Structural Characteristics of High Strength Palm Oil Fuel Ash Self -Compacting Concrete

Olatokunboh OFUYATAN[1] , Festus OLUTOGE [2] Adeoye OLOWOFOYEKU [3] and Anthony IVOKE[4]

Abstract

Self-compacting concrete is a fluid mixture suitable for placing in structures with congested reinforcement without vibration. This paper reports on a research project on the structural characteristics of high strength palm oil fuel ash self compacting concrete.

The parameters investigated were compressive, flexural strength and workability. The workability was determined using slump flow, slump T_{50} flow, L-box, and V-funnel. For the compressive strength 150x150x150mm cube specimens were used and beam size150x150x750mm were cast for flexural test. The concrete mix was cast with cement partially replaced with palm oil fuel ash up to 30% at intervals of 5%. Conplast SP432MS (superplasticiser) was used as admixture. Water cement ratio of 0.35 was adopted and concrete mix of 1:2.5:3. The results showed that SCC had 90 day compressive strength of 80.5N/mm^2; the ultimate failure load for SCC was 130kN with a deflection of 11.24 and NC 100kN, deflection of 8.37; the passing ability, filling ability and segregation resistance are well within the limits. The performed tests showed that the compressive strength and workability of self-compacting concrete in this investigation is better than that of normally vibrated concrete.

Keywords: self-compacting concrete, high strength concrete, palm oil fuel ash, compressive strength, flexural strength

Introduction

Self-compacting concrete is defined as a type of concrete that no additional inner or outer vibration is necessary for the compaction with a high performance in flow-ability and passing ability. Development of self-compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. SCC has been applied worldwide because of its advancement to overcome the problem in heavily reinforcement, to reduce workmanship cost and to shorten the period of construction (Ouchi 2002). Self compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped at longer distances (Bartos, 2000). The concept of self-compacting concrete was proposed in 1986 by Professor Hajime Okamura (1997), but the prototype was first developed in 1988 in Japan, by Professor Ozawa (1989) at the University of Tokyo. Self-compacting concrete was developed at that time to improve the durability of concrete structures. Since then, various investigations have been carried out and SCC

ISSN 2229-5518

has been used in practical structures in Japan, mainly by large construction companies.

Okamura (1997) in his study has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that self-compactability could be achieved easily by adjusting the water to cement ratio and superplasticizer dosage only. Ozawa (1989) completed the first prototype of self-compacting concrete using materials already on the market. By using different types of superplasticizers, he studied the workability of concrete and developed a concrete which was very workable. It was suitable for rapid placement and had a very good permeability. The viscosity of the concrete was measured using the V funnel test. He found out that the flowing ability of the concrete improved remarkably when Portland cement was partially replaced with fly ash and blast furnace slag. After trying different proportions of admixtures, he concluded that 10-20% of fly ash and 25-45% of slag cement, by mass, showed the best flowing ability and strength characteristics.

Ferraris et al., studied the slump test which was widely used to evaluate the workability of concrete, but in the case of self-compacting concrete, it had serious drawbacks. Other flow characteristics such as viscosity or filling capacity are needed to define the flow in self-compacting concretes. The research objectives of Ferraris (1999) et al. were to test flow characteristics of SCC using two concrete rheometers and the widely recognized V-flow and U-flow tests, and to determine the correlation between the two rheometers and the tests. They found out that the slump flow alone is not enough to determine whether a flowable concrete is a self-compacting concrete.

The objective of this work describes a procedure specifically developed to achieve self-compacting concrete with the addition of superplasticiser. In addition, the test results for acceptance characteristics for self-compacting concrete such as slump flow, V-funnel and L-Box are presented. Further, the effect of varying percentages of palm oil fuel ash on workability and compressive strength for 7-days, 28-days and 90-days has been investigated and reported.

Literature Review

Hajime Okamura and Masahiro Ouchi (2003) addressed the two major issues faced by the international community in using SCC, namely the absence of a proper mix design method and jovial testing method. They proposed a mix design method for SCC based on paste and mortar studies for super plasticizer compatibility followed by trail mixes. However, it was emphasized that the need to test the final product for passing ability, filling ability, flowability and segregation resistance was more relevant

Venkateswara Rao et al (2010) developed standard and high strength self-compacting concrete with different sizes of aggregate based on Nansu's mix design procedure. The results indicated that Self Compacting Concrete can be developed with all sizes of graded aggregate satisfying the

SCC characteristics. The mechanical properties such as compressive strength, flexural strength and split tensile strengths were found at the end of 3, 7 and 28 days for standard and high strength SCC with different sizes of aggregate. The optimum size of aggregate was found to be 10mm for standard self-compacting concrete (M30), while it was 16mm for high strength self-compacting concrete (M70) though all other sizes also could develop properties satisfying the criteria for SCC. A comparison of M30 and M70 grade concrete confirmed that the filling ability, passing ability and segregation resistance were better for higher grade concrete for the same size of aggregate.

Bouzoubaa and Lachemi (2001) carried out an experimental investigation to evaluate the performance of SCC made with high volumes of fly ash. Nine SCC mixtures and one control concrete were made during the study. The content of the cementitious materials was maintained constant (400 kg/m3), while the water/cementitious material ratios ranged from 0.35 to 0.45. The self-compacting mixtures had a cement replacement of 40%, 50%, and 60% by Class F fly ash. Tests were carried out on all mixtures to obtain the properties of fresh concrete in terms of viscosity and stability. The mechanical properties of hardened concrete such as compressive strength and drying shrinkage were also determined. The SCC mixes developed 28-day compressive strength ranging from 26 to 48 MPa. They reported that economical SCC mixes could be successfully developed by incorporating high volumes of Class F fly ash.

This paper describes a procedure specifically developed to achieve self-compacting concrete. In addition, the test results for acceptance characteristics for self-compacting concrete such as slump flow, V-funnel and L-Box are presented. Further, the strength characteristics in terms of compressive strength for 7-days, 14- days, 28-days, 56- days and 90-days are also presented.

A. Experimental Procedure

1. Materials used

Cement

The cement used for the investigation was the Type 1 normal ordinary Portland cement (OPC) that conforms to BS 12 and was obtained in 50kg bags from retailers in Lagos. O.P.C Grade 43 will be used.

Sand The sand used in this research is natural river sand, with fines less than 0.125mm. The sand was dried at room temperature for 24hours to control the water content in the concrete.

Coarse Aggregates

Since the cubes were 100x100x100mm in size, the nominal maximum size must not exceed 20mm size of coarse aggregate (BS 1881 PT 108, 1983). Crushed aggregate was gotten from a quarry along Sagamu, with nominal size of 10mm in accordance to BS 822 (1992) was used.

Water

ISSN 2229-5518

Portable water supplied which was used for concreting and curing of samples. Water is needed for the hydration of cement and to provide workability during mixing and placing.

Palm Oil Fuel Ash

The replacement of cement with palm oil fuel ash (POFA) is the key element of this research. POFA being selected to determine its suitability to produce SCC due to this ash has pozzolanic properties and similar characteristics to other cement replacement materials that are usually being used in producing SCC. POFA was gotten from Ketu Owode along Ikorodu road. The POFA used in the research is grayish in colour.. It was grinded to a suitable fineness which in this research is up to 45µm before it was used in the SCC mix. It was kept airtight and stored in a humid-controlled room to prevent it from being exposed to moisture.

Conplast SP432MS
(High performance superplasticising admixture)

A polycarboxylic ether based superplasticizer complying with ASTM C-494 type F, was used, Conplast SP432MS to produce SCC. Conplast SP432MS is a recent superplasticiser for concrete and mortar. It meets the requirement for set retarding or high range water – reducing superplasticiser. The color of Conplast SP432MS is brown. It is categorized as a chemical base superplasticiser which is made from modified polycarboxylate in water. In this research, the dosage used was 2% to determine the optimum volume of Conplast SP432MS which can produce SCC with the highest workability and strength.

Fig 1 Conplast SP432MS

B. Preparation of Specimen
Concrete Mixes

To achieve the research objectives, seven samples of mixes will be prepared in 0.015m^3 each and tested. Coarse aggregates size used will be 10mm. The cement will be replaced by POFA at replacement levels of 5, 10, 15, 20, 25, 30 and 40% by weight. Superplasticiser up to 2% by weight of binder was added to concrete mix in order to achieve the required slump of 60-180mm. The water-binder ratio (w/b) for each sample will remain constant at 0.35 while the POFA mixture will be varied. The SCC mixtures are prepared using ordinary Portland cement. The details of the samples and mixture are shown in Table 3.1., 3.2 and table 3.3 respectively.

C. Test Setup and Methods

The slump flow test was used to evaluate deformability and filling ability of the SCC (ASTM C 143). The passing ability was determined using the V-funnel, L-box, tests. As shown in Fig. 2, the V-funnel that was employed in this study has an outlet of 75 x 75 mm; this is different from the 65 x 75 mm outlet proposed by Ozawa *et al.* The test is used to evaluate the ability of aggregate particles and mortar to change their flow paths and spread through a restricted section without segregation and blockage. In this test, the concrete is cast in the funnel and left for a given period of time, usually 1 minute, before removing the dividing gate. The time required for the concrete to flow through the tapered outlet is then determined. The L-box apparatus had 12 mm-diameter bars set at clear distance of 35 mm between adjacent bars. The vertical part of the box is filled with 12.7 L of concrete and left at rest for 1 minute. The gate separating the vertical and horizontal compartments is then lifted, and the concrete flows out through closely spaced reinforcing bars at the bottom. The time for the leading edge of the concrete to reach the end of the 600 mm-long horizontal section is noted. The height of concrete remaining in the vertical section ($h1 = 600 – H1$) and that at the leading edge ($h2 = 150 – H2$) are determined. The L-box blocking ratio ($h2/h1$) was used to evaluate the narrow-opening-pass-ability and self-leveling characteristics of the SCC.

Recommended Limits for Different Properties

Sr. No.	Property	Range
1.	Slump Flow Diameter	500-700 mm [7]
2.	T_{50cm}	2-5 sec [7]
3.	V-funnel	6-12 sec [8]
4.	L-Box H2/H1	≥ 0.8 [9]

ISSN 2229-5518

Fig. 2 The V-Funnel Test

Fig 3 The L-box test

Fig 4 T-$_{50}$ Slump test

Table 1 Details of Samples prepared

ISSN 2229-5518

Sample	Main Composition	Condition
A1	OPC ONLY	Not Compacted
A2	OPC + POFA	Compacted
A3	OPC + POFA 5%+SP	Not Compacted
A4	OPC +POFA 10%+SP	Not Compacted
A5	OPC + POFA 15%+SP	Not Compacted
A6	OPC +POFA 20%+SP	Not Compacted
A7	OPC +POFA 25%+SP	Not Compacted
A8	OPC +POFA 30%+SP	Not Compacted

D. Compressive and flexural Strength Tests Method

Workability in terms of slump of fresh concrete was studied in accordance with ASTM C143/C 143M-05. Compressive and flexural strength tests were conducted on HSPOFA and OPC concrete at 3, 7, 21 28, 56 and 90 days using cylindrical specimen of 100 x 200 mm length in accordance with ASTM C 39/C 39M-05 specification. The size of mould used to produce the cubes for compression test was 100 x 100 x 100mm. Three (3) cubes for each sample with a total of 72 cubes for different percentages of superplastisizer needed for the casting and beam size of 150 x 150 x 750mm. In investigating the flexural behavior aspect two types of concrete from optimum mix of SCC and normal concrete (NC) was prepared. The details of both beam mix composition are shown in Table 3.3.

Table 2 Details of beam Mix Composition

Beam	Cement Kg	Sand Kg	Coarse Agg. Kg	Water Kg	POFA Kg	Conplast 430MS	w/b
NC	22.63	36	26.25	7.5	-	-	0.36
SCNC	16.44	36	26.25	7.5	8.50	0.15	0.36

A 3-point flexural strength test was conducted after all preparation for the concrete beams were done. Magnus frame apparatus was used in the testing of the beams. Flexural strength test defines two important parameters. The first parameter, known as first crack strength is primarily controlled by the matrix. The second parameter is known as the ultimate flexural strength or the modulus of rapture, which is determined by the maximum load that can be attained.

Flexural formula below applied to calculate the maximum flexural strength.

Modulus of rupture, f_b (N/mm^2) = PL/bd^3 if $a>L/3$

Modulus of rupture, f_b (N/mm^2) = 3Pa/bd^3 if $a<L/3$

Load P

Where,

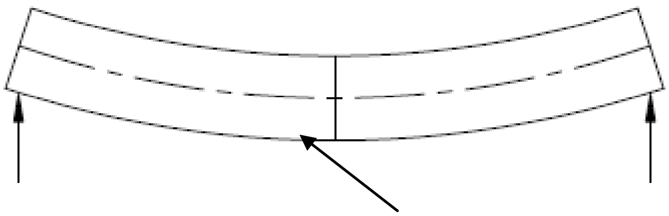
P = maximum load

L = span of beam (750mm)

b = width of beam

d = depth of beam

a = position of fracture from near support.



Bottom of beam in tension

Fig 5 Typical deflection of a loaded beam

E. Results and Discussion

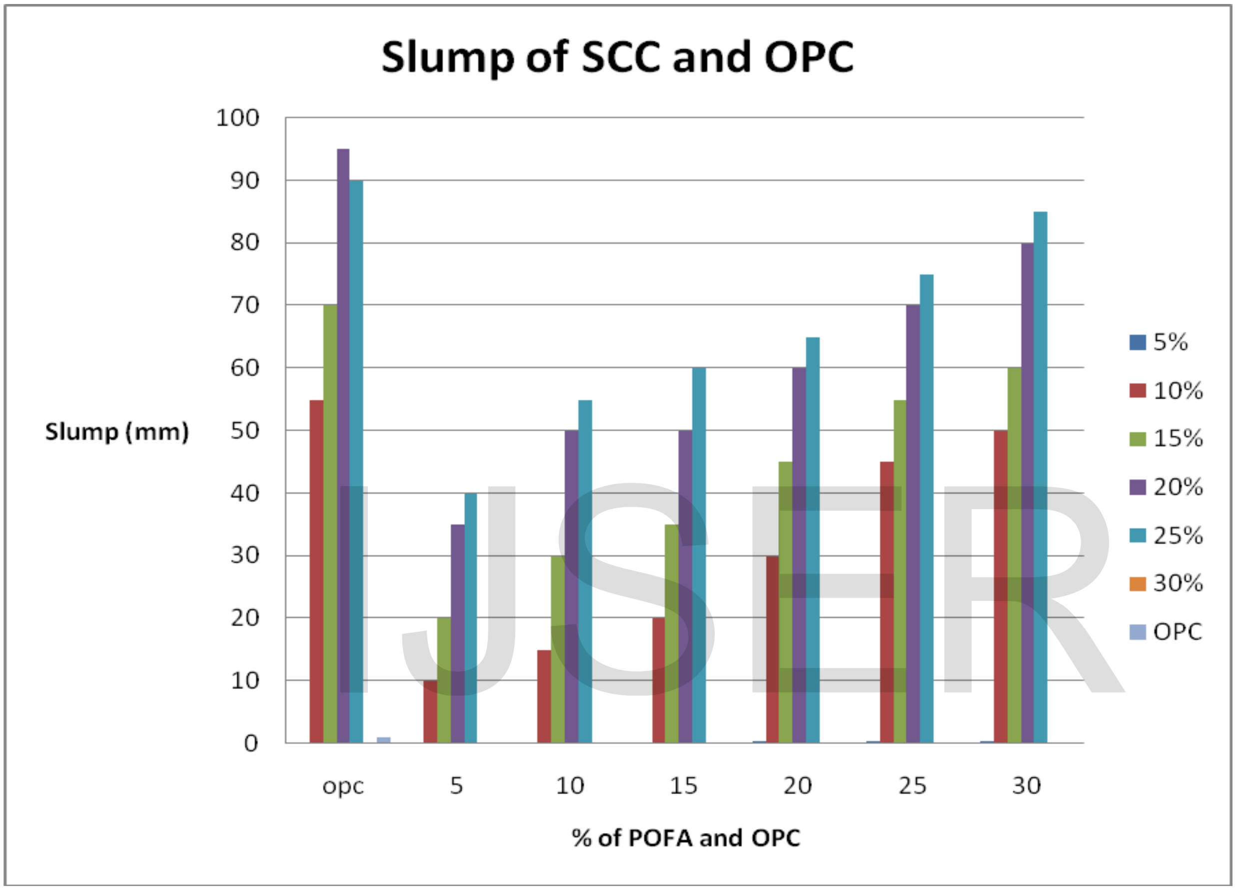
Slump flow test, T_{50} test and slump test

The results obtained for slump flow test, slump flow T_{50} and slump test is shown in table 3. The slump flow test for sample A2 had a value of 550mm for OPC and 400, 550, 670, 720 and760 mm for POFA replacement at 5, 10, 15, 20, 25 and 30% respectively. The acceptable range of SCC criteria for slump flow is between 650mm and 800mm. the higher the slump flow value, the greater its ability to fill formwork under its own weight. Samples A2 and A3 were compacted by following the normal procedure for normal concrete and the slump values were 30mm and 50mm

Specimen	Slump flow Test 650-800(mm)	Slump flow T_{50} test (secs) (2-5secs)	Slump test (cm)	Concrete condition	Remark
A1	350	-	120	No flow	Non SCC
A2	550	-	30	No flow	Non SCC
A3	400	-	20		Non SCC
A4	550	1	-		Non SCC
A5	670	2	-	Flow	SCC
A6	720	3	-	Flow	SCC
A7	740	3		Flow	SCC
A8	760	3		Flow	SCC

respectively had good slump value due to its compaction; while the slump flow T_{50} of sample A4, A5 and A6 had good results which were within the acceptable ranges of SCC mixtures. The T_{50} time of 2-3secs indicate a greater flow-ability, because a lower time taken means a better flow.

Table 3 Result of the slump flow, slump T_{50} test and slump test



ISSN 2229-5518

The average compressive strength at 90 days for A2 is 38.7 N/mm2 which is low in strength due to incompact condition if to be compared with sample A1 as shown in table 4. This shows the impact and importance of compaction works. The utilization of superplastiziser in samples (A3, A4, A5, A6 A7 and A8) had higher average compressive strength compared to other samples. Sample A5 is selected as the optimum mix design which had higher average compressive strength of 79.8N/mm2 at 90 days. The difference between the compressive strength of A6 and A5 is due to the increase in the percentage of the superplastiziser in the design mix of the sample.

Table 4 Average compressive strength result

		Compressive Strength (N/mm²)					
Sample	**Mix**	**3 days**	**7 days**	**14 days**	**28 days**	**56 days**	**90 days**
A1	OPC only	20.94	35.60	40.10	49.60	56.80	80.50
A2	OPC only	8.10	10.80	15.20	17.30	26.20	38.70
A3	OPC +POFA 5%	22.50	29.40	32.30	45.70	53.50	61.30
A4	OPC +POFA10%	23.00	31.80	36.30	54.50	60.20	66.40
A5	OPC +POFA15%	26.70	32.20	39.50	56.70	65.30	69.80
A6	OPC +POFA 20%	28.30	33.50	46.80	58.70	60.20	75.20
A7	OPC +POFA 25%	29.08	34.90	49.82	59.51	53.79	79.54
A8	OPC +POFA 30%	30.68	35.78	50.30	60.48	61.32	85.60

The Flexural Behavior of SCC Beam

The flexural strength test results are given in table 5, 6 and 7 respectively. The normal concrete beam showed the

ISSN 2229-5518

conventional behavior of reinforced concrete beam with failure by crushing and yielding under applied loads. The ultimate strength of the SCC beam was 130.0 kN and a deflection of 11.24mm. The SCC beam showed significant enhancement of strength and stiffness compared to normal concrete beam. The effect of fiber content on the flexural strength is shown in table 5 and 6. Flexural strength was tested for 28days on forty-five (45) beams specimen of 150mm x 150mm x 750mm.

The specimens were tested at 7, 14, 21 and 28 days after curing in water. Specimens were tested for flexural strength by applying increasing load of 5kN until visible cracks were observed and failure occurred. The control beam had no fibre (POFA). The parameters that were analysed were the ultimate load, deflection, mode of failure

.

Table 5 Flexural Strength test result of SCC concrete beam

Load (kN)	Deflection (mm)
0.0	0.0
5	0.14
10	0.29
15	0.36
20	0.55
25	0.75
30	1.03
35	1.39
40	1.62
45	1.94
50	2.29
55	2.65
60	3.04
65	3.55
70	3.97
75	4.33

80	4.75
85	5.14
90	5.30
95	5.85
100	6.50
105	6.82
110	7.43
115	7.98
120	8.82
125	9.56
130	11.24

Table 6 Flexural Strength test result of Normal concrete beam

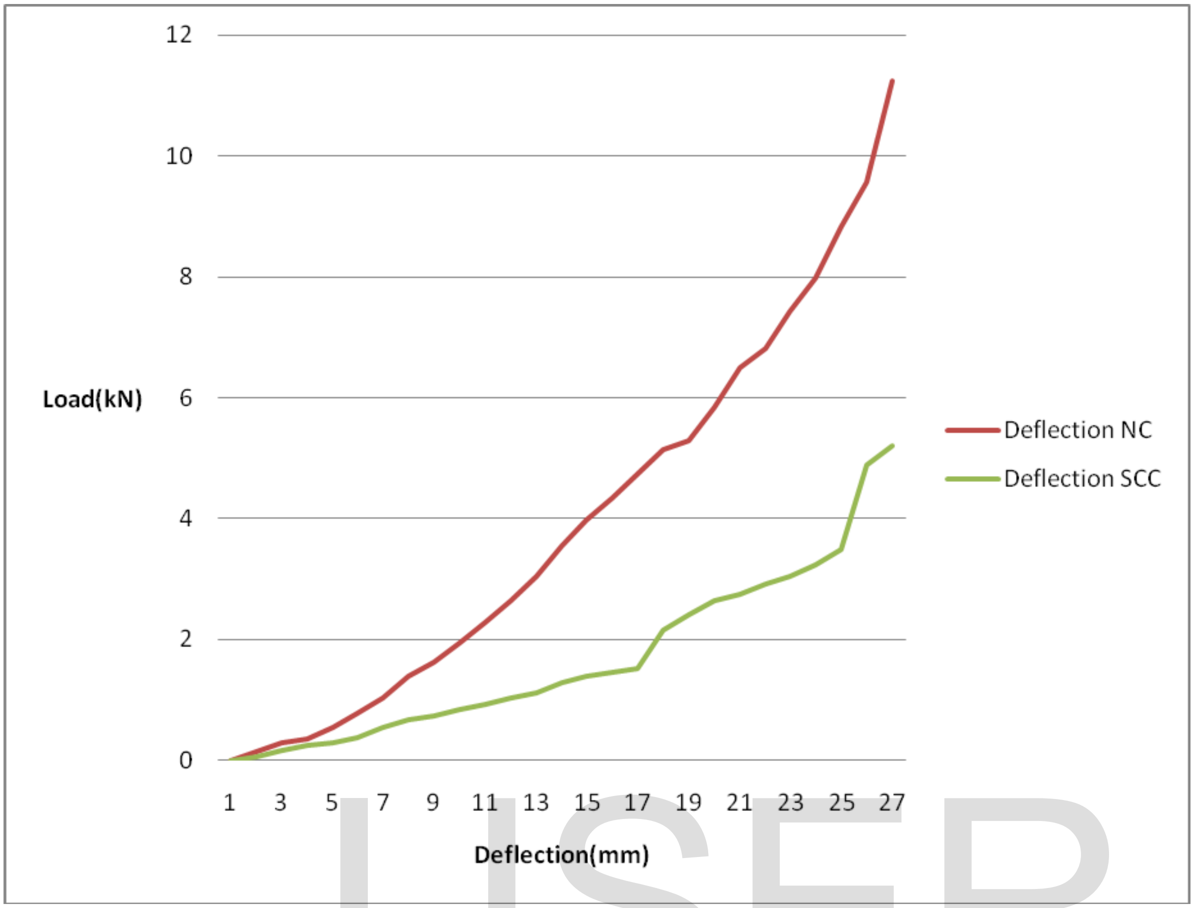
Load (kN)	Deflection (mm)
0.0	0.0
5	0.16
10	0.26
15	0.39
20	0.55
25	0.87
30	1.23
35	1.45
40	1.93
45	2.42
50	2.71
55	3.23
60	3.65

ISSN 2229-5518

65	4.10
70	4.33
75	4.84
80	5.25
85	5.90
90	6.21
95	6.43
100	8.37

Table 7 Result of the flexural test

Beam	1St crack		Beam failure	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
Normal Concrete	40	0.87	100.0	8.37
SCC	20	0.55	130.0	11.24



Conclusion and Recommendation

1. Self-compacting concrete may be produced from the combination of Palm Oil Fuel Ash (cement replacement material) and Conplast SP 432 (admixture). The optimum mix design of SCC is found to be in sample A3 as shown in table with the cement, sand and coarse aggregate mix proportion of 1:2:3 together with 30% of POFA and conplast SP 432 ms at 2%.

2. High Strength SCC can be produced from the combination of Palm Oil Fuel Ash(cement replacement) and conplast SP432MS (admixture). The optimum mix design was found to be 1:2.5: 2 together with 30% of POFA, water cement ratio of 0.35 and MS432 conplast superplastisizer.

3. The flexural strength of the SCC beam indicates a comparable behavior to normal concrete beam at lower loads. However, the SCC beam achieved a higher ultimate strength and showed large ductile behavior compared to normal concrete beams.

4. The HSSCC maximum average compressive strength at 90 days was higher than normal concrete. This is due to the ability of POFA to increase the setting time, also the presence of POFA enhanced for better strength development and durability of SCC compared to NC.

References

Awal, A.S.M.A. and Hussin, M.W. (1997) The Effectiveness of Palm Oil Fuel Ash in preventing expansion due to alkali-

ISSN 2229-5518
silica reaction, Journal of Cement Composites, 19:367-372, Elsevier Science Ltd.

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.

Bartos, J. M., "Measurement of Key Properties of Fresh Self-compacting Concrete", CEN/PNR Workshop, Paris (2000)

Bouzoubaa and Lachemi (2001) "Self-compacting concrete incorporating high volumes of class F fly ash Preliminary results", Cement and Concrete Research, 31, 2001, pp 413-420.

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, 925-9951.

Nakamura, S., Ouchi,M., *et al.,*(2003). Application of Self Compacting Concrete in Japan, Europe and United State, Proceedings of the 2003 ISHPC, 1-20.

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

Okamura, H., and Ouchi, M. (2003). Self Compacting Concrete, Journal of Advanced Concrete Technology. (1) 5-15

Okamura, H., and Ozawa, K. (1995). Mix design for Self Compacting Concrete. Concrete Library Journal of JSCE. 25:107-120

Olutoge, F., and Olafusi, O., (2012) Investigation of the Strength Properties of Palm Kernel Shell Ash Concrete. ETASR-Engineering Technology and Applied Science Research. Vol.2, No. 6, 2012, 315-319

Ouchi, M., (2002). Self Compacting Concrete Development Application and Investigation, Lacer, Japan, 7:407-429.

S. Venkateswara Rao,M.V. Seshagiri Rao and P. Rathish Kumar, "Effect of Size of Aggregate and Fines on Standard and High Strength Self Compacting Concrete", Journal of Applied Sciences Research, 6(5), 2010, pp 433-442.