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Effect of Steel Fiber Content on Properties of Fresh Self-compacting Geopolymer Concrete

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HIGHLIGHTS

- Curing regime was successful in achieving the targeted strengths of SCGPC.
- Fresh properties of SCGPC are significantly affected by the addition of steel fiber.
- V_f =1% was the maximum fiber content that could be used in producing SCGPC.

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ABSTRACT

Self-compacting geopolymer concrete (SCGPC) is a cutting-edge sustainable engineering material in construction that eliminates the need for both compaction and Portland cement. In this study, the impact of various steel fiber content on the workability of SCGPC was investigated. The basic workability features of freshly made SCGPC, such as filling ability, passing ability, and segregation resistance, were assessed by employing slump flow, V-funnel, L-box, and J-ring test techniques. Obtained results showed that all the investigated characteristics of SCGPC have retreated due to the inclusion of steel fibers. Findings presented in this research confirmed that the basic requirements of EFNARC could only be satisfied when Vf ≤ 1.0%.

1. Introduction

Recently, geopolymeric materials have attracted great attention and interest due to its environmental effectiveness, including the reduction in the use of natural resources and reduced CO_2 generation [1]. The production of raw materials of Geopolymer does not necessitate a significant amount of energy since high-temperature calcining is not required compared to Portland cement [2-3]. Industrial waste and/or by-products can be recycled into useful construction material by using geopolymer concrete technology. [4].Limited research work on geopolymer concrete GPC has been performed in Iraq, including the study of its properties, durability, and structural behavior [5]. Several factors may influence the production and characteristics of GPC such as curing systems and constituent ratios [6, 7, 8, 9]. The performance of the GPC under hard conditions was evaluated in line with the criteria of ACI 318-14[10, 11]. Local resources were used in the production of geopolymer concrete, which was investigated [12]. Over the past two decades, concrete construction has placed a strong focus on increasing efficiency and enhancing the working environment. A new concrete technique, self-compacting concrete (SCC), is gaining prominence. self-compacting concrete (SCC) flows into and around impediments by its weight to fill the formwork fully and self-compacts without any segregation or blockage.[13].SCC has several technical, economic, and environmental advantages over conventional concrete, including improved concrete quality, faster construction, easier placement in congested reinforcing bars, homogenization, and completion of the consolidation, increased bond strength, reduced noise levels due to the absence of vibration, lower overall cost, and safe working conditions. [14-18]. these benefits are offset by a lack of professional supervision and a lower tolerance for aesthetic flaws, excessive noise, and workplace accidents. The basic ingredients used in SCC are identical to those used in conventional concrete, with the exception that SCC is made in different contents. These mixes usually contain more ultra-fine components than other mixes. Because of its decreased coarse aggregate content and the use of super plasticizers and viscosity modifying agents, SCC has a better flow ability [19-20]. Supplementary cementations ingredients and mineral fillers are frequently used to lower the cost of concrete, enhance its workability, and improve its hardened characteristics [21-22]. The use of supplementary cementitious materials, such as fly ash, ground granulated blast-furnace slag, and silica fume, is well established because of the improvement in concrete properties and also

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for environmental and economic reasons [13].Self-compacting Geopolymer concrete, SCGPC, as the name indicates, has a self-compacting property as well as the fact that it is made without Portland cement. The advantages of both are combined [23-25]. Fibers can improve the concrete ductility by possibly increasing the post-cracking energy absorption. The geometry, size, and content of steel fibers can greatly affect the properties of self-compacting concrete. Great care should be paid when adding the appropriate steel fibers content [26]. Limited literature that examines the influence of steel fiber inclusion on the performance of GPC, especially those studies related to SCGPC. This research aims to see how steel fiber content affects fresh characteristics such as slump flow diameter, V-funnel flow duration, L-box height ratio, and J-ring.

2. Material Selection

Low-calcium fly ash conforming to (ASTM C618-19 Class F) [27] was utilized as source material in this research work for the synthesis of SCGPC. EUROBULID "CONSTRUCTION CHEMICAL & COATINGS" provided the fly ash. Table 1 lists the physical characteristics of fly ash. The particle size analysis test was performed using the BROOKHAVEN 90 Plus. In a range of 0.21-50µm, the size distribution is bimodal with a dominant particle effective size of 0.5-5µm. Table 2 shows the proportion of oxides in fly ash as determined by X-Ray Fluorescence (XRF) findings at the Ministry of Science and Technology Department of Materials Research.

Table 1: Fly ash's physical characteristics

Characteristics	Test results
State	Powder
Appearance	Grey
Specific surface area	380 m^2/kg
Effective grain size	491 nm

Table 2: Oxides concentration of source materials

Oxides	Concentration %	ASTM C 618-Type F Requirements
SiO_2	59.95	
Al_2O_3	26.36	Min 70%
Fe_2O_3	4.39	
TiO_2	2.24	
K_2O	1.29	
CaO	1.07	
MgO	0.32	
SO_3	0.26	Max 5%
Others	0.89	
LOI	3.23	Max 6%

The alkaline solution employed in this investigation was a combination of sodium silicate solution $\alpha SiO_2.\beta Na_2O$ with a specific gravity of 1.54 and a modulus ratio α/β ($M_R=SiO_2/Na_2O$), M_R=2.4, (Na_2O=13.1-13.7% and SiO_2=32-33% by mass) and sodium hydroxide solution, were purchased from the local market. Dissolving commercial-grade sodium hydroxide (NaOH) flakes (99 percent purity) in water yielded the sodium hydroxide solution. One day previous to use, both alkaline solutions were made and mixed. Natural sand from Al-Ekhaider region as a fine aggregate was utilized FA. The maximum size utilized was 4.75 mm. It was sieved to meet the IQS No.45/1984 grading criteria for grading [28]. The sulfate content of the fine aggregate was found to be 0.037% and the bulk density was 2600 kg/m^3, the test was conducted according to the ASTM C29-17 [29].

Crushed gravel CA from AL-Nibaai region was used in this study with a maximum size of 9.5mm, and a bulk density of 2660 kg/m^3. Results showed that the coarse aggregate used in this research is met with ASTM C33-18 [30]. SikaViscoCrete®-5930 is the 3rd generation of high-performance water reducer admixture for concrete and mortar, it is a modified Polycarboxylicaqueous solution, and does not contain chloride or other steel corrosion promoting ingredients. It meets the requirements of ASTM C494-19 [31] type G and F, therefore suitable for the production of self-compacting behavior. Table 3 lists the technical description of ViscoCrete®-5930.

Table 3: Technical data of Visco Crete®-5930*.

Characteristics	Test results
State	Modified Polycarboxylic aqueous solution
Freezing	Under -1°C
Appearance	Turbid substance
Density	1.095 kg/lt
pH	8.0 ± 1.0
Chloride Content	Nil
Toxicity	According to applicable health and safety standards, it is non-toxic.

* Manufacturer's specifications.

Fine steel fibers were used in the experimental program to enhance the SCGPC ductility. The steel fibers used in GPC are straight and brass-coated of 13 mm length and 0.20 mm diameter. The properties of the fiber are shown in Tables 4.

Table 4: Table IV: Properties micro steel fiber *

Characteristics	Specifications
State	Brass coated
Density	7860 kg/m^3
Tensile Strength	> 2400 MPa
Shape	Straight
Melting	1500°C
Length	13±1 mm
Diameter	0.2mm±0.02mm

* Manufacturer's specifications.

3. Mixes

Mix proportions of SCGPC were selected to achieve 30 MPa as compressive strength at 28-day. The requirements of filling ability, passing ability, and segregation resistance according to EFNARCguidelines were also targeted. Slump flow, T_{500}, V-funnel, L-box, and J-ring tests were done on SCGPC in this study [32]. One reference mix, $SCGPC_0$, was produced with $V_f = 0.0\%$. The proportions of this mix are shown in Table 5. To evaluate the effect of steel fiber content on the behavior of fresh SCGPC, another six mixes were produced. The V_f's of these mixes were: 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5 %.

Table 5: Details of reference mix

Mix	Fly ash (kg/m^3)	Alkaline solution(kg/m^3)		Aggregate (kg/m^3)		HRWRA (kg/m^3)	Extra water(kg/m^3)
		NaSiO$_3$	***NaOH***	***Fine***	***Coarse***		
SCGPC0	410	130	80	760	960	15	14

According to The European Guidelines EFNARC [32] a concrete mixture can only be categorized as SCC if the requirements for fresh concrete are met. The requirements of fresh SCGPC were investigated through conducting the following tests:

1) Slump flow and T_{500};
2) V-funnel;
3) L-box; and
4) J-ring.

Moreover, to verify that the produced reference mix, $SCGPC_0$, has achieved the targeted strength at the age of 28 days, concrete cylinders with 100 mm diameter and 200 mm height were tested for compressive strength according to the ASTM C39 [33] and for splitting tensile strength according to the ASTM C496 [34].

4. Results and Discussion

Table6 displays the results of compressive and splitting tensile strengths at 28-day age for heat-cured fly ash-based self-compacting Geopolymer concrete. The adopted mix proportions and curing regime were successful in achieving the target strength. Mix $SCGPC_0$has yielded 32.1 MPa compressive strength and 3.3 MPa splitting tensile strength.

Table 6: : Mechanical properties results of SCGPC

Mix	Steel Fiber, SF%	Compressive Strength, MPa	Splitting Tensile Strength MPa
$SCGPC_0$	0.00	32.1	3.3

Table 7 listed the results of the abovementioned tests and the EFNARC requirements. According to Table6 and Figures1-5, there were retreats in all the investigated characteristics of SCGPC due to the inclusion of steel fibers. Table 8 clarifies these retreats. This trend could be attributed to the increase in internal friction. The existence of fibers and the increase in their volume fraction is the source of this friction. For higher V_f, balling of fibers is highly expected [35, 36]. Mixes $SCGPC_{0.25}$, $SCGPC_{0.50}$, $SCGPC_{0.75}$, and $SCGPC_{1.00}$ have met the EFNARC requirements; meanwhile, mixes $SCGPC_{1.25}$ and $SCGPC_{1.50}$ have not. Therefore, V_f= 1.0 % was considered as the maximum fiber content that could be used in producing fiber-reinforced SCGPC.Table 8 supports this conclusion where the negative variation of results has been multiplied beyond this ratio (V_f= 1.0 %).

Table 7: Results of fresh SCGPC

Mixes		Slump flow (mm)	T_{500} (sec)	V-funnel (sec)	L-box, H_2/H_1	J-ring (sec)
$SCGPC_0$		750	2.5	8.0	0.94	7.0
$SCGPC_{0.25}$		700	3.6	9.5	0.96	8.2
$SCGPC_{0.50}$		680	3.9	10.3	0.97	8.5
$SCGPC_{0.75}$		660	4.4	10.8	0.99	8.8
$SCGPC_{1.00}$		650	4.6	11.4	1.00	9.2
$SCGPC_{1.25}$		530	6.9	14.9	1.16	11.2
$SCGPC_{1.50}$		500	7.7	15.7	1.22	11.9
EFNARC requirements [22]	Min.	650	2.0	6.0	0.8	6.0
	Max.	800	5.0	12.0	1.0	10.0

Table 8: Variation in results of fresh SCGPC due to steel fibers inclusion

Mixes	Decrease in Slump flow, %	Increase in T_{500} time, %	Increase in V-funnel time, %	Increase in H_2/H_1, %	Increase in J-ring time, %
$SCGPC_0$	0	0	0	0	0
$SCGPC_{0.25}$	7	44	19	2	17
$SCGPC_{0.50}$	9	56	29	3	21
$SCGPC_{0.75}$	12	76	35	5	26
$SCGPC_{1.00}$	13	84	43	6	31
$SCGPC_{1.25}$	24	176	86	23	60
$SCGPC_{1.50}$	33	208	96	30	70

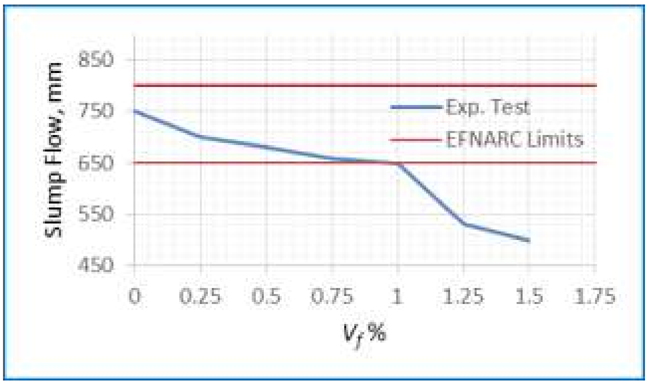

Figure 1: Steel volume fraction versus slump-flow test

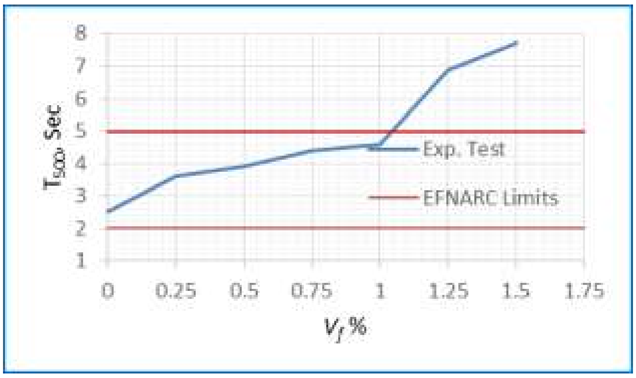

Figure 2: Steel volume fraction versus T_{500} test

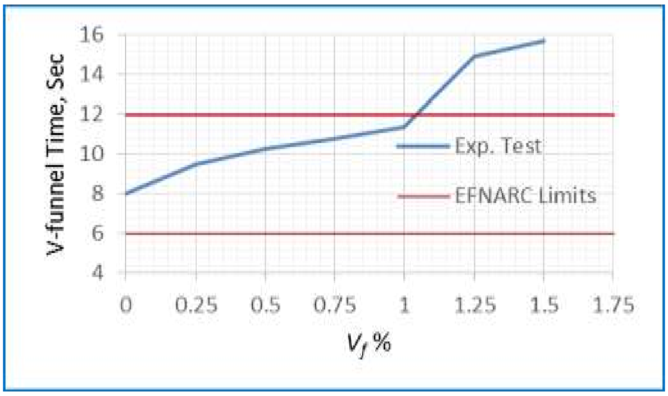

Figure 3: Steel volume fraction versus V-funnel test

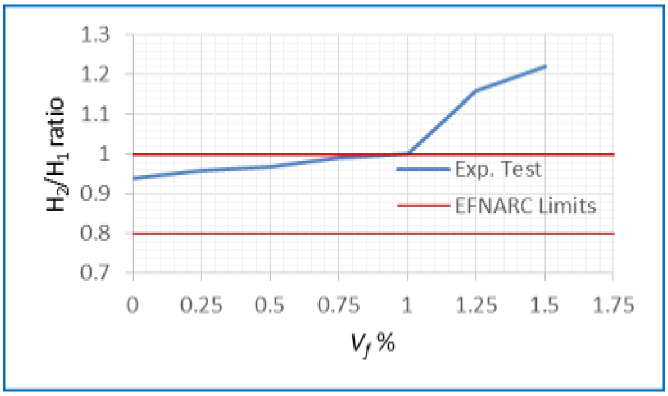

Figure 4: Steel volume fraction versus L-box test

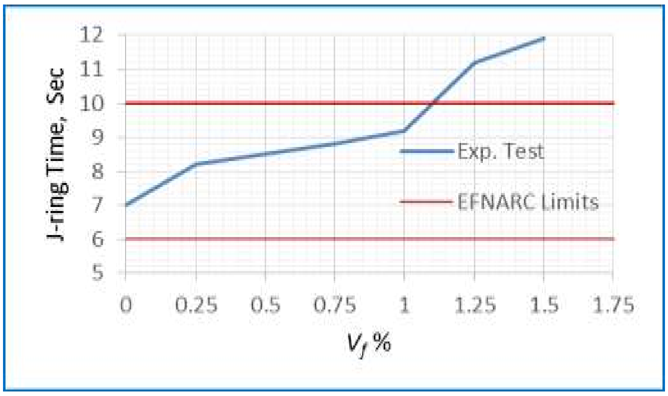

Figure 5: Steel volume fraction versus J-ring test

5. Conclusions

Based on the experimental results, the following conclusions have been made:

1) The adopted mix proportions and curing regime were successful in achieving the targeted strengths. Mix $SCGPC_0$has yielded 32.1 MPa compressive strength and 3.3 MPa splitting tensile strength at 28-day age.
2) The fresh properties of SCGPC are significantly affected by the addition of steel fiber. All the investigated characteristics of fresh SCGPC have retreated due to the inclusion of steel fibers.
3) This retreat could be attributed to the increase of internal friction. The existence of fibers and the increase in their volume fraction is the source of this friction.
4) For higher V_f, balling of fibers is highly expected, leading to losing SCC fresh properties.
5) All studied mixes, except for mixes $SCGPC_{1.25}$ and $SCGPC_{1.50}$, have good flowability and showed the desired workability characteristics according to the EFNARC requirements for SCC.
6) V_f = 1.0 % was considered as the maximum fiber content that could be used in producing fiber-reinforced SCGPC.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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