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STRENGTH, MODULUS OF ELASTICITY AND SHRINKAGE BEHAVIOUR OF POFA CONCRETE

A.S.M. Abdul Awal*, M. W. Hussin

Department of Structure and Materials, Faculty of Civil Engineering
Universiti Teknologi Malaysia, 81310UTM Skudai, Johor, Malaysia

*Corresponding Author: *asmawal@yahoo.com*

Abstract: An investigation was carried out to study strength, modulus of elasticity and shrinkage of concrete containing palm oil fuel ash (POFA). Following DoE mix design, OPC concrete was made to have a target mean strength of 50 MPa with 50 ± 5 mm slump. Having the same workability, POFA concrete was prepared where OPC was replaced, mass for mass, by 30% POFA. Laboratory test results based on short-term investigation revealed that the modulus of elasticity of POFA concrete in association with its compressive strength was slightly lower than that of OPC concrete. The measured values of shrinkage, however, demonstrated that the shrinkage strain of POFA concrete was higher than that of OPC concrete. On the basis of short-term investigation, the one-year shrinkage values of both OPC and POFA concrete were also predicted by extrapolating the data obtained during this period.

Keywords: *Palm oil fuel ash, pozzolans, concrete strength, modulus of elasticity, shrinkage*.

1.0 Introduction

The utilisation of pozzolans, either naturally occurring or artificially made in concrete has been in practice since the early civilisation. Of the artificial pozzolans, fly ash has already gained global acceptance as a supplementary cementing material in concrete. As with the demand for concrete with high performance characteristics, the demand for such pozzolanic materials is also getting higher day by day. Perhaps the latest addition to the ash family is palm oil fuel ash (POFA), a waste material obtained on burning of palm oil husk and palm kernel shell as fuel in palm oil mill boilers that has been identified as a good pozzolanic material.

In view of utilisation of POFA as a supplementary cementing material, research programmes have been initiated in the Faculty of Civil Engineering, Universiti Teknologi Malaysia in examining various aspects of fresh and hardened state properties of concrete. Laboratory investigations, based on short and long-term study have shown that this ash has not only enabled the replacement of ordinary Portland cement but also found to play an effective role in producing strong and durable concrete (Salihuddin, 1993; Abdul Awal and Hussin,1997; Budiea, 2008). Research work and published data on deformation behaviour of this concrete, however, are not many. As a part of the program, an investigation was therefore carried out to study the modulus of elasticity and shrinkage of concrete containing this palm oil fuel ash. Based on short-term investigation, the one-year shrinkage value of concrete was also predicted by extrapolating the results obtained during the period of study.

2.0 Materials and Methods

2.1 Palm Oil Fuel Ash.

This ash, as mentioned earlier is the product of burning oil palm husk and palm kernel shell in the palm oil mill boiler. In the present study, ash was collected from Golden Hope Palm Oil Mill at Bukit Lawang in the State of Johor. After collection, the ash was sieved through 300-µm sieve to remove foreign material and bigger size ash particles. The ashes were then ground in a Los Angeles abrasion machine using steel bars (12 mm diameter and 800 mm long) instead of balls in it. A flow-chart for the preparation of ash is shown in Figure 1.

In bulk, POFA is greyish in colour that becomes darker with increasing proportions of unburned carbon. However, it is much finer than OPC and its specific gravity is 2.22. The particles have a wide range of sizes but they are relatively spherical; a typical electron micrograph of POFA is shown in Figure 2. The chemical analysis, illustrated in Table 1, reveals that POFA satisfies the requirements to be pozzolanic and may be classified as in between Class C and Class F according to the standard specified in ASTM C6I8-94a (1994).

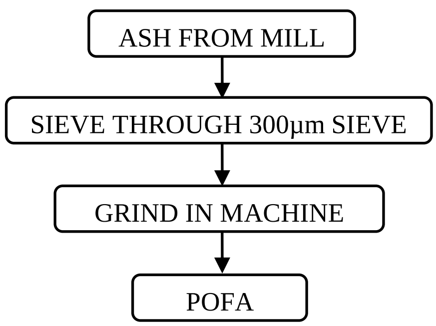

Figure 1: Flow chart for processing of POFA

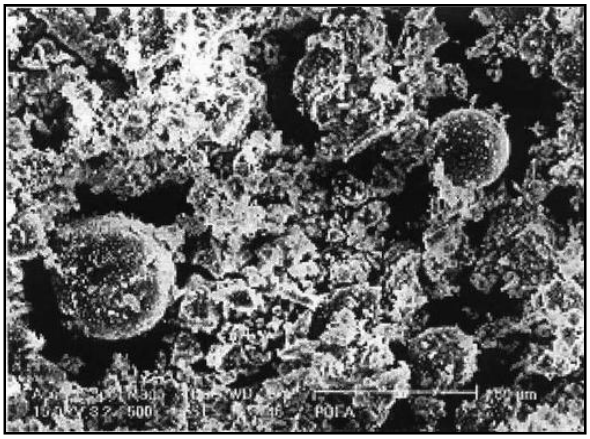

Figure 2: Scanning electron micrograph of POFA

2.2 Concrete Manufacture and Test Procedure

The manufacture of concrete and all the tests were carried out in the Structure and Materials Laboratory of the Faculty of Civil Engineering. Ordinary Portland cement (OPC) from Tenggara Cement Manufacturing Sdn Bhd was used throughout the experimental investigation. The physical properties and chemical composition of the cement are also given in Table 1. Dry mining sand with a fineness modulus of 2.4 and crushed granite of 10 mm size were used as fine and coarse aggregate respectively. Their relative density on oven-dry basis, measured according to BS 812: Part 2 (1995) were 2.50 and 2.61 respectively. The corresponding values for water absorption, however, were 1.34% and 0.76%. Supplied tap water was used throughout the study in mixing and curing purposes.

Following DoE (1997) mix design, OPC concrete was made to have a target mean strength of 50 MPa with 50 ± 5 mm slump. Having the same workability, POFA concrete was prepared where OPC was replaced, mass for mass, by 30% POFA. The detail of the mix proportion for both OPC and POFA concrete is shown in Table 2. For all tests, cylindrical specimens (150 mm x 300 mm) were prepared following the standard specified in BS 1881: Part 110 (1983). After casting, the specimens were demoulded at 24 hours and then put into water tank for curing until testing. The average temperature recorded in the laboratory was 27 ± 2^{o}C where the relative humidity, RH was 85 ± 5%.

Table 1: Physical properties and chemical composition of OPC and POFA

Tests	OPC	POFA
Physical Properties		
Fineness - Sp. surface area (m^2/kg)	315	520
Soundness - LeChatelier method (mm)	1	1
Specific Gravity	3.28	2.22
Chemical Composition (%)		
Silicon Dioxide (SiO_2)	20.20	43.60
Aluminium Oxide (Al_20_3)	5.70	11.40
Ferric Oxide (Fe_2O_3)	3.00	4.70
Calcium Oxide (CaO)	62.50	8.40
Magnesium Oxide (MgO)	2.60	4.80
Sulphur Trioxide (SO_3)	1.80	2.80
Sodium Oxide (Na_2O)	0.16	0.39
Potassium Oxide (K_2O)	0.87	3.50
Loss on Ignition (LOI)	2.70	18.00
28-day Strength Activity Index with OPC	--	112

Table 2: Mix characteristics of OPC and POFA concrete

Material / Property	OPC Concrete	POFA Concrete
OPC (kg/m^3)	440	310
POFA (kg/m^3)	--	130
Coarse Aggregate (kg/m^3)	995	995
Fine Aggregate (kg/m^3)	750	750
Water (kg/m^3)	215	218
Water-Cement Ratio	0.48	0.49
Slump (mm)	60	55

Investigation of strength involved the measurement of compressive and splitting tensile tests at the age of 1,7 and 28 days, and all the methods followed for measuring the strength of concrete specimens were in accordance with BS 1881: Part 116 (1983) and part 117 (1983). The moduli of elasticity (Young's modulus) of OPC and POFA concrete were carried out at two ages of 7 and 28 days following ASTM C 469-02 (2002).

Shrinkage of concrete can be measured by several methods with samples of various sizes. In this test, cylindrical specimens after an initial curing of 7 days were exposed to drying shrinkage. The number of specimens for each type of concrete was three and the shrinkage strains, like that in modulus of elasticity, were measured on four vertical gauge lines spaced uniformly around the periphery of the specimens by a demountable mechanical strain gauge having a gauge length of 150 mm.

3.0 Results and Discussion

3.1 Strength of Concrete

Table 3 summarises the compressive and tensile strength data of concrete at the age of 1, 7 and 28 days. Short-term strength data as shown in the table reveal that, at all ages the strength of POFA concrete were lower than the corresponding values of OPC concrete. It is important to note that at early age the rate of development of strength in POFA concrete was very slow but at later ages there was an upward tendency in the rate of strength gain. There has been a school of thought that the strength development of concrete containing pozzolans at early ages is slower than that of concrete with only Portland cements. There is also a common understanding that a period of about three months is usually needed for fly ash concrete to achieve the full benefit through pozzolanic reactions. This has been evidenced in the long-term investigation where POFA concrete was found to achieve higher strength gain at later ages (Abdul Awal, 1998). The observations made in this study are also in well agreements with the research findings on other pozzolanic materials like rice husk ash, silica fume and C class pozzolans (Yuan and Cook, 1983; Malhotra, 1992; Mehta, 1992; Neville, 1995).

3.2 Modulus of Elasticity

The static chord modulus of elasticity of OPC concrete and concrete with 30% POFA measured at two ages of 7 and 28 days is shown in Table 4. The corresponding values of compressive strength are also presented in the same table. The results obtained in this study clearly demonstrate that the modulus of elasticity of POFA concrete in association with its compressive strength was lower than that of OPC concrete. For example, the 28-day modulus of elasticity of OPC concrete with the corresponding compressive strength value of 46.60 MPa was found to be 29.80 GPa. A slightly lower value of 29.05 GPa was obtained for POFA concrete having a 28-day compressive strength of 45.45 MPa. A similar trend has been reported by Sata et al. (2004) who observed a lower value in POFA concrete than in the normal one. This is to be expected, because there is a general agreement that modulus of elasticity increases with an increase in the compressive strength of concrete although there is no precise form of the relationship.

The estimated values of modulus of elasticity given in the parenthesis of Table 4 are based on the expression $E_c = 9.1 f_{cu}^{0.33}$ (Neville and Brooks, 1987), where E_c is modulus of elasticity and f_{cu} is the cube compressive strength. This is to note that the estimated values shown in the table are higher than the measured ones. However, the predicted 28-day moduli of elasticity following the expression $E_{c,28} = 20 + 0.2\ f_{cu,28}$ as recommended by BS 8110: Part 2 (1985) of OPC concrete (29.30 GPa) and POFA concrete (29.10 GPa) are somewhat closer to the measured values of 29.80 and 29.05 respectively.

Table 3: Strength development of OPC concrete and POFA concrete

Type of Concrete	Compressive Strength, MPa			Splitting Tensile Strength, Mpa		
	1 Day	7 Days	28 Days	1 Day	7 Days	28 Days
OPC Concrete	17.55	37.40	46.60	1.70	2.65	3.70
POFA Concrete	14.70	36.10	45.45	1.65	2.50	3.50

Table 4: Modulus of elasticity of OPC concrete and POFA concrete with corresponding compressive strength data

Type of Concrete	7 Days Compressive Strength, MPa	7 Days Modulus of Elasticity, GPa	28 Days Compressive Strength, MPa	28 Days Modulus of Elasticity, Gpa
OPC Concrete	37.40	26.30 (30.05)	46.60	29.80 (32.30)
POFA Concrete	36.10	24.95 (29.70)	45.45	29.05 (32.05)

3.3 Shrinkage of Concrete

The measured values of shrinkage over a period of 28 days plotted in Figure 3 reveals that the shrinkage strain of POFA concrete was higher than that of concrete with OPC alone. The magnitude of shrinkage of OPC concrete at 28 days, for example, was 275.2 x 10^{-6}. At the same time about 19% higher value of shrinkage i.e. 328.8x10^{-6} was recorded for the concrete with 30% palm oil fuel ash. The reason for this higher magnitude is not exactly known. However, the differences in the amount and nature of paste in the POFA concrete could be responsible for the higher shrinkage value in this concrete. A similar observation has been made by Brooks and Neville (1992) who have demonstrated that at a constant water-cement ratio, a higher proportion of fly ash leads to higher shrinkage by some 20%.

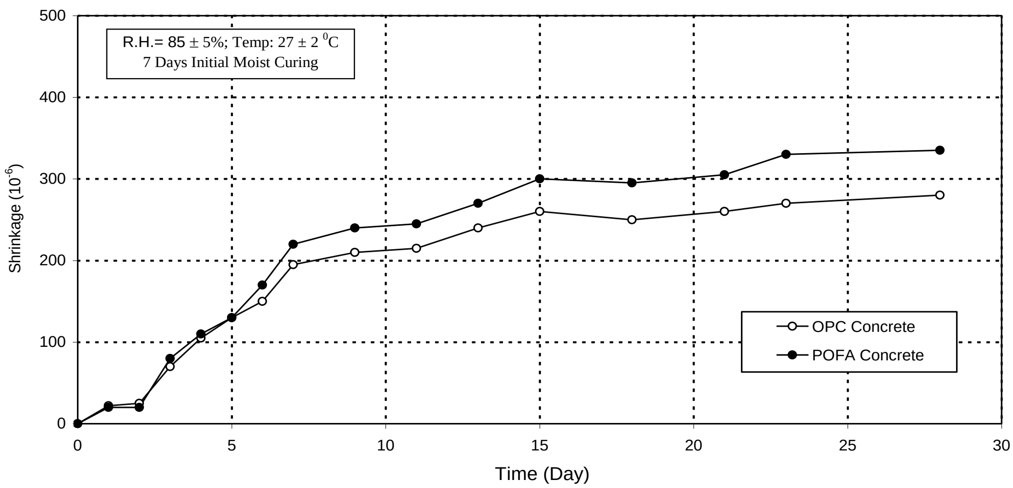

Figure 3: Shrinkage of OPC concrete and POFA concrete

3.4 Prediction of Shrinkage

Various expressions are available for the prediction of the development of shrinkage with time. Among which, the equation developed by ACI 209R-92 (1994), is perhaps the most elaborative. Although the equation can be used to estimate ultimate shrinkage of a wide range of moist-cured concretes, prediction of shrinkage by this equation is subjected to considerable variability.

An improvement in the accuracy of prediction of shrinkage is made by Neville and Brooks [1987] in which long-term shrinkage values can be obtained by extrapolating the short-term tests of 28-day duration. The following expression is, thus, applied to predict the one-year shrinkage of OPC and POFA concrete:

$$S_h(t,\tau_0) = S_{h,28} + 100\ [3.61 \log_e(t-\tau_0) - 12.05]^{\frac{1}{2}} \tag{1}$$

Where

$S_h(t,\tau_0)$ = long-term shrinkage (10^{-6}) at age t after drying from an earlier age τ_0,

$S_{h,28}$ = shrinkage (10^{-6}) after 28 days, and
$(t-\tau_0)$ = time since start of drying (>28 days)

The 1-year predicted shrinkage values, therefore, are:
$S_{h,365}$ for OPC concrete = 578.0 x 10^{-6}, and
$S_{h,365}$ for POFA concrete = 631.6 x 10^{-6}

4.0 Conclusions

This paper reports some experimental results on strength, modulus of elasticity and shrinkage of concrete incorporating palm oil fuel ash (POFA). Laboratory test data based on short-term investigation revealed that the modulus of elasticity of POFA concrete in association with its compressive strength was somewhat lower than that of OPC concrete. POFA concrete like concrete made with other pozzolanic materials, however, has been characterised to have slower strength gain at early ages. Short-term investigation having limited test data further revealed that the shrinkage strain of POFA concrete was higher than that of OPC concrete. Though it has been possible to predict long-term shrinkage of concrete by extrapolating the short-term data, long-term deformation like creep of concrete containing POFA has been considered worthwhile for future investigation.

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