

Investigation of the Behavior of Slurry Infiltrated Fibrous Concrete

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ABSTRACT

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In this paper, silica fume and fly ash class F was used as a supplementary cementing material in cement mortars to evaluate several mechanical properties of SIFCON (Slurry Infiltrated Fibrous concrete) in the way of flexural, compressive and splitting strength which were determined using the standard test method, the impact load resistance was determined using a fabricated instrument described in body paper. plate specimens with dimension of 450mm×100mm×40mm were cast with micro steel fiber of 6% volume fraction were tested under impact load for assessment with references plates at 90 days of age. From the results of the outcome it was found that the performance of conventional mortar is much less than SIFCON specimens. The compressive, splitting, flexural strength and impact resistance for conventional mortar and SIFCON specimens were investigated, a significant development in impact resistance for SIFCON mix at first crack and failure, also the energy demand for the whole failure was which is increased by 9.97 times compared with the conventional mortar. Thus, this present paper displays that SIFCON can be utilized as a powerful option in different development purposes or where the concrete or natural steel fiber reinforce concrete can't execute surprisingly/needed or in situations where such greater strength is imperative and essential.

Keywords:

Fly ash; silica fume; impact resistance;
micro steel fiber; SIFCON

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1. Introduction

Concrete is the most commonly utilized building material in the world. Reinforced concrete structures are designed and constructed to last [1-2], Concrete is brittle and weak in tensile but strong in compressive strength. To enhance concrete weakness, fibres are added as reinforcement [3]. Fiber reinforced concrete have a wide usage in a diversity of uses, which are manufactured with a range of diverse stiffness and strength characteristics [4-5]. Now slurry infiltrated fibrous concrete (SIFCON) can be deliberated as a different and new concrete category which is being demonstrated to enhance the concrete strength in terms of an unusual steel type FRC (fiber reinforced concrete). It also consists of a definite matrix of steel fiber that provides significant properties of tensile to the

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composite matrix, and as a consequence of this high steel fiber content, the SIFCON has similar one type of greater properties in both energy absorption and ductility field. The chief variation amongst the SIFCON and FRC are added to the differences in volume fraction (V_f) of steel fiber. Further, the synthesis procedure is the absence of uneven SIFCON mortar aggregates. The usage of coarse aggregates will avoid mortar penetration via the network of steel fiber. Also, SIFCON has high amount of cement in comparison with conventional concrete and (FRC) [6-7]. The method used to produce SIFCON is diverse due to the higher content of steel fibers. Such a new category of concrete is cast by firstly pouring the steel fibers into the mold until it is filled. After that, the SIFCON's steel fiber network is infiltrated with the assistance of cement-based slurry. Whereas, in FRC, the steel fibers are warmly mixed with the concrete's wet mix, before mix being sprinkling into forms. The volume of steel fibers (V_f) 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. In the process of steel fiber placement, the external vibration can be applied [8]. SIFCON specimen's behavior under impact loads was studied by Parameswaran *et al.*, [9]. This test was carried out by using the test rig. The weight of the drop was 50 kg, and the drop height was varied from (250 – 1000) mm. The consequences of the test indicated that the amount of impairment in SIFCON was because the impact load was observed to be far less in comparison to the standard fiber reinforce mortar and plain mortar. The performance of SIFCON slabs when applied impact loading was studied by Sudarsana *et al.*, [10]. The test was shown by using an impact testing machine with a drop weight of steel ball. The outcomes disclosed that 12% fiber content in SIFCON slabs presented unusual behavior in toughness and strength characteristics associated with the reinforced concrete, specimens of standard cement concrete slab, and reinforced cement concrete. In reference, Jayeshkumar *et al.*, [11], the investigators examined the experimental work on cement's partial substitution having fly ash in the design of concrete mix. Further, cement was temporarily replaced with fly ash having a range of 40, 30, 20, 10 and 0 % to make the concrete mix design reasonable and more excellent strength concrete mix. The compressive strength and splitting tensile strengths were reduced with an increased percentage of fly ash content, but the cost of concrete decreased due to the reduction of the quantity of cement. Pradeepand and Sharmila [12] Inspected the SIFCON specimens' mechanical properties and compared them with the grade (M40) normal concrete. The cement-based slurry was formed of cement, fly ash silica fume, and Ground Granulated Blast Furnace Slag. The results showed the SIFCON specimens are much better than usual concrete. Ali [13] 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, fly ash, fly ash and silica fume) as a substances of cement), and different fiber type was using (micro steel fiber, hooked end fiber, and hybrid fiber (micro steel fiber and hooked end fiber) which are varies in their aspect ratio(l/d) and geometry). Moreover, the conventional mortar of fiber reinforcement with 2 % of bent fiber content is also synthesized as a reference mix for comparing it with the combinations of SIFCON. The impact resistance of SIFCON specimens was carried out using a disc specimen (152 mm diameter by 63 mm thick). the results show that in general, SIFCON mixes exhibited higher mechanical properties as compared with the reference mix. producing different SIFCON mixes reinforced with micro steel fiber and study the behavior of mechanical properties and impact load at 90 days of age was the main objects of the research.

2. Methodology

In this research, the experimental procedure was carried out with the help of casting cubes of size (100 mm × 100 mm × 100 mm) to discover the strength of compression and prism with size (100

mm × 100 mm × 400 mm) to inspect the flexural strength while for observation of splitting tensile strength, a cylinder of (100 mm × 200 mm) and plate of size (500 mm × 500 mm × 40mm) to find impact resistance were casted. To avoid the leakage of slurry, the plaster of Paris was used to close the mold's edges. Moreover, the fibers of micro-steel are dispersed conveniently to the volume fraction (Vf) in a random way. Compaction through table vibrator was used to make sure about the whole slurry infiltrate into the pack of micro steel fibers. The 24 hours after the casting, all molds were demoulded and cured in appropriate water for test day.

2.1 Properties of Materials

The materials used to prepare regular mortar and SIFCON specimens include Portland cement, silica fume, fly ash class F, micro steel fiber, and sand. The utilized cement was Type I ordinary Portland cement (OPC), the physical properties and chemical composition is indicated in Table 1, where outcomes represent the conformation of used cement to the Iraq specification 5/1984 [14]. The SF (silica fumes) were an incomplete (10 %) replacement by cement weight. The properties of silica fume are presented in Table1 and conforming to ASTM C 1240 [15]. Cement is substituted by (20 %) of (FA) with the cementitious materials' weight; further, fly ash (FA) class F chemical & physical properties are present in Table 1 the properties conform with ASTM C 618 [16]. High Range (HRWR) Water Reducing Admixture (Glenium 54) was utilized as per HRWR which assembles with ASTM C 494-05 Type F [17]. Glenium 54 had a dosage of 2liters per 100kg of cementitious materials. Natural sand passing through 4.75 mm sieve was used as fine cumulative with an observed specific gravity of 2.62, 0.34% sulphate content and bulk density of 1670 Kg/m³. The grading curve and sieve analysis of used sand confirms the Iraq limits having a specification 45/1984 [18] and Zone 2. Also, tap water of locally available sources was used for mold specimens' curing and mixing. Micro steel fiber (6 %) volume fraction (Vf) was used in this study, and distribution in mold specimens randomly by hand. The aspect ratio was found as 65 and tensile strength as 2850 MPa.

Table 1
 Chemical Composition of Cement, Silica Fume (SF) and Fly Ash (FA)

Oxide or Compound	Cement	SF	FA	
SiO ₂	21.93	>85%	65.65	
Al ₂ O ₃	4.98	-	17.69	(SiO ₂ +Al ₂ O ₃ +Fe ₂ O ₃) ≥70
Fe ₂ O ₃	3.10	-	5.98	
CaO	66.11	< 1%	0.98	
Na ₂ O	0.35		1.35	
K ₂ O	0.75		2.98	
SO ₃	2.25			
MgO	2.0			
(C ₃ S)	58.16			
(C ₂ S)	19			
(C ₃ A)	7.95			
(C ₄ AF)	9.43			

2.2 Mix Proportion

The proportion of slurry mix is 1:1 ration by weight for the cement of ordinary Portland and cementitious SF & FA materials to sand with a constant w/b ratio by weight of 0.3. Moreover, the dosage of superplasticizer (SP) was 2 l/100kg of the cementitious materials and 6 % of micro-steel fiber's Vf, which was choosing to reinforce the mix of SIFCON. Therefore, a mortar reinforced by

conventional micro steel fiber, 2 % fiber Vf which was casted as a mix of reference or comparison mix with SIFCON mix as well. A two-layer technique was used for merging the micro steel fiber into the matrix of SIFCON, according to [13] reference. The two-layer technique includes primary 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 ability of the flow of slurry has to be adequate to confirm the infiltration through the micro-steel fiber. The repetition of the procedure was carried out for another layer in which the whole mold was packed with fiber Vf demand. However, no vibration was found practical.

2.3 Tests for Fresh SIFCON Mortars

The flow and viscosity of mortar were determined by using the test device slump – flow is shown in Figure 1. The flow time was determined using a V-funnel test; Figure 2 represents the dimension of V-funnel. The method for analysis was followed as defined in EFNARC [19].

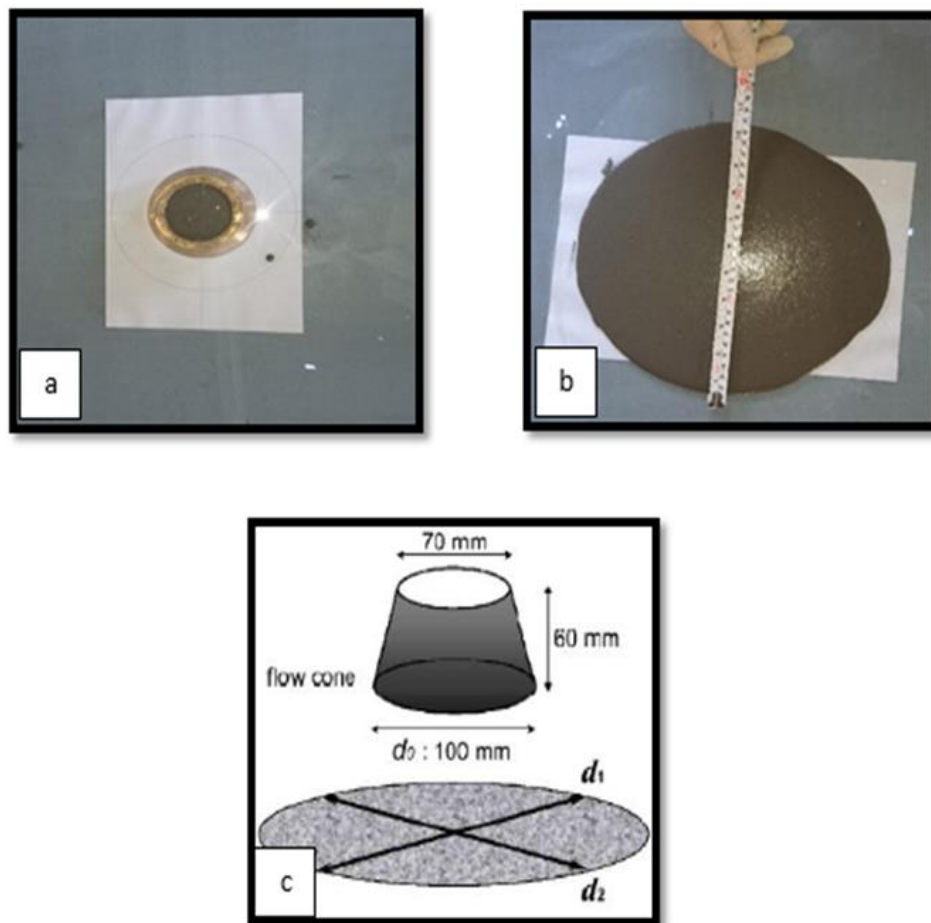


Fig. 1. (a), (b) Mini Slump Flow Test, (c)the apparatus used EFRANCE [14]

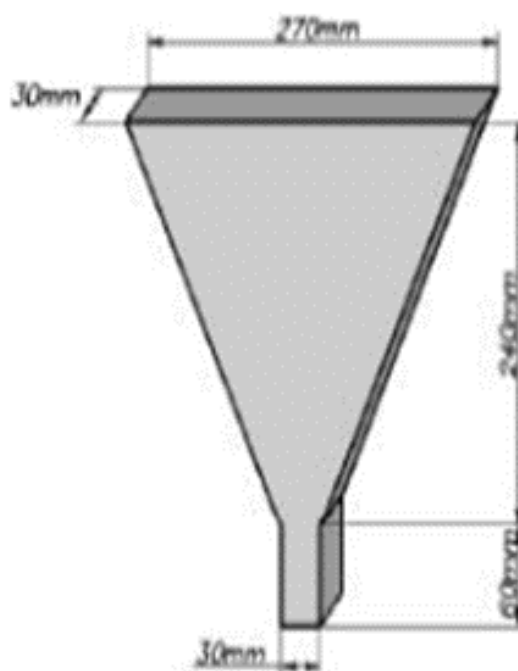


Fig. 2. V-Funnel test apparatus

2.4 Testing of Hardened SIFCON

Conferring to BS.1881: part 116, the test of compressive strength was done on a cube of 100 mm [20]. The mold of specimens was tested at the age of (7, 28 and 90 days) curing water. Moreover, the three specimens' average was observed for every variable in such test. Further, the analysis of Splitting tensile strength was done rendering to ASTM C 496-04 [21]. The 100 diameters' cylindrical specimens and of 200 mm height were casted and an average outcome of two samples at the ages (7, 28, and 90) days was measured for every mix. Further, splitting tensile strength test and Compressive strength test was carried out by using a 2000 kN capacity hydraulic testing machine type ELE digital testing. The loading rate was applied at 0.3 MPa per second. The test of Flexural strength or modulus of rupture was done with ASTM C1609-12 [22], prismatic specimens of (100 mm × 100 mm × 400mm) with a simply supported beam usage. Moreover, the specimens were tested using a two-point load with rate of 0.015 MPa/sec constant loading. Furthermore, the samples were tested at the age of (28, 7, and 90 days) while recording the average of two specimens.

2.5 Impact Resistance Test

The impact resistance test was carried out on fabricated steel mold plates (500 mm × 500 mm × 40 mm). The molds are made of (4 mm) thick steel, while side pieces are connected with bolts that can easily be detached and clipped. The impact resistance mold in casting has been indicated in Figure 3.

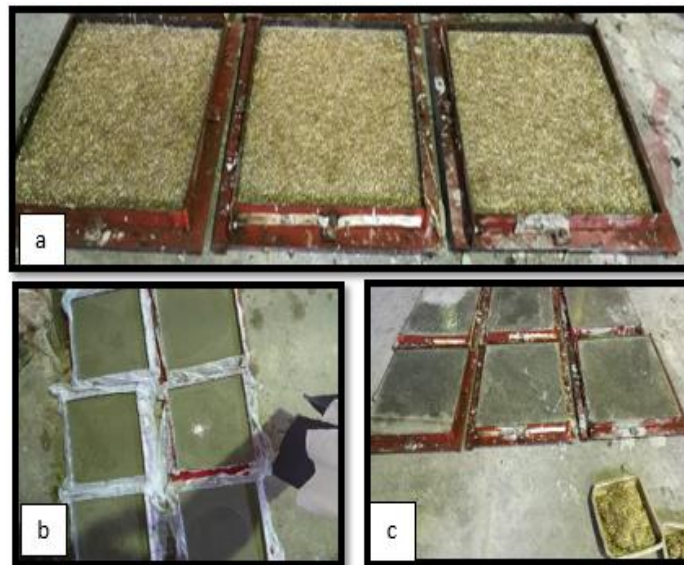


Fig. 3. Impact resistance mold during casting. (a) micro steel fiber pack, (b) during slurry cast, (c) after hardened specimens

The instrument structure mostly industrial using steel memberships. It was manufactured with a three-dimensional structure, as that seems in Figure 4. The external dimension of structure is (550 mm × 550 mm × 2000 mm). Four vertical supporters are use as primary columns of the structure, section dimension (500 mm × 500 mm × 40 mm), columns length is (2000 mm), and the distance between any two Adjacent columns is (550 mm). Iron welding is used to connect the columns collected at the top and the bottom. Horizontal memberships from a similar section of the leg, length (550 mm) were used to connection columns with others. Equal leg angles size (70 mm × 70 mm × 4 mm) used in two planes. The first plane positioned at the distance of (300 mm) from the top main structure while the second plane positioned at distance (1000 mm) also from top main structure. A steel hummer with cylindrical form and the spherical end was used as an impact hummer. The mass of this hummer is (5000 gm), and the net diameter is (50 mm) and length (250 mm). It is free dropping from a height of (1000 mm). The hummer suspended up and allowed to drop by use steel wire. Parallelogram supporting frame (500 mm × 500 mm × 250 mm) fabricated by using the same equal leg angle section that used in the main structure to bearing the concrete plate specimen during the test, two bolts size (13 mm) was used to linked parallelogram supporting frame to the main structure in each edge, also, to avoid and decrease damping influence of impact wave on support, a rubber layer (50 mm × 50 mm × 4.3 mm) was introduced below the concrete plate specimen. The test procedure adopted is as (5000 gm) steel mass was repeatedly released from a (1000 mm) height, and that came in contact with the plates top surface midpoint. The schematic diagram of impact instrument has been showed in Figure 4. Moreover, the impact blow's number until the manifestation of the first observable crack was observed. While loading was continued and the number of blows till the failure was noted down. On average, three plates are adopted for age (90) days.

Further, the value of absorption energy (E) was attained by

$$E = N \times (w \times h) \quad (1)$$

Here, E denotes the energy in joules, w represents the weight in Newton, h specifies the drop height in meters while N represents the blows in numbers.

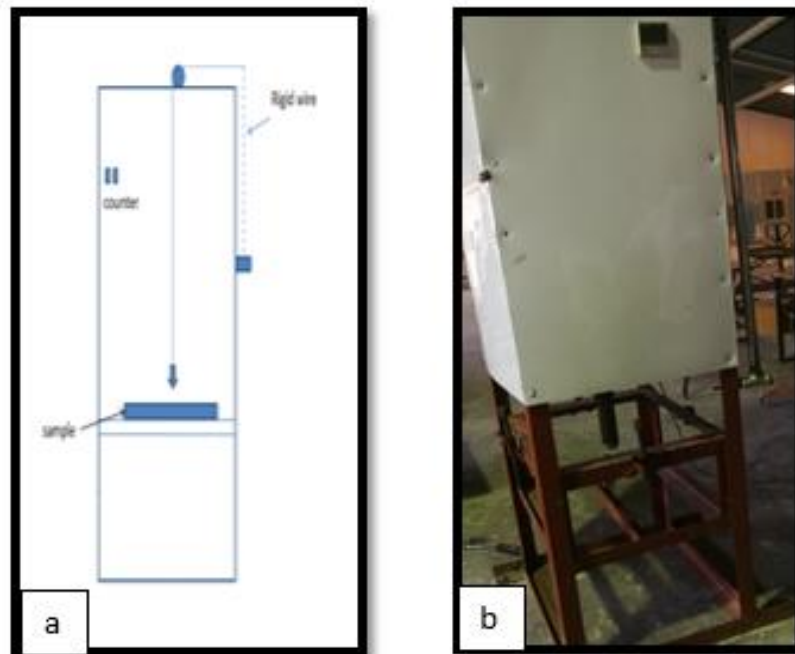


Fig. 4. Impact test apparatus, a) schematic diagram, b) impact test instrument

3. Results

3.1 Fresh SIFCON Properties

As explained previously, the fresh SIFCON properties were determined according to EFRANCE [19] and present in Table 2. From the result specify the slump- flow diameter of the mixture, the requirement for compatible EFRANCE of V-funnel flow time [19] is a required value amongst 240-260mm spread diameters for mini-slump flow test and among the (7-11) seconds flow time for the analysis of V-funnel.

Table 2
 Fresh properties of SIFCON mortars

Slump Flow Diameter (cm)	V-funnel time (s)	$G_m = \left(\frac{D_m}{D_0}\right)^2 - 1$	$R_m = \frac{10}{t}$
25.8	8	5.65	1.25

3.2 Hardened SIFCON Properties

The compression strength of the cubes was determined after curing periods (7, 28, and 90 days) in water, using the BS.1881: part 116 [20] test procedure. The results presented in Table 3 and Figure 5 and this result showed the development of compression with ages. This growth in strength of compression can be linked to a statement of continuous hydration process (C-S-H) as well as the presence of (SF) leads to the consumption of the crystals of calcium hydroxide (CaOH₂) that have been freed from the hydration procedure and leads to the calcium-silicate-hydrate (2nd C-S-H) formation. The increase in fiber fraction from 2 % (reference) to 6 % (SIFCON) mix leads to improve

the compression strength of SIFCON mix to (73.2, 75.4 and 65.3 %) at the ages of days (7, 28 & 90) correspondingly. Thus, such an increase in the strength of compression can be recognized as the development of attained bond among matrix interface and micro steel fiber by escalating the V_f of micro-steel fibers. Additionally, the effect of micro steel fiber in associating the micro-fissures growth, and therefore lead to the higher strength of the composite, these consequences are in agreement with other studies [8-9, 13].

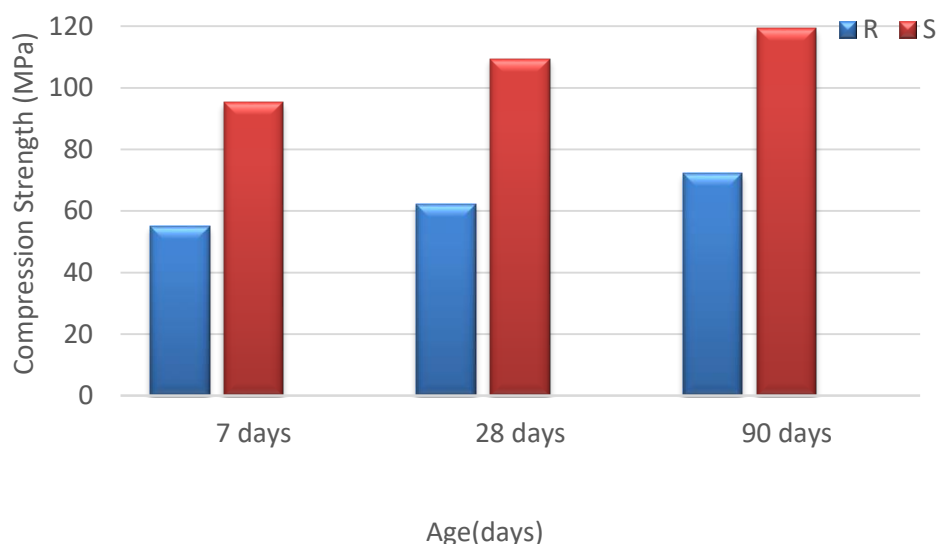


Fig. 5. Comparison of compression strength development

The tensile strength of cylinders was determined after curing periods (7, 28, and 90 days) in water, using the ASTM C 496-04 [21] test procedure. The outcomes are indicated in Table 3 and were plotted in Figure 6. It designated that the specimens of SIFCON have higher tensile properties, important enhance in tensile strength by about (1.92, 1.81 and 1.21 %) at ages of (7, 28, and 90) days respectively. This improved can be attributed to the micro cracks can be controlled by arresting and bridging the mechanism of fiber. Also, the using micro steel fiber leads to an enhanced bond between fiber and matrix, hence improvement in the mechanical properties of SIFCON. This result is in agreement with other authors [8-9, 13].

The prisms specimens' flexural strength was measured after the curing periods (7, 28, and 90 days) in water, using the ASTM C1609-12 [22] at different ages for SIFCON mix and also the flexural strength of reference mix, are presented in Table 3 and shown in Figure 7. It is obvious that important enhance in flexural strength by about (1.36, 1.45 and 1.54 %) at the age of 7, 28 and 90 days respectively, when comparing the results of SIFCON specimens with that of reference specimens. Such outcomes can be ascribed to the sturdier and larger zone of interface amongst the micro steel fibers and binder that improves the strength of the bond and reduces the progression of micro-cracks while leading to the flexural failure. This result is in agreement with other researchers [8-9, 13].

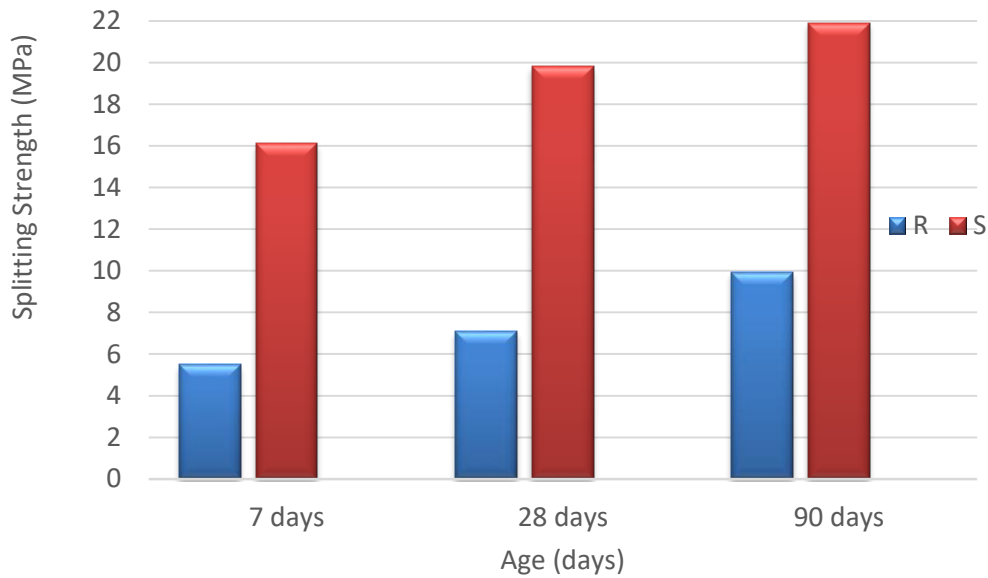


Fig. 6. Comparison of splitting tensile strength development

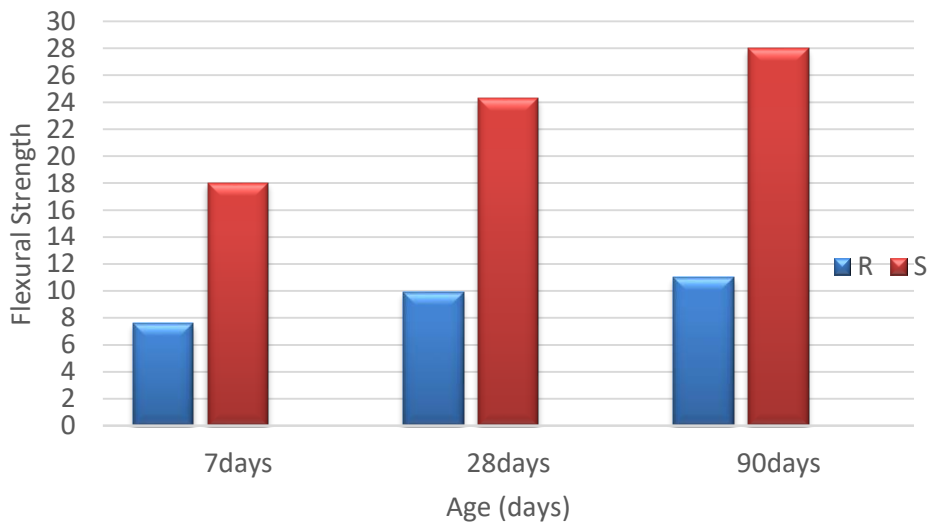


Fig. 7. Comparison of flexural strength development

3.2.1 Impact resistance

The number blow's outcomes mandatory for the first and failure crack at 90 days of age are present in Table 3 and Figure 8. The test results show that significant improvement 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 first crack and failure respectively. SIFCON mix showed the highest impact resistance, and the energy required for complete failure was (65089.35 joules), which is improved by (9.97) times, compared to the reference mix at 90 days as shown in Table 3 and Figure 9. Also, this result was much higher as compared to the fiber-reinforced concrete having high performance with a range amongst the (3000- 50000 joules) can be seen in review papers [23-24]. This result is in agreement with several researchers [9,13], and can be recognized because of the capacity of micro steel fibers while absorbing a more significant amount of impact energy due to the high ductility and tensile strength.

Table 3
 Impact resistance for SIFCON specimens at 90 days' age

Group no.	Mix symbol	Number of blows to cause		Impact energy (joules)		Residual impact strength ratio (Irs)
		First crack	Failure	Initial	Failure	
Reference	R	44	133	2158.2	6523.65	3.02
SIFCON	S	430	1327	21091.5	65089.35	3.08

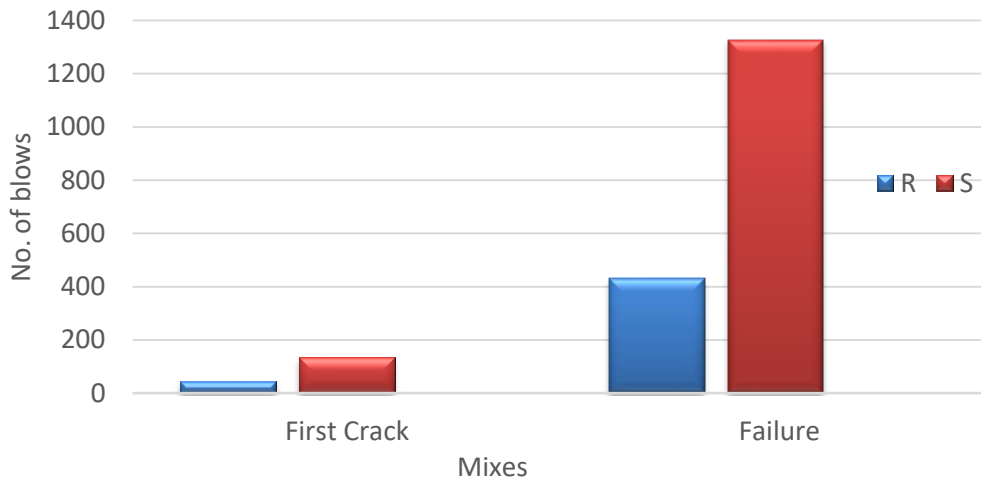


Fig. 8. Number of blows required to cause first crack and complete failure of mixes

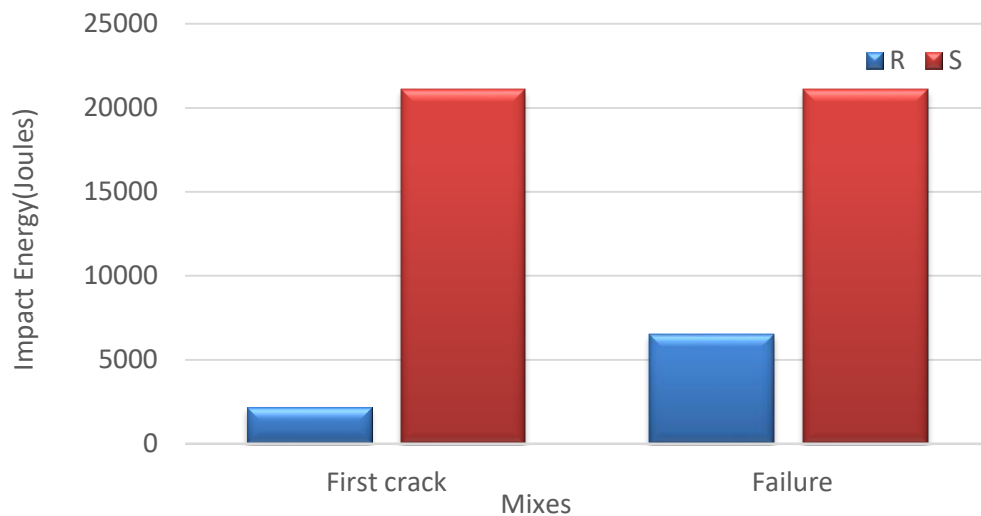


Fig. 9. Impact energy (joules)

4. Conclusions

The following conclusions can be drawn from the SIDCON mix's experimental work.

- i. The (compressive, splitting, flexural) strength increased with ages for conventional mortar (reference) and SIFCON mix.
- ii. SIFCON show enhance in the (compressive, splitting, flexural) strength for all ages test when comparing with conventional mortar (reference).
- iii. A significant development in impact resistance for SIFCON mix at first crack and failure compared with the reference mix.
- iv. SIFCON mix exhibited the highest impact resistance.

- v. The energy demand for the whole failure was which is increased by 9.97 times related to the reference mix.

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References

- [1] Miloud Hamadache, M. Mouli, O. Chaib, M. Ouldali, and E. Kh. Hamdani. "Test of a concrete bridge degraded by corrosion under the environmental effect." *Journal of Advanced Research in Materials Science* 35, no. 1 (2017): 1-6.
- [2] Kamarudin, Muhammad Hafiz, Mohd Yuhazri Yaakob, Mohd Sapuan Salit, Hasoloan Haery Ian, N. A. Badarulzaman, and R. M. Sohaimi. "A review on different forms and types of waste plastic used in concrete structure for improvement of mechanical properties." *Journal of Advanced Research in Applied Mechanics* 28, no. 1 (2016): 9-30.
- [3] Aziz, Annis Nazirah Abdul, and Roszilah Hamid. "Mechanical Properties and Impact Resistance of Hybrid Kenaf and Coir Fibre Reinforced Concrete." *Journal of Advanced Research in Applied Mechanics* 47, no. 1 (2018): 1-10.
- [4] M. Kh. Hind, M. Özakça, and T. Ekmekyapar. "A Review on Nonlinear Finite Element Analysis of Reinforced Concrete Beams Retrofitted with Fiber Reinforced Polymers." *Journal of Advanced Research in Applied Mechanics* 22, no. 1 (2016): 13-48.
- [5] Chen, Yang, Faris Matakah, Anagi Balachandra, and Parviz Soroushian. "Ultra-High-Performance Concrete: Development of On-Site Fresh Mix Rheology Test Methods." *Journal of Advanced Research in Applied Mechanics* 55, no. 1 (2019): 1-11.
- [6] Gilani, Adel Mohamed. "Various Durability Aspect of Slurry Infiltrated Fiber Concrete." PhD diss., Phd Thesis, Middle East Technical University, 2007.
- [7] Yazıcı, Halit, Serdar Aydın, Hüseyin Yiğiter, Mert Y. Yardımcı, and Giray Alptuna. "Improvement on SIFCON performance by fiber orientation and high-volume mineral admixtures." *Journal of Materials in Civil Engineering* 22, no. 11 (2010): 1093-1101.
- [8] M. Gopala Krishnan, and D. Elavarasi. "Experimental study on slurry infiltrated fibrous concrete with sand replaced by msand." *International Journal of Engineering Research & Technology* 3, no. 5 (2014): 534-537.
- [9] Parameswaran, V. S., T. S. Krishnamoorthy, K. Balasubramanian, and Santhi Gangadar. "Studies on slurry-infiltrated fibrous concrete (SIFCON)." *Transportation Research Record* 1382 (1993): 57-63.
- [10] Rao, H. Sudarsana, Vaishali G. Ghorpade, N. V. Ramana, and K. Gnaneswar. "Response of SIFCON two-way slabs under impact loading." *International Journal of Impact Engineering* 37, no. 4 (2010): 452-458.
- [11] Pitroda, Jayeshkumar, L. B. Zala, and F. S. Umrigar. "Experimental Investigations on Partial Replacement of Cement with Fly ash in design mix concrete." *International Journal of Advanced Engineering Technology, IJAET* 3, no. 4 (2012): 126-129.
- [12] Pradeep, T., and Sharmila, S. "Cyclic behavior of RC beams using SIFCON sections." *International Journal of Innovative Research in Science, Engineering and Technology* 4, no. 9 (2015): 9172-9177.
- [13] Ali, M.A. "Properties of Slurry Infiltrated Fiber Concrete (SIFCON)." PHD Thesis, Department of Building and Construction Engineering of the University of Technology, 2018.
- [14] IQS No. 5/1984. "Portland Cement." *Central Agency for Standardization and Quality Control, Planning Council, Baghdad, Iraq.*
- [15] ASTM, C. "1240-05 Standard, Specification for silica fume used in cementitious mixtures." *West Conshohocken, PA, American Society for Testing and Materials* (2005).
- [16] ASTM C618-05. "Standard specification for fly ash used in cementitious mixtures." *American Society for Testing and Material International* 4, (2005): 1-3.
- [17] ASTM C 494-05. "Standard specification for chemical Admixtures for concrete." *American Society for Testing and Material International*, (2005).
- [18] IQS No. 45/1984. "Natural sources of aggregate used in building and concrete." *Central Agency for Standardization and Quality Control, Planning Council, Baghdad, Iraq.*
- [19] EFNARC. "Specification and guidelines for self-compacting concrete." *European Federation for Specialist Construction Chemicals and Concrete Systems*, (2005): 1-32.
- [20] British Standard. "Method for determination of compressive strength of concrete cubes." *British Standards Institution* 1881, Part 116, (1989): 3.

-
- [21] ASTM C496-04. "Standard test methods for splitting tensile strength of cylindrical." *ASTM Standard 04.02*, (2004): 283-287.
- [22] ASTM C1609M-12. "Standard test method for flexural performance of fiber-reinforced concrete (using beam with third point loading)." *American Society for Testing and Material International*, (2012).
- [23] Murali, G., A. S. Santhi, and G. Mohan Ganesh. "Empirical relationship between the impact energy and compressive strength for fiber reinforced concrete." *Journal of Scientific and Industrial Research* 73, no. 7 (2014): 469-473.
- [24] Kanagavel, Ramesh, and Arunachalam Kalidass. "Mechanical properties of hybrid fibre reinforced quaternary concrete." *Journal of the Croatiaan Association of Civil Engineers* 69, no. 1 (2017): 1-10.