Effect of Impact Load on SIFCON

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Abstract

In present paper, some mechanical properties of SIFCON specimens are studied and they are compared with conventional mortar. The cement based slurry used in this work is a composition of cement, fly ash, silica fume.From the results achieved it was found that SIFCON specimens are much better than conventional mortar. The compressive, splitting, flexural strength and impact resistance for conventional mortar and SIFCON specimens were investigated and also plotted. Thus this study shows that SIFCON can be used as an effective alternative in special construction purposes or where the concrete or conventional steel fiber reinforce concrete cannot perform as expected/required or in situations where such high strength is important.

Index terms— sifcon, micro steel fiber, fly ash, silica fume, impact resistance

1 Introduction

here are several new type of concrete that are being presented to enhance the strength of the concrete. In such case SIFCON, as a special type of steel fiber reinforced concrete (FRC), has a discrete steel fiber matrix which lends important tensile properties to the composite matrix and because of its high steel fiber content, SIFCON has also unique and superior properties in the areas of both ductility and energy absorption. The major dissimilarity between FRC and SIFCON, in addition to the differences in steel fiber volume fraction and method of production, is the absence of coarse aggregates in SIFCON mortar which, if used, will prevent the infiltration of the mortar through the steel fiber network. Also, SIFCON contains high amount of cement in comparison with conventional concrete and (FRC) [1,2].The process of preparing SIFCON is different, because of high steel fiber content. SIFCON is produced by first poured steel fibers into a mold until it is completely filled. The steel fiber network of SIFCON is then infiltrated by cement-based slurry. While in (FRC) the steel fibers are mix intimately with wet mix of concrete, prior to mix being sprinkling into forms. The volume of steel fibers (Vf.) is a function of many parameters, such as the shape, diameter, and aspect ratio of steel fibers; their orientation; mold size; placement technique; and the extent of vibration.

External vibration can be applied during the steel fiber placement process. The stronger the vibration, the higher achievable Vf. Some researchers casted SIFCON members layer by layer under vibration to ensure whole infiltration of slurry into the steel fiber pack [3].Three techniques for incorporating the steel fibers in the matrix was used by [4] to produced SIFCON. In the first case, the steel fibers were repacked in the molds and the slurry was allowed to infiltrate the steel fiber pack, assisted by a table vibrator (single-layer technique). The second technique involved initial placing and packing of the steel fibers in the mold only up to one-third depth, followed by infiltration of the slurry up to this level. The contents in the mold were then vibrated. The process was repeated until the entire mold was filled and compacted (three-layer technique). The third technique consisted of filling the mold up to one-third depth by the slurry, implanting the steel fibers into it immediately thereafter, vibrating the contents and repeating the process until the mold was full (immersion technique). The researchers found that the three techniques used for incorporating steel fibers in the mortar slurry proved effective during the casting of the SIFCON specimens. However, the three-layers and immersion techniques were found to be easier and simpler in real practice than the single-layer technique. Also he studied SIFCON specimen's behavior under impact loads. The impact test was carried out using the test rig. The weight of drop was50 kg, and The drop height was varied from (250 -1000) mm. The test results show that, the extent of damage in SIFCON due to impact load was found to be far less when compared to plain mortar and normal fiber reinforce mortar. The

SIFCON process needs special attention relating mostly to the need of avoiding non-uniform fiber distributions and of avoiding unfavorable fiber orientation. The fiber density at the interior can be much higher, compared to the edges. Also, a number of fibers may align vertically along the outer surface. One method to escape the edge effect and fiber orientation problems is to cast a slab and get the test specimens by coring. Also, care should be paid to the orientation of fibers. If fibers are aligned along the diameter of the cylinder, a much higher compressive strength can be expected related to a cylinder in which fibers are aligned along the axis of the cylinder [5]. The behaviour of SIFCON slabs under impact loading was studied by [6]. The test was conducted by using impact testing machine with steel ball drop weight. The results reveals that SIFCON slabs with 12% fiber content shows excellent performance in strength and toughness characteristics compared to fiber reinforced concrete, reinforced cement concrete and plain cement concrete slab specimens. [7] studied the experimental investigations on partial substitution of cement with fly ash in concrete mix design. Cement was partially replaced with fly ash in the range of 0%, 10%, 20%, 30% and 40% for making concrete mix design normal and high strength concrete mix. The compressive strength and splitting tensile strengths were reduced with increased percentage of fly ash content, but cost of concrete decreased due to reduction of quantity of cement. [8] studied the mechanical properties and flexural properties of SIFCON specimens and compared with conventional concrete of grade M40. The cement based slurry is a composition of cement, fly ash, silica fume, Ground Granulated Blast Furnace Slag. From the results obtained it is found that SIFCON specimens are much better than conventional concrete. [9] investigated the effect of several factors on the impact resistance of SIFCON. These factors are; fiber volume fraction (6%,8.5%, and 11%), SIFCON mortar type (using silica fume and/or fly ash as a replacement of cement), and different fiber type was using (hooked end fiber, micro steel fiber and hybrid fiber which are varies in their aspect ratio(l/d) and geometry). A conventional fiber reinforced mortar with 2% hooked fiber content is also produced as a control (reference) mix to be compared with SIFCON mixes.The impact resistance of SIFCON specimens was carried out using disc specimen (152 mm diameter by 63 mm thick). the results show that in general, SIFCON mixes exhibited higher mechanical properties as compared with reference mix.

2 II.

3 Experimental Program

The experimental work was carried out by casting cubes of size 100 × 100 ×100mm to find the compressive strength, prism of size 100×100×400mm to investigate the flexural strength, cylinder of 100mm diameter and 200mm height were casted to obtain the splitting tensile strength and plate of size 500×500×40mm to find impact resistance. The edges of the mold were sealed with plaster of Paris to prevent the leakage of slurry. The micro steel fiber is dispersed in a random manner to the volume fraction. Compaction by table vibrator was used to ensure complete penetration of the slurry into the micro steel fiber pack. After twenty-four hours of casting, the cubes were demolded and cured in water for the test day.

4 III.

5 Materials Used a) Cement

Ordinary Portland cement which is commercially known as (Krasta), produced in Sulaymaniyah, was utilized in this study. It's chemical composition and physical properties are presented in Table (1), the results show that the cement utilized conforms to the Iraq specification No. 5/ 1984 [10]. [10] Limits Fineness, Blaine, cm 2 /gm 3300 >2300

Setting Time: Initial hrs.; min Final hrs.; min 1;08 4;00

6 ?45 min ?10hrs

Compressive Strength MPa 3-days 7-days 20,0 25,0?15 ?23 b) Fine aggregate (sand)

Locally available river sand passing through 4.75 mm sieve was used. The specific gravity was found as 2. 62. Table (2) shows the sieve analysis and the grading curve of the used sand. It conforms to the limits of Iraq specification No. 45/1984 [11], Zone (2). The chemical and physical properties of natural sand are illustrated in Table (3). ii. Fly Ash Class F fly ash (FA) produced from Thermal Power plant in Turkey is used as an additive according to ASTM C 618 [13], cement is replaced by (20%) of fly ash by weight of cementitious material. The physical and chemical properties are presented in Table (5). Fresh water available from local sources was used for mixing and curing of specimens.

7 f) Micro Steel Fiber

Micro steel fibers are used in SIFCONs to enhance some properties and improve the ductility, the properties are summarized in Table (7). Micro steel fiber (6%) volume fraction Vfwas randomly distribution by hand. The proportion of the constituents for the prepared slurry mix is 1:1 (by weight) of ordinary Portland cement and cementitious materials (Silica fume and Fly ash) to sand, while the water/binder ratio was kept constant as 0.3 (by weight). The super plasticizer (SP) had a dosage of 2liters per 100 kg of cement materials, (6%) volume fraction of micro steel fiber was choosing to reinforced SIFCON mix. A conventional micro steel fiber reinforced mortar, with (2%) fiber volume fraction, was also prepared as a comparison (reference) mix with SIFCON mix. The mixing procedure used to produce SIFCON was as described:

? Before mixing operation, the mixer was cleaned off from any remaining fresh or hardened materials from the older mix. ? Firstly, add cement, fly ash and silica fume while mixer operating at low speed for 30 sec. until a uniform distribution is reached, ? Secondly, add sand and mixing for 1 min. at medium speed,0 ? Thirdly, first part (2/3) of water was added and mixed thoroughly for 30 sec. at low speed, ? stop 2 min to clean blades, ? Now, adding SP and remainder water and mixing for 2 min. at normal velocity, ? Stop the mixer and wait for 1 min., and then finalize the process by mixing at normal velocity for 3 min. After many trails of casting technique in the laboratory, two-layer technique was used for incorporating the steel fiber into the SIFCON. According to reference [9] two-layer technique was utilized for combining the micro steel fiber into the SIFCON matrix. The two -layer technique involved primary placing and packing the micro steel fiber which were oriented in random method, in the mold only up to half depth, followed by filling the mold by the slurry up to half depth. The slurry has to be flow able enough to ensure infiltration through the micro steel fiber. This procedure was repeated (for the second layer) where the entire mold was filled with the required volume fraction of fiber. No vibration was applied.

8 IV.

9 Tests for Fresh Sifcon Mortars a) Determination of Slump-Flow

The test apparatus for measuring the flow and viscosity of mortar the dimension of slump -flow is show in Fig. (1).The subsequent diameter of the mortar marked on the glass plate, filled with mortar and lifted upwards. Fresh properties of mortars were calculated by the mean value two perpendicular flow diameters in the spread test. The procedure for test was followed as described in [15]. Fig . **??**: V-Funnel test apparatus [15] V.

10 Testing of Hardened Sifcon a) Compressive strength test

The compressive strength test was carried out on 100 mm cube, by using a 2000 kN capacity hydraulic testing machine type ELE digital testing. The loading rate was applied at 0.3 N/mm 2 per second according to BS.1881: part 116 [16]. The Specimens were tested at the ages of 7, 28, and 90 days of water curing. The average of three specimens was recorded for each variable in this test.

11 b) Splitting tensile strength test

Splitting tensile strength test was carried out according to ASTM C496-04 [17]. Cylindrical specimens of 100×200 mm were employed and the average result of two specimens at ages of 7,28, and 90 days was taken for each mix. The splitting tensile strength can be calculated from equation (1). Splitting tensile strength test was made by ELE Digital Elect testing machine. The loading rate used in the test is 0.3 N/mm 2 per second. Where:

Fst: Splitting tensile strength (MPa). P: applied load (N).

D: diameter of the specimens (100mm). L: length of the specimens (200mm). c) Flexural strength (modulus of rupture)

This test was performed in accordance with ASTM C1609-12 [18], using prismatic specimens of 100×100×400mm simply supported beam. The specimens were tested under two point loads with a constant rate of loading about 0.015MPa/sec. The specimens were tested at ages of 7, 28 and 90 days and the average of two specimens was recorded. The flexural strength (modulus of rupture) was calculated using the following formula:f r = PL bd 2

(2) where P: maximum applied load, (N). L: Span length of specimen, (mm). b: the width of the specimens, (mm). d: the depth of the specimen, (mm d) Impact resistance test Steel molds with (500×500×40mm) are fabricated for casting the plats specimens. The molds are made of (4 mm) thickness steel and their side pieces are connected by bolts which can simply be removed and fastened. The same procedure casting for other SIFCON test was utilized for impact resistance. Fig (3) show the impact resistance mold during casting. **??**).The test procedure adopted is as (5kg) steel mass was released from a height of (1m) repeatedly, which would come in contact with the top surface of the center of plate specimens. The number of impact blows until the appearance of first visible crack was recorded. The loading was then continued and the number of blows until failure was recorded. In average, three plate specimens are adopted in this instrument for90 days' age. The energy absorption value was obtained by:E = N × (w × h)**(3)**

Where; E is the energy in joules, w is weight in Netwton his the drop height in meter and N is the blows in numbers.

12 Results and Discussion

13 a) Fresh SIFCON Properties

The test results related to the slump flow diameter, V-funnel flow time are presented in Table (8). From result show the mixture had slump flow diameter, V-funnel flow time conforming [15]. Where Dm is the mean value of the two perpendicular diameters, measured in (mm); D 0 is the initial diameter of the base of the cone, measured in (mm), and finally, the (t) represents the time of flow in the v-funnel, which is measured in second.

Table (8) The compressive strength test results for SIFCON cubes 100×100×100mm cured in water until days of test at age of 7,28 and 90 days, from the results showed in Table (9)and Fig. (4), the strength increased with ages. This development in compressive strength can be attributed to the fact continuous the hydration process (C-S-H), also present of silica fume tends mainly to consume the calcium hydroxide crystals released from the hydration process leading to the creation of further calcium -silicate-hydrate (secondary C-S-H).

The increase in fiber fraction from 2% (reference) to 6% (SIFCON) mix leads to enhance the compressive strength of SIFCON mix to (73.2,75.4 and 65.3%) at age of 28,60 and 90 days respectively. This enhance in compressive strength is due to the developed gained bond between micro steel fiber/ matrix interfaces by increasing micro steel fiber Vf, in addition to the effect of micro steel fiber in bridging the microcracks growth, and therefore lead to higher strength of the composite, these results are in agreement with other researchers [3,4,5,9]. ii. Splitting Strength

The tensile strength values of SIFCON mix were carried out at the different ages of 7, 28, and 90 days, are presented in Table (9) and plotted in Fig. (5). It is shows that, SIFCON specimens have superior tensile properties, important enhance in tensile strength by about (1.92, 1.81and 1.21%)at age of 7, 28 and 90 days respectively. This enhanced can be attributed to the microcracks can be controlled by arresting and bridging mechanism of fiber. Also the using micro steel fiber leads to an improved bond between fiber and matrix, hence improvement in mechanical properties of SIFCON. This result is in agreement with other researchers [3,4,5,9]. The flexural strength values of SIFCON specimens at different ages for SIFCON mix and also the flexural strength of reference mix, are presented in Table (9) and presented in Fig. (6). It is obvious that, important enhance in flexural strength by about (1.36, 1.45and 1.54%) at age of 7,28 and 90 days respectively, when comparing the results of SIFCON specimens with that of reference specimens. This result can be attributed to the stronger and greater interface zone between binder and micro steel fibers which enhances the bond strength and decreases the growth of microcracks which leads to flexural failure. This result is in agreement with other researchers [3,4,5,9]. The results of number blows required to first and failure crack at age of 90 days are present in Table (10) and Fig. (7). The test results show that a significant development in impact resistance for SIFCON mix at first crack and failure compared with the conventional mortar (reference) mix by about 8.77%, 8.97% for initial crack and complete failure respectively. SIFCON mix exhibited the highest impact resistance, and the energy required for complete failure was (65089.35 joules) which is increased by 9.97 times, compared to the reference mix at 90 days as show in Table (10) and Fig. (8). Also this result was much higher than that of high performance fiber reinforced concrete which is ranged between (3000-50000 joules) [19,20]. This result is in agreement with other researchers [4,9],and can be attributed to the ability of micro steel fibers in absorbing high amount of impact energy because of its high tensile strength and high ductility.

14 Conclusion

From the experimental study of SIFCON, the following conclusion is drawn.

1. The (compressive, splitting, flexural) strength increased with agesfor conventional mortar (reference) and SIFCON mix. 2. SIFCON show enhance in the (compressive, splitting, flexural) strength for all ages test when comparing with conventional mortar (reference). 3. a significant development in impact resistance for SIFCON mix at first crack and failure compared with the reference mix. 4. SIFCON mix exhibited the highest impact resistance. 5. The energy required for complete failure was which is increased by 9.97 times compared to the reference mix. [1]

1 

Figure 1: Fig. 1 :

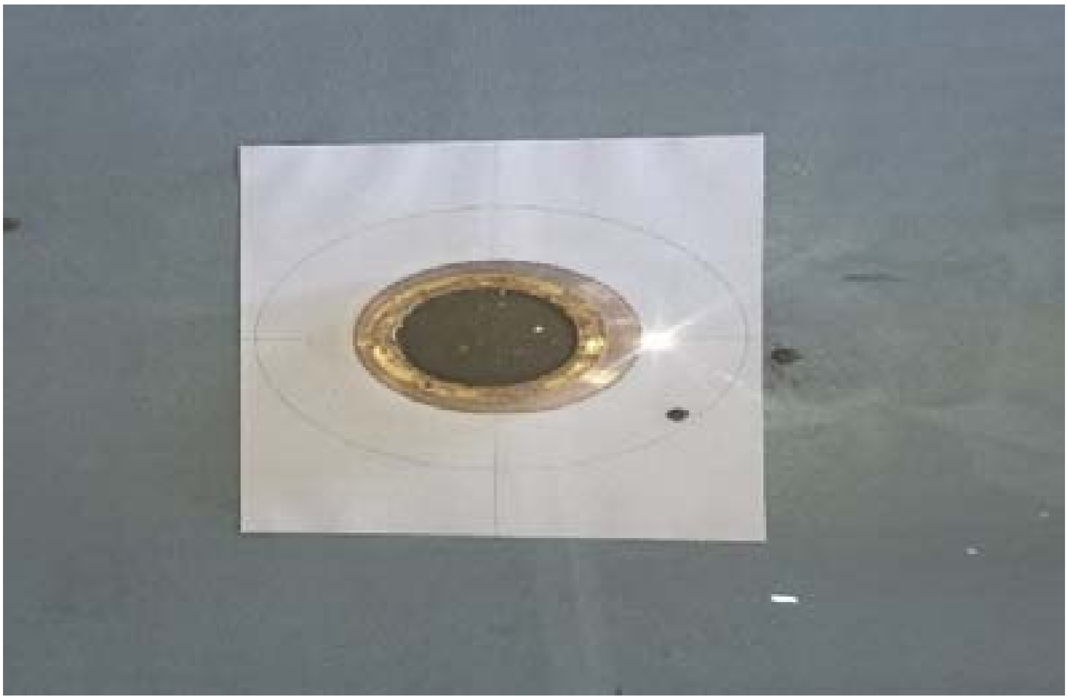


Figure 2: E

3 

Figure 3: Fig. 3 :

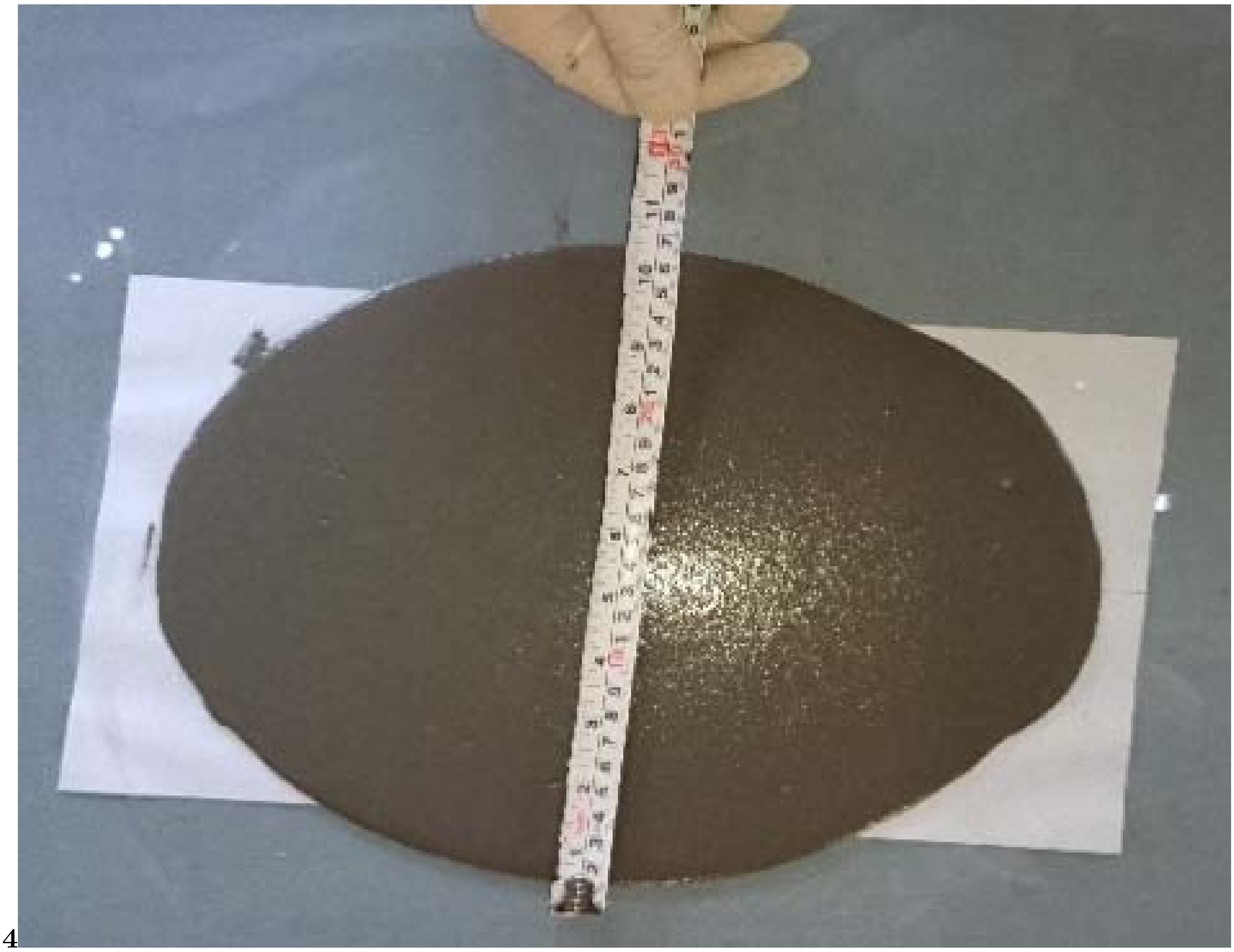
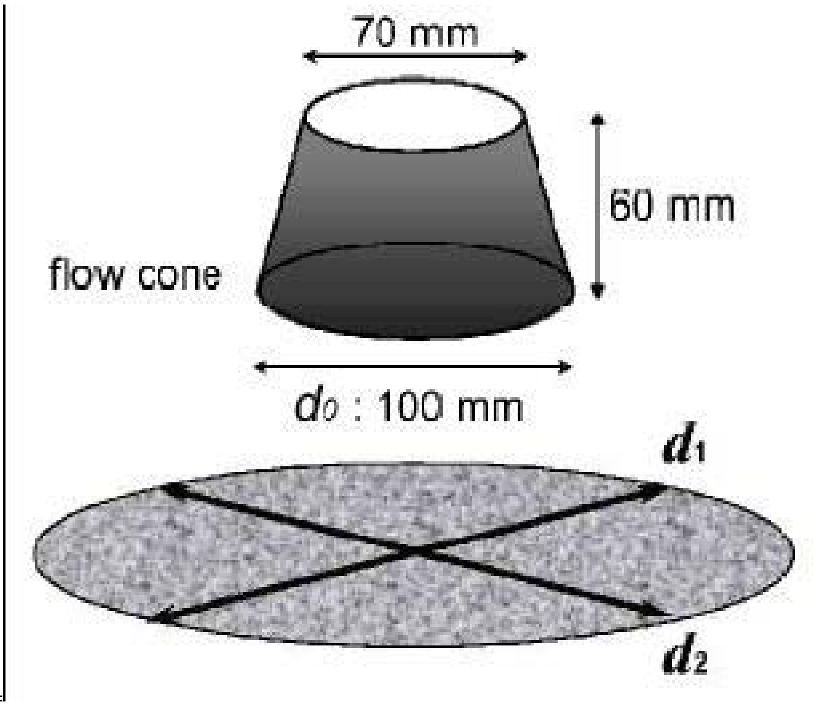
4 

Figure 4: Fi g. 4 :

Figure 5: :*



4

Figure 6: Figure (4)

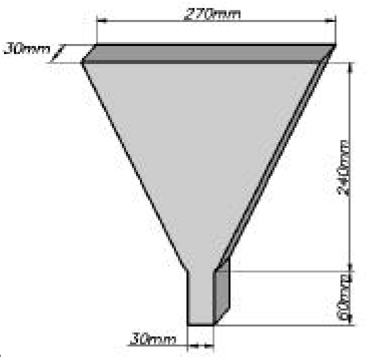


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Figure 7: Figure (5)

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Figure 8: Figure (6)

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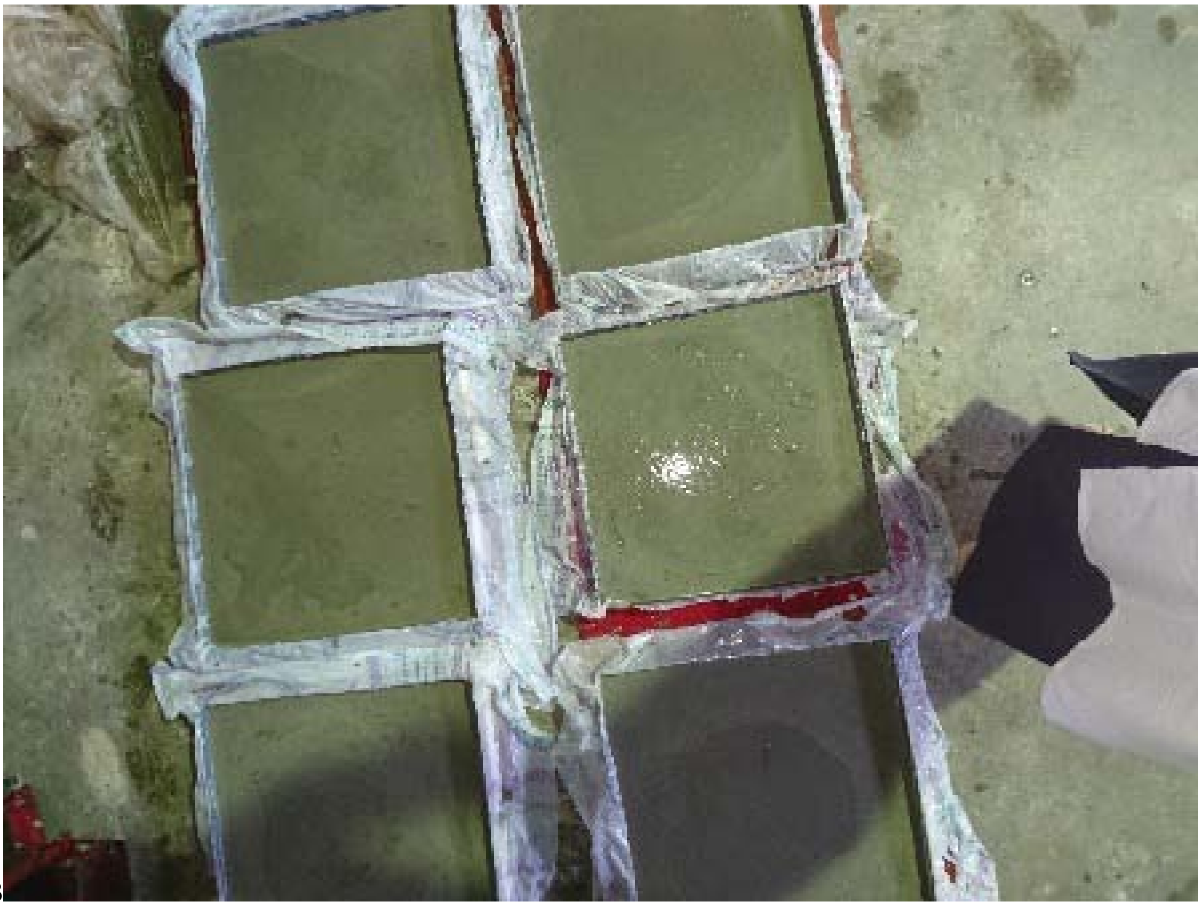

Figure 9: Fig. (8)

1

Oxide	%	I.Q.S. 5: 1984 [10] Limits
CaO	66.11	_
SiO 2	21.93	_
Al 2 O 3	4.98	_
Fe 2 O 3	3.10	_
MgO	2.0	< 5.0
K 2 O	0.75	
Na 2 O	0.35	
SO 3	2.25	< 2.8
Loss on Ignition (L.O.I)	2.39	< 4.0
Lime Saturation Factor	0.93	0.66 -1.02
(L.S.F) Insoluble residue (I.R)	1.29	< 1.5 %
Free lime (F.L)	0.67	-
Compound Composition	%	I.Q.S. 5: 1984 [10] Limits
C 3 S	58.16	_
C 2 S	19	_
C 3 A	7.95	_
C 4 AF	9.43	_
Physical Properties	Test Results	I.Q.S.5:1984

Figure 10: Table 1 :

2

Sieve size (mm)	Passing by weight%	I.Q.S.45/1984 [11] Zone(2)
9.5	100	100
4.75	98.5	90-100
2.36	92.4	75-100
1.18	82.0	55-90
0.6	47.5	35-59
0.3	14.4	8-30
0.15	3.2	0-10
pan	2.23	<5

Figure 11: Table 2 :

3

Properties	Test results	I.Q.S.No.45 [11]/1984
Specific gravity	2.6	-
Bulk density(kg/m 3)	1670	-
Sulfate content%	0.34	? 0.5%
Absorption	2	-
c) Supplementary Cementitious Material	by weight of cement. The technical specifications of	
i. Silica Fume	silica fume are presented in Table (4).	
Silica fume conforming to ASTM C 1240[12]		
was utilized in this study as a partial replacement	(10%)	

Figure 12: Table 3 :

4

Structure of material	Silica fume	Limits of ASTM C 1240-05 [12]
Color	Dark gray	
Density	0.55-0.7 kg/m 3	
Chlorine amount	< 0.1 %	
Specific surface area (cm 2 /gm)	> 150000 cm 2 /g	? 150000 cm 2 /g
SiO 2	> 85 %	? 85 %
CaO	< 1 %	
Activity index	156 %	? 105 %
Specific gravity	2.2	

Figure 13: Table 4 :

5

Particular	Fly ash (Class F)	ASTM C 618 Class F fly ash[13]	
Chemical composition			
)% Silica (SiO 2	65.65		
Alumina (Al_2O_3)%	17.69	(	SiO_2 + Al_2O_3+ Fe_2O_3)? 70
Iron Oxide (Fe_2O_3)%	5.98		
Lime (CaO)%	0.98		
Magnesia (MgO)%	0.72		
Sulphur Trioxide (SO_3)%	0.19		Max. 5.0
Loss on Ignition	3.1		Max. 6.0
Na_2O	1.35		
K_2O	2.98		
Physical properties			
Specific gravity	2.12		
Fineness (cm^2/gm)	3600		Min. 2250cm^2/gm

Figure 14: Table 5 :

6

Form	Viscous Liquid
Commercial name	Glenium 54
Chemical composition	Sulphonated melamine and naphthaline formaldehyde condensates
Appearance	Whitish to straw colored liquid
Relative density	1.07 gm/cm^3 at 20 ^{o}C
Chloride content	Nil.
pH	5-8
Storage	Should be stored in original containers and at above 5°C
Transport	Not classified as dangerous
Labeling	Not hazard label required
Alkali content (as NaO_2) equivalent)	0.26%
According to manufacturer	
e) Water	

Figure 15: Table 6 :

7

Property	Specification
Type	WSF 0213
Surface	Brass coated
Tensile Strength	2850MPa
Length	15mm
Diameter	0.2mm
Aspect ratio	65
	*According to manufactu 4-Mix:

Figure 16: Table 7 :

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Group NO.	Mix	Compressive Strength (MPa)			Splitting Strength (MPa)			Flexural Strength (MPa)		
	Symbol	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days
Reference	R	55	62.3	72.1	5.5	7.1	9.9	7.6	9.9	11.0
SIFCON	S	95.3	109.3	119.2	16.1	19.8	21.9	18.0	24.3	28.0

Figure 17: Table (9

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Effect of Impact Load on SIFCON

Group No. Reference SIFCON 8 10 12 14 16 18 20 22 30 28 26 24 Flexural Strength 6 4 2 1000 0 200 400 600 800 1200 1400 No. of blows Fig. (7): 0

Mix symbol R S 7days

Number of blows to cause Initial Crack Complete Failure 44 133 430 1327 Flexural Strength Impact energy (joules) Initial Failure 2158.2 6523.65 21091.5 65089.35 28days Age (days) Initial Crack Complete Failure Residual impact strength ratio (Irs) 3.02 3.08 R S 90days SIFCON Mix

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Figure 18: Table (10

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