Flowability and Strength Properties of High Volume of Fly Ash Material on Self-Compacting Concrete

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Abstract. The detail complexity level of the building structure is getting more complicated. The use of a high volume of fly ash self-compacting concrete (HVFA-SCC) with better flowability properties is one alternative to address this problem. This research aims to investigate the strength properties and flowability of a high volume of fly ash self-compacting concrete (HVFA-SCC). The primary materials of HVFA-SCC were Ordinary Portland Cement (OPC), fly ash as OPC replacement material, fine and coarse aggregates. The ratio of OPC to fly ash was 0.500:0.500, 0.475:0.525, and 0.450:0.550. The strength properties were determined based on compressive strength and porosity in hard concrete conditions at 28 days. While the flow abilities were identified conforming slump test and slump flow in fresh concrete condition directly after a mixing process. The results show that the substitution of 0.500 fly ash as shown by the HVFA-SCC-2 specimen gives the best strength properties and flow abilities. The highest strength was achieved at 32.4 MPa with a porosity of 0.48 at 28 days-age. The slump and slump flow properties also demonstrate a good flow behavior under EFNARC standard with a slump of 26.1 cm and a slump flow of 656.9 mm. It can be concluded that the 50% substitution ratio of fly ash can replace the role of OPC in HVFA-SCC and improve its strength properties and flow behavior. The use of fly ash also able to overcome the global warming issue regarding OPC production.

1. Introduction

The detail complexity level of the building structure is getting more complicated and many angular details that cannot be filled with the use of traditional concrete materials. The low flowability of traditional concrete causes the angular details of the building to be unfilled with the concrete material during the casting process. Thus, it requires to be finished with a manual hand which is caused by the strength reduction of the structure. Therefore, the use of new self-compacting concrete (SCC) method is advisable. SCC is a new concrete material that has a high flowability [1-2] so that it can fill in the gaps in complex building details which has a high level of complexity.

Previous researches have shown that SCC has a comparable compressive strength to traditional concrete so that it can be used as a structural material [3-4]. However, the main issue in SCC is the use of cement as its primary material. The production of 1 ton of cement also produces about 1 ton of CO_2 gas which is the main cause of world global warming [5-6]. Hence, it is necessary to look for alternative cement replacement materials that are more environmentally friendly. The use of fly ash as a waste material of coal power plants has been widely used as a cement replacement material. Several studies have shown that the use of fly ash can produce a comparable strength to traditional concrete [7-8]. The spherical shape of fly ash [9] also affects the flowability which can fill in the gaps in the concrete to reduce the pore of the concrete.

This research aims to investigate the strength properties and flowability of a high volume of fly ash self-compacting concrete (HVFA-SCC) with the primary materials of Ordinary Portland Cement

(OPC), fly ash as OPC replacement material, fine and coarse aggregates. The strength properties are determined based on its compressive strength and porosity in hard concrete conditions at 28 days-age. While the flow abilities are identified in accordance with slump test and slump flow in fresh concrete condition directly after a mixing process. This research is expected to have a contribution to the environment due to the global warming issue by using a high volume of fly ash as a substitute for OPC.

2. Method

2.1. Materials

The primary material of HVFA-SCC is OPC, fly ash, fine and coarse aggregates from local suppliers. Type I OPC from Semen Gresik with a specific gravity of 2.94 was used as the primary HVFA-SCC binder. Class C fly ash with a composition of 11.9 wt.% of Aluminate (Al), 29.1 wt.% of Silicate (Si), 32.6 wt.% of Ferrite (Fe), and 14.1 wt.% of Calcium (Ca) conforming ASTM standard [10] was used as OPC replacement material. The fine and coarse aggregates have a fineness modulus of 2.37 and 6.25, respectively. The density of fine and coarse aggregates is 2.66 and 2.75, respectively.

2.2. Mixture

The ratio of mixture design of HVFA-SCC, which consists of OPC, fly ash, fine and coarse aggregates, and water, are developed based on weight ratio as shown in Table 1. A total of 0.35 type F hyper plasticizer to binder weight was added to improve the workability and flowability of HVFA-SCC during the mixing process. The total weight of all specimens was kept on 2450-2500 kg/m^3. The mix proportion was design for cylinder mold with 15 cm diameter and 30 cm height. The total of 4 cylinder specimens was cast for each mixture proportion.

Table 1. Mixture proportions of HVFA-SCC (kg) for 4 cylinder specimens

Mixture	OPC	Fly ash	Fine aggregate	Coarse aggregate	Water
HVFA-SCC-1	64.33	-	141.09	115.51	28.98
HVFA-SCC-2	32.23	32.23	141.09	115.51	28.98
HVFA-SCC-3	30.54	33.79	141.09	115.51	28.98
HVFA-SCC-4	28.98	35.34	141.09	115.51	28.98

2.3. Testing

The properties of HVFA-SCC specimens were determined based on their strength and flowability properties. The strength properties were calculated using compressive strength and porosity test methods in accordance with ASTM C-39 [11] and ASTM C-642 [12], respectively. Further, the flowability properties were measured using slump and slump flow tests [2]. The slump test was carried out conforming ASTM C-143 [13] and the slump flow test was performed conforming to the EFNARC standard [14]. The compressive strength and porosity test were applied for hard HVFA-SCC specimens at 28 days-age. While the slump and slump flow tests were carried out in fresh specimens condition directly after a mixing process.

3. Results and Discussion

3.1. Strength properties

Figure 1 gives the strength properties of HVFA-SCC which are determined based on compressive strength and porosity test results. The highest compressive strength was achieved by HVFA-SCC-2 (50% fly ash substitution to OPC) with a strength of 32.4 MPa at 28 days-age. Further fly ash addition tends to reduce the strength as shown by HVFA-SCC-4 (55% fly ash content). This shows a significant reduction from 32.4 MPa to 26.1 MPa. The high compressive strength of HVFA-SCC-2 was also corroborated with the porosity test result. The porosity of HVFA-SCC-2 was merely 0.48%. It was slightly higher than HVFA-SCC-1 with 0.42% porosity, however with a lower compressive strength compared to that HVFA-SCC-2. The further addition of fly ash in HVFA-SCC specimen tend to increase the pores of the concrete material. A similar finding was also found by Sonebi [15]. The author found that the strength of SCC can be achieved around 30 MPa – 35 MPa in 28 days.

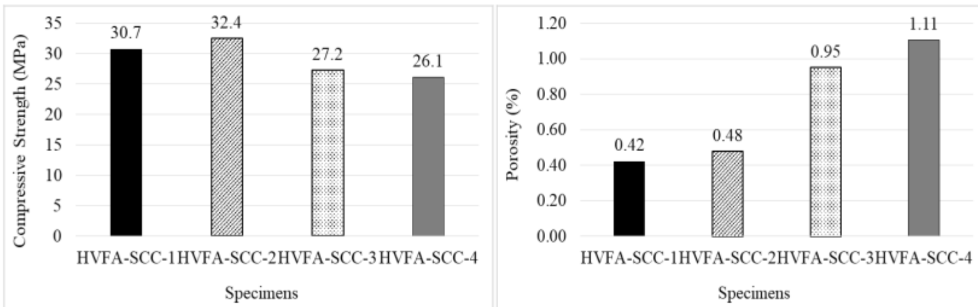

Figure 1. Compressive strength and porosity of HVFA-SCC specimens

Figure 2 exhibits the relationship between compressive strength and porosity tests. The higher compressive strength will be followed with the lower porosity test result as shown by HVFA-SCC-2 specimens with strength and porosity of 32.4 MPa and 0.48%, respectively. This demonstrates that HVFA-SCC-2 has a denser density compared to all HVFA-SCC specimens. The increase of porosity as shown by HVFA-SCC-3 and HVFA-SCC-4 which was followed by the decrease of their strength indicates that more addition of fly ash as OPC replacement tends to increase the volume of pores in HVFA specimens.

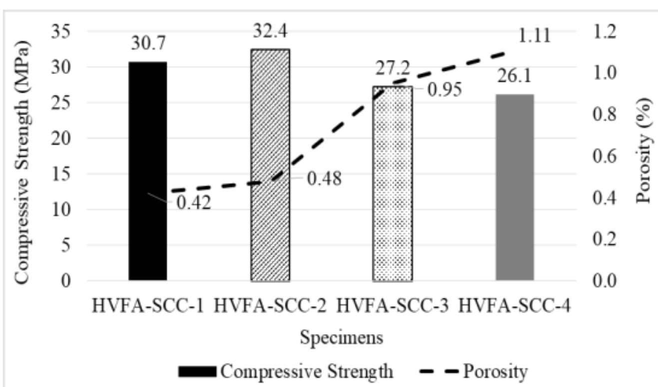

Figure 2. Correlation between compressive strength and porosity

3.2. Flowability properties

The slump and slump flow test results are shown in Figure 3. The HVFA-SCC-2 gives a better flowability behavior compared to that of all HVFA specimens, with the slump test of 26.1 cm and the slump flow diameter of 656.9 mm. The slump test value of 26.1 indicates that HVFA-SCC-2 exhibits better workability. It has a denser fresh concrete compared to that of other HVFA-SCC specimens with a lower slump value [8].

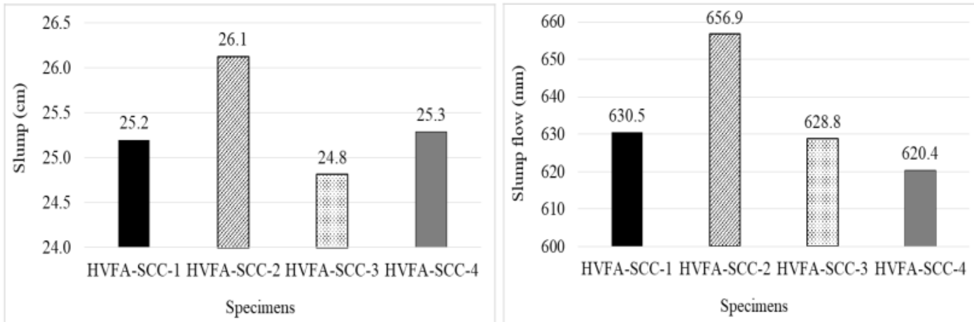

Figure 3. Slump and slump flow of HVFA-SCC specimens

Figure 4 and Figure 5 provide a correlation between the compressive strength with the slump value and slump flow test results, respectively. Both correlations demonstrate a similar trend which indicates a reduction of compressive strength along with the reduction of both slump value and slumps flow test with an addition of more than 50% fly ash.

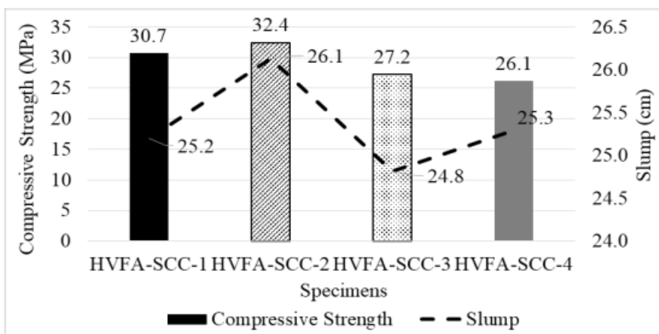

Figure 4. Correlation between compressive strength and slump

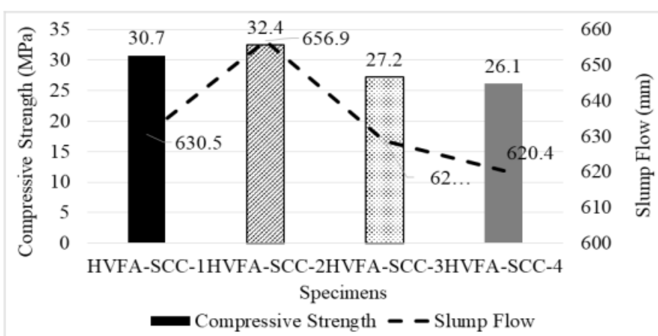

Figure 5. Correlation between compressive strength and slump flow

These findings suggest that the strength properties of HVFA-SCC demonstrate a slightly higher strength compare to normal SCC with no fly ash addition (HVFA-SCC-1). However, further addition of fly ash tends to reduce the compressive strength of HVFA-SCC at 28 days. A similar finding was also found by Dinakar et al. [16]. According to the authors, the further addition of fly ash in high volumes of fly ash in SCC tends to decrease the compressive strength. This finding is also corroborated by Sidiqque et al. [17] with the maximum compressive strength of SCC at the addition of 25% to 35% fly ash. Further, this decrease was also followed by a decrease in the slump value, which means a decrease in the workability of SCC and a decrease in slump flow, which indicates a decrease in the flowability of the SCC. According to Dinakar et al. [18], the use of fly ash as OPC replacement materials of around 30% to 50% will be ideal for developing SCC. This is due to the absorption and water penetration depths in SCC which is increases along with the increase of fly ash content at higher fly ash addition.

4. Conclusions

This research is focussed on the strength properties and flow abilities of a high volume of fly ash in self-compacting concrete. Based on the discussion, it can be concluded that the use of 50% fly ash as OPC replacement material gave the best strength and flowability of the HVFA-SCC specimen. The highest compressive strength was achieved by HVFA-SCC2 with 50% fly ash. It also demonstrated a denser HVFA-SCC compared to other specimens with the porosity of 0.48. HVFA-SCC2 also exhibited better flow abilities conforming EFNARC standard with the slump test value of 26.1 cm and a flow diameter of 656.9 mm which was achieved in 2.37 seconds. Thus, the use of fly ash is one alternative as OPC replacement material in a high volume of fly ash self-compacting concrete to overcome the global warming issue regarding the OPC production process.

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