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Some properties of SIFCON made by reactive powder

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ABSTRACT

This study is important to reduce environmental pollution by reducing CO2 emissions associated with cement production, which is used as a bonding material in the concrete industry; it has been replaced by slag or other geopolymer materials. This study aims to explain the manufacturing of SIFCON concrete using slag as a base material. Two types of fibers (hooked steel fiber and straight steel fiber) are used in different ratios: 5%, 10%, and 15%. Each type of fiber was utilized separately, while the third type was combined with both of them. The flow table test was used to select the suitable mix design. Several tests were conducted (compression strength test, Water absorption test, and Abrasion resistance test) after 28 days. The highest compressive strength was achieved with a 10% inclusion of micro steel fibers, while the water absorption was negatively affected. Achieve the highest abrasion resistance by using 10% of hooked.

1. Introduction

Concrete is widely used in construction due to its mechanical properties**,** but on the other hand, it causes harm to the environment due to the presence of cement involved in its production, because the cement manufacturing process produces high energy consumption and cause to emission of carbon dioxide gas. [1] The concrete is enhanced by adding fibers and the cement-filled space between the fibers to increase the strength bonding; this is defined as a slurry infiltrated fibrous concrete (SIFCON)" by Lankard. [2, 3] Many previous researches of SIFCON were discussed consists; Dalya H. Hameed had study some of the mechanical characteristics of SIFCON and its role in enhancing the useful life of ordinary concret. [4] R. Sonone studied the enhancement of (high-performance concrete) on the characteristics of SIFCON fibrous concrete. [3] Adraa M. Najeeb studied the effect of spreading steel fiber into the slurry mortar on some characteristics of SIFCON [5]

To avoid the damage that produced by cement, it was replaced with reactive materials such as (fly ash, slag, metakaolin, silica fume...etc.) and it was called geopolymer concrete by Davidovits. [6] Many previous researches of slag were discussed such as, Abhay V. studied the effects of steel fibers and fluid-to-binder ratio on self-compacted geopolymer concrete. [7] NakumMohammad Rafiq Wani studied fresh and hardened properties of self-compacting geopolymer concrete based on (GGBFS) with curing at room temperature. [8] Ola A. Mayhob had study the primary goal to

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produce geopolymer RPC and assess its durability and mechanical qualities using various curing methods. [9]

The studies above focused on SIFCON and the other on slag. However, in this study, slag was utilized to produce SIFCON.

2. Experimental part

2.1 Materials used

2.1.1 Slag

The slag supplied from DCP company was used in this investigate as shown in figure (1). Relying on ASTM C989 [1٠] the both properties physical and chemical are referred in Table (1).

Figure 1

Table 1: slag physical and chemical properties

Properties	Standard requirements	Values	Test results
MgO	≤ 18%	5.00 – 10.00	8.8
Sulfide (S)	≤ 2,0 %	0.40 – 0.70	0.55
Sulfate (SO3)	≤ 2,5 %	0,30 – 0,60	0.46
Loss on ignition, corrected for oxidation of sulfide	≤ 3,0 %	0,00 – 2,00	1.8
Chloride	≤ 0,10 %	0,01 – 0,03	0.02
Moisture content	≤ 1,0 %	0,10 – 0,30	0.25
Specific surface (Blaine) cm /g^2	≤ 2750	5800 - 6100	5955

2.1.2 Fine aggregate

In this study it used the sand from (Alkhudaier Place-Karbala-Iraq) with sieving until the fine grain acceptable. Depending on ASTM C33 standards, [11] the properties shown in Table (2)

Table 2: sand properties

Properties of sand and	**Result**
Specific gravity	2.69
Bulk density	1670 Kg/m3
Absorption (%)	0.66
SO3 content	0.40
Fineness modulus	3.05

2.1.3 Highly-ranged water reduced admixture (HRWRA)

In this study used a high-range water reducer type (KUT PLAST SP 400) from Sika Company for Building Materials and is compatible with ASTM C494. [12]

2.1.4 Sodium hydroxide

The other name of sodium hydroxide is a "caustic soda", the concentration molarities of this study are 12 M made by dissolving 362 grams' weight of the NaOH flake in 638 grams of distilled water.

2.1.5 Sodium Silicate

UAE Ltd provided the Na_2SiO_3 solution obtainable from the Iraqi market, used in this study in liquid form.

2.1.6 Water

The distilled water used in this study.

2.1.7 Steel fiber

Two types of steel fiber are used in this study as shown in Figure (2), the first type is hooked steel fiber with dimensions (0.75mm diameter and 50 mm length), and the other type is straight steel with dimensions (0.3 mm diameter and 25 mm length), the two types manufactured in china with the properties shown in Table 3 and chemical analysis in Table 4 depending to ASTM C820. [13]

a) b)

Figure2. a) Micro steel fiber **b)** Hooked steel fiber

Table 3. Steel fiber properties

Technical properties	Micro steel fiber	Hooked End steel fiber
Length	25 mm	50 mm
Appearance closure	Gold copper cover	Grey
Diameter	0.3 mm	0.75 mm
Density	7840 kg/m^3	7800 kg/m^3
Aspect ratio(L/D)	83	67
Tensile strength	1000 MPa	2800 MPa

Table 4. the chemical analysis of hooked and micro steel

Elements	Micro steel fiber	Hooked steel fiber
Mo	---	0.45
Cr	0.01	0.06
Fe	91.57	90.98
C	0.17	3.48
P	0.01	---
Cu	5.39	1.19
Ni	0.019	0.60
Si	0.30	2.59
Mn	0.41	0.26
Ti	0.23	0.07
Mg	---	0.03
Al	1.05	---

2.2 Mix Preparation

2.2.1 Alkaline solution preparation

Prepared by mixing a constant ratio [1:2.5] of sodium hydroxide solution with sodium silicate solution.

2.2.2 preparation geopolymer concrete

This study depends on a prior mixture Mohammad Rafiq Wani researches [8], modified to obtain a better result of workability; the rations of water and plasticizer were changed, as shown in Table 5, to obtain the highest diameter in the flow table test without bleeding. The flow table test is done according to ASTM C230. [14] The cone of flow table test is placed in the center of the flow table and filled with fresh geopolymer slurry in two equal layers. After waiting half a minute, the cone is lifted to allow the geopolymer slurry to flow onto the table and drops 15 times for 15 seconds. In the end, calculate the diameter of the fresh geopolymer slurry. Figure 3 shows the flow table test.

Figure 3. flow table test

Table 5. The density and water percentages

-	NaOH Molarity (12)	Water ratio	Density Kg/m^3	GGBFS Kg/m^3	SP 8% from GGBFS Kg/m^3	Sand Kg/m^3	Na2SO3 Kg/m^3
S1	100	20%	2095	778	63	1625	250
S2	100	24%	2102	778	63	1625	250
S3	100	26%	2130	778	63	1625	250
S4	100	28%	2118	778	63	1625	250
S5	100	30%	2092	778	63	1625	250

2.2.3 preparation SIFCON geopolymer concrete

Mix the slag and sand (dry materials) for two to three minutes, then add the steel fiber randomly with a mix for enough time until homogeneity the mix is homogeneous. Add the alkaline solution and superplasticizer (liquid materials) into the mixture and mix into a mixer machine. Finally, lubricate the mold and cast the geopolymer SIFCON mixture.

Table 6. shown the geopolymer SIFCON mixes

Mix	Type and percentage of steel fiber	Sand Kg/m^3	Na_2SO_3 Kg/m^3	NaOH Molarity Kg/m^3	GGBFS Kg/m^3	SP Kg/m^3	Water Kg/m^3
GS	---	1625	250	100	778	63	202.28
H1	5% hooked	1625	250	100	778	63	202.28
H2	10% hooked	1625	250	100	778	63	202.28
H3	15% hooked	1625	250	100	778	63	202.28
M1	5% micro	1625	250	100	778	63	202.28
M2	10% micro	1625	250	100	778	63	202.28
M3	15% micro	1625	250	100	778	63	202.28
HM1	2.5% hooked + 2.5% micro	1625	250	100	778	63	202.28
HM2	5% hooked + 5% micro	1625	250	100	778	63	202.28
HM3	7.5% hooked + 7.5% micro	1625	250	100	778	63	202.28

Curing

The specimens were cured for 28 days at room temperature to prepare them for examination, the mixes of geopolymer SIFCON are shown in Table 6.

3. Tests

3.1 Compression strength Test

The importance of test lies in improving the strength of the concrete. Depending to EN 12390-3 standards [15], the cubic specimen with dimensions (100x100x100) mm. After the curing date, the specimens are tested using a calibrated compression machine, and the sample is placed on the face perpendicular to the casting face with a constant loading rate within the range of 0.6 N/mm.

3.2 Water Absorption Test

Depending on ASTM C642 [16], the cubic specimen with dimensions (100 x100 x 100) was dried in the furnace at 100-110 C^o for 24hr, measuring the first weight (W1), then the specimen was in the water for 48hr, measuring the second weight (W2). The water absorption can be found by equation below.

Water absorption% = (W2 – W1 / W1) x 100

W1: dry specimen weight.

W2: wet specimen weight.

3.3 Abrasion Resistance Test

Depending on EN 1338 standard [17], the specimen with (100 x 100 x 70) mm dimensions has been test. The testing device consists of a cylinder with a diameter of 200 mm and a length of 70 mm and a Brinell hardness of between (203HB-245HB) It is driven at 75 revolutions per minute.

4. Results

4.1 compression strength

Table (7) and Figure (4) show the outcomes; it noted that when steel fibers were added, there was an improvement in compressive strength compared to general specimens this is because of the bonding between the fibers and the binding material in the fiber significantly hinders or delays the crack occurrence. [18, 19] The highest compression strength results when adding 10% of micro steel fiber due to the aspect ratio (L/D) of this steel fiber being higher than hooked steel fiber, which makes it have higher diffusion inside the slurry. [20] The compression results decreased when adding 15% of any steel fibers due to less geopolymer slurry infiltration, which weakens the region and causes the specimen to fail [20, 21]. Hybrid specimens have the advantages of both (hooked and micro steel fiber), while the side effects consist of losses of some parts from a gain of aspect ratio.

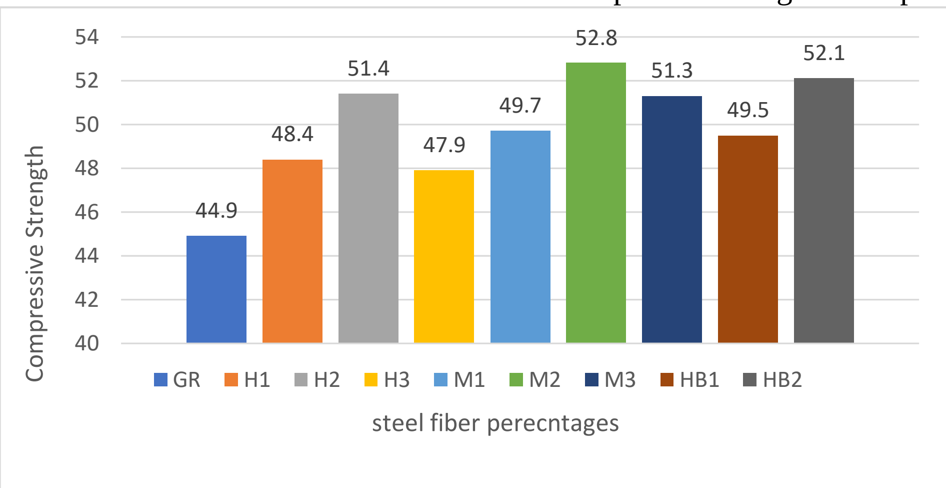

Figure 4. Compression Strength Results

Table 7.

Specimen	Compression strength results Mpa
GS	44.9
H1	48.4
H2	51.4
H3	47.9
M1	49.7
M2	52.8
M3	51.3
HB1	49.5
HB2	52.1
HB3	51.1

4.2 Water absorption

Table (8) and Figure (5) show the interpretation of the test results, where it was noted that adding steel fibers increases the absorption of concrete compared to the general concrete, and this is considered an adverse effect of adding the fibers caused the generation of voids between them and the binding material. As for the positive effect, the presence of hooked and micro steel fibers may cause the channels inside the concrete to close, as this prevents water from entering inside. In addition, the Hooked type is considered better than the Micro type because, due to its hooked shape, it forms an entanglement between the fibers and the binding materials. [22]

Table 8.

Specimen	Water absorption
GS	2.33
H1	2.41
H2	2.98
H3	4.30
M1	2.51
M2	3.18
M3	4.96
HB1	2.43
HB2	3.11
HB3	4.57

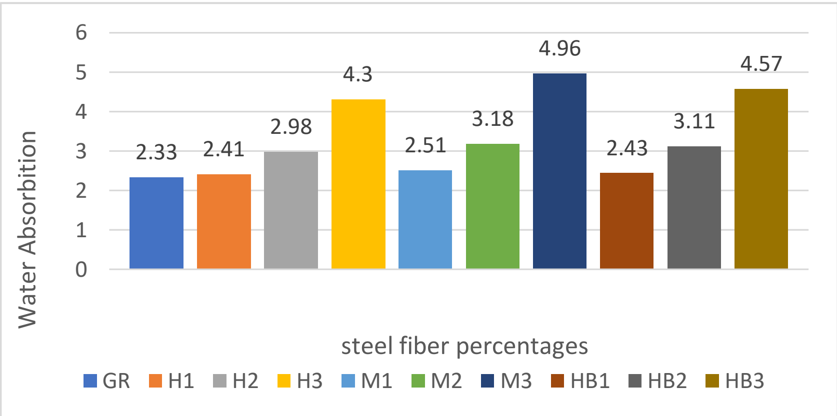

Figure 5. Water Absorption Results

4.3 Abrasion Resistance Test

The outcomes shown in Table (9) and Figure (6) noted that when steel fibers were added, the wearing resistance increased. Adding 10% of hooked steel fibers obtained the best-wearing resistance compared with the micro steel fiber that is because hooked steel fiber contains a higher carbon percentage than micro steel fiber, as shown in Table (4), and this reason made it the better to abrasion resistance; in addition, the hooked steel fiber which acts as anchoring and this enhanced the bonding between geopolymer mortar particles. Adding 15% of steel fiber accelerates the abrasion due to the voids inside the slurry and impedes grooves from forming during the test. [23]

Table 9.

Specimen	Abrasion Resistance mm
GS	20
H1	7.5
H2	5.5
H3	6
M1	8.5
M2	7.5
M3	8
HB1	7.5
HB2	6
HB3	6.5

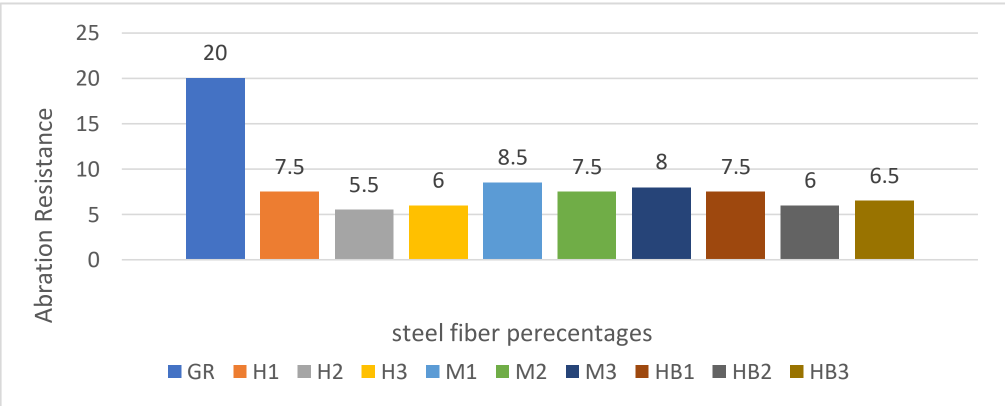

Figure 6. Abrasion Resistance Results

5. Conclusion

In general, adding steel fibers to geopolymer concrete has many effects, and according to the tests conducted above, the effect of the fibers is summarized as follows:

1. The compressive strength of the specimen cast with 10% micro steel fiber was the best, 14.96% higher compared to the general specimen.
2. In examining the water absorption, it was found that the value of adding fiber had a negative effect on the increase of the water absorption to 3.4% compared with the general specimen.
3. The best results in the abrasion resistance examination were when adding 10% of

hooked steel fiber, where the abrasion resistance ratio decreased to 72.5%.

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