.2641-2646.

[14] Weerachart T., Tirasit, S., Chai, J., Kraiwood, K., Anek, S.(2007) 'Use of waste ash from palm oil industry in concrete',Waste Management, 27(2007),pp. 81–8.