



Utilization of Iron Filings as Partial Replacements for Sand in Self-Compacting Concrete

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Abstract

The use of industrial by-products in concrete production is part of concerted efforts on the reduction of environmental hazards attributed to the mining of conventional aggregates. Consideration of iron filings (IF), a by-product from steel production process, is an environmentally friendly way of its disposal which is expected to yield economic concrete production. Six self-compacting concrete (SCC) mixes were made by partially substituting river sand with IF at 5%, 10%, 15%, and 20% and the mix without IF (0% IF) served as the control. The water-binder (w/b) ratio of 0.45 was adopted for all mixes. The fresh state properties of SCC evaluated include: filling ability determined using slump flow and T_{500 mm} slump flow tests, passing ability determined using L-box test and segregation resistance determined using V-funnel tests. The strength properties of SCC considered were compressive and tensile strengths. All the SCC mixes met the fresh properties requirements for filling capacity, passing ability, and segregation resistance. The 28-day compressive and tensile strengths of SCC increased by 3.46% and 8.08%, respectively, with IF replacement up to 15% compared to the control SCC. However, there was reduction in compressive and tensile strengths of SCC with IF replacement beyond 15%. The strength properties of SCC is considerably enhanced with the addition of up to 15% IF. Hence, the optimum content of 15% IF is considered suitable as a replacement for river sand in SCC.

Keywords: Self-compacting concrete, iron filings, fine aggregates, filling ability, passing ability.

Introduction

Concrete is a composite material with cement, water and aggregates (fine and coarse) as the constituent material (Ghannam et al. 2016). The ease of obtaining concrete raw materials made concrete a popularly known construction material. Concrete offers low costs, high strength, weather resistance, high thermal and sound insulation, and the ability to

be formed into a variety of shapes, among other benefits. It is used to construct high-rise and low-rise buildings, bridges, drainage systems, and dams, among other things (Gunalan 2016). SCC is a form of concrete that compacts under its own weight without the necessity for external vibration (Okamura and Masahiro 2003). The invention of self-compacting concrete has resulted from a recent

breakthrough in concrete technology. A well-prepared SCC, according to Aggarwal et al. (2008), must strike a good balance between deformability and stability.

Aggregate constitutes most of the concrete volume as 70 to 80% of concrete is occupied by aggregate (Neville 2011). Natural sand has been the commonly used fine aggregate in concrete production and infrastructural development. The importance of aggregate in concrete production has resulted in increasing high demands for sand. Researchers, on the other hand, are concerned about the environmental impacts of using natural sand. The industrial materials which have been introduced as substitutes for fine aggregates in conventional concrete are coal bottom ash (Bilir et al. 2012), fly ash (Siddique 2003, Rafieizonooz et al. 2016), foundry sand (Khatib et al. 2013), copper slag (Ambily et al. 2015), steel slag (Rajan et al. 2014), iron filings (Alzaed 2014, Olutoge et al. 2016.).

Iron filings are generated as by-products of metal cutting, grinding, filing, or milling of finished iron products, especially in workshops and foundries (Alserai et al. 2018). When not properly recycled, they are discharged in great amounts into the environment, thereby causing the pollution of water bodies, blockage of drainage systems which could aggravate flooding (Alzaed 2014, Olaniyan et al. 2016). Thus, reusing IF in any productive form serves as an alternative means of disposing of the waste, and at the same time reducing the problems attributed to pollution and the costs incurred in the disposal of the waste, which in turn enhances the achievements of considerable environmental protection and production of affordable concrete.

Alzaed (2014) investigated the effects of replacing natural sand using various IF contents (10%, 20%, 30%, and 40%) in conventional concrete and discovered that increasing the IF content increases compressive strength while little improvement in tensile strength was found with IF addition above 10%. Al-hashimi et al. (2018) evaluated the performance of traditional concrete with

varying percentages of IF as a substitute for fine aggregate by weight, finding that as the percentage of IF rises, workability, compressive and tensile strength increased. In the study conducted by Yusuf (2019), cement and sand were partially replaced separately by IF of varying contents of 0%, 5%, 10% and 15% to produce cement paste and mortar. The results revealed that the workability of mortar decreased upon IF addition and the maximum strength of cement paste and mortar were achieved at 10% substitution level of cement and sand with IF. Olutoge et al. (2016) produced concrete using IF of 0%, 10%, 20% and 30% as replacement for sand and found the maximum compressive, splitting tensile and flexural strength at 20% replacement level.

Taking into account the novelty of SCC, limited pieces of literature are available on the use of IF as a partial substitute for fine aggregates in SCC. As a result, the mechanical properties of SCC with iron filings as a fine aggregate replacement are investigated in this study.

Materials and Methods

Materials

The materials used for this study were cement, river sand, crushed granite, iron filings, conplast SP 430 and water. In this research, Portland limestone cement (grade 42.5 N) with specific gravity of 3.15 was used as a binder and was obtained from retailing stores in Ede, Osun State, Nigeria. River sand that passes via sieve No. 4 (4.75 mm) was obtained from suppliers within the study location and was used as fine aggregate. Crushed granite of 19 mm maximum size used was sourced from Ayofe Quarry at Iwoye Iwo area, Nigeria. The details of the aggregates physical properties are presented in Table 1. The IFs (Figure 1) used as substitutes for river sand were obtained from the iron and steel milling workshops in Ede and Osogbo, Nigeria. Conplast SP 430 super plasticizing admixture which is brown in colour having a density of 1.2 kg/Lt, air entrainment of 1%, specific gravity of 1.19 and pH value of 8 was used as

an additive in this work. Clean water was collected from a borehole around the Civil Engineering Department of Federal Polytechnic, Ede and applied according to the mix proportion of 1:1.18:2.64:0.45 (cement, sand, granite, water). The gradation curves of river sand, granite and iron filings are shown in Figure 2.



Figure 1: Iron filings sample.

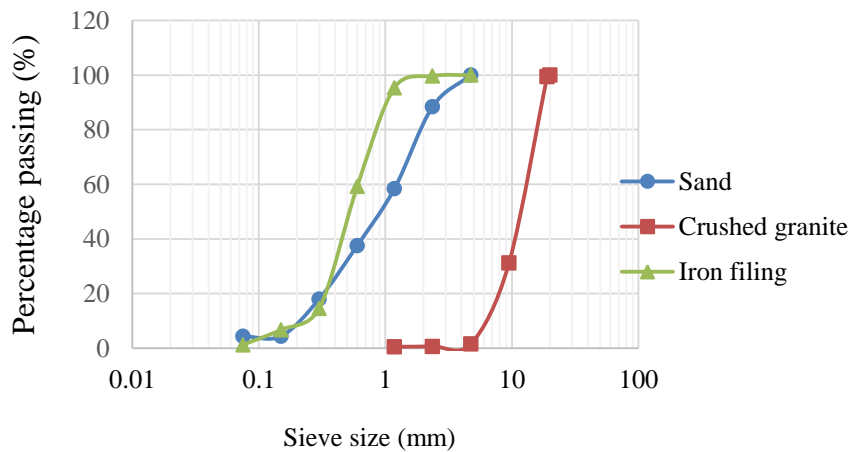


Figure 2: Gradation curves of aggregates.

Table 1: Physical properties of aggregates

Properties	Sand	Granite	Iron filings
Specific gravity	2.65	2.71	2.62
Fineness modulus	3.89	7.65	3.23
Particle size (mm)	< 2.36	< 19.00	< 2.36

Mix proportion for SCC and specimens preparation

The batching of materials for SCC mix preparation was done by weight in accordance with EFNARC (2005). The SCC mixes with w/b ratio of 0.45 were produced to achieve a targeted strength of M30 grade at 28 days curing age. A total of six SCC mixes were prepared by substituting 5%, 10%, 15%, 20% and 25% of river sand with IF and the SCC mix

without IF (0% IF) represented the control mix. The detailed mix proportions used for the production of SCC are shown in Table 2. The specimens were cast in steel moulds and removed after 24 hours and placed in the curing chamber as specified in ASTM C192 (2007). The hardened concrete specimens were subjected to mechanical tests after curing in water.

Table 2: Mix proportion for producing 1 m³ of SCC

Materials	Percentages IF (%)					
	0 (Control)	5	10	15	20	25
Cement (kg)	498	498	498	498	498	498
Sand (kg)	588	558.6	529.2	499.8	470.4	441
Granite (kg)	1315	1315	1315	1315	1315	1315
IF (kg)	0.00	29.4	58.8	88.2	117.6	147
Water (kg)	224.1	224.1	224.1	224.1	224.1	224.1
SP (%)	0.37	0.37	0.37	0.37	0.37	0.37

Experimental procedure

The fresh concrete mixtures were tested for filling ability by conducting slump flow and T_{500 mm} slump flow tests in accordance to EFNARC (2005). They were also tested for passing ability and segregation resistance by conducting L-box test and V-funnel test, respectively, in accordance to EFNARC (2005). The hardened concrete specimens were tested by carrying out compressive strength and splitting tensile strength tests as specified in BS EN 12390-3 (2009), and BS EN 12390-6 (2009), respectively, at the defined testing ages of 7, 14, 21 and 28 days using a 2000 kN capacity Universal Testing Machine at the Materials Laboratory of the Department of Civil Engineering, Osun State University, Osogbo.

Results and Discussion

Fresh SCC properties

Slump flow

The results of slump flow of fresh concrete presented in Figure 3 ranged between 596 and 762 mm and fall within the specified limits of EFNARC (2005). The slump flow diameter of fresh concrete decreased as the content of IF increased, suggesting that the workability of SCC decreased with the addition of IF, as shown in Figure 2. The IF particles form, which is rough, angular, and spherical and capable of causing flowability hindrance interrupted the smooth flow due to internal friction, is responsible for the reduction in SCC workability (Kareem et al. 2019, Miah et al. 2020). The increase in replacement level of IF having higher fine particles contents compared with sand as indicated in the gradation curves (Figure 1) can cause an increase in water demands. Furthermore, since IF has a lower fineness modulus than sand, the amount of water needed to lubricate the particles will increase as the specific surface area of the IF particles rises (Sandhu and Siddique 2019).

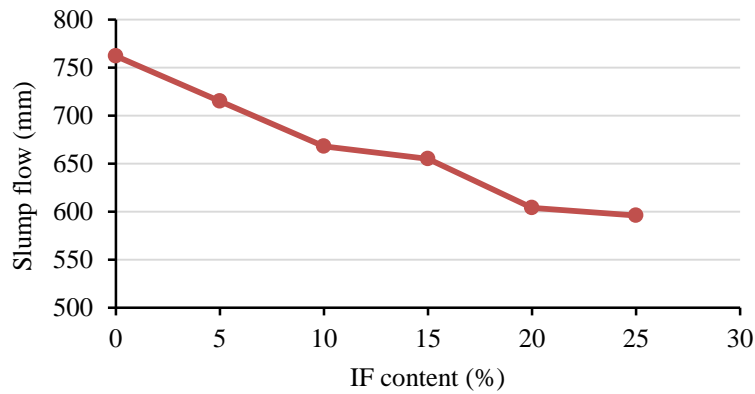


Figure 3: Effect of IF substitution on slump flows of SCC.

The slump flows of all the SCC mixes fall within different categories of classes according to EFNARC (2005). Control SCC (0% IF replacement) falls under Slump-Flow class 3 (SF3) with slump flows ranging from 760 to 850 mm and suitable for densely reinforced concrete structures, while SCC with 5% to 15% IF replacement fall under SF2 with slump flows ranging from 660 to 750 mm and found applicable in walls and columns. In addition, SCC with 20% and 25% IF replacement fall under SF1 with slump flows ranging from 550 to 650 mm and appropriate for housing, tunnel, pile and deep foundation construction works. It can be inferred from these classifications that the flowability of SCC mixes declined as the IF content increased. The highest slump was attained by Control SCC. For SCC with up to 15% IF, the reduction in workability was negligible. However, increasing the IF content above 15% resulted in a significant reduction in SCC workability. This agrees with the findings reported by Miah et al. (2020) for conventional concrete where the loss of workability was recorded with increase in the addition of

recycled iron powder as partial replacement for natural sand. Contrary to these findings in the present study, Al-hashimi et al. (2018) reported an increase in workability of fresh conventional concrete as the IF content increased.

$T_{500 \text{ mm}}$ (sec) slump flow

The $T_{500 \text{ mm}}$ (sec) flow time indicating the rate of flow of SCC mixtures is illustrated in Figure 4. The results show that the $T_{500 \text{ mm}}$ (sec) flow time ranging between 2.2 and 3.4 secs fall in the category of VS2 according to EFNARC (2005). It can be deduced from the results that the $T_{500 \text{ mm}}$ (sec) flow time increased as the IF content increased. According to Mark (2021), at lower water-binder ratio and higher IF content, the kinetic energy increases, leading to increase in $T_{500 \text{ mm}}$ (sec) flow time. The lowest $T_{500 \text{ mm}}$ (sec) flow time exhibited by control SCC implies the highest workability. In contrast, the maximum $T_{500 \text{ mm}}$ (sec) flow time at 25% IF contents showed the negative influence of IF in SCC especially at higher substitution rate.

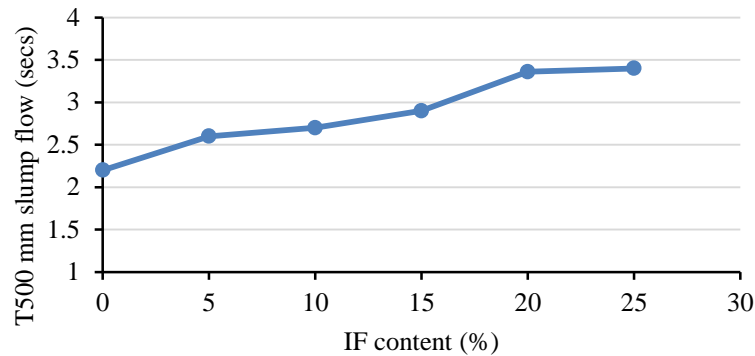


Figure 4: Effect of IF substitution on slump flow of SCC.

L-Box ratio

Figure 5 shows the effects of the L-box ratio or blocking ratio (H_2/H_1), which indicates the capacity of fresh SCC to move through a compact or restricted zone. According to EFNARC (2005), the L-box ratios varied between 0.83 and 0.98, and they fell into the PA2 category. It can be deduced from the results that the L-box ratios decreased as the IF contents increased. However, all the SCC mixes were within the acceptable range of L-box ratios of 0.8 to 1.0 specified by EFNARC (2005). These findings indicate that IF is

appropriate for use as replacement for river sand in SCC production for civil engineering infrastructures. The maximum value of L-box ratio was observed for the control SCC, which is an indication of higher fluidity. In contrast, minimum value of L-box ratio which was attained for 25% IF contents showed the negative influence of IF in SCC on the fluidity of SCC especially at higher substitution rate (Okamura and Masahiro 2003, Jagadeesh et al. 2017).

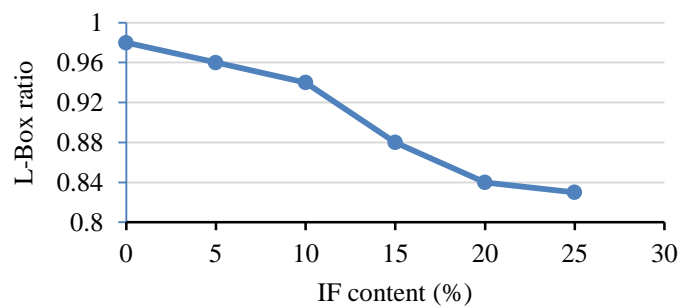


Figure 5: Effect of IF substitution on L-box ratio of SCC.

V-Funnel time

The results of V-funnel time indicating the segregation resistance of SCC are presented in Figure 6. The results revealed that the V-funnel time ranged from 2.35 to 3.80 secs. These results indicated that the V-funnel time increased as the IF content increased, which is

the similar trend observed for $T_{500\text{ mm}}$ (sec) flow time. However, despite the higher V-funnel time recorded for SCC containing IF, the values obtained fall within the category of V-Funnel time class 1 (VF 1) with the V-funnel time of less than 8 as recommended by EFNARC (2005). The lowest V-funnel time

recorded for control SCC is an indication of smooth flow of SCC (Sandhu and Siddique 2019). However, the inclusion of IF increased the volume fraction and surface area of SCC, leading to increase in concrete viscosity and the subsequent increase in the flow time of

concrete (Kim et al. 2007). These results agree with the findings of Jagadeesh et al. (2017), where the V-funnel time of SCC increased with increase in the addition of manufactured sand and recycled clay roof tile as partial replacement for sand and granite, respectively.

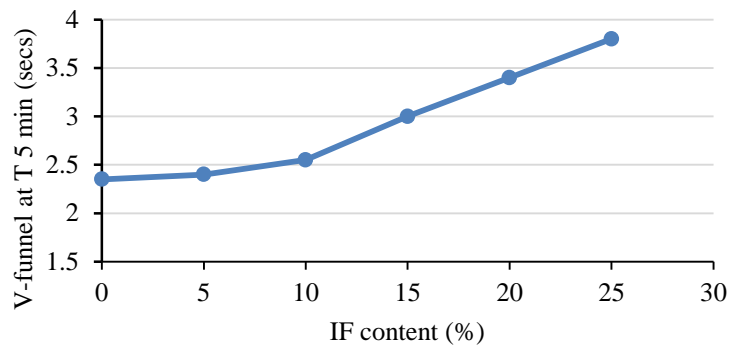


Figure 6: Effect of IF substitution on V-funnel time of SCC.

Hardened SCC properties **Compressive strength**

The compressive strength results of SCC are presented in Figure 7. The results show that the compressive strength of the SCC increased as the IF contents increased from 0% to 15% replacement, but began to decrease as the IF contents increased from 15% to 25% replacement for all curing ages. In addition, the compressive strength increased for each percentage of IF replacement as the curing age increased. This agrees with the findings in the previous studies (Raheem and Kareem 2017, Kareem et al. 2021) where the concrete strength increased with curing ages. For the control SCC, the compressive strengths were 23.4 N/mm², 26.0 N/mm², 29.6 N/mm² and

33.3 N/mm² at 7, 14, 21 and 28 days, respectively. The 28-day compressive strength of the control was higher than the design strength of 30 N/mm². At 7 days of curing, the compressive strength for SCC with 5% to 15% IF replacement showed increasing trend of 1.47%, 3.60%, 3.69% with respect to the control SCC. However, the compressive strength decreased by 7.63% and 9.80% at 20% and 25% IF replacement, respectively, with respect to the control SCC. At 28 days of curing, all of the concrete incorporating IF had compressive strengths greater than the design strength of 30 N/mm². SCC containing 15% IF, on the other hand, had the highest compressive strength value.

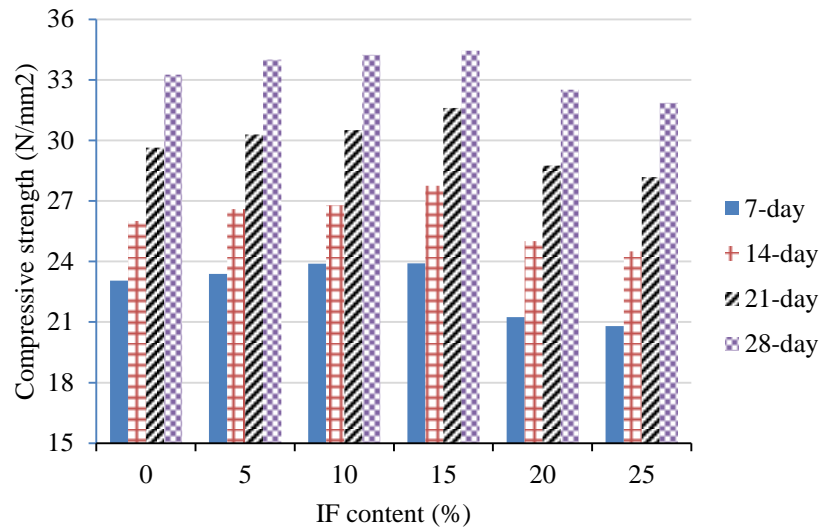


Figure 7: Effects of IF substitution on compressive strength of SCC

The compressive strength of the SCC showed a similar trend at 14 and 21 days after curing as the 7-day compressive strength. At these curing ages, the SCC with 15% IF also had the highest compressive strength when compared to the control SCC. At 28 days, the percentage increase in compressive strength were 2.23%, 2.95%, 3.46% with increase in IF contents at 5, 10 and 15% IF replacement, respectively. However, the compressive strength decreased by 2.26% and 4.18% with increase in IF replacement at 20% and 25%, respectively, compared to the control SCC. Again, SCC containing 15% IF showed maximum compressive strength compared to the control SCC. These results are in agreement with the previous findings (Ismail and Al-hashimi 2008), though the maximum compressive strength was attained with 20% waste iron as partial replacement for sand in conventional concrete. Alzaed (2014) and Olutoge et al. (2016) also provided comparable results in conventional concrete. The findings from the present study suggest that the optimum of 15% IF is suitable as replacement for sand in SCC. The increase in compressive strength of the SCC which occurred at the 15%

IF replacement can be attributed to the filling of void of concrete by IF which made the concrete denser and durable leading to increase in compressive strength (Al-hashimi et al. 2018). The decrease in concrete compressive strength observed after 15% IF replacement could be attributed to IF's lower fineness modulus compared to sand, resulting in a higher demand for cement in the SCC mix. Furthermore, the higher water absorption rate of IF compared to sand will reduce the amount of water needed for hydration, which can affect the SCC strength (Alzaed 2014, Olutoge et al. 2016). As a result, it was easy to infer that increasing the replacement value of sand with IF above 15% in SCC may be detrimental to the concrete's compressive strength.

Splitting tensile strength

The splitting tensile strength results of SCC are presented in Figure 8. The splitting tensile strength results showed similar trend as the compressive strength, i.e., as the curing age increased, the splitting tensile strength increased with each percentage of IF replacement. The control SCC splitting tensile strength values were 2.55 N/mm², 2.91 N/mm²,

3.28 N/mm², and 3.64 N/mm² at 7, 14, 21, and 28 days, respectively, as shown in Figure 8. In comparison to the control SCC, the percentage increase in splitting tensile strength after 7 days, were 1.54%, 4.85% and 8.63% at 5, 10 and 15% IF replacement, respectively. In contrast, the percentage decrease of 3.92% and 7.45% were recorded for SCC with 20% and 25% IF replacement, respectively, with respect

to the control SCC. The maximum splitting tensile strength was achieved for the SCC containing 15% IF at 7 days. At 14 and 21 days of curing, a similar pattern of 7-day splitting tensile strength was observed, and the maximum splitting tensile strength was also achieved for the SCC with 15% IF replacement at these curing ages.

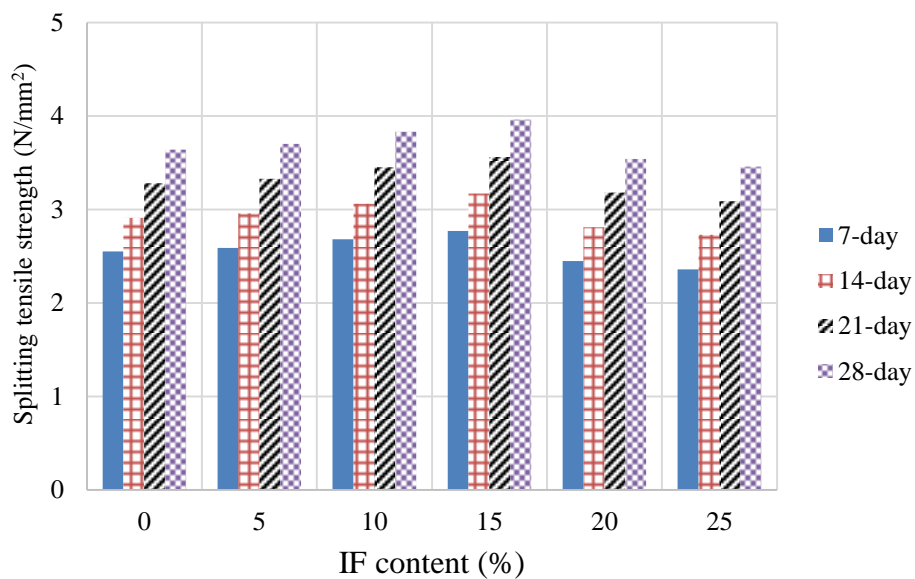


Figure 8: Effects of IF substitution on splitting tensile strength of SCC.

With upsurge in the addition of IF from 5% to 15%, the percentage increase in splitting tensile strength were 1.62%, 5.22% and 8.08% at 28 days. Conversely, the splitting tensile strength decreased by 2.75% and 4.95% with increase in IF replacement from 20% and 25%, respectively. The highest splitting tensile strength value was also achieved for SCC containing 15% IF as replacement for sand. This corroborates the findings from the previous study by Al-hashimi et al. (2018), where the maximum splitting tensile strength value was attained with 15% IF as partial replacement for sand in conventional concrete. Olutoge et al. (2016) also provided similar results in conventional concrete, although the maximum splitting tensile strength value was

recorded at 10% IF as partial replacement for fine aggregate. The results from the current study suggest that the optimum of 15% IF is suitable as replacement for sand in SCC. The increase in splitting tensile strength of SCC which occur at the 15% IF replacement can be ascribed to the strength toughness of IFs as well as the pozzolanic properties exhibited by IF (Al-hashimi et al. 2018). In addition, the increase in splitting tensile strength can also be related to the ductility of IF. Conversely, the decrease in the SCC splitting tensile strength observed after 15% IF replacement could be attributed to the IF's lower fineness modulus compared to sand, resulting in a higher demand for cement in the SCC mix.

Conclusions

The purpose of this study was to evaluate the fresh and hardened properties of SCC using IF as partial replacement for sand. The findings indicated that all the SCC mixes met the recommended fresh properties requirements for filling capacity, passing ability, and segregation resistance. The slump flow and L-box ratio declined with rise in IF content. Nonetheless, the $T_{500\text{ mm}}$ flow time increased with rise in IF content. SCC with IF above 15%, on the other hand, showed a decrease in fluidity, suggesting increased viscosity. The incorporation of 15% IF increased the compressive strength by 3.69% and 3.46% at both 7 and 28 days. However, as the IF contents increased above 15%, the compressive strength decreased. It was also noticed that the addition of IF up to 15% increased the SCC splitting tensile strength up to 8.63% and 8.08% in both 7 and 28 days. In contrast, as the IF contents were increased above 15%, the splitting tensile strength decreased. Therefore, the use of 15% IF as a sand substitute is ideal for improving the fresh and hardened properties of SCC.

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