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Literature Review of Cement Matrices and Fibers Used in SIFCON

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Abstract: Conventional concrete is categorized as brittle. As a result, researchers continued working to develop it into a substance having ductile characteristics. Concrete showed remarkable improvement when fiber was incorporated at a ratio of 1-2%. Slurry-infiltrated fiber concrete (SIFCON) allows for the use of up to 20% more fiber when combined with unique cement slurry. Concrete that was produced had increased strength and ductility. The influence of slurry and fiber forms with different volumes on the resistance of concrete to compression, flexural, shear, and bond was the main focus of this review study. The outcomes of several previous investigations revealed a significant relationship between the strength of concrete and the slurry mixture, fiber type, and fiber volume. Additionally, it was shown that the majority of research all agreed that certain methods should be followed when employing a volume of more than 5% fiber. These processes entail employing fine-sand less than 1 mm in size to create a suitable cement slurry and replacing up to 30% of the cement with fly ash (FA), silica fume (SF), and metakaolin to create a cement slurry capable of penetrating interlocking with fiber of all forms and volumes.

Keywords: SIFCON, cement slurry, metakaolin, steel fiber, fly ash

1. Introduction

Fiber reinforced cement-based composites are used worldwide especially in the earthquake modified design, structures under fulminatory and impact effects. In spite of their comparatively high cost and high performance, concrete with high or ultrahigh compressive strength rates remains essentially a brittle material. The implying of a suitable number of fibers gets better tensile strength and ductility for concrete in all cases [1-13]. The fiber volume proportion of conventional fiber-reinforced concrete and ultrahigh performance fiber-reinforced concrete is generally restricted to 1 – 3% [14-17]. Furthermore, some specific composites are product with fiber volume amounts from 5% to 30%. The aim of using fibers is to resist the tension of concrete exposed in the presence of external load. Therefore, these fibers will reduce the width of cracks with time [18]. The composites can be classified as Slurry Infiltrated Fiber Concrete (SIFCON), which have high tensile strength and ductility properties. There is difficult to mix the dry materials of concrete and steel fiber together due to the high volume of steel fiber. In order to beat this problem, the

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mold can be firstly filled with the steel fiber up to the top level. It is also difficult to obtain a uniform distribution of fibers by manual filling, but a satisfactory distribution can be obtained using special sieves [19]. After that, a fine and cement rich slurry is poured or pumped into the mold.

The first used of SIFCON was in 1984 by Lankard [20] by pumping the mixture components of Portland cement, water, and super plasticizer into a mold filled with steel fibers. Many studies on a mechanical characteristic of SIFICON were adopted. Increased in the compressive, flexural, and tensile strength was singed for concrete [21-24]. High volume fiber in the SIFCON significantly improved properties such ductility, toughness, durability, and compressive and flexural strengths [25-30].

Some researchers developed a SIFCON mixture used cement slurry, pozzolana, sand, water, and chemical additives with steel fibers of a volume ratio up to 30% [31]. The SIFCON can be produced by placing a high-volume percentage of fibers pouring the slurry in a special mold. The mixed slurry is produced from a high amount of cement, silica powder, very fine sand, and a super-plasticizer. The model subjected to the vibrator to ensure that the slurry arrives smoothly between steel fibers [32]. High compressive strength, ductility, and toughness were obtained by using volume percent range between 8 to12% in which the range of compressive strength from 80 to 100MPa. [33]. One of the studies proved that the use of a SIFCON jacket around the columns that earthquake-prone improves their performance significantly in terms of shear and flexural strength, energy dissipation capacity and ductility [34,35].

2. Literature Review

The use of slurry to form the SIFCON must be consistent with a number of fibers used to implement a mixture that penetrates the interlacing of the fibers in all directions. In this study, several previous literature were reviewed regarding the effect of the types of slurry mixtures, considering the effect of volume and the fiber type on compressive and flexural strength of SIFCON concrete.

Balaguru and Kendzulak (1987) [36] investigated that the adding silica fume to slurry of SIFCON containing hooked steel fiber with 8% volume conducted to 62%,80%,78% and increasing in strengths of axial tension, flexure, and direct shear, respectively. According to Mondragon (1987) [37], matrices containing silica fume and a fiber content of around 8% or matrices containing fly ash and a fiber content of roughly 12% can be predicted to have tensile strengths higher than 14 MPa. SIFCON has a quite large strain capacity. The energy absorption could be 1 to 2 orders of magnitude higher than that of a plain matrix [38].

Reinhardt et al. (1989) [39] In comparison to volume fractions below 10%, tensile strengths are higher for fiber volume fractions above 10%. Higher tensile strengths are provided through improved matrix bonding, which is achieved by a lower water-cement ratio. For fibers with a relatively poor binding strength, the discrepancies are more pronounced. For hooked fibers that have a strong mechanical link, for instance, lower water-cement ratios do not considerably increase the tensile strength.

Van and Timmers, (1991) [40] came to the conclusion that the use of a sufficient proportion of sand(50%, fly ash (20%), GGBS (20%), and silica fume (20%) in SIFCON slurry led to compressive strengths of up to 110 MPa. Additionally, it was shown that matrix strength had a greater impact than fiber geometries. With an increase in fiber length, it shows that the appropriate fiber volume declines. Longer fibers give a significant advantage in flexural strength for a specific fiber volume [41] (1992). Compressive strength is reduced when sand is added in excess of a cement-to-sand ratio of 1:1, whereas flexural strength is reduced once the ratio exceeds 1:1.5. The restricted results show that sand can be added to cement up to a ratio of 1:1.5 (cement: sand) without negatively affecting the flexural strength. However, the drop in compressive strength is more rapid than the decrease in flexural strength. These outcomes concur with the findings for compressive strength. [42].

Hamza (1992) [43] indicated the SIFCON with 5% steel fiber volume strengthened the bond strength by 2–4 times more than plain concrete. The peak load can be maintained while reinforcing bars inserted in SIFCON can withstand slip up to ten times higher than when immersed in conventional concrete.

Naaman, A. E., & Baccouche, M. R. (1995) [44] concluded that the compressive strength and shear strength at maximum load were 51 MPa 2.8 MPa respectively, for the plain slurry. While the addition of 6 % steel fibers by volume to the slurry matrix increased the compressive strength to 77 MPa and shear strength about 10 times (28 MPa).

Yan and Qu (1999) [45] utilized cement mortar contained fine sand, cement, silica fume replaced cement, super-plasticizer, and water/cement by cement weight ratios as 1: 1: 0.15: 0.015: 0.28 respectively. The steel fiber of aspect ratio of 62 and different volumes of 6%, 8%, 10%, and 12% was used to investigate the effect of steel fiber volume on the compressive strength of SIFCON. The results demonstrated the compressive strength were 68.2, 76.8, 77.6, and 92.8MPa as fiber volumes 6%, 8%, 10%, and 12% respectively. On the other hand, in each case when the slurry contained cement with an additional 10% silica fume, W/C ratio of 0.3., and superplasticizer 4.8% by weight of the cement. The best dimensions (length/diameter) of straight steel fibers were 30/0.5 and 10% in volume achieved better value for flexural strength [46].

Sonebi et al. (2005) [47] concluded that a matrix incorporating fly ash or silica fume offers greater strength than a plain matrix. Silica fume gives higher strength in compared with fly ash. Since fiber weak-bonding and matrix spalling are the two main causes of failure, a denser matrix should offer more strength.

Yazıcı et al. (2006) [48] investigated the compressive and flexural strengths of SIFCON specimens prepared by using three volumes of steel fiber 2%, 6%, and 10% and fly ash replaced cement by 20%, 40%, and 60%. The mix proportion is shown in Table 1. The results showed that the unsuitable volume of steel fiber such as 2% has a negative effect on compressive strength because of there was no control on shrinkage of SIFCON slurry. While an effect in terms of flexural strength was obtained due to its limited effects on cracks configuration. Also, the obtained result pointed to the compressive strength increased (19%) with steel fiber 6% up to 60% fly ash replacement. For others volumes and fly ash replacement noticed decreasing in compressive strength about 10 to 20%. This was due to the behaviour of fly ash as pozzolanic material. On the other hand, the flexural strength gained good strength with increasing fiber volume and ratios of fly ash replaced cement. The results of compressive strength and flexural strength are present in Table 2. Here it should be noted that the flexural strength increases with fiber volume fraction for a constant fiber length, but only to a certain limit. Due to a lack of matrix between the fibers after certain fiber content, the bond strength weakens, which lessens the flexural strength. The best fiber range tends to be from 8% to 10% [49].

Table 1 - The proportion of slurry mix materials

Components	FA_0	FA_{20}	FA_{40}	FA_{60}
cement kg/m^3	800	640	480	320
Fly ash kg/m^3	0	160	320	480
Silica fume kg/m^3	120	120	120	120
Water kg/m^3	313	313	314	322
Basalt kg/m^3	600	562	524	486
0-1mm quartz kg/m^3	160	150	140	130
0-0.1mm quartz kg/m^3	160	150	140	130
Super-plasticizer L/m^3	35	35	35	35

Table 2 - The compressive and flexural strength with different ratios of fly ash

Sample	Steel fiber volume %	Compressive strength MPa	Flexural strength MPa
FA_0	0	80	14
	2	71	20
	6	84	31
	10	143	55
FA_{20}	2	60	21
	6	92	31
	10	142	48
FA_{40}	2	64	20
	6	95	38
	10	140	50
FA_{60}	2	68	24
	6	100	39
	10	130	70

Yazıcı et al. (2010) [50] prepared slurry mixes by using fine aggregate (crushed limestone sand, limestone powder and quartz powder with maximum size, 1mm, 0.125mm, 0.075 mm), fly ash (**Class C**), slag, silica fume, A poly-carboxylate as reducing water admixture, and cement. Steel fiber of hooked ends, diameter 0.75 mm, and 30 mm length by three placing types (parallel, perpendicular, and random) was used. The mix proportions are listed in Table 3. Table 4 shows the steel fiber ratios and the results of compressive strength and flexural strength for each specimen. The results displayed the best mix is IGGBS50 which contain a high amount of Superplasticizer (19.4 kg/m3), quartz powder (147 kg/m^3), slag (400 kg/m^3), lower amount of water (231 kg/m^3), limestone powder (342 kg/m^3), and water/binder (0.26) with random fiber alignment ratio 16% for compressive strength and with perpendicular fiber alignment ratio 25% for flexural strength. From the results can be noted clearly improved in compressive and flexural strength with this mix when compared with others mixes.

Table 3 - Slurry mix proportion

Item	Control	FA50	GGBS50	IGGBS50
Cement (kg/m3)	800	400	400	400
Fly ash(kg/m3)	0	400	0	0
slag(kg/m3)	0	0	400	400
Silica fume(kg/m3)	80	80	80	80
water(kg/m3)	339	339	339	231
0–1 mm limestone (kg/m3)	397	330	388	489
0 – 0.125 mm	397	330	388	342
0 –0. 075 mm quartz	0	0	0	147
Super-plasticizer (kg/m3)	7.3	6.3	5.2	19.40
Water/cement	0.42	0.85	0.85	0.85
Water/binder	0.39	0.39	0.39	0.26

Table 4 - Compressive and flexural strength with fiber content and alignment

Slurry mix	Fiber content%	Fiber alignment	Compressive strength (MPa)	Flexural strength (MPa)
control	0	-	29	4.4
	25	Parallel	26	-
	25	perpendicular	29	55.0
	16	random	43	47
FA50	0	-	65	5.3
	25	parallel	56	-
	25	perpendicular	52	84.7
	16	random	98	73.1
GGBS50	0	-	71	5.9
	25	parallel	76	
	25	perpendicular	77	89.7
	16	random	101	77.2
IGGBS50	0	-	127.7	8.4
	25	parallel	143.2	
	25	Perpendicular	172	137.9
	16	random	183	87.2

Dagar (2012) [51] employed cement slurry with silica fume and fly ash replaced cement from 10%-15%, water reducing admixture 2-5 by weight of cement, cement: sand 1:1 or 1:1.5, water/cement ratio 0.3-0.4 and steel fiber by volume 4-12% to formed SIFCON. The compressive strength of the hardened slurry developed from 50MPa to 70MPa. For the SIFCON the compressive strength developed from 90MPa to 160MPa and the flexural strength from 25MPa to 75MPa.

Abdollahi et al. (2012) [52] studied the effect of SIFCON jacket confinement for many cylindrical samples of concrete. The cylindrical concrete samples with different compressive strength 15 MPa, 25 MPa and 40 MPa were utilized. The slurry of SIFCON used was contained of cement, fine aggregate, silica fume replaced cement, and super-plasticizer by quantities 900kg, 700 kg, 240 kg, and 3.5 kg, by cement weight respectively. And water/cement 0.3. A 30 mm length, 0.3 mm diameter and 950MPa tensile strength of steel fiber was used in SIFCON with different jacket thickness specimens. The result showed that the use of SIFCON jacket has a good confinement effect on cylindrical concrete specimen which appeared in compressive strength values of concrete specimens with different concrete strength. The obtained compressive strengths of confinement specimens were 25MPa, 57MPa, and 65MPa compared with the specimens without SIFCON jacket with compressive strength 15MPa, 25MPa, and 40MPa respectively. There was an effect of jacket thickness on compressive strength of concrete in which the 20 mm SIFCON jacket thickness increased the compressive strength by about 50% and when the thickness is 15mm the compressive strength was 14% increasing for a concrete specimen for strength 25MPa.

Parthiban et al. (2014) [25] examined reinforced beam specimens and compared the results of steel fiber replaced of reinforcement by using different ratios of replacement (10, 20, 30, 40, and 50%) as a SIFCON concrete. Ordinary cement mortar was used with sand (1:1 by weight) and a water/cement ratio of 0.5. The steel fiber with length 50mm, diameter 1mm, tensile strength 1050 MPa, and aspect ratio 50 was used in SIFCON concrete. The result showed that the use of 40% of steel fiber as a reinforced replacement was very effective on the flexural strength of the beam which was 22.0 MPa when compared with the ratios 10, 20, 30, and 50 which were 17.54, 18.23, 17.78 MPa respectively.

Ipek et al. (2014) [53] was developing SIFCON samples by applying external pressure on samples during the setting time to minimize the voids in the cement slurry. The quantities of used materials for SIFCON slurry are shown in Table 5. Two types of steel fiber in all SIFCON specimens were utilized, the first type with length=35mm, diameter=0.55 mm, and tensile strength=1345MPa by volume ratio 10.44%. The second type with length=60 mm, diameter=1.05mm, and tensile strength=1115MPa by volume ratio 6.67%. The external pressures 3MPa, 6MPa, 9MPa, 12MPa, 15MPa were applied to SIFCON samples during the setting time (24 hours). The results showed there was an increase in compressive and flexural strengths versus externally applied pressure. Table 6 pointed to the obtained strengths of compressive and flexural. 42% increment in compressive strength was obtained when the externally applied pressure was equal to 15MPa in comparison with the reference sample without pressure. Also, about 43% increment in flexural strength was obtained in the same case above.

Table 5 - Quantities of cement slurry materials

Material	Quantities (kg)
cement	900
Quartz 0.3-0.6	252
Quartz 0.1-0.3	252
Quartz 0.0-0.1	278
Silica fume	270
Water	270
Super-plasticizer	36

Table 6 - Compressive and flexural strength versus external pressure

External pressure (MPa)	Compressive strength (MPa)	Flexural strength (MPa)
0	17.2	47.06
3	20.5	55.81
6	21.2	58.00
9	22.0	60.26
12	23.3	63.41
15	24.5	67.54

Thomas and Mathews (2014) [54] investigated the compressive and flexural strengths of SIFCON samples consisting of cement slurry (Portland cement grade 53, sand passing sieve size 4.75 by proportion 1:2, and super-plasticizer 2%) and steel fiber (50 mm in length and 1mm diameter). The results showed that an increase in compressive strength (54% increment) and flexural strength (about 30% increment) for steel fiber volume from 4% to 5% and decreasing in compressive and flexural strengths in 6% steel fiber volume due to the entanglement in the steel fibers of this volume makes it difficult for the cement mortar to pass through them.

Jain and Kumar (2015) [55] studied the influence of slurry components and steel fiber volumes on the flexural performance of SIFCON. Cement slurry included cement to sand 1:2 and water/cement as 0.35 with calcium nitrate as accelerating admixture. The used sand consists of 60% Fine River sand and 40% stone dust. GGBS as partially replaced cement by ratios 10%, 20%, 30%, and 40% was utilized. Three volumes of steel fiber 3%, 6%, and 9% placed by hand in prism moulds of SIFCON. They concluded the slurries without GGBS replacement cement has good improvement on flexural strength with increasing fiber volume to 9% compared with that have partially replacement of cement.

Giridhar et al. (2015) [56] investigated the mechanical characteristics of SIFCON for volume fractions of steel fibers (4, 6, and 8). Used with lengths of 50 mm and 35 mm were hooked ends fibers. The ratio of the slurry mix's components was 1:1 cement to sand, 0.4 water to cement, and 2% Superplasticizer. The researchers have found that as the fiber volume fraction rises, SIFCON' mechanical characteristics do as well. After 28 days of water curing, the 35 mm steel fiber's compressive strength was (90, 110, 120 MPa) and its flexural strength was (4.47, 6.84, and 8.90 MPa), respectively. Additionally, short length fibers have greater compressive strength than longer ones.

Kumar and Rajasekhar (2017) [57] tested three samples of SIFCON with different volume of steel fiber (6%, 8%, and 12%) to evaluate the compressive strength of them. The properties of steel fiber were 50 mm length, 1mm diameter, and 417MPa tensile strength. The cement grade 43 and crushed quartz with maximum size 1mm were used. The obtained result showed that the SIFCON with steel fiber volumes 8%, 10%, and 12% were 36, 47, 52MPa respectively.

Vijayakumar and Kumar (2017) [58] used Portland cement grad 53, fine sand passing sieve 600 µ and remain 300 µ sieve, fly ash (class F), steel fiber (D= 0.33mm, length= 25mm, unit weight = 7850 kg/m^3), and super-plasticizer (CONPLAST SP- 430) to product SFICON style. The proportions of mixing were, cement to: sand = 1:1, fly ash= 50% of cement weight, SP= 2% of cement weight, steel fiber = 6%, 8%, 10%, and 12% by volume, and W/C = 0.45. They were concluded that the compressive strength and the flexural strength increase with increasing of the steel fiber volume. The use of 12% steel fiber conducted a 36.2% increase in compressive strength and a 64.4% increase in flexural strength when compared with the conventional concrete specimens.

Balaji et al. (2018) [59] evaluated the results of compressive strength and flexural for reinforced beams were done by covenantal concrete and SIFCON concrete. The mixed properties of each beam are shown in Table 7. The width, height, and length of the used beam were 100 x 150 x 1100 mm. The steel fiber used in SIFCON was 30 mm in length and 0.5 mm in diameter. The result showed that the SIFCON beam gives a 115% increase in carrying capacity and an 11% increase in deflection when compared with the covenantal reinforced beam.

Table 7 - Conventional and SIFCON concrete mixes

Material	**Conventional concrete**	**SIFCON**
Cement (kg/m3)	456	680
Coarse aggregate (kg/m^3)	1284	-
Fine aggregate (kg/m^3)	530	-
Silica fume (kg/m^3)	-	68
Fly ash (kg/m^3)	-	340
Quartz powder (kg/m^3)	-	340
Super-plasticizer/cement	-	1.5
Water/cement	0.45	-
Steel fiber (%volume)	-	9
Compressive strength (MPa)	33	42

Balaji and Thirugnanam (2016) [60] used the SIFCON concrete to strengthen the beam- column reinforced joint and compared it with the reference reinforced beam-column joint. The style of beam-column joint is shown in Fig. 8. The components of SIFCON slurry were cement, fly ash, micro-silica, quartz powder by proportion 1: 0.5: 0.1: 0.5, water-cement ratio was 0.45, and super-plasticizer dosage 1.5 by cement weight. The result indicated that the use of SIFCON in connection joint of beam-column increased the ultimate load about 69% greater than the reinforced joint with conventional concrete and about 43% more than the using of fiber reinforced concrete with 1.5% content of steel fiber.

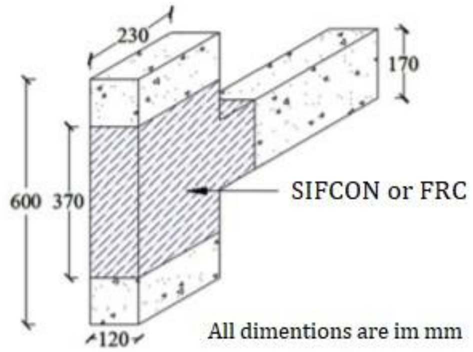

Fig. 1 - Beam-column reinforced joint with SIFCON or FRC strengthen

Sharma et al. (2017) [61] evaluated the SIFCON slurry with 4% volume of steel fiber and 10% steel slag replaced sand. The findings confirmed that compressive strength and flexural strength were improving by 11% and 20%, respectively. Strength declined as the replacement ratio rose.

According to Manolia et al. (2018) [62] replacing cement in a mixture of fly ash (20%) and silica fume (10%) enhances the workability of SIFCON mortar, lowers its viscosity, and uses as little HRWR as feasible. Therefore, by substituting silica fume and/or fly ash with the appropriate dosage of HRWR, SIFCON mortar with the necessary qualities for flow and filling ability can be created. The findings further demonstrate that after 100 freeze-thaw cycles, all SIFCON specimens suffer less loss in flexural strength and weight, reaching (13.3% and 0.95%) loss, respectively, as opposed to (21.8% and 2.5%) loss in strength and weight of the control mix (without steel fiber). The loss is reduced by increasing the fiber percentage from 6% to 11%.

Salih et al. (2018) [63] investigated cement slurry of SIFCON with partial replacement of cement by silica fume (10%). The slurry mix was cement 885 kg/m^3, sand 885 kg/m^3, water 265.5 L/m^3, silica fume 88.5 kg/m^3, super-plasticizer 2.4 by weight of cement. Also, a reference mix was prepared without silica fume and super-plasticizer 1.2 by weight of cement. Hooked steel fiber (0.7mm diameter and 50mm length) was utilized in different volumes (6%, 8.5%, and 11%) to form SIFCON concrete. The result showed an increase in compressive strength with the increase of steel fiber volume for all mixes, the reference specimens with 6%, 8.5%, and 11% recorded compressive strength 70.7MPa, 74.8MPa, and 76.5MPa respectively. And the specimens of silica fume 10% replaced cement with steel fiber volumes 6%, 8.5%, and 11% resulted in compressive strength 78.5MPa, 81MPa, and 83.7MPa respectively.

Kimet et al. (2018) [64] employed cement mortar and steel fiber volume 6%, 7%, 8% with aspect ratios 40, 60, and 80. The results were showed that the use of steel fiber with an aspect ratio equal to 80 and 7% volume conducted high flexural strength of SIFCON specimen up to 65MPa.

Ali and Riyadh (2018) [65] utilized a slurry mix by using Portland cement: sand 1:1 with silica fume as 10% replaced cement and super-plasticizer. A straight and end hooked steel fiber were using by volumes of 2%, 6%, 8%, and 12% to examine compressive and flexural strengths for each type of fiber. An increment in compressive strength of 30.2%, and 77.5% for SIFCON specimen content 6%, and 8% of hooked steel fiber. Compared with SIFCON content 2% was observed, while the specimen with straight steel fiber recorded increasing 34.09%, and 74.5%. In general, it was observed that the SIFCON specimens with straight fibers produced to the more compressive strength (average 3.5%) than specimens with hooked end steel fiber in all volumes. This is due to the more interlocking of hooked steel fiber which makes it difficult for cement mortar to cover all areas. In terms of flexural strength, the specimens with straight steel fiber 2%, 6%, and 8% resulted in 7.51MPa, 12.12MPa, and 15.41MPa respectively. While the specimens with end hooked steel, fiber were 8.3MPa, 13.1MPa, and 15.21 MPa respectively.

Reddy (2018) [66] investigated the use of metakaolin as a replacement admixture of cement and compared it with the same replacement of cement by silica fume and cement slurry without admixture. The proportion of replacement to each admixture was 10%, 20%, 30%, 40%. Steel fiber volume that was used to form SIFCON samples were 6%, 8%, 10%, 12%. They were concluded that the use of metakaolin up to 40% increases the compressive and flexural strengths with all volumes of steel fiber when compared with slurry containing silica fume.

Ipek and Aksu (2019) [67] carried out slurry mix by using cement, silica fume, quartz, and super-plasticizer by quantities as shown in Table 8. Steel fibers with lengths 35mm, 60mm, 6mm and square waved polypropylene fiber with length 50 mm were used. The properties of fibers are shown in Table 9. The SIFCON samples were done firstly using each type of fiber alone in the same ratio, secondly mixing for two of fiber with different ratios. The results showed that the use of different lengths of fiber 60 mm and 35 mm with a ratio 50% of volume conducted to good flexural strength 44.02MPa when compared with other specimens. Additionally, the use of suitable differences in the length of steel fiber could increase the flexural strength rather than the steel fibers with the same length. As well as the flexural strength increased with the increasing aspect ratio of steel fiber. On the other hand, incorporated polypropylene and steel fibers in length 60 mm by ratio 33% and 66% of volume respectively, in SIFCON can be obtained 72.2%

increment of flexural strength when compared with specimen included 50% short steel fiber and 50% propylene which has the best value of flexural strength as shown in Table 11.

Table 9 - Martials quantities in SIFCON mix

Material	Quantities (kg)
Cement	90
Silica fume	27
0-0.1mm quartz powder	27.8
0.1-0.3 fine quartz sand	25.2
0.3-0.6 quartz sand	25.2
Super-plasticizer	3.6
water	27

Table 10 - Fibers properties

Fiber type	Length (mm)	Diameter (mm)	Aspect ratio (L/d)	Tensile strength (MPa)
Steel fiber	35	0.55	63.64	1345
Steel fiber	60	1.05	57.14	1115
Steel fiber	6	0.16	37.5	2250
Polypropylene	50	1.0	-	500

Table 11 - Flexural strength and fiber content

Specimen	Steel fiber 60mm%	Steel fiber 35mm%	Steel fiber 6mm%	Polypropylene %	Flexural strength (MPa)
1	100	0	-	-	39.88
2	0	100	-	-	40.74
3	0	0	100	-	15.73
4	66	33	0	0	38.86
5	50	50	0	0	44.02
6	33	66			36.09
7	66	0	33		37.19
8	0	66	33		36.09
9	33	0	66		17.06
10	50	0	50		24.17
11	66	0	0	33	41.23

12	33	66	16.68
13	50	50	23.90
14	66	33	23.27

Soylu and Bingöl (2019) [68] studied the effect of many types of steel fibers by different ratios. The slurry components were cement, fine sand, silica fume replaced cement by 10%, superplasticizer 1.5% of cement weight, and water to binder ratio 0.35. Steel fiber of 40, 55, 65, and 80 respect ratios were utilized by different volume (0, 4%, 8%, and 12%) to each fiber type. They were concluded that an increase in compressive and flexural strengths with increase steel fibers up to 8% and decreasing in fiber volume 12%. The decreasing explained due to the difficulty of cement slurry penetration through interlocked steel fiber. Also, they concluded that by increasing the aspect ratio of fiber up to 80 conducted a good increase in compressive and flexural strengths.

Khamees et al. (2019) [69] investigated compressive strength of SIFCON specimens with different fiber geometry. The first type of steel fiber was, straight (length =13mm, diameter = 0.2mm). The second, was end hooked (length=30mm and diameter=0.5). The slurry components to all specimens were cement = 872.1 kg/m^3, sand = 969 kg/m^3, silica fume replaced cement = 96.9 kg/m^3, (w/c) ratio = 0.33, and super-plasticizer by weight of binder = 3.7. The volume of steel fiber was 6% for all specimens. Another group of SIFCON was prepared by using two types of steel fiber together. The outcomes displayed that the straight, hybrid, and hooked steel fibers conducted compressive strength 88MPa, 71MPa, and 65.5MPa respectively.

Naser and Abeer (2020) [70] studied the effect of fiber type on compressive and flexural strengths of SIFCON by using three types of fiber as follow:

1. End hooked steel fibers with length, diameter, and tensile strength 35mm, 0.5mm, and 1300MPa respectively.
2. Steel fibers with length, diameter, and tensile strength 13mm, 0.2mm and 2300MPa respectively.
3. Propylene fiber with length, diameter, and tensile strength, 12mm, 38µm, and 320-400MPa respectively.

The cement slurry consists of cement with fineness 346m^2/kg and compressive strength 27MPa and super-plasticizer 1.76 by cement weight. Outcomes displayed that used of steel fiber by volume 7% increased the compressive strength and flexural strength about 39% and 112% respectively when compared with reference samples without steel fiber. Furthermore, using of the end hooked steel fiber by 4.0% volume increased the compressive and flexural strengths by about 30% and 466% respectively. On the other hand, propylene by volume 3% increased the compressive and flexural strengths by 4.49% and 19.94% respectively.

Al-Abdalay (2020) [71] employed cement slurry included Portland cement, silica fume (20% replaced cement), fly ash (20% replaced cement), Glenium-54 as water-reducing admixture (two litters per 100kg of cement), and sand (passing sieve size 4.75mm). Micro steel fiber with an aspect ratio 60 by volume 6% was used to produce SIFCON samples. The samples tested at 7, 28, and 90 days to evaluate the strength development with time. The results showed development in compressive strength (98MPa, 109MPa, and 120MPa) and flexural strengths about 18MPa, 24.2MPa, and 28MPa at ages 7, 28 and 90 days respectively. Comparing with reference samples of compressive strength and flexural strength 58MPa, 61.5MPa, 72.2MPa, and 7.9 MPa, 10 MPa, ,11.2 MPa respectively at 7, 28, 90 days respectively.

Hanadi et al. (2021) [72] investigated the influence of using Nano Metakaolin with size <10µm with adding ratio 3%, 5% and 7% in the slurry of SIFCON. The slurry components were fine silica sand (size 0.08mm to 0.2mm), ordinary Portland cement with 41MPa compressive strength at 7 days, Nano Metakaolin and super-plasticizer. The steel fiber used of 13 mm length, 0.2 mm diameter, more than 2600MPa tensile strength and utilized in volume ratios 6%, 7%, and 8%. The experimental results showed significant improvement with increasing ratios of Nano Metakaolin in the slurry mixture and fiber volume on compressive and flexural strength.

3. Conclusions

In this review study, the results obtained from the experimental tests of many of previous studies were relied upon to evaluate the effect of the type of slurry mix used in the production of SIFCON, as well as the type and volumes of the fibers. From all these studies, we can conclude the following:

- The use fiber volume equal and less than 2% was not suitable to SIFCON because of difficulty controlling on shrinkage in slurry.
- Utilized fly ash replacement cement more than 50% with 10% silica fume replacement cement has negative impact on compressive and flexural strengths.
- Compressive and flexural strengths increased with increasing steel fiber volumes in slurry mix have a maximum size of fine sand 1mm.
- An increase in compressive and flexural strengths was obtained by using quartz powder as sand with a maximum size 1 mm in slurry.
- The increase of aspect ratio (L/d) of steel fiber has a significant influence on SIFCON strength.

- The use of steel fiber with different aspect ratios was conducted to increment in compressive and flexural strength of SIFCON more than that with one type.
- The use of slag as a replaced cement up to 50%, silica fume up to 10%, quartz with size less than 1mm and steel fiber volume 12% conducted to good increases in compressive and flexural strengths.
- The use of propylene and steel fibers with ratios 33% and 66% respectively for 12% of all fiber volume gave good results.
- Hooked steel fiber good improved the flexural strength with some positive effect on compressive strength.
- With an increase the volume of steel fiber in SIFCON the slurry should be ensured to penetrate to all areas of mold and with sufficient softness that qualifies it to lineage through the fibers.
- Random distribution of steel fiber considered a best case to obtain good compressive and flexural strengths rather than parallel and perpendicular distribution cases of steel fiber.
- An improvement of compressive and flexural strengths was obtained by using Nano Metakaolin with fine sand in the slurry of SIFCON.

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