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Fresh and mechanical properties of self-compacting concrete with coarse aggregate replacement using Waste of Oil Palm Shell

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Abstract. Self-compacting Concrete (SCC) is a real innovation that can solidify itself without the help of tools to ease field practice. In its implementation, SCC can use alternative materials to reduce waste, such as Oil Palm Shell (OPS). In this research, OPS used as a replacement of crushed stone as the main coarse aggregate. The concrete mixture used consists of cement, sand, crushed stone, OPS as a variation of aggregate substitutes, palm oil fuel ash, and superplasticizer. OPS used were variated with 0%, 5%, 10%, 25% and 50% of crushed stone aggregate weight with age up to 28 days. Tests were conducted on fresh and mechanical properties. From the results, it is known that replacement of aggregate using OPS meets fresh properties criteria and although the compressive strength of OPS concrete mixture is lower than normal SCC, OPS still can be an alternative in making SCC and reducing palm oil industrial waste.

1. Introduction

Self-compacting concrete (SCC) can be defined as concrete that can compact itself without the need to be compacted by tools such as the vibrator or manual manpower. The use of SCC has many advantages, for example, SCC can reach areas that are difficult to be reached as in the corner of cast and SCC can pass through the concrete with a complicated and tight rebar spaces. Many research has been done on SCC, one of them concerning to process of standardization in SCC testing and the composition of concrete mixtures in SCC [1].

In its development, SCC concrete does not only use the general concrete material, but also added various kinds of additional materials, both organic and non-organic. This addition has a variety of purposes, such as reducing waste and increasing strength of the concrete. Additional or partial replacements of fine aggregate or coarse aggregate that have been done previously are using recycled concrete aggregates [2-3], iron slag [4], coal fly ash and rice husk ash [5], and also from palm waste which is palm oil fuel ash [6-7] and oil palm shell [8-10].

In Indonesia, there are much waste produced and not utilized properly, one of which is oil palm shell (OPL) waste. This country is one of many countries that produce a lot of palm oil [11] which is commonly produced on Sumatra Island and Kalimantan Island. Waste from the palm oil industry is oil palm shell (OPL) and palm oil fuel ash (POFA). In this paper, it will be discussed using OPL waste as a substitute for an aggregate of SCC to reduce the use of gravel as coarse aggregate and to utilize the available waste. The study was conducted at Universitas Muhammadiyah Yogyakarta to find out new

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and mechanical properties of SCC by replacing partially coarse aggregate using OPL and using POFA added materials.

2. Materials and Test Method

2.1. Palm Oil Fuel Ash (POFA) and Oil Palm Shell (OPS)
The POFA and OPS materials are obtained from the waste produced by one of the palm oil industries in Riau Province, Indonesia as depicted in figure 1 and figure 2. The POFA is firstly dried in an oven for 24 h with 100 ^{0}C and the material that is used passes the No. 200 filter size (particle size < 75 µm). Oxide composition test is also conducted, and the result is served in table 1 which has a great amount of silica (SiO_2) that good for the concrete mixture. The OPS material used has the size of 2 mm - 15 mm. Test of particular material was not conducted but referred to previous research [12] and compared with stone aggregate that is used in this research as written on table 2.

Figure 1. Picture of Palm Oil Fuel Ash (POFA)

Figure 2. Picture of Oil Palm Shell (OPS)

Table 1. Chemical composition in Palm Oil Fuel Ash (POFA)

Material	Oxide composition (%)										
	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	K_2O	MnO	SiO_2	P_20_5	TiO_2	LOI
POFA	8,87	3,24	1,06	1,42	0,57	3,22	0,03	52,63	1,86	0,31	27,7

Table 2. Characteristic of OPS [12] and coarse aggregate used

Parameter	Value	
	OPS [12]	coarse aggregate
Specific gravity (SSD)	1,17	1,62
Water absorption (24 h), %	23,32	6
Aggregate abrasion (with Los Angeles), %	4,8	9,9
Bulk density (compacted), kg/m^3	592	1480
Fineness modulus	6,24	-
Aggregate impact value (AIV), %	7,86	3,7

2.2. Concrete materials
SCC materials used consist of cement, fine aggregate (sand), coarse aggregate (gravel), water and superplasticizer. The cement used is Portland-pozolan cement (PPC) that meets ASTM C-150 [13] while fine aggregate and coarse aggregates are passing with ASTM C-33[14] requirements. Gradation values of fine aggregate and coarse aggregates grains can be found in figure 3 and figure 4. Superplasticizer is also added to the SCC mixture with viscocrete-10 from SIKA.

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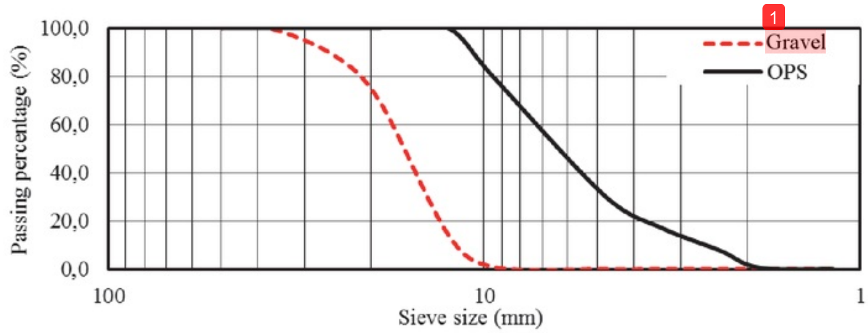


Figure 3. Grain size distribution of crushed stone aggregate/gravel and OPS

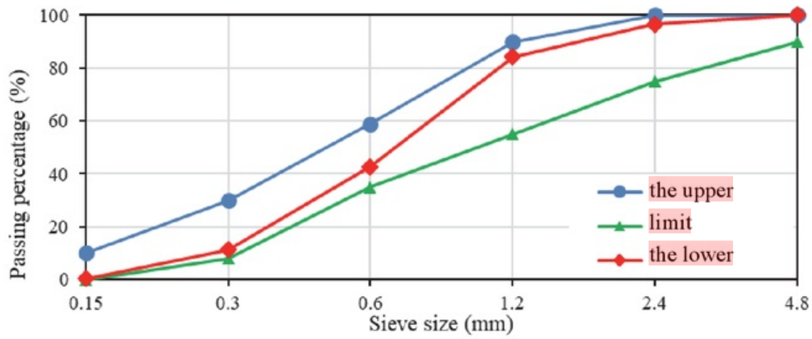


Figure 4. Grain size distribution of fine aggregate

2.3. Detail of variation samples and concrete mix design

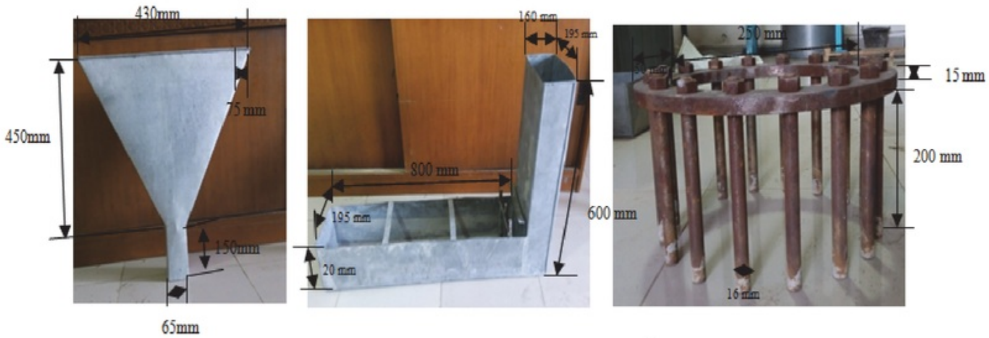
In this research, Oil Palm Shell (OPS) is used as a replacement of gravel with variations of 0%, 5%, 10%, 25%, and 50% with curing time up to 28 days to find out the compressive strength value (f'_c) produced. In addition to Palm Oil Shell (OPS), the Palm Oil Fuel Ash (POFA) is added with a fixed value for all variations of 27.7% of cement and also superplasticizer viscocrete-10 added with 1.14% of cement. For the mix design, it follows the proportion of the European Federation of National Trade Associations (EFNARC) [15] as given in Table 3.

Table 3. Mixed design of SCC for every various replacement aggregate

Material	Aggregate Replacement by Oil Palm Shell				
	0%	**5%**	**10%**	**25%**	**50%**
Fine aggregate (kg)	5,18	5,18	5,18	5,18	5,18
Cement (kg)	2,58	2,58	2,58	2,58	2,58
Coarse aggregate (kg)	2,98	2,83	2,68	2,23	1,49
OPS (kg)	0	0,15	0,3	0,75	1,49
Superplasticizer (kg)	0,0375	0,0375	0,0375	0,0375	0,0375
POFA (kg)	0,716	0,716	0,716	0,716	0,716
Water (kg)	1,65	1,65	1,65	1,65	1,65
Number of samples	5	10	10	10	10

2.4. Testing method on fresh and mechanical properties of SCC

Several tests which are V-Funnel Test, L-Box Test, and J-Ring Test were performed to seek the fresh properties of SCC. Those following methods are conducted based on EFNARC [15] with some demand of V-Funnel Test value between 6-12 seconds, L-Box Test value (which is H2 / H1)> 0.8 and J-Ring Test value> 50 cm. The test equipment is presented in figure 5. For mechanical properties testing, the compressive strength of the concrete and the classification of collapse type refers to ASTM C-39 [16].



(a) (b) (c)

Figure 5. Tools on fresh properties test (a) V-Funnel, (b) L-Box, dan (c) J-Ring

3. Result and discussion

3.1. Properties of fresh concrete

From the test result, it was obtained for all samples with all the percentage of coarse aggregate replacement variation with OPS complied with V-Funnel Test, L-Box Test, and J-Ring Test according to EFNARC 2002 requirements. The results of fresh concrete properties test are presented in table 4.

Table 4. Result of fresh concrete properties test

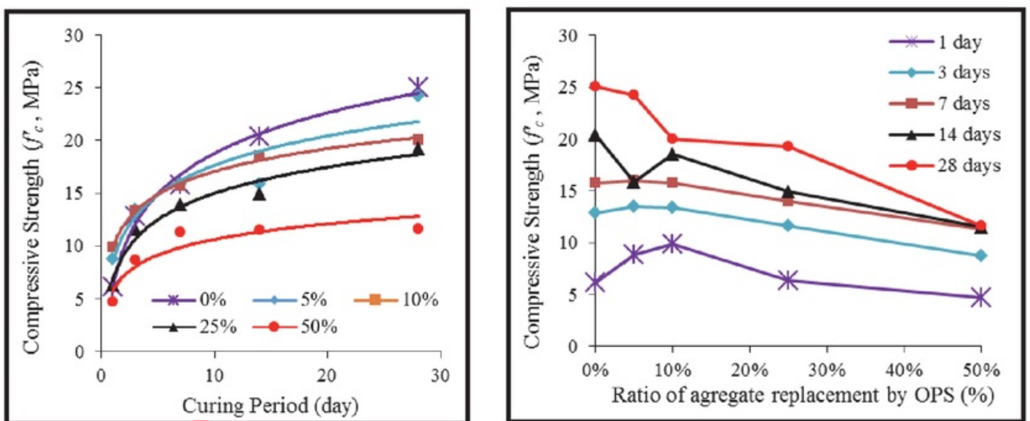
OPS Percentage	V-Funnel (seconds)	L-Box H_2/H_1	J-Ring (cm)
0 %	7	0,8	51
5 %	5	0,8	51
10 %	6	0,875	51
25 %	8	0,9	51
50%	10	1	51

3.2. Compressive strength of samples

The summary of the compressive strength result is presented in table 5. From comparison graph between curing periods and compressive strength shown in figure 6a, it can be seen that all of compressive strength variations increase along with increasing age logarithmically, whereas in the comparison graph between compressive strength and variations of coarse aggregate replacement with OPS presented in figure 6b, it is known that at the early age of 1-3 days, there are several compressive strength values outperforms the normal SCC which are 5% and 10% OPL variation. However, for the final compressive strength value at 28 days, all variations have lower value compared to normal SCC. For all types of failures that occur, it can be classified as columnar vertical cracking through both ends that are classified as type 3 on ASTM C-39. Illustration of failure of the specimen can be seen in figure 7.

Table 5. Value of compressive strength for every age and variation of replacement aggregate by OPL

Code name	**Age (days)**	**Compressive strength of SCC with OPL (MPa)**								
		0%	**5%**	**Mean**	**10%**	**Mean**	**25%**	**Mean**	**50%**	**Mean**
1A	**1**	6,1	8,41	8,79	9,35	9,87	6,69	6,33	5,46	4,7
1B	**1**		9,16		10,39		5,96		3,93	
3A	**3**	12,82	13,54	13,43	14,47	13,37	12,53	11,6	8,76	8,68
3B	**3**		13,31		12,26		10,67		8,59	
7A	**7**	15,8	15,28	15,91	17,02	15,72	16,02	13,97	10,69	11,33
7B	**7**		16,53		14,42		11,92		11,96	
14A	**14**	20,37	13,87	15,88	19,67	18,55	16,87	14,91	11,54	11,48
14B	**14**		17,89		17,43		12,95		11,42	
28A	**28**	25,06	22,25	24,22	19,4	20,04	16,87	19,24	11,03	11,63
28B	**28**		26,19		20,68		21,6		12,13	



(a) (b)

Figure 6. Compressive strength of samples based on (a) curing period and (b) various of aggregate replacement

(a) (b) (c) (d) (e)

Figure 7. Failure result of samples with aggregate replacement (a) 0%, (b) 5%, (c) 10%, (d) 25%, (e) 50%

4. Conclusion

To sum up, the replacement of rough aggregates using OCL as well as the addition of POFA meet on the properties of fresh properties. The use of palm oil waste that is OCL and POFA on SCC can be an alternative in reducing mining products usage (crushed stone aggregate). However, the normal SCC compressive strength at 28 days is still higher than the compressive strength resulting from rough aggregate replacement using OPC.

Acknowledgement
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