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# Enhancing Mechanical Properties of Fiber-Reinforced Self-Compacting Geopolymer Concrete Using Lightweight Aggregate

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**ABSTRACT**

The research aims to investigate SCGC performance as a suitable alternative to the traditional concrete. The research will study the effect of LWCA, steel fiber and curing condition on the fresh and hardened properties of SCGC. The main materials will be used for SCGC are fly ash and slag. Curing will be performed using oven, and ambient temperature. Steel fibers SF will be incorporated into the mixture at 0%, 0.5%, 1% and 1.5% of binder content. While the natural coarse aggregate will be replaced by LWCA with 0%, 33.3%, 66.67% and 100% by weight. Analysis of this (SCGC) were done for both fresh and hardened state to assess the mechanical properties of (SCGC). This study finds that the addition of both LWCA and SF decreased the blend's L-Box ratio and slump flow value. All SCGC mixtures fulfilled the EFNARC guidelines and standards. Results reported that Mixes with a greater percentage of LWCA and SF became more cohesive and viscous. Results revealed that the SCGC exposed into ambient air curing condition had lower flexural strength, compressive strength, and tensile strength than of heating curing condition. The compressive strength CS of samples(M1-M9) exposed to heating conditions compared to the ambient ones increased about 36.09%, 26.32%, 17.88%, 23.87%, 27.96%, 27.69%, 38.94%, 27.91% and 24.53% respectively. The better CS values were 38.94% for M7 mix and 36.08% for M1 Mixtures. The FS of samples exposed to heating conditions compared to the ambient ones increased about 13.39%, 13.39%, 23.78%, 18.64%, 17.85%, 11.67%, 34.70%, 8.65% and 12.24% respectively the better flexural strength value was 34.70%, of M7 mix exposed to heating conditions. The better TS value was 26.22 Mpa for M3 Mixes at 1.5% of SF, While the TS reported dropping about 38.4% when applying LWCA as partially replacement of 66.67% with ambient curing condition. The study findings that the (CS) of mixes were proportional directly with steel fibers percentage till (1.0%). The CS, FS and TS of SCGC decreased when increasing LWCA. As a result, the SCGC that cured in oven showed enhancement in each fresh and mechanical properties, therefore, it is recommend to utilize the (SCGC) in hot areas and utilize wastes such as steel fibers and LWCA in SCGC as an economic, affordable and eco-friendly material.

## 1. INTRODUCTION

Recycling and reusing waste materials is an eco-friendly material, it requires minimum energy in the production and emits minimum pollutants like carbon dioxide [1].

Traditionally, natural aggregates (NA) represent about three-fourth of concrete building percentage and work an important role in many different concrete characteristics such as the, durability, flexibility, compressive strength (CS) and stability. The application of different discarded waste and elements demonstrates the later uses in the building and construction industry as substitute to normal materials that can be used as a limited replacement for fine aggregate (FA) [2]. Geopolymer self-compacted concrete SCGC is an unorganized three-dimensional, semi-crystal structure with high acid and temperature renitence. Moreover, since geopolymers are an eco-friendly, they can apply as a green alternative to Portland cement (PC) [3].

SCGC has numerous advantages such as fireproof, low price, environmental sensitivity and permeability, in comparison with the PC [4].

Fly ash (FA), gels, ground granulated blast furnace slag GGBFS and red mud are the major binders more usually used by researchers [5-7]. Sodium silicate ($Na_2SiO_3$) (SS) and sodium hydroxide (NaOH) (SH) were used as main alkali activators. SCGC are with high performance can be produced by a specified mix ratio. Many studies revealed that SCGC show very high thermal resistance, minimizing curing period, and improvement mechanical properties comparing with ordinary concrete (OC) [8-11]. The researchers noticed increment on the mechanical parameters and durability improvement of geopolymer GP by adding fine materials and fibers [11-13]. Huge quantities of trash and debris material are disposed yearly due to the removal of aged buildings [14]. Engineers began to recycle several of these disposal and waste materials like a steel residuals and other slag in concrete [14] However, small ratio of waste material were recycled approximately about one - third and the rest were dumped in landfills, causing significant environmental impacts [15-17]. Therefore, eco-friendly concrete become necessity as sustainability goals to solve environment and energy problems. Light weight coarse aggregate (LWCA) represents one of such material. LWCA is a new kind of concrete designed by replacing natural aggregates partly or totally with (LWCA) [18]. The major recycled aggregate (RA) such as LWCA are waste that are cleaned and crushed, and mixed on a certain ratio [19]. However, the behavior of LWCA is dependent on the RA quality itself [20].

Due to its optimistic development and environmental conservation issues, many researchers have studied in-depth studies on RA. Recently, an attempt to create excellent GP by adding metallic fibers like steel fibers (SF) to geopolymer binders has been made [21].

A considerable amount of FA is produced as a result of the rising demand for energy, both domestically and industrially. In the previous 10 years, more than 1 billion tonnes of FA are produced per year. Given the significant costs associated with disposal, using these industrial by-products in the cement industry is a beneficial environmentally safe way to handle them. Because low-calcium FA (referred to as the "F" class) has pozzolanic qualities, it is frequently utilized as an additional cementitious material during the PC manufacturing process in an effort to reduce greenhouse gas emissions that arise from the usage of conventional pozzolanic aggregates. As reported by Vargas and Halog [22]. When 10% of these secondary raw materials are added to the mix, using industrial waste or by-product to replace clinker can lower $CO_2$ emissions by up to 12% [22].

This new material holds outstanding properties, adding steel fibers SF improve the flexural fatigue capacity, flexural toughness, and impact resistance [23]. By adding SF and using ambient temperature curing ATC, Ambily et al. successfully produced a slag-based geopolymer with a largest CS of 175 Mpa [21]. Brittleness is a characteristic of GP binders challenges that causes brittle failures [24]. SF could be used to solve it [25, 26]. Steel fibers can impact the mechanical properties of fresh SCGC, potentially lowering density, increasing segregation, decreasing flowability, and increasing viscosity. Dispersing discontinuous steel fibers at random can increase tensile, flexural, shear, impact, and shrinkage strength, while also limiting crack propagation. Studies on SF's impact on concrete properties are rare [27].

Because of the very strong interaction between the matrix and fibers, scientists noticed that SF and GP concretes worked better together than typical binder systems [28, 29]. According to Ding and Bai's findings [30], slag-based geopolymer mortars' CS increased as their SF quantity increased. While Koeing et al. detected a post-hardening response when SF was used, the CS declined as a result of the GP mixes' lower workability [31].

Bouteldja and et al evaluate the mechanical, characteristics of GP mortars produced from meta-kaolin (MK) and (GGBFS), activated with SS solution. CS and FS and were assessed. It was concluded that GP mixture consist of 75% alumina-silicate and 25% SH, with a ratio of (1:2) of liquid-to-solid and SS solution of 1.8 molar ratio of ($SiO_2/Na_2O$). This specific mixture produced the highest CS compared of the PC mortar [32]. As reported above, it is showed that more scholars about replaced the normal ingredients of concrete to produce SCGC. So, the FA and SF and dross are the major of the material which applied as a partly substitution. Additionally, the research revealed a development and enhancement about applying these elements. This research focused on enhancing the mechanical properties of SCGC as a suitable alternative to the traditional concrete. The research will study the effect of LWCA, SF, SP and curing condition on the mechanical properties of SCGC. Four mixing ratio of LWCA have been made with NCA, Each mixture reinforced with four mixing ratio of SF and SP Samples were exposed and cured under ambient air temperature ATC until test and others curing in oven at (70°C) for (72 hours).

## 2. EXPERIMENTAL WORK

### 2.1 Materials

The resources that will be used to produce the SCGC samples are low calcium fly ash FA and slag GGBFS as the source material, natural aggregate NCA, lightweight aggregates LWCA, as the filler, alkaline such as sodium hydroxide SH solution, sodium silicate SS solution were as binder and water with SP as workability measure. All materials used in this study are obtained from locally based suppliers.

2.1.1 Fly ash (FA)

FA, category F- based ASTM C618 was employed as binder agent. In this study light grey low calcium FA of 2.29 specific gravity, specific area of 8150 ($cm^2/gm$) and modulus of fineness of 4% was applied [33]. chemical composition as analyzed by X-ray diffraction was shown in Table 1.

**Table 1.** Chemical composition of FA

| **Component** | **CaO** | **$SiO_2$** | **$Al_2O_3$** | **$Fe_2O_3$** | **MgO** |
|---|---|---|---|---|---|
| % | 1.59 | 62.34 | 21.13 | 7.16 | 2.39 |
| **Component** | **$SO_3$** | **$K_2O$** | **$Na_2O$** | **LOI** | **SG** |
| % | 0.11 | 3.38 | 0.37 | 1.57 | 2.29 |

2.1.2 Ground granulated blast fiber slag (GGBFS)

GGBFS, a secondary product of blast furnace in metallic alloy fabrication, is applied with specific gravity of 2.62, specific area of 6515 ($cm^2/gm$). GGBFS is made up of about 40% of calcium oxide (CaO) with 30% - 40% of silicon dioxide ($SiO_2$). GGBS were produced by submerged the molten slag quickly by water after being tapped off. Table 2 shows the physical characteristics and chemical composition GGBFS as measured by X-ray diffraction. Moreover, GGBFS decreases hydration heat and improves the performance at long-term of PC [34].

**Table 2.** Chemical composition of GGBFS

| **Component** | **CaO** | **$SiO_2$** | **$Al_2O_3$** | **$Fe_2O_3$** | **MgO** |
|---|---|---|---|---|---|
| % | 41.33 | 31.89 | 15.46 | 0.95 | 5.68 |
| **Component** | **$SO_3$** | **$K_2O$** | **$Na_2O$** | **$TiO_2$** | **LOI** |
| % | 2.81 | 0.46 | 0.41 | 0.86 | 0.51 |

2.1.3 Aggregate

Natural coarse aggregate NCA, fine aggregate F.A and low weight coarse aggregate LWCA were used. Crushed limestone rocks of 1.2 specific gravity were used as LWCA. LWCA supplied from western desert, Anbar province, Iraq. NCA and F.A were supplied from Al-Nebaai area in Anbar province, Iraq. It used to produce SCGC with a high theoretical size of a 19 mm and specific gravity value of NCA is 2.75 and 2.46 for F.A as illustrated in Figure 1. It separated by sieve analysis and recombined it to meet the grading according to ASTM C330. LWCA Iraq were used with the same maximum nominal size of NCA [35].

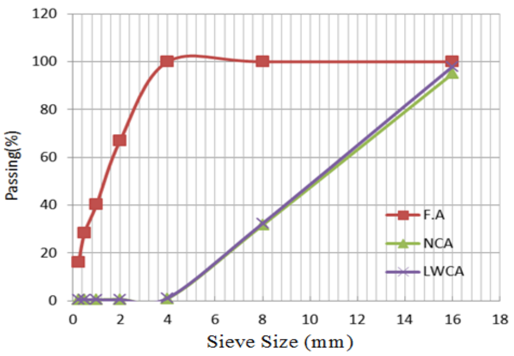


**Figure 1.** The properties of aggregates

2.1.4 Steel fibers (SF)

Steel fibers SF were used in the work to increase the SCGC ductility. The SF shown in Figure 1 are copper-coated 0.2 mm diameter and 13.0 mm length. Table 3 concluded the SF properties. Three ratio of 0%, 1% and 1.5% of SF were applied. Figure 2 shows the steel fiber image.

**Table 3.** concluded the SF properties

| Property | Specification |
|---|---|
| State | Cooper Coated |
| Tensile Capacity | >2400 MPa |
| Density | 7860Kg/m$^3$ |
| Melting Point | 1500°C |
| Shape | Straight |
| Diameter | 0.2 ±0.02mm |
| Length | 13.0 ±1.0mm |

**Figure 2.** The steel fibers applied in study

2.1.5 Potable water

Water represents major ingredient due to its actively collaboration in the reaction with mixture material. It guarantees workability. Tap water that pass the normal standards for drinking water were used.

2.1.6 Activator

The alkali activator is a combination of sodium silicate SS ($Na_2SiO_3$) and sodium hydroxide SH (NaOH) of 12 Molarity solutions [36]. The SS $Na_2SiO_3$ was gotten from a local provider in Anbar, Iraq [37]. The SH used had a concentration of 12 molarity and purity of 97%-98%, which was reported to be the better characteristics for SCGC mechanical performance [38].

2.1.7 Super plasticizer

All mixture combinations will contain a poly carboxylic-ether type super plasticizer (SP) with a pH value of 5.7 and a specific gravity (S.G.) of 1.07. This type of super-plasticizer is a liquid and complies with the (ASTM, 2005) [39]. Dosage of (8%, 10% and 12%) of super plasticizer of weight used. Table 3 shows the main properties of supper plasticizer.

The parameters will be selected based on the preceding studies. Table 4 shows the main properties of SP.

**Table 4.** main properties of SP

| Property | Description |
|---|---|
| Color | Dark brown / black liquid |
| Specific gravity | 1.07 at 25°C |
| Air entrainment | < 1% |
| Chloride content | < 0.1% |
| Alkaline content | < 3% |

2.1.8 An alkali-solution

An alkali-solution to binder ratio about of 0.35–0.40 was presented to give satisfy strength of the geopolymer concrete. SH/SS ratios of (1.5-2.5) was given to be appropriate. All solid material (FA, GGBFS, SF and aggregates Where mixed adequately by using sold binder (500 Kg/m$^3$), fine aggregate of (850 Kg/m$^3$), SH of (57 Kg/m$^3$). Liquid mixture of (activator and SP with extra water were added to premixed solid mixture [40]. Figure 3 shows the material applied in the study.

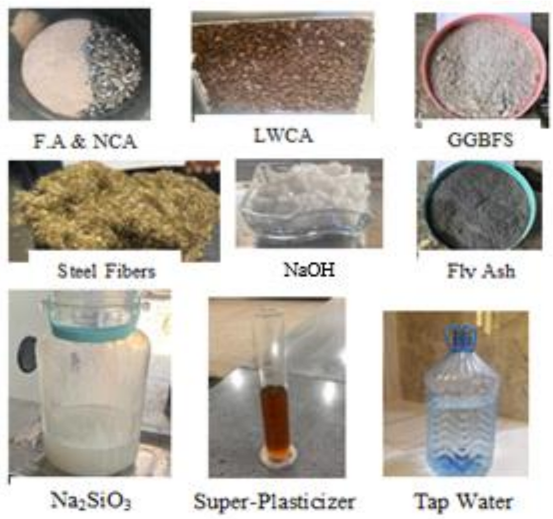


**Figure 3.** Raw materials applied in the SCGC production

## 2.2 Mixtures design

There is no set procedure for designing SCGC mixes, it is best to use a trial-and-error approach to determine the right amounts of components to ensure that SCGC standards are met. Mixtures set of SCGC samples given in Table 5. The experimental program will be conducted to identify the effects of LWCA, SF, and Curing Conditions CC on the fresh and hardened properties of SCGC.

**Table 5.** Mixture proportioning of the SCGC samples

| Mix ID | Curing Conditions | Binder 500 Kg/m³ | | Aggregate | | | | Sodium Hydroxide Kg/m³ | | | Sodium Silicate | W | SP | SF | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GGBFS slag | FA | LWCA | | NCA | FA | | | | | | | | |
| | | Kg/m³ | Kg/m³ | Kg/m³ | Kg/m³ | Kg/m³ | % | Flak | Water | M | Kg/m³ | % | % | % | % |
| M1OC | | | | | 772.64 | 0 | | 23.74 | 40 | | 160.56 | | 8 | 0 | 0 |
| M2OC | | | | | 772.64 | 0 | 0 | 23.74 | 40 | | 160.56 | | 10 | 78.5 | 1 |
| M3OC | | | | | 772.64 | 0 | | 23.74 | 40 | | 160.56 | | 12 | 117.8 | 1.5 |
| M4OC | | | | | 257.52 | 515.11 | | 23.74 | 40 | | 160.56 | | 8 | 0 | 0 |
| M5OC | **Oven** | 250 | 250 | 909.36 | 257.52 | 515.11 | 66.67 | 23.74 | 40 | 12 | 160.56 | 30 | 9 | 39.3 | 1 |
| M6OC | | | | | 257.52 | 515.11 | | 23.74 | 40 | | 160.56 | | 12 | 117.8 | 1.5 |
| M7OC | | | | | 0 | 772.64 | | 23.74 | 40 | | 160.56 | | 8 | 0 | 0 |
| M8OC | | | | | 0 | 772.64 | 100 | 23.74 | 40 | | 160.56 | | 10 | 78.5 | 1 |
| M9OC | | | | | 0 | 772.64 | | 23.74 | 40 | | 160.56 | | 12 | 117.8 | 1.5 |
| M1AC | | | | | 772.64 | 0 | | 23.74 | 40 | | 160.56 | | 8 | 0 | 0 |
| M2AC | | | | | 772.64 | 0 | 0 | 23.74 | 40 | | 160.56 | | 10 | 78.5 | 1 |
| M3AC | | | | | 772.64 | 0 | | 23.74 | 40 | | 160.56 | | 12 | 117.8 | 1.5 |
| M4AC | | | | | 257.52 | 515.11 | | 23.74 | 40 | | 160.56 | | 8 | 0 | 0 |
| M5AC | **Ambient** | 250 | 250 | 909.36 | 257.52 | 515.11 | 66.67 | 23.74 | 40 | 12 | 160.56 | 30 | 9 | 39.3 | 1 |
| M6AC | | | | | 257.52 | 515.11 | | 23.74 | 40 | | 160.56 | | 12 | 117.8 | 1.5 |
| M7AC | | | | | 0 | 772.64 | | 23.74 | 40 | | 160.56 | | 8 | 0 | 0 |
| M8AC | | | | | 0 | 772.64 | 100 | 23.74 | 40 | | 160.56 | | 10 | 78.5 | 1 |
| M9AC | | | | | 0 | 772.64 | | 23.74 | 40 | | 160.56 | | 12 | 117.8 | 1.5 |

Where the natural traditionally coarse aggregate will be partially replaced with LWCA which is represented by crushed limestone rocks. NaOH flake will be dissolved by water to prepare an alkaline solution.

The alkali activator solution will be produced by blending NaOH solution (after cooling the NaOH solution down to an ambient temperature) of (27-30°C) with $Na_2SiO_3$. Fly ash and slag will be used for SCGC production. The experimental program will be involved the design and preparation of a total of 18 SCGC mixtures.

A concrete mixer will be used for about 1 min to mix the coarse and fine aggregate together. Thereafter, the blended powder raw materials and alkali activator solution, including superplasticizer, were gradually added to the concrete mixer one by one.

Once the mixing process will be completed, the resulting fresh mixture was poured into pre-oiled molds in three layers. It will be well compacted with a vibrator table to prepare specimens for testing. After specimens prepared, specimens will be tested to identify the mechanical, transport properties to evaluate LWCA-SF reinforced SCGC performance.

Mixtures (M1OC - M9OC) were stayed in the molds for 24 hours then they were cured in oven (Heat Condition HC) for 48 hours at 70°C, while other Mixtures samples (M1AC-M9AC) were kept in Ambient air temperature Condition (AC) (ambient 25 ± 2°C) for 28 days until test time.

### 2.3 Curing condition

Mixtures (M1OC- M9OC) were cured by putting in to the oven for 48 hours until the test (24 hours in the mold, then 48 hours in the oven) at 70°C. Mixtures (M1OC- M9AC) were cured by keeping in to the ambient air temperature (25 ± 3°C) for 28 days until the test. After curing, the cube and cylinder specimens are tested under Compression, flexural and tensile machines. Figure 4 shows the flow chart of work methodology.

### 2.4 Testing of SCGC

2.4.1 Fresh properties of SCGC

The fresh properties of SCGC mixes were carried according to EFNARC [40]. The fresh properties have to meet the limitations for passing and filling capacity without the occurrence of partitioning or segregation. As a result, fresh-state testing was conducted on these specimens immediately after mixing. The flowing abilities (L-box) of SCGC and the filling capacities (V-Funnel, slump flow) are calculated [40].

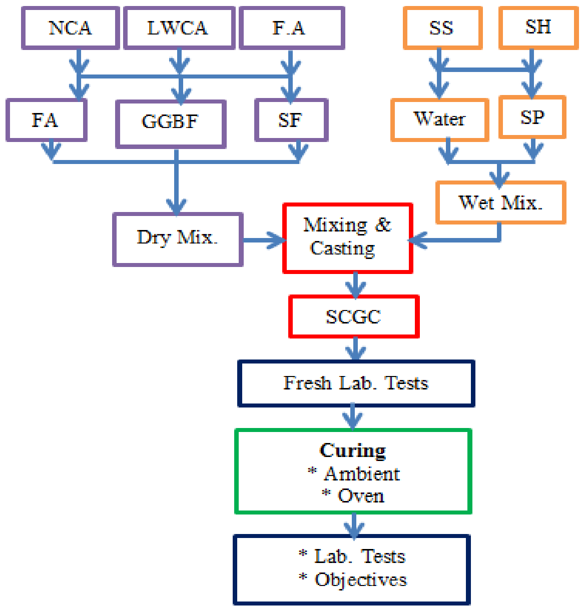


**Figure 4.** The flow chart of work methodology

Slump flow test

The fresh SCGC's uniformity is evaluated using the SCGC slump flow diameter (SFD) prior to setting. It is carried out to assess the fresh SCGC's workability and, consequently, its flowability. It can also serve as a sign that a batch was not properly mixed. The test's popularity can be attributed to its straightforward methodology and basic equipment. Under field conditions, the slump test is utilized to guarantee homogeneity for various loads of SCGC [40].

V-funnel test

The filling ability (or flow ability) of the SCGC can be determined using the V-funnel test. Concrete is poured into the funnel, and the length of time it takes for it to pass through the device is recorded [40].

L-box test

The test evaluates the SCGC's flow. The device is a rectangular box with a sliding door separating the horizontal and vertical sections. Vertical lengths of reinforcement bar are installed in front of the door. The box is shaped like a letter "L." After the SCGC is poured into the vertical part, the door is raised to allow the SCGC to flow into the horizontal area. As soon as the flow stops, the height of the SCGC at the horizontal section's end is expressed as a percentage of the vertical section's remaining height. It shows the SCGC's resting-state slope. This is a sign of passing ability, or the extent to which concrete cannot pass through the bars [40].

2.4.2 Mechanical properties of SCGC

Compressive strength test

In order to characterize and assess the SCGC, CS is the most frequently utilized measurement. Since other measurements of concrete frequently correlate well with the CS, it is employed as an indicator of the other mechanical properties.

A cube with (100×100×100) mm were produced from different mix designs and tested according to BS EN 12390-3 using a (3000 KN) universal compression testing device [41]. All SCGC mixture were duplicated and tested three times, and the mean outcome from these tests were computed and fixed. It has been established that when SCGC is cured at the ambient temperature or through heat activation, it can achieve noticeably high CS. The higher CS was obtained when heat activation is used instead of natural cure since it speeds up the geopolymerization action. When cured at room temperature, the addition of fly ash and slag to the matrix greatly increases the CS of the SCGC [42].

Tensile strength test

In comparison to other tests, the tension test provides more reliable results because it is an indirect and straightforward way to assess the TS of concrete. According to ASTM C496M [43]. The TS of SCGC will be calculated in this study by averaging three cylindrical samples with dimensions of 100 x 200 mm for each SCGC mixture. The cylindrical sample is loaded until stress failure manifests as splitting along the diameter, with its axis horizontally positioned between two plates of the available testing apparatus [44].

Flexural strength test

Flexural strength FS of a concrete is a measurement of its bending resistance. "Modulus of rupture" is a word that can be used to describe the FS. The specimen, which has dimensions of (100×100×500) mm, is bent using three-point loading until it breaks. The tests were carried out according to ASTM C78-04 [45].

## 3. RESULTS AND DISCUSSIONS

### 3.1 Fresh properties of SCGS

Table 6 shows the fresh properties of SCGS, The SCGS have 50% of FA and 50% of GGBFS combined with LWCA and SF on the fresh phase of SCGC is demonstrated in Table 5. The combination of 100 percent of NCA and 0.0 percent SF had the largest slump flow diameter (630 mm). The combination of 100 percent of NCA and 0.0 percent SF had the largest slump flow diameter (SFD) (630 mm). The SFD was reduced from 630 mm (100% NCA) to 600 and 520 mm after SF was added (1% and 1.5%) respectively.

The biggest SFD (630 mm) was occurred when 0.0 percent of SF and 100% of NCA were combined. Following the addition of SF by (1% and 1.5%), the SFD decreased from 630 mm (100% NCA) to 600 and 520 mm, respectively.

The replacement of all NCA by LWCA and 1.5 percent SF had SFD (490 mm). Then, the SFD was increased from 490 mm to 580 and 530 mm after SF was added (0.0% and 1.0%) respectively.

The SFD was decreased from 630 mm (100% NCA) to 600 and 520 mm after SF was combined (1% and 1.5%) respectively. The combination of 33.33 percent of NCA and 66.67 percent of LWCA and 1.5 percent SF had the lowest SFD (395 mm). Then, the SFD was increased from 395 mm (33.33 % NCA and 66.67 percent of LWCA) to 590 and 460 mm after SF was added (0.0% and 1.0%) respectively.

**Table 6.** The test results of fresh properties of SCGS

| Mix. No. | Slump Flow mm | $T_{50}$ mm | V-funnel Flow (Second) | L.box % |
|---|---|---|---|---|
| **M1** | 630 | 1.43 | 6.09 | 0.832 |
| **M2** | 600 | 1.84 | 6.85 | 0.835 |
| **M3** | 520 | 16.91 | 7.46 | 0.913 |
| **M4** | 590 | 2.38 | 8.25 | 0.815 |
| **M5** | 460 | 3.95 | 8.69 | 0.901 |
| **M6** | 395 | 4.28 | 9.48 | 0.982 |
| **M7** | 580 | 1.41 | 6.35 | 0.844 |
| **M8** | 530 | 6.3 | 7.45 | 0.892 |
| **M9** | 490 | 6.86 | 10.92 | 0.984 |
| **Avg.** | 532.78 | 5.04 | 7.95 | 0.889 |
| **S.D** | 71.30183 | 4.60781 | 1.47268 | 0.059692 |

The replacement of all NCA by LWCA and 1.5 percent SF had SFD (490 mm). Then, SFD was increased from 490 mm to 580 and 530 mm after SF was added (0.0% and 1.0%) respectively.

Based on the EFNARC limitations, all of the SFD results were within the SF2 class, which is comfortable for a large selection of reinforced parts (beam, slab and column) [39].

Similar to SFD findings, the better $T_{50}$ time and V-funnel flow time grew as a result of LWCA and SF.

However, in accordance with the EFNARC specification, every V-funnel and $T_{50}$ result in the current study was declared to be acceptable [39]. The amount of LWCA and SF ratios had a negative impact on the flow-ability of SCGC, according to the T50 duration data; mixes containing 100% LWCA and 1.5% SF showed the longest $T_{50}$ duration. Slump flow value is decreased by LWCA and SF, although T50 time, V-funnel flow time, and L-Box ratio are increased.

Higher amounts of LWCA and SF in mixes caused them to become more cohesive and viscous, while SCGC combinations' flow-ability and fluidity declined. Additionally, all SCGC mixes met the SCGC criteria, according to EFNARC.

However, it was shown that higher LWCA and SF mixes were more cohesive than lower one's mixes, and that the GGBFS concentration improved both bleeding and segregation resistance [46, 47].

### 3.2 Hardened properties of SCGS

3.2.1 Compressive strength

This research examines the SCGC using FA/ slag as binder, The behavior of SCGC exposed into ambient temperature and heating curing (oven @ 75°C) conditions obtained in Table 7 and Figure 5. The samples exposed into ambient air condition had lower CS than of heating condition, The CS of samples exposed to heating conditions compared to the ambient ones increased about 36.09%, 26.32%, 17.88%, 23.87%, 27.96%, 27.69%, 38.94%, 27.91% and 24.53% respectively. The CS increased for (M3, M6 and M9) when increasing the steel fibers, CS decreased when increasing LWCA, the compressive strength decreased due to unreacted fly ash materials result in high dehydration [44]. The highest values of CS for both ambient air and heating conditions were for M3 mixtures, which was 42.37 and 51.60 Mpa respectively. The lowest CS value for both ambient air and heating conditions were (18.21 and 24.13) Mpa respectively, increasing the LWCA ratios decreased the CS of SCGC. M9 specimens had the lowest CS because of the lower activity of fly ash [47]. The enhancement of CS is due to the combination of SF in SCGC was more significant than conventional binder systems due to the robust and strong link between the matrix and fibers [21, 48].

**Table 7.** Compressive strength of SCGC samples

| Compressive Strength (Mpa) | Condition | | Increment Ratio % |
|---|---|---|---|
| | Ambient | Oven | |
| **M1** | 26.35 | 41.23 | 36.08 |
| **M2** | 35.63 | 48.36 | 26.32 |
| **M3** | 42.37 | 51.60 | 17.87 |
| **M4** | 22.38 | 29.39 | 23.86 |
| **M5** | 25.68 | 35.65 | 27.95 |
| **M6** | 27.54 | 38.09 | 27.69 |
| **M7** | 12.02 | 19.69 | 38.93 |
| **M8** | 15.81 | 21.94 | 27.91 |
| **M9** | 18.21 | 24.13 | 24.53 |
| **Avg.** | 25.11 | 34.45 | 27.90 |
| **S.D** | 9.00 | 10.82 | 5.95 |

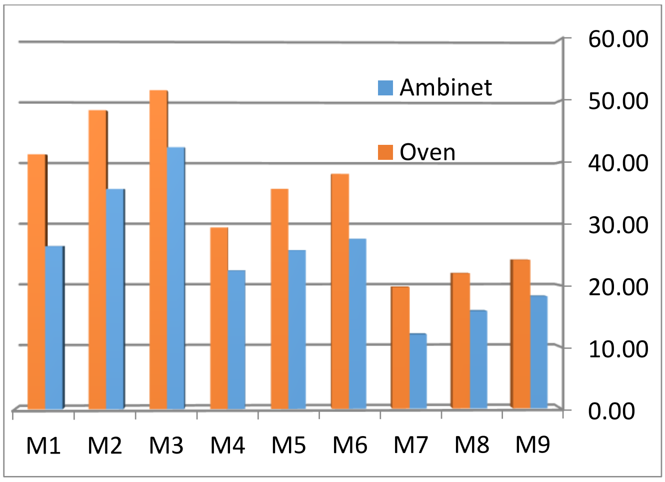


**Figure 5.** The CS values of specimen

3.2.2 Flexural strength (FS)

The behavior of SCGC exposed into ambient temperature and heating curing (oven @ 75°C) conditions obtained in Table 8 and Figure 6. The samples exposed into ambient condition had lower flexural strength than of heating condition, The FS of samples exposed to heating conditions compared to the ambient ones increased about 13.39%, 13.39%, 23.78%, 18.64%, 17.85%, 11.67%, 34.70%, 8.65% and 12.24% respectively. The FS increased for (M3, M6 and M9) when increasing the steel fibers, FS decreased when increasing LWCA, The FS decreased due to unreacted fly ash materials result in high dehydration [49].

The highest values of FS for both ambient air and heating conditions were for M3 mixtures, which was 3.128 and 4.104 Mpa respectively. The lowest FS value for both ambient air and heating conditions were (1.60 and 1.83) Mpa respectively. The greater temperature curing leads to major strength enhancement. Similarly, longer curing period enhanced the geopolymerisation processes and obtained greater strength [50].

**Table 8.** Flexural strength for Ambient and Oven samples

| Flexural Strength (Mpa) | Condition | | Increment Ratio % |
|---|---|---|---|
| | Ambient | Oven | |
| **M1** | 2.35 | 2.72 | 13.39 |
| **M2** | 2.79 | 3.16 | 11.74 |
| **M3** | 3.13 | 4.10 | 23.78 |
| **M4** | 1.36 | 1.67 | 18.64 |
| **M5** | 1.87 | 2.27 | 17.85 |
| **M6** | 2.29 | 2.60 | 11.67 |
| **M7** | 0.71 | 1.09 | 34.70 |
| **M8** | 1.44 | 1.58 | 8.65 |
| **M9** | 1.60 | 1.83 | 12.24 |
| **Avg.** | 1.95 | 2.34 | 16.96 |
| **S.D** | 0.72 | 0.87 | 7.63 |

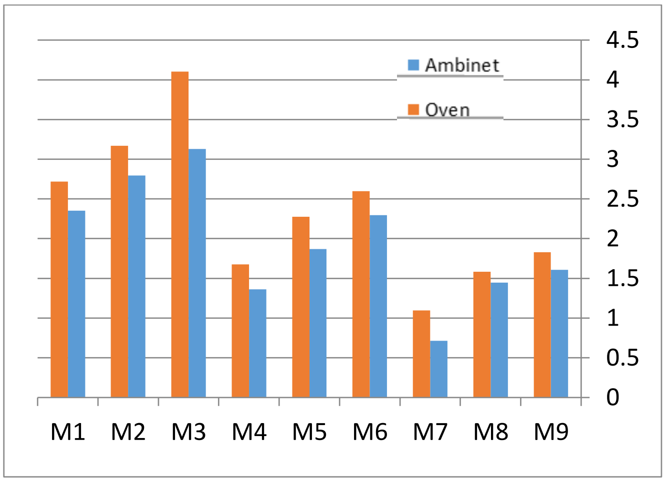


**Figure 6.** The FS values of specimen

3.2.3 Tensile strength (TS)

The behavior of SCGC exposed into ambient temperature and heating curing (oven @ 75°C) conditions obtained in Table 9 and Figure 7. The specimens exposed into ambient air condition had lower Flexural strength than of heating condition, The TS of samples exposed to heating conditions compared to the ambient ones increased about 24.64%, 14.68%, 26.22%, 21.10%, 11.21%, 15.86%, 14.91%, 6.90% and 1.71% respectively. The TS increased for (M3, M6 and M9) when increasing the steel fibers, TS decreased when increasing LWCA, The TS decreased due to unreacted fly ash materials result in high dehydration [49, 50].

The highest values of TS for both ambient air and heating conditions were for M3 mixtures, which was 3.41 and 4.62 Mpa respectively. The lowest TS value for both ambient air and heating conditions were (1.15 and 1.17) Mpa respectively.

That was due to incomplete moisturizing process and increased blanks in concrete mixes [48, 51].

**Table 9.** Tensile strength of SCGC samples

| Tensile Strength (Mpa) | Condition | | Increment Ratio % |
|---|---|---|---|
| | Ambient | Oven | |
| **M1** | 1.82 | 2.42 | 24.64 |
| **M2** | 4.19 | 4.91 | 14.68 |
| **M3** | 3.41 | 4.62 | 26.22 |
| **M4** | 1.29 | 1.64 | 21.10 |
| **M5** | 2.10 | 2.37 | 11.21 |
| **M6** | 2.44 | 2.90 | 15.86 |
| **M7** | 0.97 | 1.14 | 14.91 |
| **M8** | 1.49 | 1.60 | 6.90 |
| **M9** | 1.15 | 1.17 | 1.71 |
| **Avg.** | 2.10 | 2.53 | 15.25 |
| **S.D** | 1.03 | 1.32 | 7.55 |

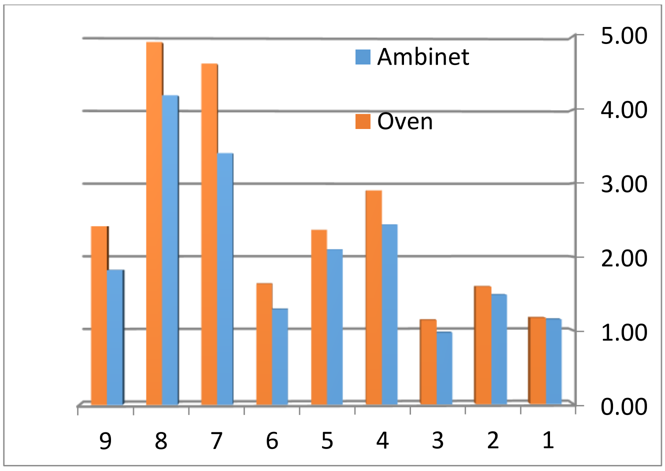


**Figure 7.** Splitting tensile strength

## 4. CONCLUSIONS

The conclusions of this study are obtained as follows:

1. LWCA and SF addition decreased the L-Box ratio and SFD value of the SCGC Mixes. Mixes have a larger ratio of LWCA and SF became stronger and more viscous, As the ratio of GGBFS grew, the flow-ability and liquidity of SCGC mixes decreased and their resistance to segregation and bleeding increased.
2. The EFNARC standards and requirements for flow-ability and passing-ability have been satisfied by all SCGC mixtures.
3. The SCGC exposed into heat curing condition had greater compressive strength than of ambient curing condition, Subsequently the CS value improved by 36.08% for M1 Mixture.
4. The steel fibers constrain the fresh properties, while it is enhanced the mechanical properties of SCGC, the better performance of mechanical characteristics, The CS was 48.36 Mpa with 1.0% SF percentage at HC.
5. LWCA had clear influence in fresh properties. It has limited effect on workability, and reduced the mechanical properties, The LWCA reduced the FS, The FS was 2.72 Mpa and 1.67 Mpa for partially replacement of 66.67% and 0.0% respectively with HC.
6. The TS of SCGC exposed into ambient air condition had lower TS than of heating condition, The better TS value was 26.22 Mpa for M3 Mixes at 1.5% of SF, While the TS reported dropping about 38.4% when applying LWCA as partially replacement of 66.67% with ambient curing condition.
7. It is recommended to utilize the (SCGC) in hot areas and utilize wastes such as steel fibers and LWCA in SCGC as an economic, affordable and eco-friendly material.
8. Raw and some waste materials such as Fly ash, steel fiber and slag can be used as a supplementary material, reducing $CO_2$ emissions by up to 12%, This approach also improves the mechanical properties of geopolymer concrete.
9. It is recommending to utilize the (SCGC) in hot areas and utilize wastes such as steel fibers and LWCA in SCGC as an economic, affordable and eco-friendly material.
10. It is recommended to apply other waste material like recycled LWCA and recycled steel fibers
11. It is recommended to apply different curing conditions such as Microwave environment.

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