Fresh State and Mechanical Properties of SCC-POFA-CF Mixture

M.A. Iman\textsuperscript{1}, N. Mohamad\textsuperscript{1, *}, Fasya Raain\textsuperscript{1}, Anis Sofia\textsuperscript{2}, Azree Mydin\textsuperscript{3} and A.A.A. Samad\textsuperscript{1}

\textsuperscript{1}Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Johor.
\textsuperscript{2}School of Materials Engineering, Universiti Malaysia, 02600 Arau, Perlis, Malaysia
\textsuperscript{3}School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
*Corresponding author: noridah@uthm.edu.my

Abstract. This paper presents the fresh state and mechanical properties of self-compacting concrete (SCC) with addition of coir fiber (CF) as filler in range of 0.2\% to 0.6\% and replacing the cement in 10\% with palm oil fuel ash (POFA). The workability test such as slump flow and J-ring test were used on the fresh SCC-POFA-CF mixture. The mechanical properties of SCC-POFA-CF in form of compressive, tensile and flexural strength were determine using the compressive test on cube, split tensile test on cylinder and four-point bending test on prism respectively. The increasing amount of CF in mixture resulting the decreasing of workability of SCC-POFA-CF. The SCC mixture with 0.2\% CF was selected as optimum as the strength reached the allowable limit of strength. The less crack was occurred on SCC-POFA-CF compared to the control specimen. Therefore, the propagation of crack in prism of SCC was control by coir fiber.

1. Introduction

Self-compacting concrete is a non-segregated, highly flowable concrete, free of air and spaces which used its own weight to consolidate. SCC has high flowing nature that allows it to fill formwork completely and complete compaction can be achieved even in the tightly arranged reinforcements situation [1-2]. Due to high flowability, SCC does not need compaction process, thus contribute to ease and fast construction. Some advantage of using SCC are cutting off the construction time, environmentally friendly and produce no sound as there are no vibrations. The creation of SCC has led to better the working situations that led to reduction of energy usage, less vibration, increase productivity, reduction of unnecessary sound and increase the attendance of workers in site due less health problems [3].

The agricultural waste is by-products from the activities associated with agriculture, that come in be organic and non-organic form. Palm oil fuel ash and coconut fiber are the examples of organic waste that always being dumped. The disposal of such wastes has brought problems and pollute the environment. Recycling these wastes can solve the problems and innovate new construction materials.

In this study, coir fiber (CF) and palm oil fuel ash (POFA) were used as a filler and cement replacement, respectively, in the self-compacting concrete mixture, SCC. SCC is used in this study because it is a high strength concrete which can flow by itself and does not need vibration [4-5]. It is environmentally friendly since it uses less aggregates. CF is a natural organic resource which is extracted...
from the outer shell of a coconut [6]. Due to the high tensile strength, CF was used as reinforcement in cement paste, cement sand mortar and concrete [4-5]. The combustion of oil palm waste in the oil palm factory to generate steam for electricity generation produced POFA as agricultural by-product, which has been disposed as waste in landfills [7]. The addition of POFA in concrete mixture to replace cement or sand was proven to improve its strength and performance [8-12]. Utilization of POFA, which replaced cement partially, caused reduction in carbon footprint and help preserve natural resources. Meanwhile, the SCC prism’s propagation of crack can be controlled by adding coir fiber as filler in concrete mixture.

The main objective of this experimental work is to determine the effects of coir fiber and POFA on the structural behavior of PSCC under flexure. The effects of these agricultural wastes were measured from the physical and mechanical properties of SCC with and without addition of coir fiber, and the flexural behavior of SCC with and without addition of coir fiber.

The usage of SCC in construction can benefit in many ways such as prolong the formwork usage tendency, effective reinforcement covers, concrete can be produce industrially, quality improvement, concrete structures reliability and durability, improves working environment, construction time reduction and cost saving on related to concrete consolidation [13].

2. Methodology

Ordinary Portland Cement (OPC) was used in every mix design of SCC concrete following the guidelines provided in BS EN 206-1:2006 [14]. Coarse aggregate used in was prepared according to BS EN 812-2:1995 [15]. As the cement replacement, POFA was sieved using 75 µm then were added into the SCC mixture at 10% of cement’s total weight. The SCC mixture were incorporated with coir fiber at multiple percentages in range of 0.2% to 0.6% of the binder’s total weight. The CF was prepared to have length that range from 15 mm to 20 mm long.

EFNARC [16] was referred to propose mix design in this study. The mix design of SCC without addition of coir fiber was shown in Table 1. The strength of the SCC was determined from the mix design. Table 2 show the specimens of various SCC mixture that were added with coir fiber the range of 0.2%, 0.4% and 0.6%.

| Table 1. Mix Design of SCC (EFNARC, 2002) |
|------------------------------------------|
| Cement (kg/m³) | Aggregates (kg/m³) | Sand (kg/m³) | POFA (kg/m³) | Superplasticizer (%) | Water Cement Ratio (w/c) |
| 360 | 800 | 800 | 40 | 2 | 0.6 |

| Table 2. Number of Specimens |
|-------------------------------|
| Specimens | Cube (150mm x 150mm x 150mm) | Cylinder (150mm diameter x 300mm height) | Prism (100mm x 100mm x 500mm) |
| Curing Days | Compressive | Tensile | MOE | 4-Point Bending |
| SCC + 10% POFA + 0% CF | 7 Days | 28 Days | 7 Days | 28 Days | 28 Days | 3 |
| SCC + 10% POFA + 0.2% CF | 3 | 3 | 2 | 2 | 3 |
| SCC + 10% POFA + 0.4% CF | 3 | 3 | 2 | 2 | 3 |
| SCC + 10% POFA + 0.6% CF | 3 | 3 | 2 | 2 | 3 |

There were two phases in laboratory tests: the determination of properties in fresh SCC mixture in first phase and the determination of the mechanical properties of SCC structure with and without addition of coir fiber in second phase. Slump flow test and J-ring test were conducted on fresh state SCC to determine the flowability and workability, while compressive test, splitting tensile test and four-point bending test were conducted on hardened SCC specimens to determine the SCC mechanical properties.
3. Data Analysis

3.1. Slump Flow
Slump flow, S, is determined by using the formula in Equation (1). The biggest value of flow spread was expressed as $D_{\text{max}}$ while the diameter of perpendicular direction was expressed as $d_{\text{perp}}$.

$$ S = \frac{d_{\text{max}} + d_{\text{perp}}}{2} $$  \hspace{1cm} (1)

Figure 1. Graph of Slump Flow and $T_{500}$

As where shown in Figure 1, the increment of coir fiber content in SCC mixture resulting the decrement in slump flow maximum diameter. Meanwhile, as the percentage of CF content increased, the time taken from the $T_{500}$ test was also increase. The CF addition in SCC mixture developed the flow resistance SCC matrix. This is in good agreement with the investigation conducted by Mohamad et al. [9] as addition of coir fiber in foamed concrete resulting the decrement in slump flow in fresh state foamed concrete.

The highest value for slump flow was 600 mm recorded with $T_{500}$ of 2 seconds, while SCC with addition of coir fiber recorded highest slump flow of 580 mm with $T_{500}$ of 4 seconds that occurred when 0.2% of coir fiber were added in SCC mixture as shown in Figure 1. Thus, 0.2% was the optimum percentage of coir fiber to achieved highest workability and flowability compared to the other SCC mixture with addition of 0.4% and 0.6% coir fiber.

3.2. Passing ability of SCC
Passing ability of the SCC were determine using J-ring test. The average of the differences in height at four direction as stated in EFNARC [16] will determine the height of flow, $B_J$, using the Equation (2).

$$ B_J = \frac{(hx1 + hx2 + hy1 + hy2) - ho}{4} $$  \hspace{1cm} (2)

Figure 2. Height of flow versus percentage of CF
Figure 2 shows the increase of CF content in SCC mixture makes the height of flow increased from 2.5 mm to 15 mm. The water content in SCC mixture were affected by the existence of coir fiber that absorb the water in mixture.

3.3. Density
Density, \( \rho \), is the mass of unit volume of hardened concrete expressed in kilograms per cubic meter. Figure 3 shows the mix design obtained the density in the range 2100 kg/m\(^3\) to 2300 kg/m\(^3\). The highest value of density was 0.2% of coir fiber compared to the other SCC mixture casted.

The density recorded in all SCC-CF mixtures are as shown in Table 3. In general, the density of all mixture with added POFA and CF were recorded higher than the control SCC mixture. It can be seen that mixture SCC-POFA-0.2%CF obtained highest density at age 28 days. SCC-POFA-0.4% recorded lowest density, but close to the density obtained by SCC-POFA-0.6% CF.

3.4. Compressive Strength
Compressive strength for SCC-POFA-CF mixtures were shown in graph in Figure 4 for 7 and 28 days. SCC mixture with 0.2% coir fiber added achieved the maximum compressive strength for 7 and 28 days the recorded value of 25.7 MPa and 28.5 MPa respectively as referred to graph in Figure 4.
The compressive strength of SCC mixture was improved by approximately 5% with added 0.2% CF. Similar situation also happens in previous research’s findings, which determine varied percentage of coir fiber added mixture strength [9, 17] which study the effect in utilization of coir fiber as filler to the fresh and hardened properties of concrete. The cohesive bonding between concrete particles were affected by CF addition that tends increased the strength in SCC mixture.

However, the increment of CF addition of 0.4% and 0.6% in SCC mixture resulting the decrement in compressive strength, compared to compressive strength control specimen. The characteristic of CF that high water absorbance makes the amount of water in SCC mixture reduced, resulted achieved compressive strength was lower.

3.5. Splitting Tensile Strength
Splitting tensile strength test was done on the cylinder with size 150 mm diameter and 300 mm height as Figure 5 show the result from tensile strength test for each type of SCC mixture. Addition of 0.4% of coir fiber achieved the highest value of tensile strength of SCC mixture that was 2.35 MPa. The lowest tensile strength value of 2.20 MPa was recorded when 0.2% of coir fiber was added in SCC mixture. The coir fiber has fibrous nature that higher in tensile which help tensile strength to increase in SCC mixture as the coir fiber content was increased until the optimum percentage of 0.4%.

![Figure 5. Graph of Tensile Strength](image)

3.6. Modulus of Elasticity
Figure 6 shows the modulus of elasticity collected from the experiment. The value of 20.27 GPa was recorded for control specimen MOE while the value of 26.26 GPa was recorded for SCC with addition of 0.2% of coir fiber that show some increment of MOE value. Then, the MOE value decreased to 13.49 GPa and slightly increased to 15.08 GPa. The MOE shows the highest value when added with 0.2% coir fiber and the lowest value of MOE was shown when the coir fiber was added with percentage of 0.4% into the SCC mixture.

![Figure 6. Graph of MOE](image)
Addition of 0.2% CF in SCC mixture shows higher MOE value compared to control SCC mixture. However, the MOE values were significantly decrease with the increase of coir fiber content, which indicates the excessive addition of coir fiber can affect the SCC mixture elasticity. Therefore, 0.2% CF addition in SCC mixture was determined as the optimum percentage to achieve highest MOE value.

3.7. Flexural behavior of SCC-POFA-CF
The four-point bending test on prism specimens were conducted to determine the flexural strength of SCC-POFA-CF mixture. The ultimate load, crack pattern and load-deflection curve were collected from the laboratory work the were analyzed for further discussion.

Figure 7. Graph of Flexural Strength

Figure 7 shows the flexural strength of each SCC-POFA-CF mixture were collected and recorded. The control specimen was used as reference to determine the increment in flexural strength of SCC-POFA-CF mixture. Addition of 0.4% CF shows the highest value of flexural strength that was 3.90 MPa, about 11% higher than control SCC-POFA-CF mixture. The coir fiber has high tension strength and elasticity that can be used as the filler in SCC mixture. The filler from coir fiber was proved to improve the internal bonding in SCC mixture, that can enhanced the flexural capacity [9, 18]. However, as the percentage of CF addition increased to 0.6%, the flexural strength of SCC was decreased to 3.83 MPa. Thus, addition of 0.4% CF in SCC mixture was determined as the optimum percentage to achieve highest flexural strength.

Figure 8. Crack Pattern

Figure 8 shows the crack pattern of SCC-POFA-CF prism specimen. The flexural crack on control specimen was started at the mid zone that propagate extremely at ultimate load that broke the prism into two. Meanwhile, SCC prism with added 0.2% and 0.6% CF shows smaller crack width and length compared to control SCC prism, which flexural crack were developed near its mid zone and propagate
upward as the ultimate load achieved. Lastly, SCC prism with 0.4% coir fiber shows the smallest crack propagation compared to other SCC prism, in conjunction to its highest tensile strength. The addition of coir fiber controls the crack propagation and reduced the severity of cracking due to concrete bridge. Based on the observation, it is concluded that in general, control specimen experienced more crack compared to SCC with addition of CF and the optimum percentage to crack propagation control is 0.4%.

Figure 9. Load-Deflection Profile

From Figure 9, the control specimens have higher deflection compared to SCC mixture with added CF. The creation of concrete bridges in structure due to addition of CF in SCC was proved by the crack control on the SCC prism. SCC prism with addition of 0.4% CF has highest first crack load which is 9.78 kN, while SCC prism with addition of 0.6% CF has first crack load of 9.56 kN, slightly lower that 0.4% CF addition achieved. The control SCC mixture behave in the most ductile manners compared to SCC mixture with addition of CF. The natural characteristic of CF, which absorbance to water resulting SCC mixture dried up. The water content in mixture was affected and the brittleness of SCC mixture also affected. The SCC mixture became more brittle as the water content decreased. The addition of 0.4% CF in SCC mixture shows more ductile behaviour compared to the other two SCC mixture with addition of CF. Thus, 0.4% CF addition in SCC mixture was the optimum percentage to achieved acceptable deflection and ductility.

4. Conclusions
Based on results analysis and discussion, the fresh state and mechanical properties of SCC-POFA mixture were affect significantly as the CF added into the mixture. The limited content of CF addition in SCC-POFA mixture produce better flowability and workability compared to plain or control SCC-POFA mixture. The addition of 0.2% CF in SCC-POFA mixture improved the mechanical properties as the compressive strength and modulus of elasticity (MOE) was increased by 11% and 30% respectively. The addition of CF more than 0.2% resulting the decreasing in compressive strength and modulus of elasticity (MOE).

Meanwhile, addition of 0.4% CF resulted highest tensile strength and flexural strength with recorded value of 2.35 MPa and 3.9 MPa, respectively. The crack pattern propagation was observed to all SCC-POFA mixture prism and the 0.4% CF added mixture shows the least crack developed in prism. The added CF SCC mixture also attained lower deflection and behave less ductile compared to control SCC
mixture. CF has the high-water absorbance traits that can affect the water content in SCC mixture that resulting the SCC-POFA-CF mixture become more brittle. Thus, 0.2% CF addition in SCC-POFA mixture was chosen as the optimum percentage considering the compressive strength that achieved the minimum targeted compressive strength and fresh state behavior compared to 0.4% CF addition that not achieved the targeted strength.

5. References

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Acknowledgement
The authors would like to thank Jamilus Research Center and Universiti Tun Hussein Onn Malaysia for its financial support (GPPS Vot U788).