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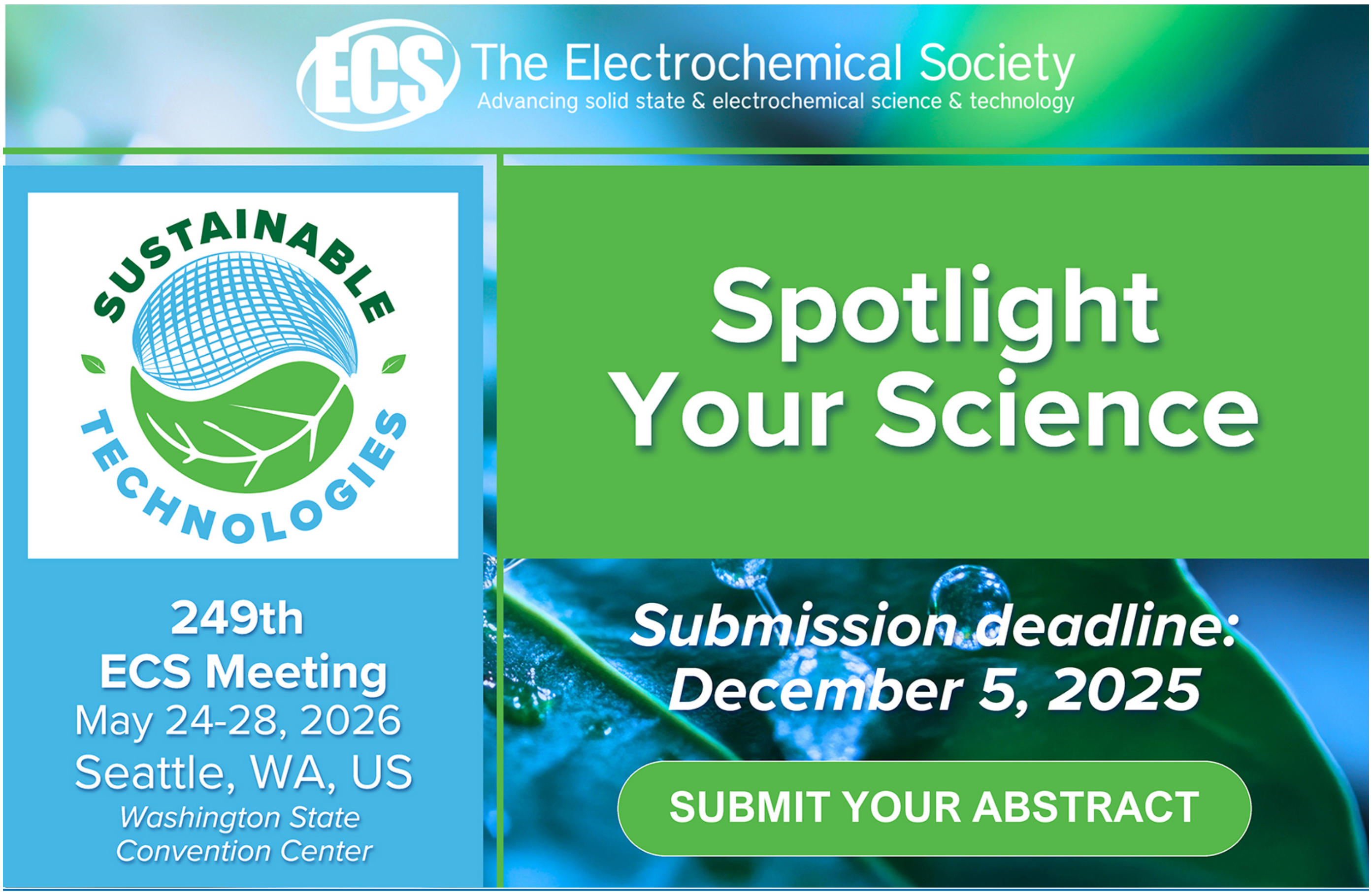

Properties and Flexural Behavior of Self-Compacting Concrete with Added Coir Fiber And POFA

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Abstract. This paper presents the mechanical properties and flexural behavior of self-compacting concrete (SCC) with addition of 0.2%, 0.4% and 0.6% coir fiber (CF) as filler, and 10% palm oil fuel ash (POFA) as partial cement replacement. Fresh SCC-POFA-CF mixture was tested under slump flow and J-ring tests to determine its workability. SCC-POFA-CF cubes and cylinders were tested under compressive and tensile tests to determine its compressive strength, tensile strength, and flexural strength, while prisms were tested under four point bending load to determine its flexural behavior. It is found that workability of SCC-POFA-CF decreased when CF increased. The optimum percentage of CF in SCC mixture was found to be 0.4%. SCC-POFA-CF experienced less crack compared to the control specimen. This shows that CF in SCC prisms managed to control the crack propagation.

1. Introduction

Self-compacting concrete is a non-segregated and highly flowable concrete, which is able to consolidate under its own weight. The easy flowable nature of SCC allows it to completely fill the formwork and achieve complete compaction even in the presence of congested reinforcements [1, 2]. The development of SCC has led to improvements in the working conditions which in turn, results with less energy consumption, less vibration, greater productivity, and less noise [3, 4]. SCC concrete has been proven to have improved fresh and hardened properties compared to conventional concrete [5, 6].

Meanwhile, the disposal of wastes from the activities associated with agriculture has created nuisance and environmental issues. One of the solutions to tackle this problem is by recycling these wastes as the new innovative 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 SCC mixture. CF is a natural organic resource which is extracted from the outer shell of a coconut [7]. It has been used as reinforcement in cement paste, mortar and concrete, due to its high tensile strength [8, 9]. POFA is an agricultural waste generated by the burning of oil palm residue in the oil palm industry to produce steam for electricity generation [10]. It has been used in concrete mixture as cement or sand replacement to enhance its strength and performance [11-15].

Previous research on properties of SCC concrete added with new materials as cement replacement have shown promising results in the aspects of its fresh and hardened properties. Dinesh et al. conducted experimental study on SCC with added fly ash and silica fume at various percentages. It was found that the compressive and tensile strength decreased with the increase in the percentage of fly ash and increased with the increase in percentage of silica fume [16]. Tarun et al. [17] replaced Portland cement by fly ash in the range of 35% to 55% by the mass of cement. The results showed it obtained 28-day strengths up to 62 MPa. Kumar et al. conducted an experimental investigation on flow properties and compressive strength of SCC with ultrafine natural steatite powder (UFNSP) as cement replacement. The results showed that the addition of UFNSP influences the flow property, by reducing the flow, and increases the compressive strength up to 20% replacement [18].

This paper presents the study on the mechanical properties of SCC concrete incorporating CF as filler and POFA as cement replacement. The main aim of this work is to determine the effects of CF and POFA on the mechanical properties of SCC as compared to properties of control SCC.

2.Materials and methods

Ordinary Portland Cement (OPC) was used in every mix design of SCC concrete according to BS EN 206-1:2006 [19]. Coarse aggregate used in this study was prepared according to BS EN 812-2:1995 [20]. POFA, sieved using 75 µm, was incorporated in the SCC mixture as a cement replacement at 10% of mixture's total weight. The percentage of 10% POFA was chosen based on findings from previous research. Munir et al. replaced OPC with POFA in foamed concrete as a cement replacement at 10%, 20%, 30%, 40% and 50% by weight of cement in the foamed concrete. The results showed that 20% cement replacement by POFA in the foamed concrete is the optimum percentage [21]. From this finding, the 10% POFA was chosen because the density of SCC is much higher than foamed concrete; thus, lower POFA percentage is needed. CF was incorporated in the SCC mixture at various percentages of 0.2% to 0.6% of the total weight. Its length was varied from 12 mm to 20 mm long. These various percentage was chosen based on study by Sureshkumar et al. [22], which investigated the SCC properties with various percentages of coir fiber, 0.25, 0.5 and 1% by weight of cement. It was found that 0.5% CF is the optimum percentage to be used.

The mix design in this study was conducted according to EFNARC [23]. Table 1 shows the mix design of SCC without addition of coir fiber. Coir fiber was added in SCC in the range of 0.2%, 0.4% and 0.6%. as shown in Table 2.

Table 1. Mix Design of SCC.

Cement (kg/m^3)	Aggregates (kg/m^3)	Sand (kg/m^3)	POFA (kg/m^3)	Superplasticizer (%)	Water Cement Ratio (w/c)
360	800	800	40	2	0.6

Table 2. Mechanical properties of SCC-POFA-CF with 10% POFA and various percentages of CF.

Specimens	Cube (150 mm x 150 mm x 150 mm)		Cylinder (150 mm diameter x 300 mm height)		Prism (100 mm x 100 mm x 5 00mm)
Testing	Compressive		Tensile	MOE	4-Point Bending
Curing Days	7 Days	28 Days	28 Days		28 Days
SCC + 10% POFA + 0% CF	3	3	2	2	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

Laboratory tests were divided into two phases; the first phase was to determine the fresh properties and the second phase is to determine the mechanical properties of SCC-CF-POFA mixtures. Tests for fresh properties include slump flow test and J-ring test which were conducted according to BS EN 12350: Part 8 2010 [24] and BS EN 12350: Part 12 [25], respectively. Meanwhile, tests for hardened properties included compressive test, splitting tensile test and four-point bending test which were conducted according to BS-EN 12390:2002[26], BS-EN 12390-6 [27] and BS EN 12390: Part 5 [28], respectively.

3. Results and discussions

3.1. Slump Flow

Slump flow, *S* is determined by using the formula in Equation (1). D_{max} is the maximum diameter of the flow spread while the d_{perp} is the diameter of perpendicular direction.

$$S = \frac{d_{\max} + d_{perp}}{2} \tag{1}$$

From the slump flow diameter recorded, it is noticed that the diameter decreases as the percentage content of CF increase. Meanwhile, from the T_{500} recorded, it is shown that the time recorded increased as the percentage content of CF increased. This is caused by the flow resistance in the SCC matrix developed by CF which was added in the SCC mixture. This is in good agreement with the investigation conducted by Mohamad et al. 2018[12] on fresh and hardened properties of foamed concrete consisting coir fibres where the results showed decreased slump flow.

From Figure 1, the highest value for slump flow was 600 mm with T_{500} at 2 seconds but for SCC with addition of 0.2% coir fiber, the highest slump flow was 580 mm with T_{500} at 4 seconds. This is because CF is organic material which has high water absorption; thus, increased the hydration process of SCC and generate the cohesiveness between the particles. From the results recorded, the optimum percentage of coir fibre is 0.2% where workability was highest.

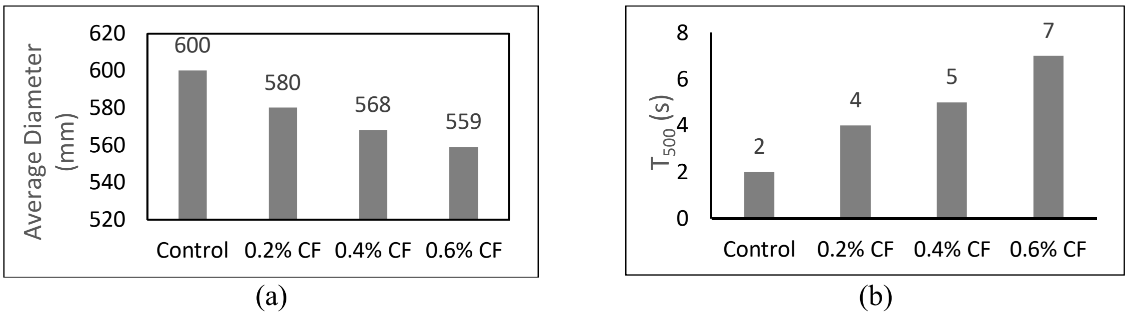

Figure 1. (a) Slump flow diameter, and (b) Time taken for 500 mm diameter.

3.2. Passing ability of SCC

J-Ring test was conducted to determine the passing ability of the SCC. The average of the differences in height at four direction will determine the height of flow, B_j, as shown below.

$$Bj = \frac{(hx1 + hx2 + hy1 + hy2) - ho}{4} \tag{2}$$

From Figure 2, the difference in the height of flow was increasing from 2.5 mm to 15 mm as the content of CF in SCC mixture increased. This is due to less water content of the SCC mixture, caused by existence of CF in the mixture, which absorb the water. The greater difference in height of flow indicated the less passing ability of the concrete.

3.3. Compressive strength

Figure 3 presents the graph of compressive strength for SCC-POFA-CF mixtures at 7 and 28 days. From the figure, it is seen that the maximum strength was achieved when the mix was added with the 0.2% of CF. The highest value of compressive strength for 7 and 28 days was 25.7 MPa and 28.5 MPa, respectively, for this SCC mixture.

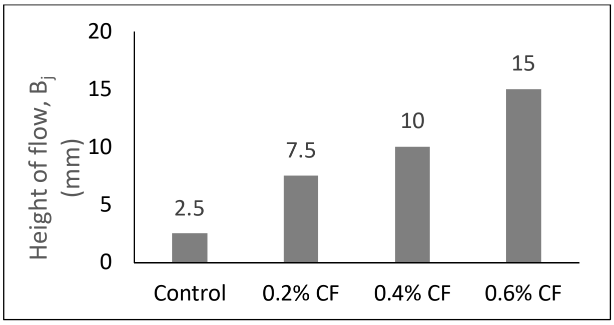

Figure 2. Height of flow versus percentage of CF from J-Ring test.

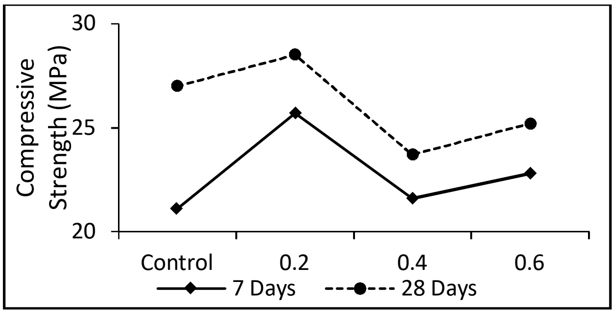

Figure 3. Compressive Strength for SCC-POFA-CF mixtures at 7 and 28 days.

The addition CF has proven to improve the compressive strength by approximately 5% with added 0.2% CF. This is in agreement with the findings from previous research, which investigated the strength of concrete containing various percentage of CF [12, 29] which examined the fresh and hardened properties of concrete when CF was utilized as filler. The results showed that CF improved the cohesive bonding between the concrete particles which tends to increase the strength in concrete.

However, the compressive strength was decreased, compared to compressive strength control specimen, when CF in the mixture was increased to 0.4% and 0.6%. This is due to CF with its high absorbance characteristic, reduced the amount of water in SCC mixture, resulted with less strength achieved.

3.4. Tensile strength

Splitting tensile strength test was carried out to determine the tensile strength of cylinder with size 150 mm diameter and 300 mm height. Figure 4 shows that the highest value of tensile strength of SCC is 2.35 MPa, achieved with addition of 0.4% of coir fiber. The lowest value of tensile strength was 2.20 MPa which is SCC with addition of 0.2% of coir fiber. Tensile strength in SCC mixture is higher when the content of coir fiber is higher because the fibrous nature of coir fiber which is higher in tensile.

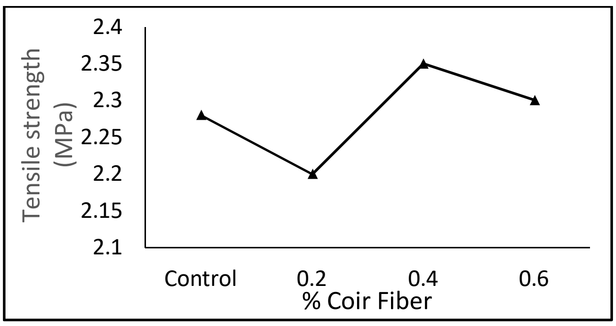

Figure 4. Tensile Strength of SCC-POFA-CF at 28 days.

3.5. Modulus of elasticity

Modulus of elasticity obtained from the experiment is shown in Figure 5. The modulus of elasticity, MOE, for control specimen recorded was 20.27 GPa and increased to 26.26 GPa which is SCC with addition of 0.2% of coir fiber. After that, the MOE value decreased to 13.49 GPa and slightly increased to 15.08 GPa. The highest value for MOE was SCC with addition of 0.2% of CF while the lowest value for MOE was SCC with addition of 0.4% of CF.

The results from Figure 5 shows that with addition of 0.2% CF, the MOE of SCC was higher compared to control specimen. However, with the increment of CF content, the MOE significantly reduced, which shows that more addition of CF reduced the elasticity of SCC. Thus, the optimum percentage concrete is 0.2%.

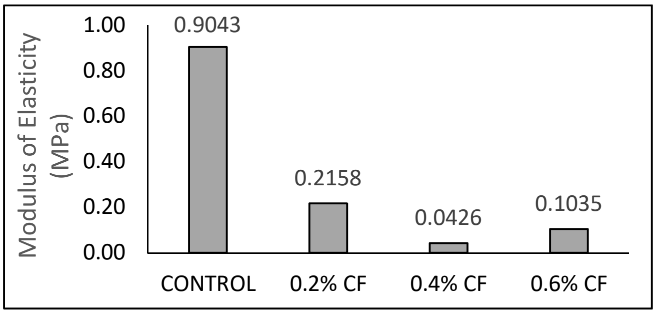

Figure 5. Modulus of Elasticity of SCC-POFA-CF.

3.6. Flexural strength, crack pattern and load-deflection profile

The flexural strength of SCC-POFA-CF mixture was obtained from the four-point bending test on prism specimens. From the test, the ultimate load, crack pattern and load-deflection curve were analyzed.

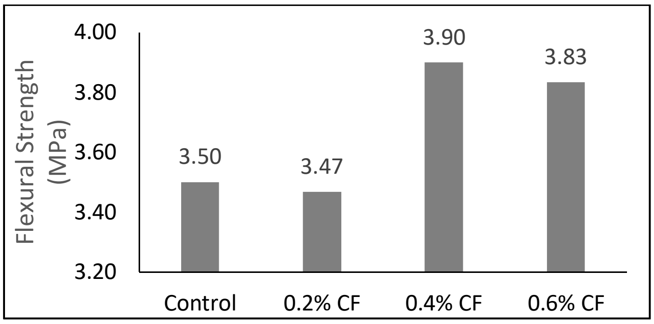

Figure 6. Flexural strength of SCC-POFA-CF.

From Figure 6, the highest value for flexural strength was 3.90 MPa, about 11% higher than control specimen, which was obtained from SCC-POFA-CF mixture incorporating 0.2% CF. This is caused by the CF, as filler in the SCC, was high in tension and elasticity. It is proven that CF as filler resulted with enhancement in the internal bonding in the mixture, which was responsible to improve the flexural capacity [12, 29]. However, for the 0.6% of coir fiber in SCC mixture, the ultimate strength decreased to 3.83 MPa. Thus, the optimum percentage of coir fiber for tensile strength of SCC mixture is found to be 0.4%.

From Figure 7, the control specimen experienced the extreme crack propagation where it finally broke into two at its ultimate load. SCC with added 0.2% and 0.6% CF developed flexural crack near its mid zone, with smaller crack width and length, compared to control specimen. Lastly, the smallest crack propagation was observed in SCC prism with 0.4% of coir fiber, which was highest in tensile strength. Based on the observation, it is concluded that in general, SCC with addition of CF experienced less crack compared to the control specimen.

Figure 7. Crack pattern.

From Figure 8, the SCC mixtures with added CF obtained lower deflection values compared to control specimens. This indicate that the CF in SCC prisms managed to create the concrete bridges in structure which in turn control the crack. The first crack load was highest in specimen with 0.4% CF, which is about 9.78 kN, continued with specimen with 0.6% CF, which is 9.56 kN. It is also seen from the figure that control specimen behaved in most ductile manner compared to the other specimens. This is caused by CF, which absorbed more water. Thus, as the SCC mixture dried up, the water content in the mixture decreased, and caused the concrete to be more brittle. Among the three specimens with different CF percentage added, it is observed that 0.4% CF resulted with more ductile behavior of SCC mixture.

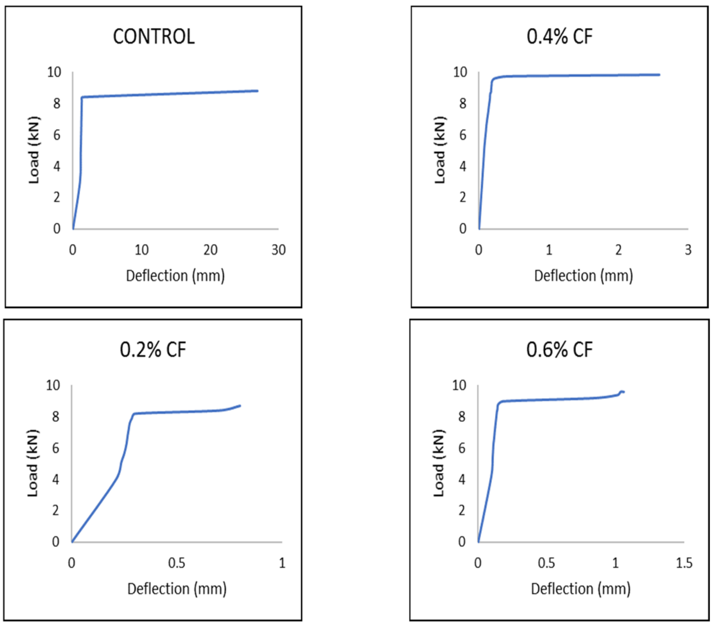

Figure 8. Load-deflection profile

4. Conclusions

From the results obtained, CF has proven to have significant effects on fresh and mechanical properties of SCC-POFA mixture. It increased the workability of SCC-POFA mixture, where the bigger content of CF resulted with higher workability. From the mechanical properties obtained, it is found that 0.2% CF content increased the compressive strength and modulus of elasticity by 11% and 30%, respectively. Meanwhile, the tensile and flexural strength achieved their highest values, 2.35 MPa and 3.9 MPa, respectively, when 0.4% CF was added to the mixture. The crack pattern recorded showed that SCC-POFA-CF prisms developed the least crack in prism with 0.4% CF added. It is also noticed that mixture with added CF attained lower deflection and less ductile behavior compared to the control specimen. This is mainly cause by the characteristic of CF, which is high water absorbance, which in turn reduce the water content in the mixture. This makes the SCC-POFA-CF mixture more brittle. Thus, considering its effects on all the properties of SCC-POFA-CF mixture, 0.2% CF was chosen as the optimum percentage of CF to be added into the mixture.

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