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Mechanical Properties of SIFCON with Variation Steel Fiber Ratio and Nano Kaolin

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ABSTRACT

The aim of study the effect of sustainable of Nano Kaolin (NK) on some properties of SIFCON (slurry infiltrated fiber concrete). In this study, SIFCON specimens were designed, prepared and cured at 28 days. The suggested specimens' dimensions consist of cubes with (100mm), cylinders with (100×200 mm) and prisms with (100x100x400 mm), to study compressive strength, splitting tensile strength, and modulus of rupture with varied Nano metakaolin content (0, 3%, 5% and 7%) by weight of cementitious materials as an addition and the effect of SIFCON with variation of steel fiber ratio (4%,5% and 6%), which contains a volume fraction of fibers. Steel fiber contains 1% was chosen as a reference because non-fibrous concrete is a brittle material that fails suddenly during the testing

KEYWORDS

SIFCON, Nano metakaolin, Concrete

INTRODUCTION

ACI defined SIFCON is an advanced type of is a reinforced concrete using steel fibers, where it is distributed at random in the formwork mold before casting, usually in the loose condition, a cement-based slurry infiltrates the resulting fiber network and steel fiber ratio (usually 8 to 20 volume percent) according to ACI code. SIFCON is not the same as FRC. The steel fibers content is contained in FRC from (1% to3%) in terms of volume , however the steel fiber content in SIFCON is changing from (4 %to 20%) . The produce of SIFCON is not quite the same as FRC (Fiber Reinforced Concrete) [1]. Unlike FRC, for which steel fibers are added to wet or dry concrete, the mortar used for SIFCON mostly contains a proportion of fly ash (or) liquid silica (or) both. SIFCON is produced by first dispersing the steel fibers until they are completely filled and adding cement slurry [2,3, 4, 5]. During preparation and stuffing molds, vibration can be held to dodge pores occur in concrete[6]. SIFCON It can be used well in hard-to-reach places and the fibers greatly help bond old and new concrete. Depending on the type of repair, different techniques can be followed, similar to the fast quality that can be obtained with accelerators [7].

One of the headways made is the recognition that used of Nano-Kaolin can enhancement the mechanical properties of mortar. cement concrete matrix, kaolin responds with calcium hydroxide and produces Calcium Silicate Hydrate, Calcium Aluminate Hydrates and hydrated gehlenite. A few works clarify that kaolin (in miniature size) is a successful pozzolan in upgrading early quality [8], and some enhancement in the long-term strength [9]. Balaguru[10] studied the behavior of SIFCON in compression strength, splitting tensile, flexure strength and direct shear under monotonic and high amplitude cyclic loading. Dog bone specimens were used to determine the direct tensile strength and double L specimens were used to determine the shear strength of SIFCON. The author has founded that the length of fibers does not have a significant effect on strength and the addition of silica fume has increased the compressive and flexural strength and cement-sand ratio up to 1:1.5 can be used for cement slurry without affecting the strength of SIFCON. Sashidhar et al.[11] studied the compressive strength and tensile strengths of SIFCON at elevated temperatures. Used the steel fiber by three different volume fraction (8, 10 & 12%) for this investigation.

The properties were studied at three different temperatures (100Co, 200Co& 300Co) and three different exposure periods (4, 6 and 8 hours). The results appeared that the compressive and tensile strengths of SIFCON increased when specimens exposed to 100Co for 4 hours. At a temperature of 200Co and when it increases it decreases compressive and tensile strength of SIFCON. Further, the strength of SIFCON decreased as the exposure duration increased. Naaman et al.[12] studied the elasticity modulus of the sifcon under compressive and tensile stresses. Two kinds of steel fibers (deformed and hooked steel fibers) were used, as well as two kinds of aspect ratios (60 and 100). Compression cylinders were used to determine the stress-strain curve and and dog-bone tension specimens were used to the elasticity modulus.

The study concluded that the elasticity modulus of the sifcon depends on compressive strength , the volume fraction-fiber ratio, fiber orientation, and alignment and fiber aspect ratio. The peak strength and elastic modulus of SIFCON in tension do not seem to be very sensitive to the W/C ratio.

Fiber length was constant, the modulus of elasticity of SIFCON in the tension is a direct proportion to the volume fraction of fiber. Everything else being equal, the higher the length of the fiber, the higher is the elastic modulus of SIFCON. There is extremely restricted data about the conduct of SIFCON consist of Nano kaolin as a substitution of concrete. Accordingly, the target of this research is to study the impact of Nano kaolin as an incomplete substitution 10% by weight of cement and the impact of volume fraction of steel fiber from 4 % to 6 % on mechanical properties of SIFCON.

Experimental Program

study the effect of the addition of steel fibers and Nano Kaolin on the compressive, tensile and flexural strength of the concrete. 4%,5%and 6%steel fiber content and 0, 3%, 5% and 7% Nano Kaolin content were used to find out the effect of steel fibers and Nano Kaolin on the mechanical properties (compressive strength, splitting tensile strength and flexural strength) of the concrete by using 117 specimens. For compressive strength test, a set of 39 specimens cubes specimens (100 x 100x 100) mm ,39 cylinders specimens (100x200) mm for tensile and flexural strength and 39 prisms 100 x 100 x 400 mm for flexural strength of concrete were tested at 28 days ago.

MATERIALS

The following materials were used in the study:

Cement

Ordinary Portland cement (ASTM Type I) produced in Saudia Arabia of Al-Sharqiya as trade mark was used. Plastic containers with tight cover was used to store the cement and to protect it from exposure to the moisture. Its chemical and physical properties of the cement are illustrated in Table 1 and 2 respectively.

Table 1. Chemical composition and main compounds of ordinary Portland cement

Oxides composition	**CaO**	**SiO2**	**Al2O3**	**Fe2O3**	**MgO**	**SO3**	**L.O.I.**	**Insoluble residue**	**Lime Saturation Factor,L.S.F.**
Content %	61.21	21.8	5.1	2.80	2.11	1.09	3.51	0.98	0.84
Main compounds									
Oxides composition	C3S	C2S3	C3A	C4AF					
Content %	42.06	31.02	8.78	8.51					

Table 2. Physical Properties of Cement

Physical properties	Test Results
Specific surface area m2/Kg	483
Setting time Initial setting , hr:min Final setting, , hr:min	 2:45 4:45
Compressive strength MPa days 3 7 days	 31.30 41.00
Soundness %	0.35

Sand

Fine silica sand known as glass sand was used. This type of sand was purchased from Sika company. The grain size of this type of sand is 0.08-0.2mm. The fineness modulus was 3.22.

Nano Kaolin (NK)

Nano Kaolin was was brought from (Egypt). According to previous investigation [13]. The calcinations temperature and the time of calcinations at that temperature adopted in this study were 750 Ċ and 2 hr. respectively. The materials used in this study were nano-clay of Blaine surface area ≈ 480000 cm2/g and of average dimensions of 200*100*20 nm. Table (3) gives the grading of NK, and Table (4) gives the chemical composition of NK.

Table 3. Grading of NK fraction %.

Sieve size (µm)	Passing %
<10µm	100
<4µ	93
<2µm	88

Table 4. Chemical Properties of NK.

Chemical content	Sio2	Al2O3	Fe2 O3	Tio2	CaO	MgO	Na2O	K2O	L.O.I
%	45.5	37	0.2	1.5	0.01	0.02	0.03	0.07	12.5

Steel Fiber

The steel fiber used in this experimental work were of 0.2mm diameter and 13mm length .They were straight steel fibers manufactured by Bekaert Corporation company and of properties described in Table (5) .

Table 5. Physical properties of steel fiber

Description	Length	Diameter	Density	Ultimate Tensile Strength
Straight	13 mm	0.2 mm	7850 kg/m3	More than 2600 MPa

Water

Ordinary tap water was used for mixing and curing all the concrete specimens used this research.

High Range Water Reducing Admixture

A superplasticizer commercially named Flocrete PC 260 which conforms to ASTM C494-99[14] type A&G was used in the mixes.

Mix Design

13mixes of SIFCON were cast. Table (6) shows the mix proportions. For each mix, it was cast three cubes (100mm x 100mm x 100mm) for testing of compressive strength, three cylinders (100mm x 200mm) for testing of tensile strength and three prisms (100mm x 100mm x 400mm) for testing of flexural strength as shown in Fig. (1). Non-fibrous concrete is a brittle material that fails suddenly during the testing. The Mix number 1 was chosen as a reference which contains steel fiber 1% .

Table 6. Properties of the Different Type of SIFCON Mixes

Mix. No	Cement	Sand	NK%	Vf %	W/C	SP
1	900	900	0	1	0.3	2.4
2	900	900	0	6	0.3	2.4
3	900	900	3	6	0.3	2.4
4	900	900	5	6	0.3	2.5
5	900	900	7	6	0.3	2.5
6	900	900	0	7	0.3	2.4
7	900	900	3	7	0.3	2.4
8	900	900	5	7	0.3	2.5
9	900	900	7	7	0.3	2.5
10	900	900	0	8	0.3	2.4
11	900	900	3	8	0.3	2.4
12	900	900	5	8	0.3	2.5
13	900	900	7	8	0.3	2.5

Figure 1. Testing Specimens

Testing of specimens

Compressive Strength

The compression test was evaluated using cubes (100x100x100)mm using hydraulic test machine (ELE-Digital Elect 2000) of 2000 kN capacity at a loading rate of 0.25 ± 0.05 MPa per second . Average of three specimens were used to obtain the mean compressive strength as required by ACI 318M-08 Code[15].

Splitting Tensile Strength

The splitting tensile strength was performed according to ASTM C 496-04[16]. Cylinders of 100X200mm were loaded continuously up to failure using a digital testing (ELE-Digital Elect 2000) machine of 2000kN capacity .

Flexural Strength

Using flexural strength testing machine of 2000 kN capacity, prismatic specimens of 100X100X400 mm were tested under two point loading for modulus of rupture according to ASTM C 348-02[17].

RESULTS AND DISCUSSION

Hardened properties of SIFCON

Compressive Strength

The test results of cubs compressive strength are shown in Table (7)and in Fig.(2) in which it is clear that increasing each of steel fiber volume ratio or Nano kaolin content increases the compressive strength.The presence of SIFCON ratio (4%,5%,and6%) resulted in an increase in the compressive strength by 66.3%, 82.5 %, and 102.4% respectively, in comparison with steel fiber reinforcement concrete. This raise in compressive strength is due to the higher bond between fibers and matrix interfaces by increasing fiber volume fraction .These findings are concurred with different researchers[18] and [19].Increasing the percentage of Nano kaolin content 3% ,5% and 7% leads to an increase by 8% ,14.5% and 17.5% respectively when the ratio of sifcon 4% . increase by 9.6% ,14% and 20.1% respectively when the ratio of sifcon5% and increase by 10.9% ,15.1% and 25.2% respectively when the ratio of sifcon 6%.

The effect of Nano kaolin on enhance the compressive strength of sifcon mixes is due the the nano kaolin have high surface area that fills in the voids between cement grains. . Also Nano kaolin rev the hydration of cement by provision nucleation sites where the products of cement hydration can more facilely precipitate from thaw result in more condenser microstructure and alsoenhance the consolidate force between fiber and matrix. Nano kaolin is a very reactive pozzolana material which reacts with (CH)to form additional binder material called calcium silicate hydrate [20]

Splitting Tensile Strength

addtion of steel fiber to the improvement of splitting tensile of sifcon is higher than its improvement of compressive quality. Alluding to Table (7) and Figs (3), The presence of fibers at volume fractions of 4%, 5%, and 6% resulted in an increase in the splitting tensile strength by 55.3%, 77.6%, and 106.3% respectively, in comparison with steel fiber reinforcement concrete. SIFCON will in general act in an unexpected way, in such concrete, the inception of breaking means the start of another stage in the material's conduct, however, it does not signify failure of the material. With SIFCON in particular, the load will continue to increase after cracking.

Effect of increasing Nano Kaolin content on splitting strength is similar to its effect on compressive strength and this may be related to the same reasons as those stated in case of compressive strength . Increasing the percentage of Nano kaolin content 3% ,5% and 7% leads to an increase by 4.8% ,9.6% and 13.6% respectively when the ratio of sifcon 4% , increase by 4.2% ,10.7% and 13.8% respectively when the ratio of sifcon 5% and increase by 6.2% ,10.8% and 14.9% respectively when the ratio of sifcon 6%. It turns out that the steel fiber effect, the effect of enormous surface area and the effect of pozzolanic , and the enormous surface area improve the bond between the fibers and the matrix interface as well as limition the growth to the small cracks, and this explains the enhance mechanical properties.

Flexural Strength

Table (7), Fig.(4) shows the effect of changing the sifcon ratio and nano kaolin content on the flexural strength, where it is clear that changing sifcon ratio 4%,5% and 6% resulted in an increase in the modulus of rupture by 130.9%, 178.7 %, and 284.5% respectively, in comparison with steel fiber reinforcement concrete. Found that adding steel fibers increases flexural strength .This behavior was attributed to the effect of fibers which usually bridge matrix crack and apply a closing pressure at the crack tip, and require a higher energy input to further extend the crack.

The increase in strength of flexural due to increasing Nano Kaolin content can be refer to the same causes that mentioned for the corresponding increases in compressive strength and splitting tensile strength. Increasing the percentage of Nano kaolin content 3% ,5% and 7% leads to an increase by 5.6% ,8.9% and 12.6% respectively when the ratio of sifcon 4% , increase by 6.9% ,10.2% and 13.4% respectively when the ratio of sifcon 5% and increase by 6.2% ,10.1% and 13.3% respectively when the ratio of sifcon 6% .

Table 7. Mechanical Properties of SIFCON

Mix Symbol	Compressive Strength (MPa)	Splitting Tensile Strength(MPa)	Modulus of Rupture (MPa)
M1(Ref.)	49.6	9.4	15.5
M2	82.5	14.6	35.8
M3	89.12	15.3	37.8
M4	94.5	16	39.1
M5	96.9	16.6	40.5
M6	90.5	16.7	43.2
M7	99.2	17.4	46.2
M8	103.2	18.5	47.6
M9	108.7	19	49
M10	100.4	19.4	59.6
M11	111.4	20.6	63.3
M12	115.6	21.5	65.6
M13	125.7	22.3	67.5

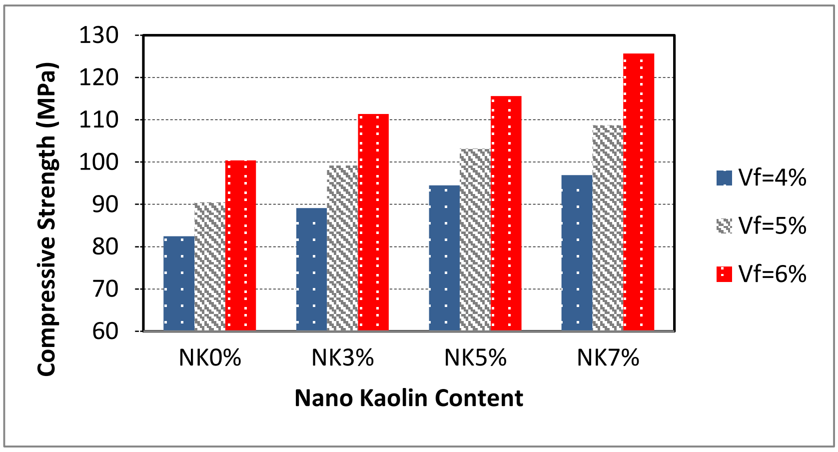

Figure 2. Comparison of the compressive strength of SIFCON with different Nano Kaolin Content

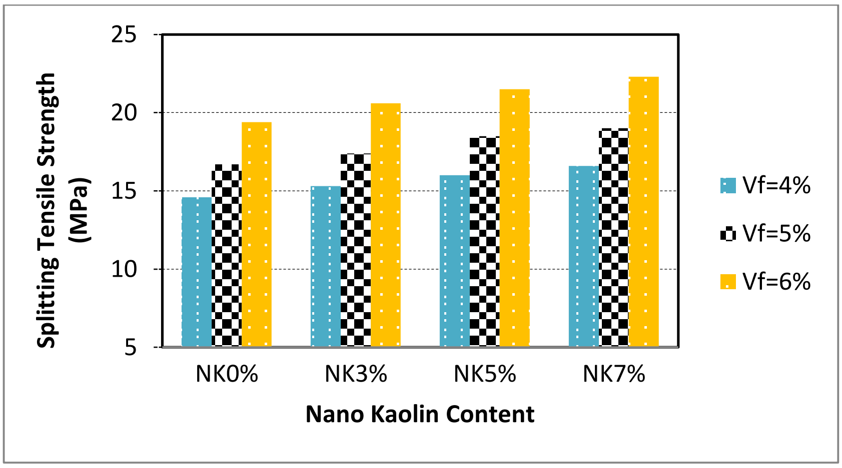

Figure 3. Comparison of the Splitting tensile strength of SIFCON with different Nano Kaolin Content

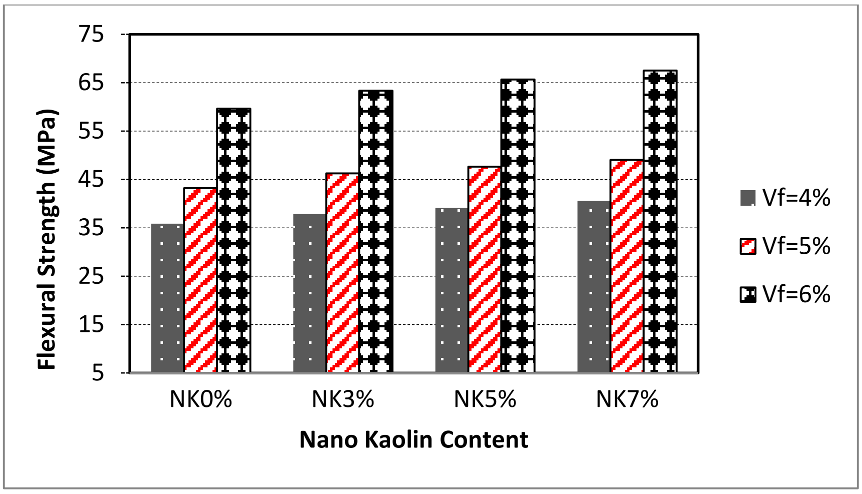

Figure 4. Comparison of the Modulus of Rupture strength of SIFCON with different Nano Kaolin Content

CONCLUSION

1-Results showed that there was a significant improvement in the compressive strength (fcu) of sifcon due to the addition of steel fibers. The presence of fibers at volume fractions of 4%, 5%, and 6% resulted in an increase in the compressive strength by 66.3%, 82.4 %, and 102.4% respectively, in comparison with steel fiber reinforcement concrete. The addition of the steel fiber reduces the crack width and provide bridging between the cracks and improves the resistance of concrete to deformations.

2-The splitting tensile strength increased by increasing the SIFCON ratio (4%, 5%, and 6%). It was increased by 55.3 %, 77.6%, and 106.3% in comparison with steel fiber reinforced concrete.

3-flexural strength was more significant. It was increased by increasing the SIFCON ratio (4%, 5%, and 6%) It was increased by 130.9 %, 178.7%, and 284.5% in comparison with steel fiber reinforced concrete.

4-For SIFCON ratio 4%, increasing the percentage of Nano kaolin content (3%, 5% and 7%)leads to an increase by 9.6% ,14%and 17.5% for compressive strength , 4.8% ,9.6% and 13.6% for splitting tensile strength and 5.6 %, 8.9 % and 12.6% for flexural strength is compared with the Nano kaolin free mixture that includes the ratio of SIFCON 4% .

5-For SIFCON ratio 5%, increasing the percentage of Nano kaolin content (3%, 5% and 7%)leads to an increase by 9.1% ,14%and 20.1% for compressive strength , 4.2% ,10.7% and 13.8% for splitting tensile strength and 6.9 %, 10.2 % and 13.4% for flexural strength is compared with the Nano kaolin free mixture that includes the ratio of IFCON

6- For SIFCON ratio 6%, increasing the percentage of Nano kaolin content (3%, 5% and 7%)leads to an increase by 10.9% ,15.1%and 25.2% for compressive strength , 6.2% ,10.8% and 14.9% for splitting tensile strength and 6.2 %, 10.1 % and 13.5% for flexural strength is compared with the Nano kaolin free mixture that includes the ratio of SIFCON 6% .

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