The influence of palm oil fuel ash on the fresh properties of green self-compacting concrete

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Abstract. This paper investigates the influence of palm oil fuel ash (POFA) on the fresh properties of green self-compacting concrete (GSCC) via the slump flow, slump flow T₅₀₀, L-box, and sieve stability tests when 0%, 20%, 40%, and 60% of the Portland cement content was replaced by POFA on mass-for-mass basis. The slump flow values obtained were 695 mm, 720 mm, 732 mm and 740 mm for OPC-SCC, POFA-SCC 20, POFA-SCC 40 and POFA-SCC 60, respectively, and the slump flow T₅₀₀ values were 3s, 2.8s, 2.5s and 2.4s for OPC-SCC, POFA-SCC 20, POFA-SCC 40 and POFA-SCC 60, respectively. The results obtained for slump flow and slump flow T₅₀₀ were satisfactory, whereby the inclusion of up to 60% POFA improved both the slump flow and slump flow T₅₀₀ values. In addition, the L-box results also showed that the inclusion of POFA in the GSCC exhibited a greater passing ability performance. The sieve stability test proved that the higher the POFA content, the better the segregation resistance index of the GSCC. Thus, the overall results portrayed that it is very much viable to produce GSCC utilizing up to 60% POFA with improved fresh properties.

1. Introduction

It is well known fact that concrete is the most widely used material in the construction of civil engineering structures. Concrete mainly consists of a binding medium (cement) and water as well as aggregates [1-2]. Concrete gained its popularity due to its ability in resisting water which makes it an ideal material for building structures. Moreover, structural concrete elements (such as beams, columns, foundations, etc.) can be formed into various shapes and sizes, while the ingredients for producing concrete are relatively cheap and most readily available in comparison to other construction materials. In addition, concrete can be easily engineered to have special characteristics such as those possess by High Strength Concrete (HSC), Polymer Concrete, Fiber Reinforced Concrete (FRC), Self-Compacting Concrete (SCC), and other types of special concrete.

Self-Compacting concrete (SCC) is a recent advancement in the field of concrete technology, and it has many benefits compared to normal concrete. Khayat [3] reported that one of the benefits of SCC is that it does not require any compaction effort when it is being placed in the relevant formworks in its fresh state, while at the same time no segregation or bleeding is experienced. SCC gains its self-compacting ability due to its unique fresh state properties. In order for concrete to qualify as SCC, it must possess three excellent characteristics in its fresh state; namely filling ability (flowing ability), segregation resistance, and passing ability. Nonetheless, SCC requires higher powder and chemical admixture content especially superplasticizer than normal concrete, and this makes it more costly. According to Chindaprasirt et al. [4], Türkmen [5], and Bouzoubaa et al. [6], wastes like fly ash, rice husk ash, and
silica fume can be employed as supplementary binders on the basis of technical and environmental benefits as well as economic purposes. Thus, it is of great importance to partially replace the cement content of SCC with suitable supplementary cementitious material that is economical, environmentally friendly and could provide technical benefits to the concrete properties and performance. The present study explores the utilization of Palm Oil Fuel Ash (POFA) as a supplementary binder by partially replacing the ordinary Portland cement (OPC) in SCC to obtain a highly workable SCC while at the same time having improved strength as well as durability performance. Therefore, the aim of this research is to study the influence of POFA as a supplementary binder on the fresh properties of the resulting GSCC, specifically filling ability, passing ability and resistance to segregation.

2. Experiments

2.1 Materials and Mix Proportions

The control mix (OPC-SCC) used in this study was prepared using OPC as a sole binder material without the inclusion of POFA. The control concrete mix was designed to achieve 50 MPa at 28 days. In addition, three GSCC mixes containing 20%, 40%, and 60% POFA as partial replacement of OPC (POFA-SCC 20, POFA-SCC 40 and POFA-SCC 60, respectively) were prepared by replacing the OPC on mass-for-mass basis. A constant water/binder ratio and dosage of superplasticizer were used for all mixes in order to quantify the effects of POFA inclusion as well as its replacement levels, while at the same time satisfying the recommendations stipulated by the European Guidelines for SCC [7]. Table 1 provides the mix proportions of the SCC used in the current study. The methods of mixing and preparation were according to the European Guidelines [7], while the POFA was prepared by adopting similar approaches undertaken in a previous study [8].

| Materials (kg/m³) | Concrete Mix |
|------------------|--------------|
|                  | OPC-SCC | POFA-SCC 20 | POFA-SCC 40 | POFA-SCC 60 |
| OPC              | 526     | 420.8       | 315.6       | 210.4       |
| POFA             | 0       | 105.2       | 210.4       | 315.6       |
| Fine Aggregate   | 875     | 875         | 875         | 875         |
| Coarse Aggregate | 750     | 750         | 750         | 750         |
| Water            | 200     | 200         | 200         | 200         |
| Superplasticiser | 26.3    | 26.3        | 26.3        | 26.3        |

| *POFA Percentage | 0 | 20 | 40 | 60 |

2.2 Tests on Fresh SCC

The fresh concrete was tested to determine the concrete workability which in turn could influence the compact ability of the concrete that might ultimately affect the concrete quality. As mentioned earlier, the characteristics of the SCC with regards to filling ability, passing ability, and resistance to segregation need to be quantified to ensure their compliance with the specified guideline. Therefore, the fresh properties of the SCC were evaluated via the slump flow, slump flow T₅₀₀, L-box, and sieve stability tests.
2.2.1 Slump Flow and Slump Flow T₅₀₀ Tests

Slump flow and slump flow T₅₀₀ values portray the filling ability of a fresh SCC mix and were evaluated in this study based on EN 12350-8 [9] using a slump cone. The flat base plate used in this study had an area of 900 mm x 900 mm; its thickness was around 2 mm as shown in Figure 1. The slump flow value was obtained by taking the average of the largest diameter in two perpendicular directions, S = \( \frac{d_{\text{max}} + d_{\text{perp}}}{2} \).

![Figure 1. SCC slump flow test cone](image1.png)

2.2.2 L-Box Test

The passing ability of the SCC mixtures was tested via the L-box test according to EN 12350-10 [10]. Figure 2 depicts the L-box test equipment which is a rectangular box having L shape. Before the test, the inside of the L-box surface was lightly moistened. Twelve (12) liters of concrete was poured into the vertical section without external compaction and was left for 1 minute to observe any occurrence of segregation while the sliding gate between the two sections (vertical and horizontal) was closed. After that, the gate was opened in order to allow the concrete to flow freely out from the vertical section into the horizontal section. The heights of concrete at the vertical (H₁) and horizontal (H₂) sections of the L-box were measured. The ratio of H₂/H₁ gives the blocking ratio value that indicates the passing ability of the fresh SCC. The passing ability should be within the limit 0.8 ≤ H₂/H₁ ≤ 1.0, regardless whether L-box with 2 or 3 vertical rebar is used, as recommended by the European Guidelines [7]. A value closer to 1.0 indicates an excellent passing ability.

![Figure 2. L-box test equipment](image2.png)
2.2.3 Sieve stability test

This test was conducted to determine the segregation resistance of the SCC as recommended by EN 12350-11 [11]. Figure 3 illustrates the sieve stability test for the SCC. The apparatus used in this test (Figure 3) consisted of a 5 mm sieve, receiver (pan), weighing machine, metal container, and lid. Ten (10 liters) of fresh concrete was put into the metal container for about 15 minutes; the container was covered with a lid to prevent evaporation in order to observe any occurrence of segregation or bleeding. Then, a concrete sample of 4.8 kg was immediately poured into the sieve from a 500 mm height. The mortar that passed through the 5 mm sieve was then weighed. The percentage of mortar passing through the sieve is termed as the segregation index (SI) which indicates the segregation resistance and was calculated as follows:

\[
SI = \frac{\text{Weight of concrete passing through sieve}}{\text{Total weight of sample}} \times 100
\]

(1)

3. Experimental results and discussion

3.1 Influence of POFA on the fresh properties of SCC

3.1.1 Slump flow and slump flow \(T_{500}\) tests

The results of slump flow and slump flow \(T_{500}\) are graphically portrayed in Figure 4 and Figure 5, respectively. The measured slump flow for the control sample was 695 mm, and those for POFA-SCC 20, POFA-SCC 40 and POFA-SCC 60 were 720 mm, 732 mm and 740 mm, respectively. The recorded slump flow \(T_{500}\) values were 3 seconds for the OPC-SCC, and 2.8s, 2.5s and 2.4s for POFA-SCC 20, POFA-SCC 40 and POFA-SCC 60, respectively. All the SCC mixes recorded acceptable slump flow and slump flow \(T_{500}\) results since the slump flow results were in the 650 – 800 mm range as well as slump flow \(T_{500}\) results were within the 2 – 5 seconds range which are considered satisfactory according to the European Guidelines [7]. The same results were obtained by Alsubari et al. [12] when replacing 50%, 60%, and 70% of OPC with POFA. They found that their slump flow measured values for the three mixes were in the range of 730-740 mm and the slump flow \(T_{500}\) values were in the 2-5s range.
In this study, the POFA-SCCs exhibited higher slump flow values compared to that of the control sample indicating a better filling ability of the POFA-SCCs. In addition, the POFA-SCCs also exhibited an excellent stability since all mixes had a flow time below 5 seconds. Thus, it can be concluded that the incorporation of POFA enhanced the workability of SCC with higher workability at the higher POFA content. This may be attributed to the greater paste volume of the SCC concrete containing POFA which provides better coating and lubrication of aggregate particles promoting flow while at the same time imparting sufficient cohesiveness to provide excellent degree of stability. The trend in the improvement in workability with the inclusion of POFA concurs with previous finding of a study on the high strength green concrete containing POFA [8].

![Slump Flow of POFA-SCC mixes](image1)

**Figure 4.** Slump Flow of POFA-SCC mixes

![Slump flow T<sub>500</sub> of POFA-SCC mixes](image2)

**Figure 5.** Slump flow T<sub>500</sub> of POFA-SCC mixes

### 3.1.2 L-box test

Figure 6 shows the L-box test results obtained in this study. The blocking ratios for OPC-SCC, POFA-SCC 20, POFA-SCC 40, and POFA-SCC 60 were 0.83, 0.93, 0.96 and 0.99, respectively. The POFA-
SCCs mixes exhibit slightly higher values compared to those of OPC-SCC indicating that the passing ability was within the range of 0.8 to 1.0 and could be categorized as Class 2 (PA2) according to the European Guidelines [7]. Similarly, Alsubari et al. [12] noticed that POFA-SCCs achieved a better passing ability than OPC-SCC, and the passing ability was also in the range of 0.8 to 1.0.

Thus, the inclusion of POFA in the SCC improved the workability of the SCC by promoting better lubrication and mobility of aggregate particles, and it increased as the content of POFA increased due to the fine particles of POFA which offered greater surface area, hence providing enough viscosity and cohesiveness for the fresh SCC. The results obtained in this study are also similar with the use of a viscosity modifying agent which is usually used to improve the cohesiveness of SCC [13, 14].

![Figure 6. Blocking ratio for POFA-SCC mixes](image)

### 3.1.3 Sieve stability test

Figure 7 depicts the sieve stability test results. The value of segregation resistance indices for OPC-SCC, POFA-SCC 20, POFA-SCC 40 and POFA-SCC 60 were 9%, 11%, 12%, and 14%, respectively. The results showed that the POFA-SCCs mixes exhibited greater segregation resistance indices compared to the OPC-SCC. All the SCC mixes satisfied the requirements of the European Guidelines [7], and their segregation resistance indices could be classified as Class 2 (SR2) since they are less than 15% due to the addition of POFA. Alsubari et al. [12] also found that the segregation resistance indices increase as the POFA content increases.

Again, the use of the POFA with finer particle size and greater surface area than cement contributed positively towards enhancing the segregation resistance of the SCC [8]. Thus, the inclusion of POFA improved the overall fresh properties of the SCC.
4. Conclusions

This study examined the influence of POFA on the fresh properties of the green self-compacting concrete (GSCC) via the slump flow, slump flow $T_{500}$, L-box, and sieve stability tests. From the results, the following conclusions can be drawn:

i) The incorporation of POFA in SCC increased the slump flow value and decreased the flow rate of slump flow $T_{500}$ value. In other words, POFA tends to improve the SCC filling ability.

ii) The segregation resistant indices satisfied the stipulated range of 5-15%. Nevertheless, POFA-SCC of 60% exhibited the highest segregation resistant index value of 14% compared to all other mixes. This can be interpreted that the fine particles of POFA in SCC with lower specific gravity increased the cohesiveness and viscosity of the mixes; thus, contributing towards a better segregation resistance.

iii) The overall results of the study on properties of freshly mixed SCC proved that the inclusion of POFA up to 60% from the mass of OPC resulted in acceptable fresh properties of SCC. Thus, it is very much viable to produce SCC by incorporating up to 60% POFA as supplementary binder in the SCC. As a result, significant reduction in cement consumption could be achieved which could promote sustainability of the concrete industry.

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