

Deformation Behaviour of Self-Compacting Concrete Containing High Volume Palm Oil Fuel Ash

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Abstract. Self-compacting concrete (SCC) is an advanced type of concrete that can be placed and compacted under its own mass without vibration. Although SCC can be proportioned with a wide range of constituent materials, the utilization of supplementary cementitious materials can significantly influence the cost and performance of SCC. One of the potential supplementary cementitious materials from palm oil industry is palm oil fuel ash (POFA). The objective of the research project was to evaluate the effects of high volume POFA on the deformation behaviour of SCC. This study outlines laboratory tests, which were conducted through replacing ordinary Portland cement (OPC) by 0%, 50% and 70% of POFA by weight, with water-binder ratio of 0.4. Target properties for SCC workability were studied as a function of the application and in terms of filling ability, passing ability, segregation resistance which include slump flow, J-ring, and V-funnel at $T_{5\text{minutes}}$ for fresh properties, and compressive strength, split tensile strength, flexural strength, modulus of elasticity, creep, and shrinkage tests for hardened concrete. Test specimens comprising of cube, cylinder and prism were prepared and tested at 7, 28, 56, and 90 days. Results obtained in this study reveal that high volume palm oil fuel ash used in self-compacting concrete exhibited satisfactory performance particularly at later ages.

Introduction

Self-Compacting Concrete (SCC) is an advanced type of highly flowable, non-segregating concrete that is able to flow under its own mass without vibration and through congested reinforcement. The concept of self-compacting concrete came into being in 1980's by Okamura in Japan [1]. The use of self-compacting concrete appeared as a solution to improve the filling up of the zones, which are not very accessible to conventional methods of concrete compaction. This solution also has the advantage of overcoming the gradual decline in the number of workers qualified to handle and place concrete.

However, SCM can influence the fresh properties of SCC such as filling ability, passing ability and segregation resistance [2]. Depending on the type and properties of SCM, this effect can be positive or negative for the fresh properties of SCC. The literature review reveals that supplementary cementitious materials, such as silica fume, ground granulated blast-furnace slag, fly ash and rice husk ash were used to produce SCC with good workability properties, strength and durability [3]. Previous studies have been done to produce different SCC mixtures incorporating POFA in the range of 0-15% of cement by weight and the effects of POFA on the filling ability, passing ability and segregation resistance of SCC were examined. It was found that POFA can be used to produce SCC possessing the aforementioned fresh properties within the acceptable ranges [4]. In another study concrete was produced using a particular level of POFA replacement and same or more strength was achieved as compared to OPC concrete [5].

Considering the amount of POFA arising from oil mills in Malaysia, Thailand, Indonesia and other palm oil producing nations and the desire to address the environmental problem posed by this waste and even though there are clearly economic and environmental benefit associated with the use of POFA as cementitious material in construction works, there is relatively little or no information on the application of high volume palm oil fuel ash (HVPOFA) in production of construction materials. Researches have shown that well treated POFA will produce material with high quality

comparable to other ashes [6-7].

This research working therefore, intended to study the deformation properties of high volume POFA concrete, with a view to reduce the consumption of Portland cement and disposal cost of palm oil waste generated from palm oil mills.

Along with fresh concrete properties, results on hardened state properties like strength, modulus of elasticity, creep and shrinkage behaviour of waste containing high volume palm oil fuel ash have been presented and discussed.

Materials and Methods

The experimental program involves determination of the fresh and hardened properties of self-compacting concrete according to British Standard (BS) and American Society for Testing and Materials (ASTM) specifications. Locally available natural river sand with fineness modulus of 2.3 was used as fine aggregate and crushed granite with maximum size of 10 mm was used as course aggregate. According to MS29[8] the percentage of coarse aggregate was 50% of the total aggregates by weight. The cement used in this study was ordinary Portland cement (ASTM Type I).

In this study, RHEOBUILD 1100 liquid was used as superplasticizer. RHEOBUILD 1100 is a chloride free, superplasticizing admixture containing a synthetic polymer, and is specially formulated to impart rheoplastic qualities to concrete.

The use of palm oil fuel ash (POFA) as a cement replacement material is the principle purpose of this study. POFA is a waste material obtained by burning of palm oil husk and shell as fuel in palm oil mill boilers. Sample of POFA were obtained from oil mill located in Johor Bahru, Malaysia (Figure 1). The material is beneficiated using BS standard sieve to remove larger particles as well as reducing the carbon content in the sample. Materials collected on 75 μ m sieve were ground using Los Angeles abrasion machine at 5000 revolution per 5kg of sample in order to obtain sample whose particle size is less than 10 μ m used for the research in accordance to BS 3892; Part 1: 1993 [9]. It was kept in airtight container and stored in a humidity controlled room to resist it getting damp. In all mixes supplied tap water was used in mixing and curing purpose.



Figure 1: Palm tree (a), fruits bunch (b), POFA (c), and ground POFA (d).

In this study, the mixture proportions of the self-compacting concrete were determined according to the EFNARC specifications and guidelines for SCC [10] and previous studies on self-compacting concrete with supplementary cementitious materials, shown in Table 1. Among the three batches of concrete specimens, the first batch is for control designated as OPC, second and third batch for using POFA 50% and POFA 70% replacement of OPC designated POFA-50 and POFA-70.

Several tests were conducted on fresh properties of the SCC to investigate filling ability by Slump flow, passing ability by J-ring, and segregation resistance by V-funnel at T5minutes. The water-to-binder ratio was 0.40.

The hardened properties of concrete were determined to know the deformation behaviour of self-compacting concrete containing high volume palm oil fuel ash (HVPOFA) using 100 mm cube and 100 mm x 200 mm cylinder. Compressive strength tests conducted according to BS 1881-116 [11] were performed on the cube specimens at the ages of 7, 28, 56, and 90 days. The split tensile test was conducted in accordance with ASTM C496 [12] on the cylinder specimens at the ages of 7, 28, 56, and 90 days. The modulus of elasticity was measured at the age of 28 days following ASTM C

469-02 standard [13]. The strains were measured by the electrical resistance gauge with the help of data logger.

Table 1: Mixture proportions of SCC

Name of the constituents		Specimen ID		
		OPC	POFA-50	POFA-70
Cement (Kg/m ³)		512	256	153.6
POFA	(Kg/m ³)	-	256	358.4
	(% of cement)	0	50	70
Fine Aggregate (Kg/m ³)		790	790	790
Coarse Aggregate (Kg/m ³)		790	790	790
Water-to-binder ratio (W/C)		0.4	0.4	0.4
Water (Kg/m ³)		204.8	204.8	204.8
Superplasticizer	(Kg/m ³)	10.2	15.4	20.5
	(% of cement)	2	3	4

Creep and drying shrinkage of concrete were measured on cylinder specimen according to ASTM-C512/512M [14] and ASTM-C157M [15] at the age of 28 days. Applied load corresponds to 40% of the compressive strength of the concrete at the time of loading for the measurement of creep strains. The strains were measured every day for the first week and subsequently 14, 21, 28, 42, 56, 70, and 90 days. The samples were stored at an ambient temperature of about 27° C and relative humidity of about 85%. Figure 2 illustrates the shrinkage specimens and creep specimens under loading frame.



Figure 2 OPC (a), POFA-50 (b), and POFA-70 (c) samples under loading frame for creep measurements, shrinkage specimens (d), and Demec gauge (e).

Results and Discussion

Various tests were conducted on self-compacting concrete containing high volume palm oil fuel ash to evaluate fresh and harden state properties. These include determination of workability, strength, modulus of elasticity, creep and shrinkage.

Workability of concrete

To determine the workability of fresh concrete, slump flow, J-ring, and V-funnel at T5_{minutes} tests were performed to get filling ability, passing ability, and segregation resistance of SCC. Table 2 shows the results of three different mixes containing 0%, 50% 70% POFA replacement of OPC. The slump flow diameter of SCC ranged between 570-660 mm and can be grouped into category SF1 (550-650 mm) which is appropriate for slightly reinforced concrete structures [16]. The

diameters obtained from the J-ring test were compared to the slump flow diameters to check the blockage. The difference in diameter due to blockage in presence of J-Ring was 10, 25, and 30 for OPC, POFA-50, and POFA70 respectively. Greater the difference, lesser is the passing ability of SCC. Typical range of difference in diameter is 0 to 25 mm [17]. The V-funnel flow at T5_{minutes} for different SCC mixes varied in the range of 7 to 12 seconds. According to EFNARC [10] the typical value ranges from 0 to 15 seconds. It was also observed that the V-funnel flow time increased with the increase in percentage of POFA.

Table 2: Properties of fresh concrete

Specimen ID	W/B	POFA Content (%)	Flow Ability	Passing Ability	Segregation Resistance
			Slump Flow (mm)	J-Ring (mm)	V-funnel at T5 _{minutes} (s)
OPC	0.40	0	660	650	7
POFA-50	0.40	50	590	565	10
POFA-70	0.40	70	570	540	12

Compressive and tensile strength

The relationships between average compressive strength with the age of concrete are shown in Figure 3(a). It can be seen that the maximum average compressive strength of 57.9 MPa was recorded for control (OPC) sample at 90 days. Significant amount of strength reduction was, however, observed for the samples containing 70% of POFA in earlier stage at 28 days but it has increased more rapidly than other specimens.

A similar trend like that of the compressive strength was observed for split tensile strength development in both control samples and POFA containing samples. The split tensile strength of POFA concrete was significantly lower than the control specimens. However, samples with 50% of POFA showed a good strength development with highest strength of 3.94 MPa for OPC. Figure 3(b) shows the results of different specimens of splitting tensile strength tests.

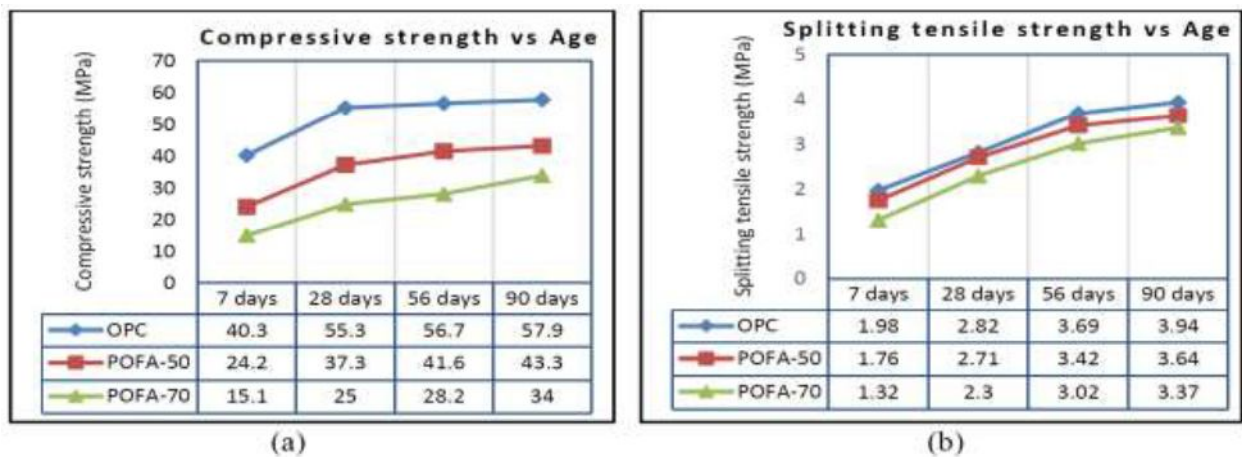


Figure 3: Compressive strength (a) and splitting tensile strength (b) of different concrete mixes.

Modulus of Elasticity (MoE)

The modulus of elasticity of concrete of different mixes was determined at the age of 28 days. The results are shown on the graph in Figure 4. Data presented in Table 3 reveals that modulus of elasticity values ranged from 19.7 MPa to 36.5 MPa. The results indicate that the highest MoE was obtained from the mixtures made using the OPC alone. The comparison between experimental and theoretical results as given in Table 3 suggest that the theoretical MoE (E_{cm}) values are higher than the values obtained from experimental results in the laboratory for all specimens but sample OPC showed almost closer value. The POFA-50 and POFA-70 were significantly different which are about 60% of the theoretical results obtained from ultimate compressive strength.

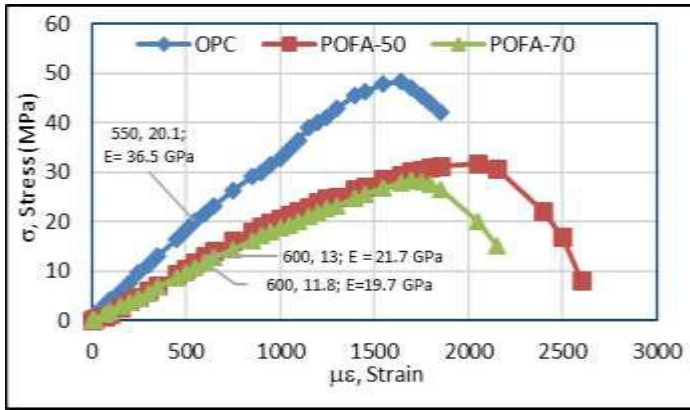


Table 3: Comparison of modulus of elasticity

Sample ID	Modulus of elasticity (GPa)	
	Laboratory experiments	Theoretical, $E_{cm} = 22 \left(\frac{f_{cm}}{10} \right)^{0.3}$
OPC	36.5	38.3
POFA-50	21.7	34.6
POFA-70	19.7	31.5

Figure 4: Stress-strain curve of different concrete mixes.

Creep and shrinkage

Figure 5(a) shows the results of creep strain that was taken directly on the cylindrical specimens at 28 days to 90 days and loaded at 40 percent of ultimate compressive strength. Figure shows the relationship between stress and strain for OPC, POFA-50, and POFA-70 concrete specimens. The creep strain value (ϵ) were 0.70×10^{-6} , 0.96×10^{-6} , and 1.05×10^{-6} for OPC, POFA-50, and POFA-70 respectively at 90 days. The results indicate that the lowest creep strains were obtained from the mixtures made using the OPC alone.

Figure 5(b) shows the similar trend like creep for shrinkage. At the age of 90 days the drying shrinkage strains were (ϵ) 0.168×10^{-6} , 0.242×10^{-6} , and 0.281×10^{-6} for OPC, POFA-50, and POFA-70 respectively. The rapid increment of strains were observed until six weeks, after that the strain increment became steady condition.

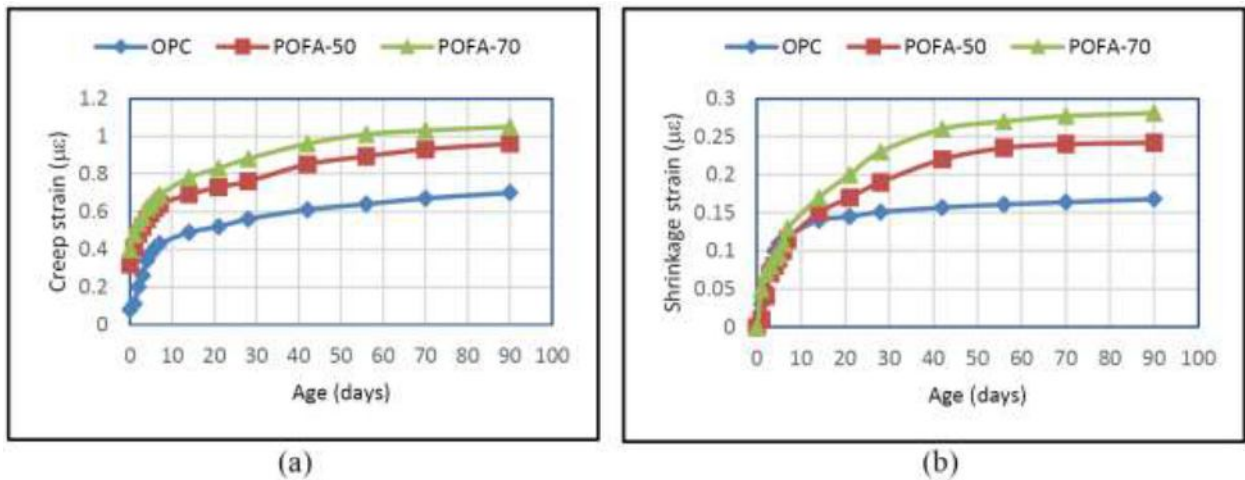


Figure 5: Concrete creep (a) and concrete shrinkage (b) of different concrete mixes

Conclusion

The aim of this study was to investigate the deformation behaviour of self-compacting concrete containing palm oil fuel ash. Based on the experimental work, the following conclusions are drawn:

- Target compressive strength was achieved by the OPC specimens only. At early days the compressive strength of POFA SCC showed lower value compared to OPC specimens; however, higher development of strength was observed at later ages.
- Along with the compressive strength, the modulus of elasticity of POFA SCC was found to be lower than that of concrete with OPC alone, but still within the acceptable range. The proportional limit was about 40 percent for all specimens.

- OPC concrete showed a lower creep strain than those of POFA-50 and POFA-70 concrete, which was 35% and 50% higher at the age of 90 days.
- Notable difference was found for shrinkage strains between OPC and POFA concrete, being 45% and 65% higher than those of POFA-50 and POFA-70 specimens respectively.
- Despite higher values in creep and shrinkage high volume palm oil fuel ash used in self-compacting concrete exhibited satisfactory performance.

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