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Investigating the Influence of Recycled Coarse Aggregate and Steel Fiber on the Rheological and Mechanical Properties of Self-Compacting Geopolymer Concrete

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ABSTRACT

This experimental study presents the effect of steel fiber (SF) and recycled coarse aggregate (RCA) on the fresh and hardened properties of Self-compacting geopolymer concrete (SCGC). Sixteenth alkali-activated based metakaolin (MK) concrete mixtures with constant binder content of 500 kg/m^3 incorporated 0, 0.5, 1.0, and 1.5% volume fraction of SF and 0, 10, 20, and 30% RCA as a partially replacement for natural coarse aggregate (NCA) with sodium hydroxide concentration of 12 Molarity at ambient conditions. Fresh state of SCGC were examined slump flow, T_{500} flow, V-funnel, and L-box test. At 28 and 90 days the compressive strength and splitting tensile strength were investigated, the flexural strength was evaluated at 90 days. The results highlighted that RCA (30%) and SF (1.5%) significantly constrain the fresh properties of SCGC mixes. Moreover, SCGC incorporated RCA can be produced with compressive strength as high as 31.91-41.13 at 28 and 90 days, respectively. However, 1% SF and 30% RCA in MK-based SCGC appear better performance than the control mixture and leads to an ecologically friendly concrete mix that has appropriate hardening properties and that would contribute to the longevity of the construction industry.

1. INTRODUCTION

One of central industries that adds to emissions of greenhouse gases is the concrete production industry [1]. It has been figured out that manufacturing of cements results in emissions of large amount of carbon dioxides CO_2, both in direct and indirect ways [2] owing to the burning of fossil fuels and heating of limestone to make cement, which is done through the process of calcination [3]. Various researches were presented on the previously-stated components where different technique and method were used and controlled to lower productions of carbon on a global scale [4]. Utilizing supplemental cementitious material (SCM) as partially substitute of traditional cement material [5], or the process of an entirely advanced binders, which does not include cement, called geopolymers (GPs), are highly effective in fulfilling the objective of reducing carbon. GPs are yet a developed cementitious materials produced by the blending base materials to high quantity of silica and alumina [6]. A reduction in the flow of CO_2 by involving geological products in concretes are probably the essential goal for the nascent interests in GPs when compared with various concrete types [7]. Taking advantage of GPs instead of consuming cement concretes in order to decrease the outflowing of CO_2 is very matter in the presented research [8]. GPs are aluminosilicate binder, in another side slag and fly ash-based material comprise huge calcium contents that called alkali-activated substances. Geopolymerization might be defined as the reactions of alumina substances plus unformed silica together 1with alkali, which makes shapeless binders of aluminosilicate [9]. Slag and fly ash could comprise geopolymer. These are secondary substances, or products from geological origins like straw, wheats, ashes, and MK [9]. GP may be implemented in the construction industries, used as filler materials, due to its fireproof qualities [10]. MK is a new mixed-pozzolanic supplemental cementitious substance [11], that is different than other available supplemental cementitious materials because it is made under a controlled environment [12]. As a result of MK significant reactivity and due to compatible ratio of silica to alumina which are essential factor for geopolymerization, MK was classified in the last ten years as an effective substance for the composition of GP binder [13]. MK could be thought of as an acceptable precursor for the GP manufacturing due to the knowable characteristic and reactivity through the GP production [10]. Researches assessed the MK-geopolymers as substitute binder instead of cement [14]. Studies have figured out that metakaolin significantly increases the compressive strengths, as mixing of 8% of MK produced increment in the concrete compressive strengths by more than 40% in 28 days [15]. Metakaolin has favorable impression on both the fresh and hardened property of concrete and has been shown to inhibit drying shrinkage [16].

To ensure the required durability and strengths durability of traditional concretes, compactions are necessary. The quality, durability, and strength are dramatically affected by insufficient compactions [17]. Normal concrete has issues in terms of compaction, but to bypass that, self-compacting concrete (SCC) was introduced as substitute of normal concrete [18]. Geopolymer concrete also naturally has a high viscosity and is less workable. In order to solve the high viscosity problem, SCGCs were developed in 2011. SCC does not need any compactions process it flows and settles by its own weights. SCC is characterized and evaluated by the capabilities to resist segregation, ability to slow, and settle. Coarse aggregate (CA) volume should be a maximum of 20 mm when used for SCC production [19].

The cement industry is expected to move closer to developing sustainable materials for construction by taking advantage of the benefits offered by combining geopolymer binders and RCA waste. During the last several years, various reports on geopolymer composite properties, when formed from recycled aggregate, have been written and published. A large number of researchers concluded successful applications of RCA interpolymer concrete [20]. The use of RCA reduces the demand for natural aggregates in engineering structures by reducing the consumption of non-renewable natural resources. Moreover, solves the problem of environmental pollution caused by waste concrete. Consequently, it has attracted a lot of attention from both the environmental and resource preservations [21]. Recently, fine RCA has also been used for manufacturing geopolymer mortar [22]. Mohseni et al. [23] assessed the impact of RCA on self-compacting concrete which has also been reinforced with fiber. The utilization of the wastes of constructions can consequentially improves the sustainability of the construction industry. According to the results, RCAs are eco-friendly materials that may be utilized in constructions and that also had adequate mechanical behavior in the comparison with traditional concrete, made with the addition of natural aggregate. On the other hand, due to the fact that RCA is not as strong as natural aggregate [24], the geopolymer composite made by incorporating RCA shows a less optimal performances compared with natural aggregates incorporation. The compressive strengths of GP went down by approximately 7-24% when coarse RCA utilized, compared to when natural aggregates were used [25]. In addition, RCA's inclusion into geopolymer mortar also decreased the acid resistance of the composite, not just its mechanical characteristics and properties [22]. Moreover, when triceratopses do not have any reinforcements, their ability to respond to tensions stress is significantly decreased, and if the tension and elasticity exceed their maximum limits (30GPa), first micro-crack appears in the concrete elements, then macro crack, failures happen finally [26]. Steel corrodes if water and various unwanted materials enter the cracks. Consequentially, the micro-crack plays significant roles in the durability of concretes [27].

Additions of fibers into cementitious materials is one way to improve their performance. It has been established that fiber usage in cements-base mixtures is extremely useful in the developing the resistance of concrete against the micro- and macro-cracks [28]. Various types of fibers are accessible commercially like nylon, glasses, steel, and synthetic and nature fibers [29]. It was found that steel fibers or strand or fibers have a positive effect on the bending strengths of the GP composite [30]. In yet another research piece, the researchers incorporated steel strands into fly ash-based GP and discovered that the concrete's capacity was improved till 22% [31].

Using recycled aggregate leads to concrete with low durability; so that, it is important to include the fibers in the concrete [32]. There is no extensive information available in the literature about the combined utilization of SF and RCA in the metakaolin-based self-compacting geopolymer concrete which demonstrates the novelty of this research. The aim of this research is to have a sustainable concrete with improved properties by adding steel fiber and recycled aggregate to evaluate the various aspects of geopolymer composites. This study will determine the suitability of recycled aggregate and steel fiber in geopolymer concrete. The mechanical and fresh characteristics were assessed. Our research assists by making the construction and concrete industry sustainable due to making cement-free concrete.

2. EXPERIMENTAL PROGRAM

2.1 Materials

MK, as illustrated in Figure 1, is applied as the base substance, that had prepared in calcining the kaolin. Kaolin clays were collected from Al-Anbar, Iraq. The kaolin was first grinded and afterward burned in a furnace at 700°C±20°C, for one hour, to form metakaolin. In the experimental program X-ray diffraction (XRD) spectra analyses and Scanning electron microscopy (SEM) were carried out on MK as shown in Figure 2 and Figure 3. The physical properties and chemical compositions of MK are completely suitable to meet the specifications of Pozzolan ASTM C618 [33], which are figured out within Table 1. The alkaline or basic solution used for the SCGC mixtures is a composition of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions, which are involved as an activator for the mix. The chemical compositions of the Na_2SiO_3 solution are (Na_2O=10.600%, SiO_2=26.500% and density=1.390g/ml at 25.00°C). Along with that, NaOH in the form of flakes (98.00% purity) was used. The alkaline solution was formed 24 hours before utilization. A superplasticizer based on a formulation of a polycarboxylic-ether mix, with a specific gravity of 1.08±0.02 and a pH value of 7±1 was utilized in all mixtures for attaining the necessary slump value for fresh SCGC.

Fine steel fibers were utilized in the experimental program to improve the SCGC ductility. The steel fibers shown in Figure 4 are straight and copper-coated 13 mm in length and 0.20 mm in diameter. The fibers' properties are illustrated in Table 2.

Figure 1. Metakaolin

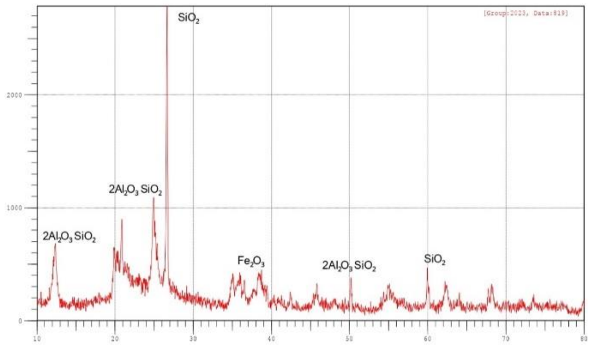


Figure 2. XRD spectra of metakaolin

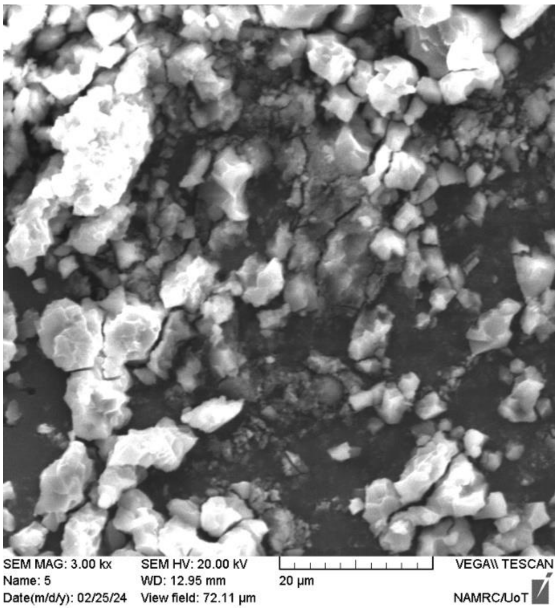


Figure 3. Scanning electron microscopy (SEM) of metakaolin

Figure 4. Steel fiber

Natural sand was used as a fine aggregate. The maximum size of the sand is 4.75 mm, its specific gravity is 2.63, and its absorption is 1.5%. these properties are all within the limits of BS.882 [34]. The grading of fine aggregate is shown in Figure 5. Crushed gravel was implemented as a coarse aggregate, having a maximum size of 19mm, and acquired from the Euphrates River in the Anbar Province, Iraq. It complies with [35]. Coarse recycled aggregate and coarse natural aggregate are shown in Figures 6 and 7. The RCA was acquired from a destroyed building in the local area; the RCA's physical properties and grading are figured out in Table 3 and Figure 8.

Table 1. Physical properties and chemical composition of metakaolin

Test Items	Result
SiO_2	52.10
Al_2O_3	43.80
Fe_2O_3	2.60
Ca O	0.20
MgO	0.210
SO_3	0.00
K_2O	0.320
Na_2O	0.110
L.O.I	0.990
PH	6.0-8.0
Surface area (m^2/g)	2.540
Specific gravities	2.600

Table 2. Properties of steel fiber

Characteristics	Specification
State	Copper coated
Density	7860.00 kg/m^3
Tensile capacity	>2400.00 MPa
Shape	Straight
Melt	1500℃
Length	13±1 mm
Dia.	0.2 mm±0.02 mm

Table 3. Physical properties of NCA and RCA

Coarse Aggregates	Size (mm)	Specific Gravity S.S.D	Absorptions (%)
NCA	5-19	2.65	1.00
RCA	5-19	2.62	2.18

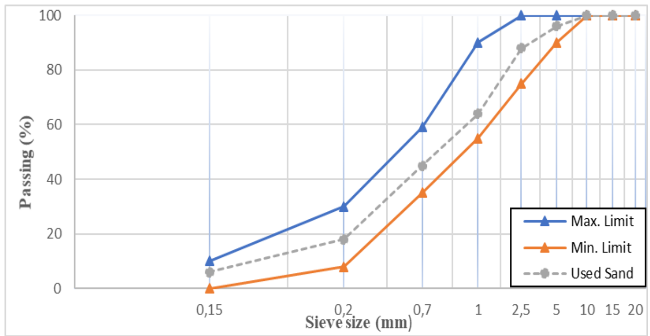


Figure 5. Grading of fine aggregate

Figure 6. Coarse recycled aggregate

Figure 7. Coarse natural aggregate

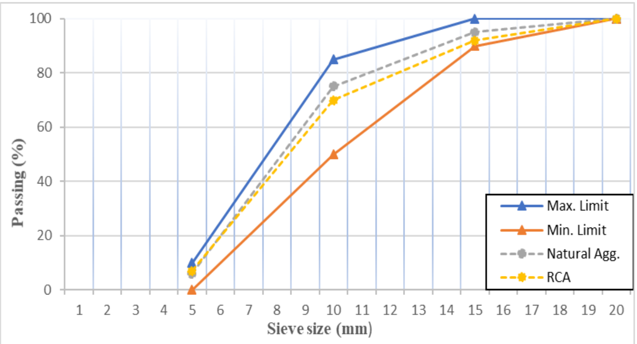


Figure 8. Grading of NCA and RCA

2.2 Mix proportion and Specimens preparation

Various series of SCGC mixtures were made, with a constant overall binder amount of 500 kg/m^3, sodium hydroxide concentrations of 12M while curing occurs in lab temperature, 8% superplasticizer, 24% extra-water, and RCA was used as replacement to NCA at a rate of 0, 10, 20, and 30% by their weight, and each percentage was mixed with 0%, 0.5%, 1%, and 1.5% steel fiber. The control concrete mixture had natural coarse aggregate and 0% SF incorporated in it. In this experimental study, all details for binder, activator, RCA and SF as shown in Table 4.

First, all mixtures need the initial combining of dry ingredients such as aggregates and MK in a pan mixer for a maximum m 2.5 min, in dry conditions. Then, an adequately shaken and premixed liquid mixture is added; this mixture is comprised of a superplasticizer, alkaline solution, and extra water, which is then mixed together for 3 min in order to create a uniform mixture. After homogenization, newly mixed concrete was assessed with critical workability tests like slump flow, T_{500} flow, V-funnel, and, L-box test, which were applied in order to describe the SCGC mixture. As soon as the workability of the freshly mixed SCGC mixture was verified, it was poured into molds (cylinders, cubes, beams), without compaction, because the mixtures' own weight works to fill in all the voids and pockets. In addition to that, cubes of 100.00×100.00×100.00 mm dimensions were performed to measure compressive strengths using ASTM C39 [36], cylinders (Ø 100.00×200.00 mm) had utilized for split tensile strength, and 100.00×100.00×400.00 mm beams specimens utilized for flexural strengths of the SCGC mixtures. After 28 and 90 days of curing, compressive, splitting tensile, and flexural were measured by testing 3 samples for each mixture. Samples were tested based on ASTM C496 [37] and ASTM C78 [38] guidelines for tensile and flexural strengths, respectively. The next day after casting, the samples were taken from their moulds and stored in a curing room with an ambient, controlled temperature until the testing day.

2.3 Testing methods

2.3.1. Fresh properties of SCGC

The fresh states of concrete mixes should fulfill the specifications for filling and passing ability without the occurrence of bleeding or segregation. Therefore, these specimens were subject to fresh-state tests immediately after mixing. The filling capacities (V-Funnel, slump flow) and flowing abilities (L-box) of SCGC are calculated according to EFNARC [39] as in Figure 9.

2.3.2. Hardened properties of SCGC

Hardened state tests had implemented to assess the combination of the effects of RCA and SF on the mechanical properties of the SCGC. Compressive strength tests were done on cubic samples (100.00×100.00×100.00 mm). Cylindrical samples (200.00 mm×100.00 mm) were cast to measure the splitting tensile strength of SCGC with various percentages of RCA and SF incorporated in. In a similar fashion, prisms (400.00×100.00×100.00 mm) were utilized to analyze the flexural strength of the SCGC mixtures, as figured out in Figure 10.

Table 4. Mix proportions of SCGC (units in kg)

Mix Code	Precursors	Activators		Aggregate			SF
	Metakaolin	Sodium Hydroxide	Sodium Silicate	NCA	RCA	FA	
RCA0-SF0 (control)	500	64.34	160.56	787.3	0	926.6	0
RCA0-SF0.5	500	64.34	160.56	787.3	0	926.6	39.3
RCA0-SF1	500	64.34	160.56	787.3	0	926.6	78.5
RCA0-SF1.5	500	64.34	160.56	787.3	0	926.6	117.8
RCA10-SF0	500	64.34	160.56	708.6	78.73	926.6	0
RCA10-SF0.5	500	64.34	160.56	708.6	78.73	926.6	39.3
RCA10-SF1	500	64.34	160.56	708.6	78.73	926.6	78.5
RCA10-SF1.5	500	64.34	160.56	708.6	78.73	926.6	117.8
RCA20-SF0	500	64.34	160.56	629.8	157.5	926.6	0
RCA20-SF0.5	500	64.34	160.56	629.8	157.5	926.6	39.3
RCA20-SF1	500	64.34	160.56	629.8	157.5	926.6	78.5
RCA20-SF1.5	500	64.34	160.56	629.8	157.5	926.6	117.8
RCA30-SF0	500	64.34	160.56	551.1	236.2	926.6	0
RCA30-SF0.5	500	64.34	160.56	551.1	236.2	926.6	39.3
RCA30-SF1	500	64.34	160.56	551.1	236.2	926.6	78.5
RCA30-SF1.5	500	64.34	160.56	551.1	236.2	926.6	117.8

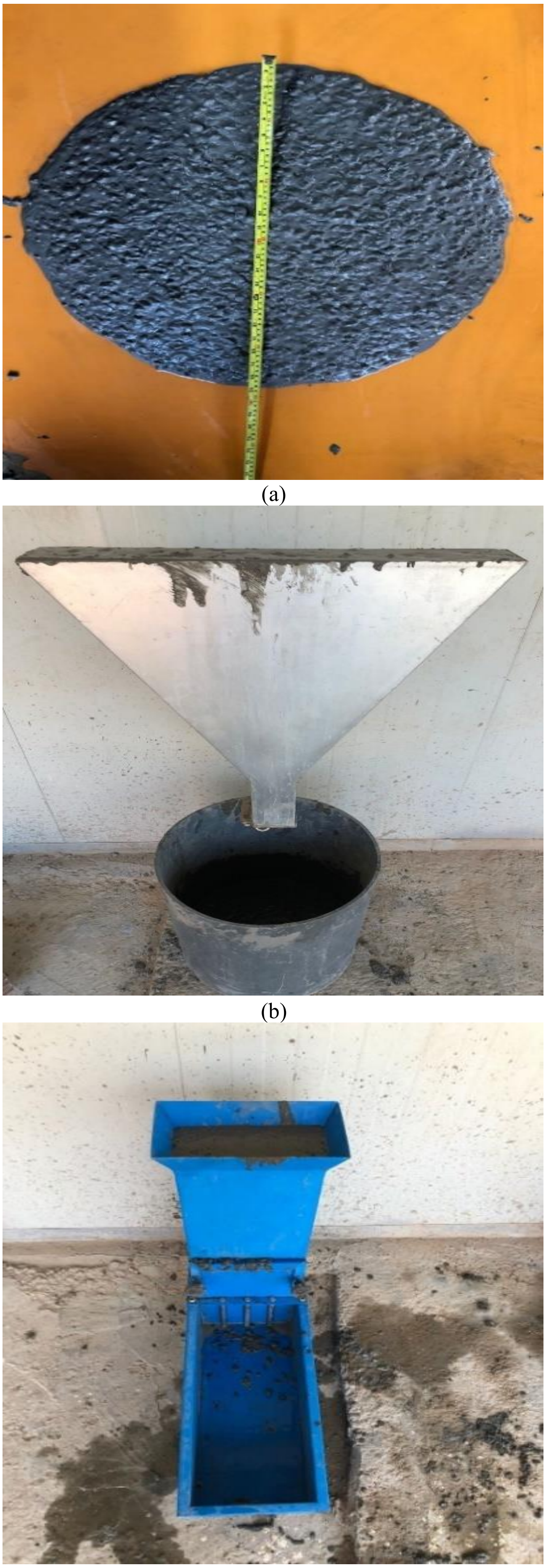
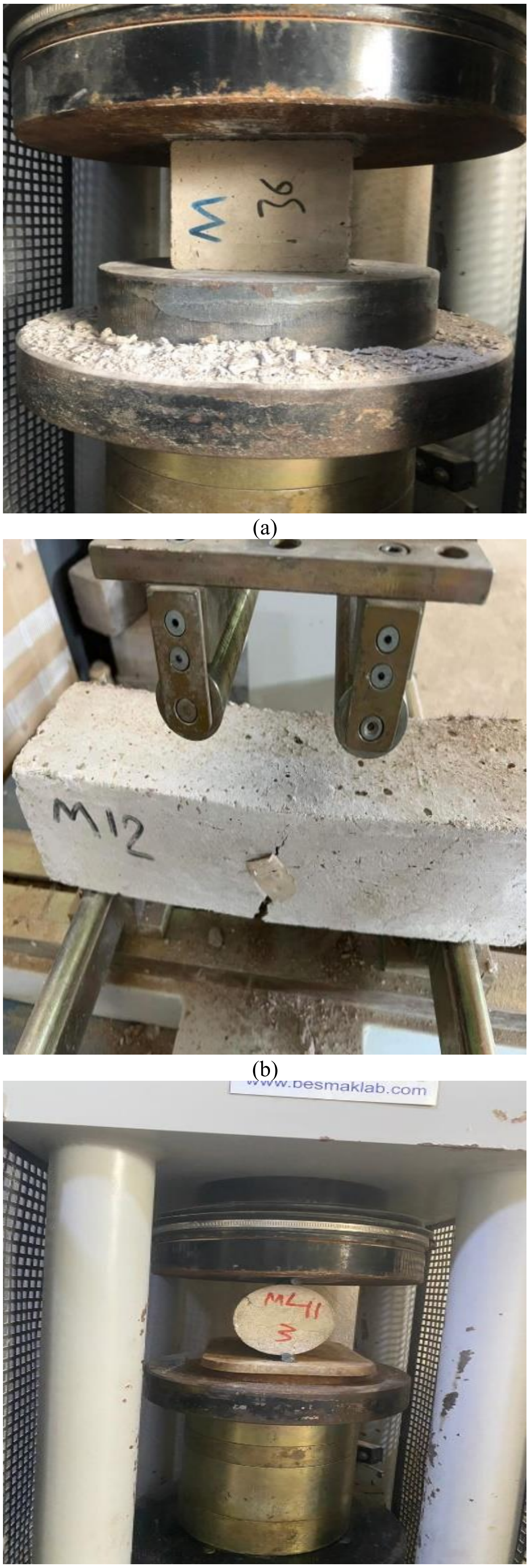

(a)
(b)
(c)

Figure 9. Workability tests on SCGC mixture: a) Slump flow; b) V-funnel Test; c) L-Box



(a)
(b)
(c)

Figure 10. Mechanical tests on SCGC mixture: a) Compress strength; b) Flex strength; c) Split. strength

3. RESULTS AND DISCUSSIONS

3.1 Fresh properties of SCGC

3.1.1. Slump-flow diameter

Figure 11 demonstrates the effect of RCA and SF over the diameter of the slump-flows. The largest diameter of slump flows is 731 mm and have been found in the control mixture (without RCA and SF). The addition of RCA decreased over the diameter of the slump-flows of the non-SF samples from 731 mm (without RCA) to 691 mm (30% RCA). The RCA being more porous and coated fully or partially with an old mortar layer for that shows less flow [17]. The incorporation of SF reduced the diameter of the slump-flows of the samples starting from 731 mm (0% SF) to 689 mm (1.5% SF). The reductions in diameter of the slump-flows resulting from adding 1.5% SF is larger than the decrease from adding 30% RCA. Moreover, the combination of SF and RCA reduced the diameter of the slump-flows significantly. The lowest diameter of the slump-flows was 653 mm, and it was noticed in the samples that included the largest percentages of both RCA (30%) and steel fiber (1.5%).

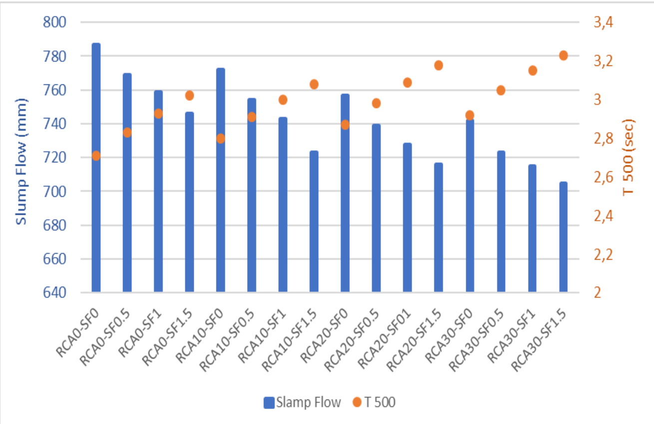


Figure 11. Slump flow and T_{500} results of SCGC mixture

3.1.2 Slump-flow time (T_{500})

The influences of SF and RCA on the time of slump-flow (T_{500}) is shown in Figure 11, which presents the shared influences of SF and RCA on the T_{500} periods. In this test, the time required for the flow diameters of fresh concretes to reach 500 mm is noted. T_{500} durations for specimens with 0%, 0.5%, 1%, and 1.5% SF, and no RCA, were measured at 4.32 s, 4.44 s, 4.53 s, and 4.62 s, respectively. These results are similar to those of previous studies adopted by Heweidak et al. [40]. However, for specimens with no SF incorporated, the T_{500} durations of 0%, 10%, 20%, and 30% RCA were 4.32 s, 4.39 s, 4.49 s, and 4.55 s, respectively. For the specimen with the maximum amount of SF and RCA, the T_{500} duration rose to 4.86s. In summary, T_{500} testing outputs had showed satisfying in accordance with EFNARC specifications.

3.1.3 V-funnel flow time

The V-funnel flow time is an experimental test that reflects the viscosity and flowability of SCGC. The time of discharging the SCGC from the V-funnel section showed similarities in the behavior compared to the slump-flow T_{500} experimental outputs. For specimens without RCA, the discharge times were recorded as 11.12 s, 11.34 s, 11.51 s, and 11.65 s for the 0%, 0.5%, 1%, and 1.5% steel fiber mixes, respectively. The discharging period for the non-fiber mixtures were 11.12 s, 11.23 s, 11.32 s, and 11.38 s for 0%, 10%, 20%, and 30% RCA, respectively. The influences of SF on discharging period were further significant than RCA's influences. Furthermore, the longest discharging period had noticed in samples that incorporated 30% RCA and 1.5% SF (combine influence) as figured out in Figure 12.

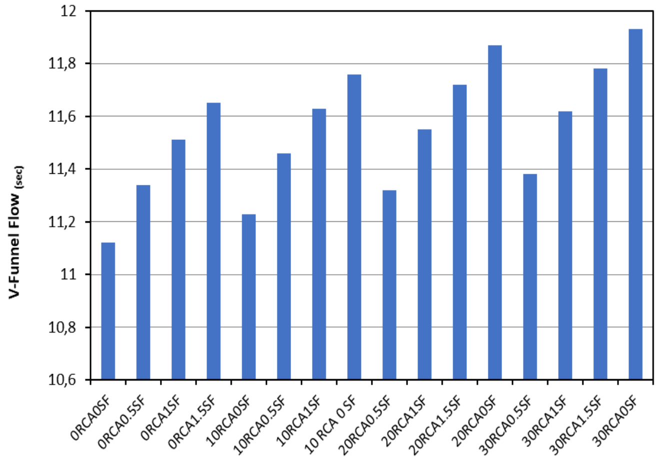


Figure 12. Test results of SCGC mixture (V-funnel test)

3.1.4 L-box height

In order to find the flowing abilities of the produced SCGC, the height percentage of L-box was found. The experimental program proffered the H2/H1 ratio as a method to measure the crossing abilities through reinforcement bars. Figure 13 shows the L-box test results of SCGC mixtures. The height percentage of L-box for a self-compacting concrete to get crossing abilities must be equal or more than 0.80. For materials that exhibit completely fluidly attitude, the ratio must be equal 1. In Figure 13, it was also figured out that all samples fulfill the EFNARC requirements for the L-box height ratios. There is an exception, however: the mixture containing 30% RCA and 1.5% SF does not meet these specifications. Another thing that can be observed is that this L-box ratio showed an inverse relation with the level of RCA replacements. Upon the RCA percentage increased, the height ratio decreased. On the other hand, incorporating SF into the 30% RCA mixture allowed for the SCGC to pass the limit ratio (less than 0.8).

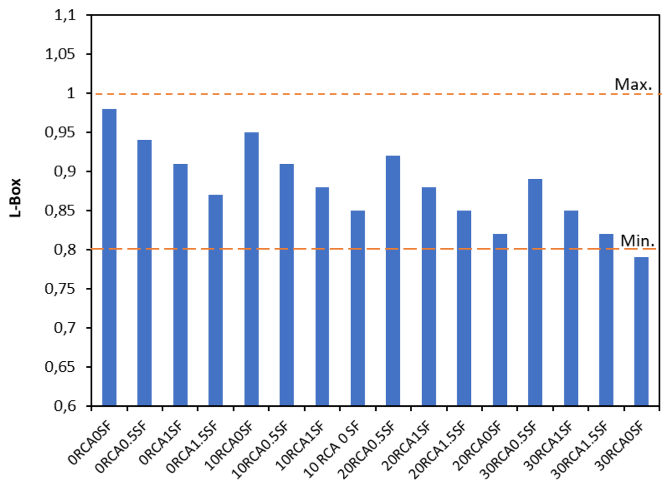


Figure 13. Test results of SCGC mixture (L-Box)

3.2 Mechanical properties of SCGC

3.2.1. Compressive strength of SCGC

Compression strength values of 28 and 90-day SCGC specimens are graphically illustrated in Figure 14. It could be figured out that compression capacities differed from 26.53 to 33.95 MPa and from 32.14 to 44.74 MPa at 28 and 90 days, respectively. However, it is clearly seen decrement in the compression strengths at 28 and 90 days and could be explained by the poor attitude of aggregates, which matches up with the incorporations of RCA in GP. For example, in comparison to control SCGC specimen, concrete samples of 28 days' age composed of 10%, 20%, and 30% of RCAs decreases the compression strengths 0.8%, 3.7%, and 6.1%, respectively, at a free ratio of steel. The lower strength of mixtures containing RCA is not only because of the porous cement mortar in RCA, which makes the aggregates weaker comparing with the natural aggregate, but it is also because of the weaker bonding of RCA and geopolymer matrix, which were assessed through SEM images. The SEM micrographs in the Interfacial Transition Zone (ITZ) of aggregate and geopolymer paste in control and 30 RCA mixtures are shown in Figure 15. As observed in this figure, the aggregate–paste interface of the control mix takes advantage of a dense and compacted microstructure Figure 15(b). In this context, a gap is observed in Figure 15(a) at the interface between the RCA and geopolymer paste, which is formed due to the presence of the masonry debris partially or fully remaining on the surface of RCA. This was a major contributor to the lower compressive strength of the mix [17].

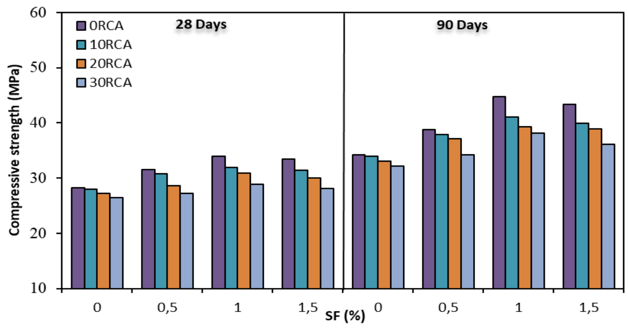


Figure 14. Compressive strength results

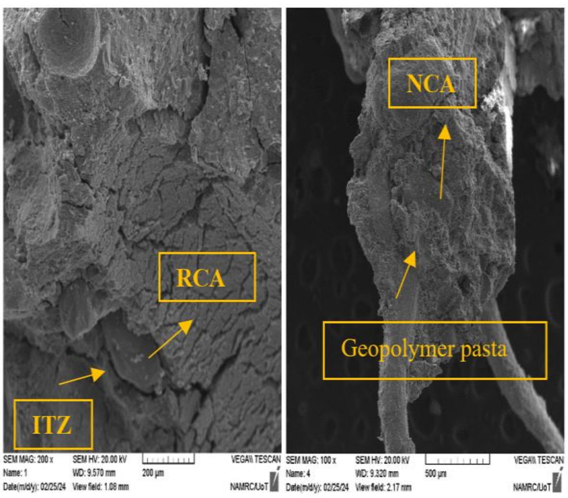


Figure 15. SEM image of geopolymer concrete incorporating: a) recycled coarse aggregate and b) normal aggregate

The addition of SF in SCGC partially increased its compressive-resistance abilities. It may be figured out that the strength increment reached the maximum at 1% SF content for all the different SCGC samples. By increasing the SF percentage to more than 1%, compressive strengths decrement was noticed parallel to the ratio increment of SF. The reduction in compressive strength after 1% dosage was due to the non-uniformity of fiber allocation in concrete mixture caused by unsuitable mixing and low workability, hence these fibers assemble and accumulate making weak points that act like voids which detract concrete total density and accordingly its compressive strength. Their and Özakça [41] concluded the same attitude of GP by adding SF. The value of compressive strengths of the control sample (excluding RCA and SF) and the samples includes the maximum quantity of RCA (30%) and SF (1.5%) are in proximity to each other's values. Using this evidence, it can be figured out that the decreasing impact of RCA having a diminished role on compressive strengths could be recovered by including SF in the mix.

3.2.2. Splitting tensile strength of SCGC

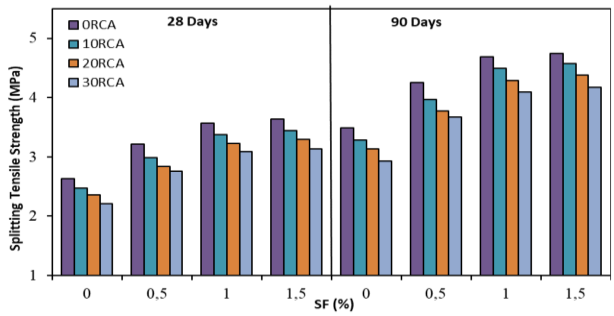


Figure 16. Splitting tensile strength results

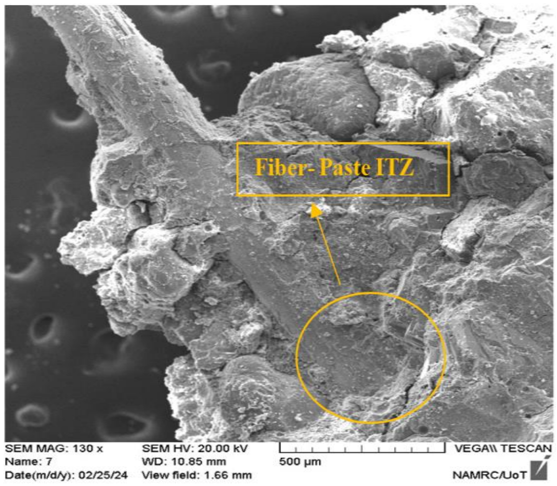


Figure 17. SEM micrograph of geopolymer concrete containing SF

The splitting tensile strengths of SCGC samples at 28 and 90 days was measured. Figure 16 also illustrates graphically these results. To determine the splitting tensile strength, 100.00×200.00 mm cylindrical samples have been used. The minimum values for the 28- and 90-day measurements were for SCGC with 30% coarse RCA and with 0% SF, recorded at 2.21 and 2.93 MPa, respectively. Moreover, the maximum splitting strengths outputs were measured at as much as 3.64 and 4.75 MPa at 28 and 90 days, respectively, for SCGC containing the natural aggregates, and 1.5% SF. The improvement is because of interaction between the fibers and micro- and macro-cracks shown in SEM micrograph (Figure 17). When the early cracks approach the fibers, the matrix interface diverts the path of the cracks; consequently, the fibrous concrete withstands additional load, leading to an increase in strength. It can be concluded that the fibers could bridge across the cracks and arrest the crack face separation during the crack propagation. The fibers sustain the load until pulling out of the matrix. This, as a result, leads to having higher fracture energy. The proper distributions of SF in the matrix causes consumption of additional energy during breakage or pulling out of the fibers, and this leads to higher toughness of the composite. However, it is shown that the SCGC's splitting tensile strength showed a decrease when natural aggregate was replaced with RCA, for all samples. For example, the splitting strengths evaluated at 28 days of RCA0-SF0 was 2.63 MPa, influence it had reached 2.47, 2.36, and 2.21 MPa for RCA10-SF0, RCA20-SF0 and RCA30-SF0 respectively. Likewise, the ninety days' splitting strengths of concretes had diminished with the implementation of RCA. The diminution in splitting strengths at age of 28 was within the range of 6 to 16%, and other samples cured for ninety days were from 7 to 17%. The SCGC attitude agrees with the conclusion that the study [42] reached: that the inclusion of RCA lowers the splitting strengths of concretes.

3.2.3. Flexural strength

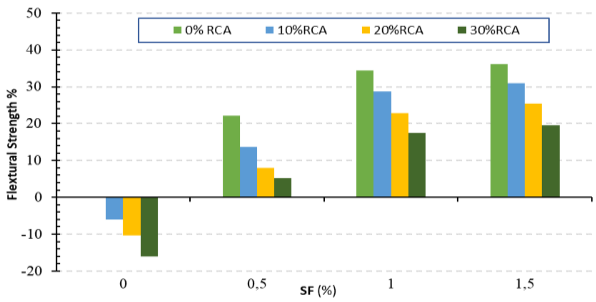


Figure 18. Flexural strength results

The impact of the volume concentration of RCA on bending strengths is like the impact of RCA on compressive and splitting strengths. It is noted that RCA had a negative influence on flexural strengths, which was the conclusion of the study [43], and as figured out in Figure 18. For plain mixtures, the decrease in flexural strengths was 6%, 10%, and 16% for RCA replacements of 10%, 20%, and 30%, respectively, in the formation of the comparative to the control sample. Utilizing SF in SCGC results in a large improvement in the samples' bending strengths. The control sample have flexural strengths of 4.01 MPa that increases to 4.90, 5.39, and 5.46MPa with 0.5%, 1%, and 1.5% SF, respectively, announcing a 36% development in the mixture with 1.5% SF incorporated. The highest value, 5.46 MPa, was attained for the mix with 0% RCA and 1.5% SF. Other researchers also observed a familiar reduction in strength with the inclusion of RCA in geopolymer concrete [44].

4. CONCLUSIONS

The mutual compacts of SF and RCA on the achievement of SCGC in fresh and hardened case were assessed in the present study. The experimental output achieved are detailed as the following:

- The test output of fresh SCGC showed that using RCA and SF simultaneously had affects negatively the diameter of slump flow, flow-time (T_{500}), flow-time of V-funnel, and flowing capacity of L-box. The most significant lowering in the fresh achievement was seen in the samples that incorporated the largest percentages of RCA (30%) and SF (1.5%). Whereas, even with the reduction, SCGC had acceptable passing and flow capacity values, as listed in EFNARC specification [37].
- All SCGC mixes that were produced were in the range for slump flow and V-funnel values. They also have adequate segregation and bleeding resistance based on EFNARC specifications.
- Compressive strengths were slightly reduced at age of 28 and 90 days with the addition of RCA into the SCGC mixes; meanwhile, additions of SF moderately enhanced the compressive strengths. Highest compression strengths of 33.45-43.32 (28- and 90-days' age) were achieved as a result of the integration impact of 1.5% SF and 0% RCA. The reduction of compression strengths by RCA can be made up for with the incorporation of steel fiber.
- The results indicate that SCGC mixtures that incorporated 10, 20, and 30% RCA had little decrement of approximately 1–5% in the compression strengths values at the comparison with control sample.
- The compression strengths lowered about 1% by SF inclusion, because of uneven dispersion of SF, which lead to a mass accumulation that eventually makes weakened areas in the concrete. These areas function as voids, subsequently causing decrement in concrete strengths.
- Adding SF led to a direct proportion in the split tensile value, while the increased use of RCA led to an inverse proportion to the tensile value. For example, the highest value was at (1.5% SF and 0% RCA) with value of 3.64 and 5.46 MPa at 28 and 90 days, respectively.
- The addition of SF improved the flexural strength for SCGC containing RCA 35% compared to the control mix without SF (30RCA-0SF), indicating that SF was able to overcome the negative effect of RCA on flexural strength.
- A decrease occurred in both flexural and splitting tensile strengths when using RCA, but both increased with the inclusion of SF.

5. RECOMMENDATIONS FOR FUTURE WORK

- In general, future work needs to be done to understand the Mercury Intrusion Porosimetry (MIP) to assess the porosity and the pore size distribution of SCGC based MK made with RCA, and SF.
- Replace metakaolin with fly ash at a rate not exceeding 15%, to increase the workability of SCGC mixtures.
- It is important to do an economic feasibility study to use RCA as a partial replacement of natural aggregate in SCGC industry.

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NOMENCLATURE

SCGC	Self-Compacting Geopolymer Concrete
MK	Metakaolin
RCA	Recycled Coarse Aggregate
SF	Steel Fiber