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Lightweight Self-compacting Concrete Incorporating Oil Palm Shell

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Abstract. This paper presents the results of an experimental research on the fresh concrete properties, density, compressive and tensile strength of lightweight self-compacting concrete (LWSCC) incorporating oil palm shell (OPS) as coarse aggregates. Three aspects of fresh concrete properties including passing ability, filling ability and segregation resistance of the mixtures have been investigated experimentally and tests were carried out in accordance with the procedures stated in European Federation of National Associations Representing for Concrete (EFNARC) guidelines. LWSCC with OPS as aggregates fulfils the fresh concrete properties requirements of the EFNARC guidelines. In this study, the compressive and tensile strengths have also been compared with granite based self-compacting concrete (SCC). It is observed that OPS based SCC achieved comparable compressive strength with granite based SCC. This research provides basic framework to develop mix design of lightweight self-compacting concrete by using OPS as aggregates. Other properties such as durability and fire resistance of the developed concrete are not considered in the present study and are recommended for future research. The experimental studies show that LWSCC, with the use of OPS as full replacement to normal weight aggregates (NWA), is potentially a sustainable alternative construction material. Its use also provides a cleaner and more beneficial solution in OPS disposal for oil palm industry. This research demonstrated that OPS can be successfully used to develop lightweight self-compacting concrete. This research will benefit the oil palm industry and the environment as a whole.

1. Introduction

Extensive research is being conducted on concrete since its potential was realized in the 19th century. It is indeed a very common construction material which has been widely used throughout the world due to its versatility, availability and economy. Concrete is generally compacted after placement with the aid of vibrator or steel bar to remove air void so that it becomes a homogeneous material with reduced macroscopic porosity. Proper compaction must be done for concrete to achieve the desired average uniformity with predicted design strength and durability properties. With the demand for innovative construction material in industry, self-compacting concrete (SCC) is gradually gaining popularity. SCC possesses the ability to flow under its own weight, filling the formwork with complex geometry, and the region of congested reinforcement more compactly and thus it eliminates the necessity of external vibration (EGSCC, 2005; Okamura & Ouchi, 2003). To achieve the self-compacting criteria, SCC should possess the characteristics of high durability, restrained flowing ability and filling ability with resistance against segregation (ACI-237, 2007; EFNARC, 2002;

EGSCC, 2005). Lightweight self-compacting concrete (LWSCC) can be produced with the use of lightweight aggregates (LWA). Generally, SCC requires more cement paste than conventional concrete to lubricate aggregates in order to facilitate self-compacting ability. In LWSCC, keeping the balance among the mix proportions is key factor to ensure the desired self-compacting ability (Lotfy et al., 2015; Vakhshouri & Nejadi, 2016).

Numerous recent research works (Bogas et al., 2012; Hubertová & Hela, 2013; Kaffetzakis & Papanicolaou, 2012; Vakhshouri & Nejadi, 2016) have focused on utilizing lightweight aggregates (LWA) as alternative materials to NWA. It is beneficial to utilize waste as alternative materials for aggregates in concrete which can mitigate the impacts to the environment in terms of energy consumption, pollution and waste disposal. Oil palm shell (OPS) is one of the waste products generated after the extraction of oil from oil palm tree (Okafor, 1988; Okpala, 1990) as shown in Figure 1. Malaysia is abundantly cultivated with oil palm trees. OPS is produced in large quantities by oil palm mill. Over 4 million tonnes of solid wastes are produced annually (Alengaram et al., 2013; Aslam et al., 2016; Nagaratnam et al., 2016). Since the demand for palm oil is increasing, the production of solid wastes by oil palm industry are expected to increase too. To minimize the environmental impact of handling and disposing these agricultural wastes, numerous researches have been carried out to study the potential of using OPS as replacement material in construction industry. Teo et al. (2007) stated that OPS has the potential to be utilized as alternative coarse aggregates in casting concrete.

For the past few decades, extensive research has been carried out to incorporate OPS as alternative aggregates for the production of lightweight concrete in South East Asia (Alengaram et al., 2013). The cellular structure of OPS reduces the weight of concrete and provides better thermal insulation. The reduction in density of OPS concrete is about 20-25% when compared to normal concrete (Shafigh et al., 2010). Shafigh et al. (2011) successfully developed OPS concrete with 28-days compressive strength of 42-48MPa. They (Shafigh et al., 2012) also reported the compressive strength of 34-53MPa in their studies. However, relatively large amount of cement was used in these cases to produce relatively high strength OPS concrete. Mo et al. (2016) also reported that relatively high amount of cement was required to achieve anticipated compression strength for OPS concrete. Since SCC also requires a large amount of cement content to achieve self-compacting ability, it would make more economic sense to incorporate OPS to produce SCC. The extra cement material cost can be compensated by the elimination of the cost for concrete vibration.

Figure 1. (a) Oil palm shell (OPS) (b) Oil palm shell solid waste in oil palm factory.

Comprehensive studies have been carried out in developing LWSCC by using different types of LWA (Vakhshouri & Nejadi, 2016). However, very limited research with respect to using agricultural waste in SCC has been done. Meanwhile, Kanadasan and Razak (2014) have successfully utilized oil palm clinker, another type of oil palm solid waste, as aggregates in SCC. The authors developed the SCC mix designs based on particle packing concept. The developed mix designs fulfilled all the fresh concrete performance criteria of EFNARC (2002). Kanadasan and Abdul Razak (2015) carried out further study on utilizing oil palm clinker as aggregates in SCC by the implementation of palm oil clinker power as supplementary filler materials. Reasonably sustainable SCC in terms of cost, energy efficiency and greenhouse gas emission can be produced with the use of oil palm clinker.

The use of OPS in producing concrete has brought about many benefits and encouraged further interest in research and development. Thus, the aim of this paper is to investigate the fresh and hardened concrete properties of LWSCC utilizing OPS as coarse aggregates. The workability, compressive strength and tensile strength have also been compared with granite based SCC.

2. Experimental Programme

2.1. Materials

All the ordinary Portland cement, river sand and superplasticizer used were supplied from the same source as Nagaratnam et al. (2016).

2.1.1. Ordinary Portland Cement (OPC)
Ordinary Portland Cement (OPC) grade 45, conforming to ASTM: C150/C150M-12 was used. The Blaine fineness of cement is 3510cm^3/g. The specific gravity and particle density are 3.14 and 2950kg/m^3 respectively.

2.1.2. Coarse Aggregates
Oil palm shell (OPS) was used as coarse aggregates in this research. OPS was acquired from palm oil mill in Lambir, Miri-Bintulu, Sarawak, Malaysia. 60% of OPS had the size within the range of 5mm-10mm. They were washed and sieved. All the OPS were soaked in water for 24 hours. OPS were then allowed to air dry so that saturated surface dry (SSD) condition can be achieved before being used in concrete mixing.

2.1.3. Fine Aggregates
Natural river sand and crushed OPS were used as fine aggregates. Crushed OPS in the size range of 600µm to 5mm and river sand with nominal size of 600µm were used.

2.1.4. Superplasticizer
Type F superplasticizer (SP) complying the requirement of ASTM C494 and BS En 934-2 European Standard was used in this study. As a high range water reducing admixture, it is capable of reducing the water demand of concrete by at least 12%.

2.2. Mix Proportion
Mix proportion of LWSCC using OPS as coarse aggregates was first determined by using particle packing theory (Kanadasan & Razak, 2014) and assessed against EFNARC (2002) requirements. However, the fresh properties of LWSCC determined from particle packing theory did not fully fulfil the requirements of EFNARC (2002). Modification was made to the mix proportions in order to obtain the mix design that fulfilled the requirements and the mix design was summarized in Table 1. Water to binder (w/b) ratio was reduced to 0.34 as the mix obtained from particle packing theory was too watery and resulted in segregation. Also, the content of coarse aggregates was slightly reduced in order to guarantee passing ability.

Table 1. Summary of mix design.

w/b ratio	0.34

Cement (kg/m3)	525
Water (kg/m3)	185
OPS (kg/m3)	460
Sand (kg/m3)	720
SP (kg/m3)	8.68

2.3. Mixing Method

Forced action cylindrical pan mixer with a vertical axis of rotation was used. LWSCC mix in the amount of about 0.07m^3 was produced for each batch. An optimum mixing procedure was selected among several different mixing procedures. The mixing procedure started with filling the pan with all the aggregates and running the mixer for 3 minutes. Then, cement was added and the mixing continued for another 2 minutes until all the materials were well mixed. Subsequently, the mixture was added slowly with the first half of the required amount of water and mixing was continued for 1.5 minutes. The SP and another half amount of water were then gradually added and mixing continued for 1.5 minutes.

2.4. Test Program

Concrete fresh state properties including filling ability, passing ability and segregation resistance was assessed immediately after the concrete mixing. The tests were conducted in accordance to the standard procedure EFNARC (2002). Filling ability was assessed by conducting slump flow and V-funnel tests. Slump flow test was carried out by filling the slump cone and the maximum uninterrupted flow diameter in two orthogonal directions were measured. The time for LWSCC to flow 500mm diameter circular spread was also noted as T_{500}. V-funnel test was also done to assess the viscosity. This was done by measuring the time required for fresh LWSCC to completely flow through the outlet controlled by trap door.

Evaluation of passing ability was done by conducting J-ring test. It was meant to measure the blockage of LWSCC by steel reinforcement bars. The test was done by positioning the J-ring around the slump cone, filling of concrete in slump cone and lifting it to allow passage of concrete in between the steel bars. The maximum spread, $T_{500\,(J-Ring)}$, and the difference in heights of the concrete at the centre and outer of the ring were measured.

Sieve segregation test was used to assess the segregation resistance. The test allowed the mass LWSCC to stand still for 15 minutes and then let it to flow through a sieve with a gap of 4.75mm for 2 minutes. Segregation ratio was then calculated by taking the ratio of the weight of sieved portion to total weight of LWSCC used.

Concrete cube specimens of size 100x100x100mm were casted for compressive strength test. Cylinder specimens of 100mm diameter and 200mm height were prepared for splitting tensile test. Three samples were prepared for each test. The fresh concrete after mixing were poured into mould immediately after fresh concrete slump flow test. No physical compaction of concrete was carried out. The concrete specimens were demoulded after 24 hours of casting and cured in water at room temperature until the day of testing.

3. Results and Discussion

Several publications such as EFNARC (2002) and ACI-237 (2007) provide the guidelines to carry out workability tests for SCC. EFNARC (2002) is used as the workability assessment criteria in this research. The workability performance requirements for SCC are shown in **Table 2**. All the test results are assessed against these criteria. According to EFNARC (2002), these criteria are developed based on the current knowledge and research. However, not all of these criteria are suitable to be used for assessing LWSCC as it performs differently for SCC. LWSCC with fresh properties outside these criteria may be acceptable if it is able to perform properly under the required conditions. OPS based SCC mix was assessed for fresh properties. These included filling ability (J-ring), passing ability (V-funnel and Slump flow) and segregation resistance (sieve segregation) tests. The fresh properties test results were shown in Table 3. These results are evaluated and discussed in the following section. Typical slump flow and J-ring were shown in Figure 2.

Table 2. EFNARC requirement.

Workability	Test	Class	Criteria
Filling ability	Slump Flow (mm)	SF1	550-650
		SF2	660-750
		SF3	760-850
	T500 (s)	VS1/VF1	≤ 2 V − Funnel ≤ 8
		VS2/VF2	≥ 2 time(s) 9 − 25
Passing ability	Step height in J-ring (mm)	PA1	Sj ≤ 15 (59 mm bar spacing)
		PA2	Sj ≤ 15 (40 mm bar spacing)
	L-Box		0.8 - 0.1
	U-Box		0 - 30
Segregation Resistance	Sieve segregation (%)	SR1	≤ 20
		SR2	≤ 15

Table 3. Fresh state properties comparison.

Test Method	OPS SCC	Rahman et al. (2014)	Chopra and Siddique (2015)
Slump flow (mm)	660	630	730
V-funnel (s)	25	5.9	6
J-Ring (mm)	12.5	5.2	-
Sieve segregation (%)	6.34	8.2	-

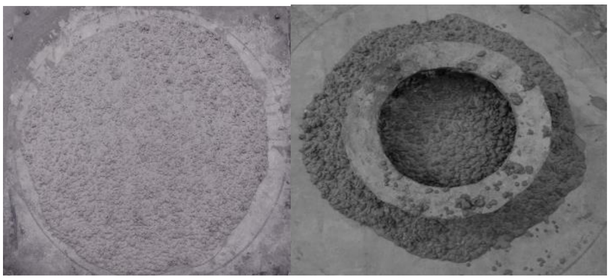

Figure 2. Typical slump flow and J-ring appearance.

3.1. Concrete Fresh State Properties

In this research, two tests which were slump flow and V-funnel tests had been carried out to assess the flow ability of LWSCC. The OPS based SCC mix design achieved the slump flow spread with the value of 660mm. The slump flow value was within the range of 550-850mm which complied with the requirement of European guidelines (EGSCC, 2005). According to European Guidelines, this mix design was classified as class SF2 as the slump flow results fell within the range of 650-750mm. As such, class SF2 SCC is suitable for normal application including walls and columns. Figure 3 shows the comparison between OPS based SCC and granite based SCC reported by various researchers. It can be seen that OPS based SCC achieved better slump flow value than Rahman et al. (2014) but poorer when compared to Chopra and Siddique (2015).

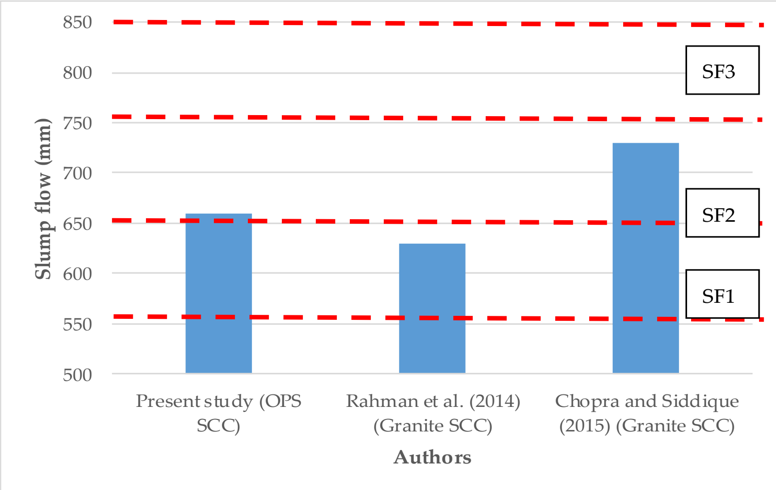

Figure 3. Slump flow comparison.

V-funnel flow time was utilized to determine the viscosity and stability of SCC. Figure 4 illustrates the comparison of V-funnel flow time. A low V-funnel flow time indicates faster filling rate of the fresh concrete due to its lower plastic viscosity. The OPS based SCC was classified as class VF2 as the flow time was more than 2s. Thus, OPS based SCC achieved poor v-funnel time when compared to granite based SCC. However, it was still within the range of European guidelines.

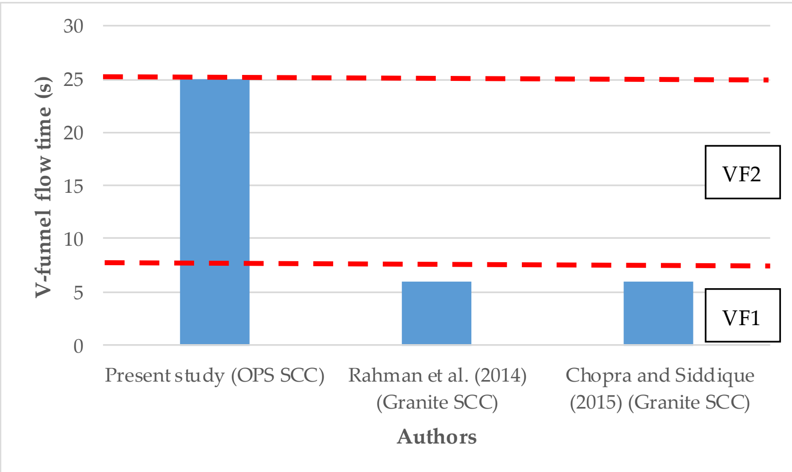

Figure 4. Comparison of V-funnel flow time.

The passing ability of LWSCC was determined by carrying out J-ring test. The main concern of J-ring is the block step which is measured as the difference in height of the concrete in the inner and outer bars of j-ring. Block step of 15mm is the acceptable limit for SCC in EGSCC (2005). The OPS based SCC achieved the block step value of 12.5mm. The higher block step value means that fresh SCC possesses higher tendency of being blocked when coarse aggregate passes through reinforcements. Figure 5 shows the comparison of block step height. It can be seen that the OPS based SCC achieved higher block step value compared to granite based SCC.

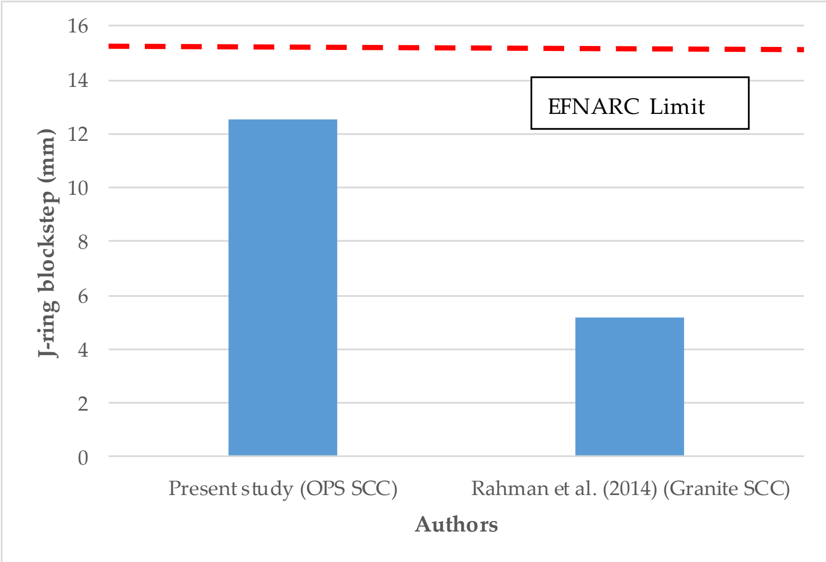

Figure 5. J-ring block step comparison.

Sieve segregation was used to evaluate the segregation resistance of LWSCC in this study. Segregation ratio is defined as the percentage of concrete mix that passes through 5mm sieve. Figure 6 shows the comparison of segregation of OPS based SCC with various researchers. Lower segregation ratio indicated better segregation resistance of LWSCC. OPS based SCC attained sieved portion value of 6.34%, which could be classified as class SR2 in segregation resistance. Class SR2 mixes are suitable for tall vertical application. OPS based SCC achieved even better segregation resistance than granite based SCC.

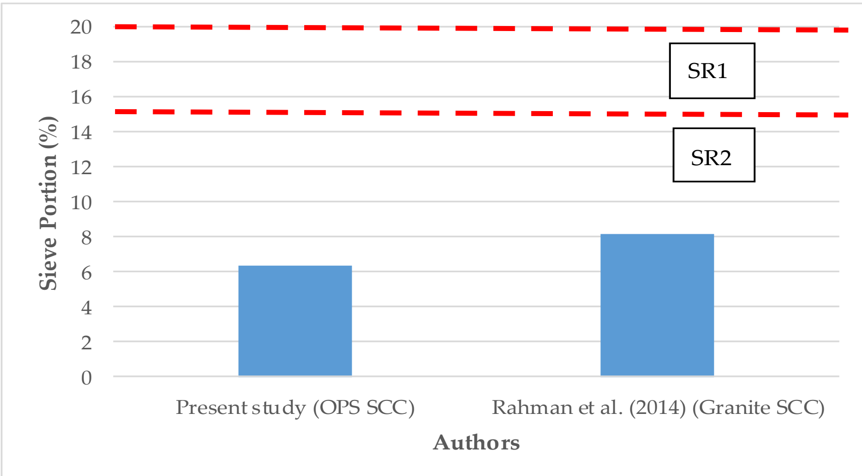

Figure 6. Sieved portion comparison.

From these experiments, it can be observed that the OPS based SCC satisfy all the requirements of concrete fresh state properties which include filling ability, passing ability and segregation resistance. Accordingly, OPS possess high potential as aggregates substitute in manufacturing SCC.

3.2. Concrete Hardened State Properties

The dry density of OPS based SCC is 1832 kg/m^3. The density falls within the range of specification stated by ASTM C330 which is 1120 to 1920 kg/m^3 for light weight concrete. In this study, the OPS based SCC attained about 20% lighter weight when compared to conventional concrete. Compressive and tensile splitting strengths of OPS based SCC were evaluated at the age of 7 and 28 days. The individual values for each sample are shown in Table 4. Compressive and tensile splitting strength of OPS based SCC when compared with granite based SCC is shown in Table 5. The average values are used for comparison. It is observed that OPS based SCC has achieved similar compressive strength with granite based SCC as studied by Chopra and Siddique (2015). However, the compressive strength of OPS based SCC is lower than the value of granite based SCC that was reported by Rahman et al. (2014). A similar trend is found for tensile splitting strength. OPS based SCC tensile splitting strength was reported to be 6.5% of compressive strength, the value of which was comparable to those reported by Shafigh et al. (2012) for OPS based normally-vibrated concrete. The same type of materials except coarse aggregates were used by Rahman et al. (2014) for OPS based SCC. It has been demonstrated that the compressive strength of concrete highly depends on the stiffness of aggregates. This can be explained that the mortar is stronger than lightweight aggregates in lightweight concrete. This is confirmed by the findings of Floyd et al. (2015) and Grabois et al. (2016) that the lightweight aggregates are generally weaker than mortar. Therefore, the strength of lightweight aggregates played a crucial role in contributing to the compressive strength of LWSCC. To sum up, the OPS based SCC is able to achieve comparable hardened state properties to granite based SCC and therefore it can be used for structural application.

Table 4. Summary of test results.

Tests	Sample No	7 day strength	28 day strength
Compressive Strength (MPa)	1	27.0	38.5
	2	27.5	38.0
	3	26.5	40.0
	Average	27.0	38.8
Tensile Splitting Strength (MPa)	1	2.26	2.58
	2	2.19	2.48
	3	2.23	2.55
	Average	2.23	2.54

Table 5. Hardened state properties comparison.

Concrete strength (MPa)	OPS SCC	Granite SCC	
		Rahman et al. (2014)	Chopra and Siddique (2015)
Compressive strength at 7^{th} day	27	32.8	30
Compressive strength at 28^{th} day	38.8	48.5	38
Tensile splitting strength at 28^{th} day	2.54	5.1	2.5

4. Conclusion

The fresh and hardened state properties of lightweight self-compacting concrete (LWSCC) with the use of OPS as aggregates was investigated and the following conclusions can be drawn:

- LWSCC which has satisfactory fresh state properties in terms of passing ability, filling ability and segregation resistance as well as hardened state properties can be produced with the use of OPS as full replacement to normal weight aggregates (NWA),

- LWSCC with OPS as aggregates has achieved desirable slump flow spread in the range of 660-750mm,
- Satisfactory V-funnel flow time that fulfils the European Guidelines has been achieved,
- Considerable passing ability has been attained by OPS LWSCC with the block step less than 15mm,
- Excellent segregation resistance with value less than 10% has been achieved,
- Satisfactory compressive and tensile strength has been achieved.

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