Malaysian Journal of Civil Engineering 23(2):54-66 (2011)

PROPERTIES OF CONCRETE CONTAINING HIGH VOLUME PALM OIL FUEL ASH: A SHORT-TERM INVESTIGATION

A.S.M. Abdul Awal[1*], Shehu Ibrahim Abubakar[1]

[1]*Faculty of Civil Engineering, Universiti Teknologi Malaysia 81310 UTM Skudai, Johor, Malaysia*

[*]Corresponding Author:*asmawal@yahoo.com*

Abstract: Utilization of pozzolanic materials in concrete works is increasing, and this trend is expected to continue in the years ahead because of technological advancement and the desire for sustainable development. This study presents some experimental results on the behaviour of high volume palm oil fuel ash (POFA) in concrete. Concrete specimens containing 50, 60 and 70% POFA were made at various water-cement ratios of 0.38, 0.42 and 0.48 with superplasticizer content of up to 2%. Workability in terms of slump and strength properties were studied, and compared with that of concrete containing 100% OPC as control. It has been found that the workability of high volume POFA concrete was quite satisfactory with superplasticizer while the development of strength at all ages of 1, 3, 7, 14 and 28 days were lowered than that in concrete with OPC alone. Among the curing methods the water curing has been found to produce the best result. The short-term investigation reveals that high volume palm oil fuel ash has good potentials in the production of concrete.

Keywords*: Pozzolanic material, Palm oil fuel ash, High volume, Workability, Strength*

1.0 Introduction

The incorporation of waste as supplementary cementing material in concrete and other construction related materials is gradually gaining recognition at appreciable rate. In Malaysia one of the common wastes from palm oil mill is palm oil fuel ash (POFA), a by-product of oil mills arising from the use of palm oil shell and palm oil bunches which are used to power oil mill plants for electricity generation (Awal and Hussin, 1997; Hussin *et al.*, 2010). At present these wastes are disposed off as land fill material without any economic return (Awal and Nguong, 2011 and Borhan *et al.*, 2010). According to Tangchirapat *et al.*, (2009) the utilization of POFA as a pozzolanic material to partially or wholly replace Portland cement has not been thoroughly investigated when compared to other materials such as fly ash, especially in high strength concrete. Safiuddin *et al.*, (2010) and Karim *et al.*, (2011) reviewed several research findings on POFA and confirmed that most research records have limited the use of POFA to a partial replacement, ranging from 0-30% by weight of the total cementitious material in the production of concrete. Indeed, the prtial replacement has a beneficial effect on the general properties of concrete as well as cost.

High volume utilization of pozzolan according to Malhotra and Mehta (2005) is the addition of 50% and above of mineral admixture either as a component of blended cement or added to concrete batch. The use of high volume fly ash in concrete has been extensively studied over the last decades and the properties are well documented. From the available literature it is generally believed that high volume fly ash content varies from 30-80% for low strength (20N/mm^2) to high strength (100N/mm^2)(CII-CANMET-CIDA 2005). Research work by CANMET and allied confirmed the utilization of high volume fly ash concrete to have excellent properties (Jiang, 1999).

Considering the amount of POFA arising from palm oil mills in Malaysia, Thailand, Indonesia and other palm oil producing nations and the desire to address environmental problem posed by this waste, there is a need to examine further on the application of POFA at higher volume particularly in concrete operations. This study therefore, seeks to investigate the properties of concrete containing high volume palm oil fuel ash (HVPOFA) for sustainable development as well as to put POFA into economic benefit.

2.0 Materials and Test Methods

2.1 Materials

Palm Oil Fuel Ash (POFA) was obtained from a local palm oil mill located at Kilang Sawit PPNJ Kahnag Batu 17, Jln Kluang Mersing, Johor Malaysia. The ash was sieved through BS standard sieves to remove larger particles as well as reducing the carbon content and to prevent glassy phase of crystallization and particle agglomeration, all of which affect the pozzolanic properties. Materials passing through 75µm sieve were ground using Los Angeles milling machine having 10 stainless steel bars of 12mm diameter x 800mm length at 5000 revolution per 4kg POFA to obtain sample with maximum of 35% retained on 45µm sieve, as specified in ASTM C 618-05.

Cement used in this study was Holcim brand of Portland conforming to ASTM C150-05. A saturated surface dry local river sand with fineness modulus of 2.9, passing through 4.75mm sieve with specific gravity and water absorption of 2.6 and 0.70% respectively was used as fine aggregate. The coarse aggregate used in this study was crushed granite of 10mm maximum size with specific gravity of 2.7 and water absorption of 0.5%. RHEOBUILD 1100 (HG) brand of superplasticizer was used as water reducing admixture to improve workability and strength of concrete.

2.2 Morphological Structure of POFA

The morphological structure of POFA sample was examined using scanning electron microscopic (SEM) technique. The analysis was performed using Energy Dispersive X-Ray Analyzer (EDX-JEOL JSM_6380LA); the equipment at the same time presents estimation of elemental composition of specimen.

2.3 Mix Proportion, Casing and Curing

Concrete of grade 40 was designed using DOE (Department of Environment) method of design. The cement was replaced by POFA at replacement levels of 50, 60 and 70% by weight. The mix proportions are shown Table 1. Superplasticizer upto 2% by weight of binder was added to concrete mix in order to achieve the required slump of 60-180mm. Fresh cast cylindrical specimens were covered with plastic to prevent rapid loss of moisture. The specimens were removed from mould after 24h, there after they were cured in fresh water in the laboratory at temperature of 23±2 ^{o}C.

Table 1: Mix characteristics of OPC and POFA concrete

Materials	OPC Concrete	50% POFA Concrete	60% POFA Concrete	70% POFA Concrete
OPC (kg/m^3)	427	214	171	128
POFA (kg/m^3)	-	213	256	299
Coarse aggregate (kg/m^3)	961	961	961	961
Fine aggregate (kg/m^3)	787	787	787	787
Water (kg/m^3)	205	205	205	205
Slump (mm)	160	140	110	80

2.4 Determination of Workability and Strength

Workability, in terms of slump, of fresh concrete was studied in accordance with ASTM C 143/C 143M-05. Compressive and tensile strength tests were conducted on HVPOFA and OPC concrete at 1, 3, 7, 14 and 28 days using cylindrical specimen of 100mm diameter x 200mm length in accordance with ASTM C 39/C 39/M – 05 specification. Three specimens were tested to obtain the average value for each test condition.

3.0 Results and Discussion

3.1 *Physical Characteristics of POFA*

Palm oil fuel ash collected from palm oil mill contains larger particle of carbon, unburnt palm oil fibre and some greyish colour particles. The physical characteristics of OPC and ground POFA are presented in Table 2. It can be seen that the particles retained on 45µm for OPC and POFA sample are 4.58 and 4.98%, with Blaine fineness of 3999 and 4935 cm^2/g respectively. The OPC sample has higher specific gravity of 3.15 over POFA sample whose specific gravity is 2.42, meaning that the cement particle are heavier and denser than that of POFA (Hussin *et al.*, 2010). Median particle of 1.69µm and 14.58µm was obtained for d_{10} and d_{50} respectively; the observations made in this study are in well agreements with the research findings on effect of POFA fineness on the microstructure of blended cement paste (Kroehong *et al.*, 2011).

Soundness of cement and cement/POFA was measured using Le-Chatelier apparatus as prescribed in BS4550: Part3: Section 3.7:1978 for detecting unsoundness due to free lime content, the expansion being measured with the aid of a digital Vernier calliper. Portland cement had an expansion of 2mm, while 3mm was observed in cement/ POFA mixes. However, the expansions of these materials are below the maximum specified value of 10mm. The materials are, therefore, sound for the intended use.

Strength activity index which is an indirect method of measurement of pozzolanic activity was used in the study to evaluate the pozzolanic property of POFA ground at 5000 revolution. The strength activity index at 7days was 79%, and 93% at 28days; these values are similar to those obtained by Tangchirapat and Jaturapitakkul (2010), and are higher than minimum value of 75% as specified in ASTM C 618-05.

Table 2: Physical properties of OPC and POFA

Physical properties	OPC	POFA
Specific gravity		2.42
Particle retained on 45µm sieve	4.58	4.98
Median particle d_{10}	N/A	1.69
Median particle d_{50}	N/A	14.58
Blaine fineness (cm^2/g)	3999	4935
Surface area (cm^2/g)	N/A	7078
Soundness (mm)	2.0	3.0
Strength activity index (%)		
At 7 days	-	79
At 28 days	-	93

3.2 Morphology of POFA

Figure 1 illustrates the typical electron micrograph of palm oil fuel ash particles. It can be observed that the ground POFA has irregular, thinner and crushed particle having clustered arrangement of spherical particles with few air space between them. While Figure 2 shows elemental composition of POFA; the pattern of distribution of element reveals the major crystalline phase to be S_iO_2 with heavy metals such as Zn, Cu and Pb. The presence of these metals may be due to steel material used in the inner surface of the mill boiler and also the grinder.

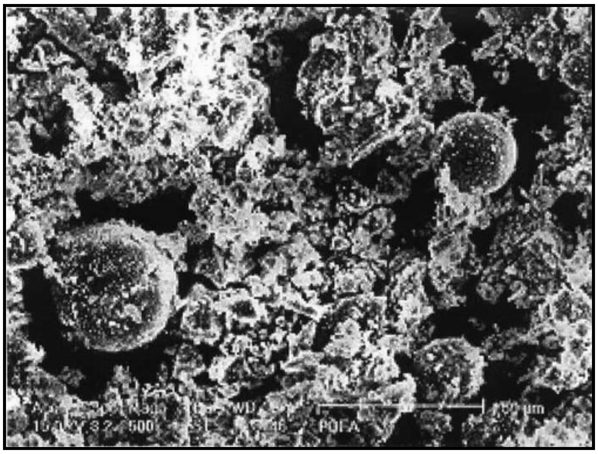

Figure 1: Scanning electron microscope of POFA

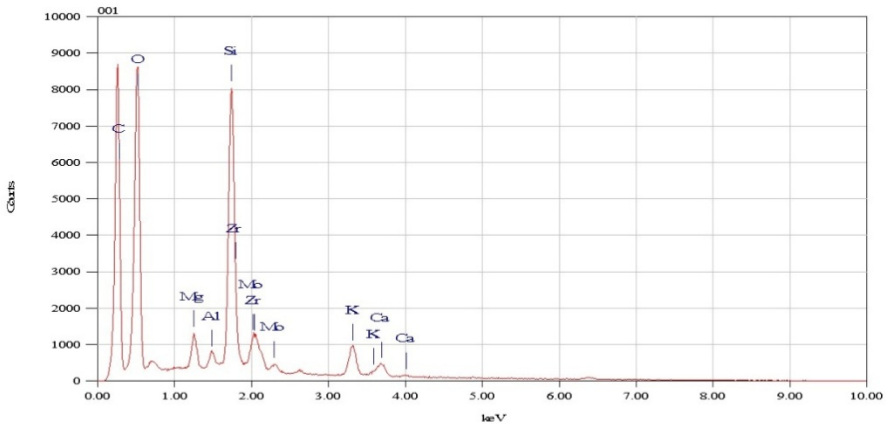

Figure 2: EDX pattern of elemental composition of POFA

3.3 Chemical Composition of POFA

Data presented in Table 3 reveals that the OPC and POFA possess similar characteristics. It can be seen that the POFA sample contains higher percentage of silica which is two times the silica content of the OPC. Obviously the presence of higher silica content influences the pozzolanic reaction when it reacts with free lime thus creating extra C-S-H gels, which is beneficial to strength development of the POFA concrete. But the alumina content of the OPC appears to be twice those of POFA, while the iron content of OPC and POFA fall on the same percentage range. The sum of silica, aluminium and iron oxide of POFA is 67.18%, which is below 70% and makes this pozzolanic material to be classified as Class C pozzolan ASTM C618-05 (Awal and Hussin, 1997; Tanchirapat *et al.*, 2009 and Chindaprasirt *et al.*, 2008). However, the high percentage of LOI and low calcium oxide content of less than 5% , a maximum SO_3 content of 5% and a maximum alkali content (expressed as Na_2O) of 1.5%, of this ash makes it to fall into class F but not class C, as enlisted in ASTM C618-05. Obviously, this finding also conforms to the observations made by Awal and Hussin (2011).

Table 3: Chemical composition of OPC, and ground POFA

Chemical composition (%)	OPC	POFA
S_iO_2	20.40	59.62
Al_2O_3	5.20	2.54
$Fe_2\,O_3$	4.19	5.02
CaO	2.39	4.92
MgO	1.55	4.52
K_2O	0.005	7.52
Na_2O	0.75	0.76
P_2O_5	0.28	3.58
Cl	0.005	0.34
SO_3	2.11	1.28
LOI	2.36	8.25
$S_IO_2 + Al_2O_3 + Fe_2O_3$	-	67.18
Residue on 45µm sieve	4.58	4.98

3.4 Workability of HVPOFA Concrete

The workability of HVPOFA concrete are illustrated in Figures 3, 4 and 5. The slump in Figure 3 reveals the slump values at 0.48 water cement ratio of 210mm for OPC and 170, 150 and 120mm for POFA replacement levels of 50, 60 and 70% by weight respectively. Figure 4 and 5 depicts the result of slump at W/C of 0.42 and 0.38 with superplasticizer at 0.5, 1.0, 1.5 and 2.0% by weight of binder for all the samples. A low slump level of 70, 50, 30 and 20mm was obtained for OPC, 50, 60 and 70% replacements at 0.38 W/C with 2% addition of superplasticizer. While a moderately high slump of 160, 140, 110 and 80mm were obtained for 0.42 W/C at similar i.e. 2% addition of superplasticizer. The observation, therefore, suggests that higher replacement of cement with POFA results in higher water demand in concrete mixture as compared to concrete with OPC alone.

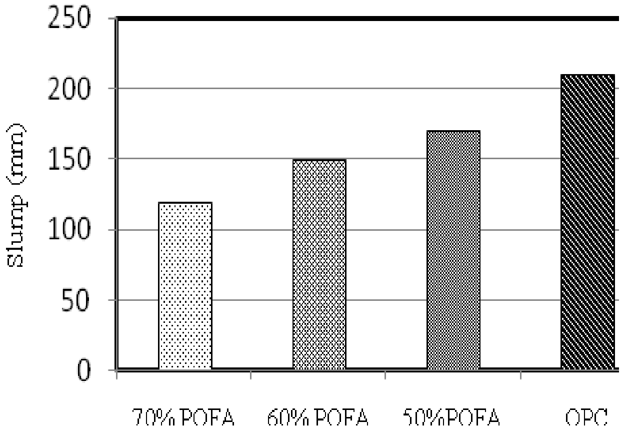

Figure 3: Slump of HVPOFA concrete at 0.48 W/C

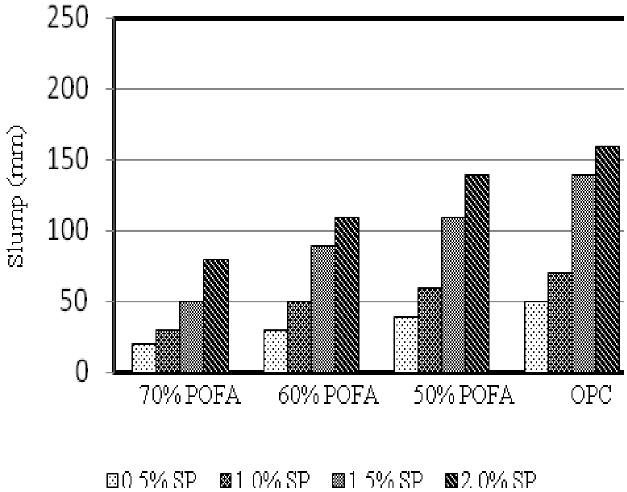

Figure 4: Slump of HVPOFA concrete at 0.42W/C

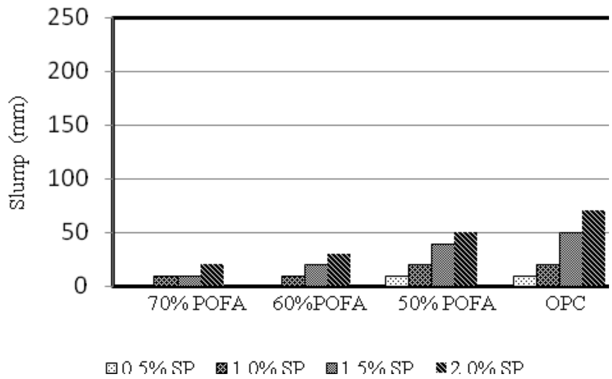

Figure 5: Slump of HVPOFA concrete at 0.38 W/C

3.5 Compressive Strength

3.5.1 Effect of Curing Period on Strength

Using the mix details specified in Table 1, concrete specimen were prepared using W/C ratios of 0.48, 0.42, and0.38 and up to 2% superplasticizer was added to mix containing 0.42 and 0.38 W/C ratios. Interestingly, the strength development of concrete with and without superplasticizer follows the same pattern. The relationship between compressive strength and curing period of concrete are shown in Figures 6, 7 and 8 at different ages of 3, 7, 14 and 28 days. Figure 6 illustrates the development of compressive strength of the concrete without superplasticizer; the results of 28 days compressive strength of OPC (control sample) was 34 N/mm^2 , while 28, 24.5 and 22 N/mm^2 were obtained for cement replacement of 50, 60 and 70% POFA respectively. The low strength is attributed to the segregation experienced during mixing because of high W/C.

Figures 7 and 8 show results of 28 days compressive strength of concrete containing superplasticizer, the strength of concrete with 0.42 W/C were 46, 41, 36 and 28 N/mm^2 for OPC, 50, 60 and 70% POFA, while, concrete made with 0.38 W/C were 37, 32, 30 and 26 N/mm^2 for OPC, 50 60 and 70% POFA respectively. Among all the samples examined in this study, the highest compressive strength was found in concrete with 0.42 W/C ratio for OPC and 50% POFA, with strength values of 46 and 41 N/mm^2 respectively. It can be observed that 50% POFA made up to 103% of the expected strength at 28 days. The increase in compressive strength of 50% POFA concrete could possibly due to superplasticizer and high fineness of POFA particles which filled the voids between the cement and aggregates (Tangchirapat, et al, 2009; Awal and Nguong, 2011).

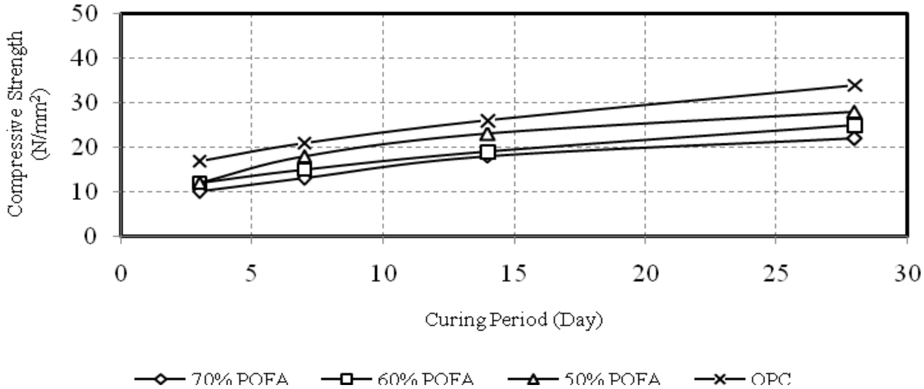

Figure 6: Compressive strength of POFA concrete at 0.48 W/C

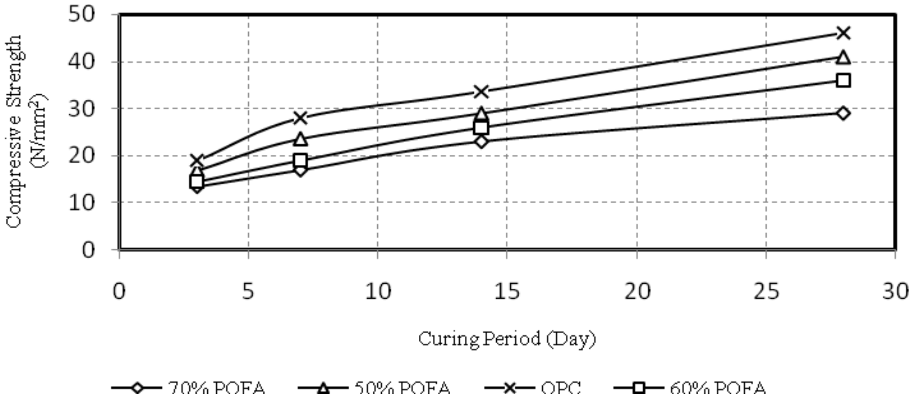

Figure 7: Compressive strength of POFA concrete at 0.42 W/C

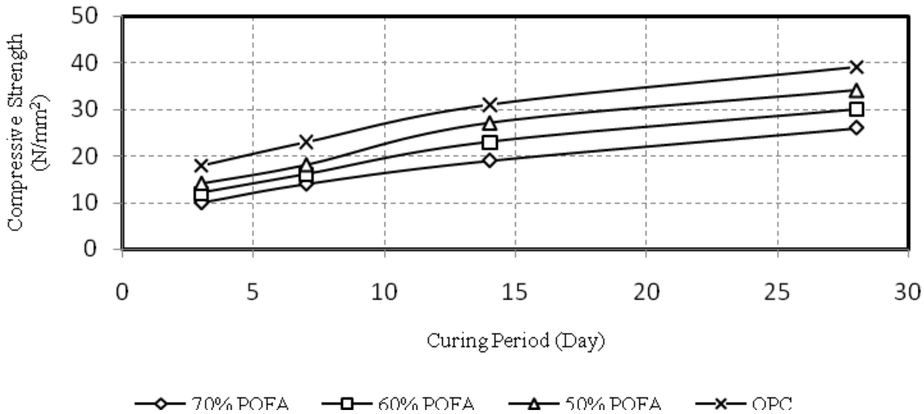

Figure 8: Compressive strength of POFA concrete at 0.38 W/C

3.5.2 Effect of Curing Condition

Strength developments of POFA concrete at three different curing regimes are illustrated in Figure 9. The study was conducted on only 50% POFA replacement; even though the period of study is not long, the effect in the curing sensitivity of concrete specimens can easily be detected. At early age say at 1 day curing, the development of strength was very close (8-9N/mm^2). At the age of 7, higher values of strength in concrete had been noticed except for those cured in air. After reaching 28 days, the differences in compressive strength appeared to be more distinct. The 28 day compressive strength of water cured POFA concrete, for instance, was found to be 41N/mm^2. A closer value of 36.0 N/mm^2 was obtained for the concrete cured at 7 days in water and the rest in air. The lowest value of 29.5 N/mm^2 was, however, recorded for concrete cured in air. This is to be expected as hydration of cement takes place in water-filled capillaries, and curing of pozzolanic concrete, in general, needs more care. It is due to this fact that the strength development of concrete containing pozzolans is more adversely affected by short curing periods under water than that with Portland cements (Neville, 1995). The observations made in this study are in well agreements with the research findings on other pozzolanic materials like rice husk ash, silica fume and C class pozzolans (Mehta, 1992 and Malhotra *et al.*, 1994).

3.6 Tensile Strength

Figure 10 shows the tensile strength of concrete at 50% POFA replacement determined at the age of 1, 7 and 28 days. A similar trend like that of the compressive strength has been observed for tensile strength development in both OPC and POFA concrete. At all ages, the tensile

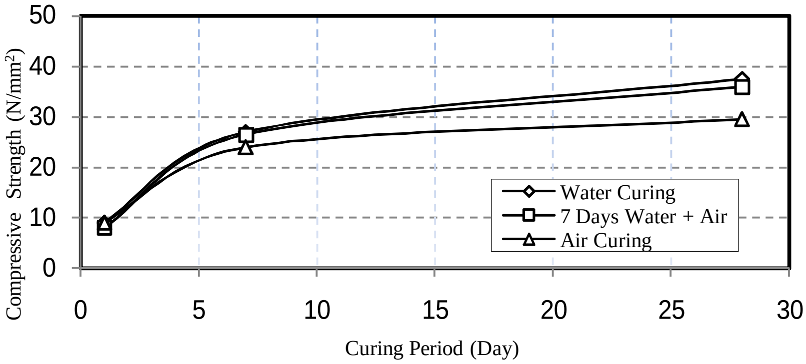

Figure 9: Effect of curing condition on compressive strength of high volume POFA concrete.

strength of POFA concrete, however exhibited lower values than those of OPC concrete. Although the rate of development of strength at early ages was very slow, an upward tendency of strength gain at later ages has been demonstrated. Limited test data on splitting tensile strength of POFA concrete also indicate that the ratio of splitting-tensile to compressive strength is of the same order for both POFA and OPC concretes at all ages.

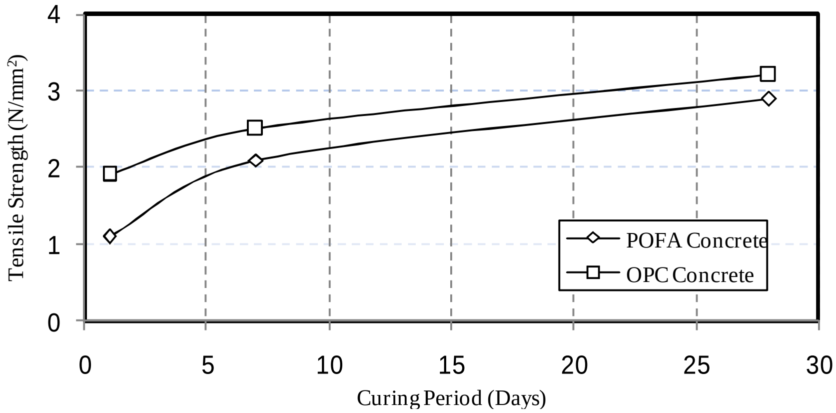

Figure 10: Development of tensile strength in OPC concrete and high volume POFA concrete.

4.0 Conclusion

The following conclusions have been drawn from the experimental results of this study:

1) Workability of concrete containing high volume palm oil fuel ash are somewhat low; with water reducing admixture like superplasticizer the workability has been found to be improved to a satisfactory level.
2) High volume palm oil fuel ash concrete like concrete made with other pozzolanic materials, showed a slower gain in strength at early age.
3) The compressive strength and tensile strength of high volume POFA concrete, in general, were found to be lower than those of normal OPC concrete.
4) Curing of POFA concrete has a great influence on the strength of concrete; water curing provided the best result.
5) Long-term studies on the development of strength as well as durability aspect of concrete containing high volume POFA have been recommended for further investigation.

References

ASTM, C 618 (2005) Standard specification for Coal, Fly Ash and Raw Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete.

ASTM, C 143/C 143M (2005) Standard Test Method for Slump of Hydraulic Cement Concrete.

ASTM, C 150 (2005) Standard Specification for Portland Cement.

ASTM, C 39/C 39M (2005) Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

Awal, A.S.M.A. and Hussin, M.W. (1997) Effect of Palm Oil Fuel Ash on Durability of Concrete. *Proceeding of the 5th International Conference on Concrete Engineering and Technology*, Kuala Lumpur, Malaysia, 299-306.

Awal, A.S.M.A. and Nguong, S.K. (2010) A Short-Term Investigation on High Volume Palm Oil Fuel Ash (POFA) Concrete. *Proceedings of the 35th Conferenece on our World in Concrete and Structure,* Singapore, 185-192.

Awal, A.S.M.A. and Hussin, M.W. (2011) Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction. Procedia Engineering*, 14; 2650-2657.

BS (1978) British Standard 4550: Part 3: Method of Test Cements Physical Properties.

Borhan, M.N., Ismail, A. and Rahamt, R.A. (2010) Evalution of Palm Oil Fuel Ash on Asphalt Mixture. *Australian Journal of Basic and Applied Science*, 4(10); 5456–5463.

CII-CANMET-CIDA. (2005) Use of High Volume Fly Ash Concrete for Building Sector. Environmental Science and Technology Division, Central Building Research Institute, Roorke.

Chindaprasirt, P., Rukzon, S. and Sirivivatnanon, V. (2008) Resistance to Chloride Penetration of Blended Portland Cement Mortar Containing Palm Oil Fuel Ash, Rice Husk Ash and Fly Ash. *Construction and Building Material,* 22(5): 932–938.

Department of the Environment (DOE), Design of Normal Concrete Mixes, Building Research Establishments U. K.,1992.

Hussin, M.W., Muthusamy, K. and Zakaria, F. (2010) Effect of Mixing Constituent Toward Engineering Properties of POFA Cement–Based Aerated Concrete. *Journal of Materials in Civil Engineering,* 287.

Jiang, L. (1999) The Interfacial Zone and Bond Strength Between Aggregate and Cement paste Incorporating High Volume of Fly Ash. *Cement and Concrete Research.* 21; 313-316.

Karim, R., Zain, M.F.M., Jamil, M. and Ismail, N. (2011) Strength of Concrete as Influenced by Palm Oil Fuel Ash. *Australian Journal of Basic and Applied Sciences*, 5(5): 990-997.

Kroehong, W., Sinsiri, T. and Jaturapitakkul, C. (2011) Effect of Palm Oil Fuel Ash Fineness on Packing Effect and Pozzolanic Reaction of Blended Cement Paste. *The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction. Procedia Engineering* 14, 361-369.

Malhotra, V.M. and Mehta, P.K. (2005) High Performance, High Volume Fly Ash Concrete. Supplementary Cementing Material for Sustainable Development, Ottawa, Canada.

Malhotra, V.M., Carette, G.C. and Sivassundaram, V. (1994) Role of Silica Fume in Concrete: a Review, *Advances in Concrete Technology,* CANMET, Ottwa, 925-991.

Mehta, P.K. (1992) Rice Husk Ash – A Unique Supplementary Cementing Material. *Advances in Concrete Technology,* CANMET, Ottawa, 407-432.

Neville, A.M.(1995) Properties of Concrete, Fourth Edition, Longman Group UK Ltd.

Safiuddin, Md., Jumaat, Z.M., Salam, M.A., Islam, M.S. and Hashim, R. (2010) Utilization of Solid Waste in Construction Materials. *International Journal of the Physical Science*, Vol. 5(13). 1952-1963.

Trangchirapat, W. and Janturapitakkul, C. (2010) Strength, Dry Shrinkage, and Water Permeability of Concrete Incorporating Ground Palm Oil Fuel Ash. *Cement and Concrete Composite*, 32; 767-774.

Trangchirapat, W., Janturapitakkul, C. and Chindaprasirt, P. (2009) Use of Palm Oil Fuel Ash as a Supplementary Cementicious Material for Producing High-Strength Concrete. *Construction and Building Materials*, 23; 2641–2646.