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Structural behavior of high strength SIFCON corbels

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Abstract

This research focuses on the investigation of corbels constructed using slurry-infiltrated fiber concrete (SIFCON). A total of twelve SIFCON corbels were fabricated in a controlled laboratory setting, with each corbel varying in certain parameters. These parameters include the volume fraction of steel fibers, which were set at three different ratios of 5, 6, and 7%. Additionally, the study examined the influence of the shear span to effective depth ratio, with values of 0.4, 0.5, and 0.6 being considered. Furthermore, the impact of a combination of micro and hook fibers, as well as the effect of reinforcement steel bars, were also investigated. The variables have affected on the mechanical properties of concrete, including the percentage of fiber, as by increasing the percentages, notice an improvement in the performance of the concrete, ultimate load, and cracking loads, also a reduction in deflection. The augmentation of steel fiber content from 5 to 7% resulted in notable enhancements in splitting tensile strength and flexural strength, with increases of approximately 32 and 22.4% respectively. Additionally, the compressive strength and modulus of elasticity shown improvements of approximately 11.3 and 12% respectively, where the effect of the shear ratio on the models was negative, as this effect appeared on the ultimate load, and on the crack load. The crack modes exhibited a flexural tension. These cracks initiated at the junction lines between the corbel and the column, or in its vicinity, and subsequently spread along the face of the column.

Keywords: *High strength, Ultimate load, corbels, SIFCON, Steel Fiber, cracking Load, shear span and effective depth.*

1. Introduction

With the development of industries in the field of civil engineering, the need has become greater for high resistance, energy absorption, durability, etc. Fiber reinforced concrete (FRC) is a commonly employed engineering material in various structural applications, aimed at improving structural resistance and performance when subjected to diverse loading conditions. Additionally, it has been observed that the utilization of this technique results in enhanced construction efficiency, potentially obviating the necessity for traditional reinforcement methods. The percentage of volume friction of Fiber Reinforced Concrete (FRC) typically ranges from 1 to 3 percent by volume. However, there are certain exceptional composites that have been developed with fiber volume fraction values ranging from 3% to 20%. The composites can be categorized as SIFCON, an acronym for slurry infiltrated fiber concrete, it is a distinct kind of fiber concrete characterized by its elevated fiber concentration [1]. The matrix typically comprises a mixture of cement slurry or fluid mortar. SIFCON exhibits significant promise for utilization in scenarios requiring high ductility and impact resistance [2]. The standard mixing processes are insufficient for the production of SIFCON due to the interlocking effect resulting from the high amount of steel fibers. In order to address this issue, the fibers are strategically positioned within the formwork molds to maximize their utilization. Subsequently, the fiber network is penetrated by a slurry composed of cement.

(Gilani, 2007) [3], investigated and Provided information about durability of SIFCON, mainly permeability, resistance to chloride penetration, freezing and thawing and drying shrinkage. The results obtained indicated that SIFCON made with the highest possible fiber volume fractions showed the best results. However, it was concluded that SIFCON needs to be protected with suitable low permeability overlays to ensure ideal improved performance by protecting the steel fibers exposed on the surfaces especially against chloride attack. (Shekarchi et al, 2010) [4] investigated the triaxial compressive behaviors of high strength concrete (HSC), HPFRC and SIFCON, according to the results increasing of fiber volumes increases peak stress, energy absorption, toughness and Poisson's ratio while increasing confining pressures increases peak stress, energy absorption and toughness. (Shafaei, 2012) [5], studied Influence of Hooked-End Steel Fibers on Some Engineering Properties of SIFCON Several experiments have been conducted to investigate different characteristics of SIFCON, including flexural testing, water permeability, and impact energy analysis. Also, the admixtures have an effect, and this was shown by (Elavarasi,2016) [6] about different proportions of silica and how it improves the performance of concrete. (Shannag, 2018) [7] studied the application of Slurry Infiltrated Fiber Concrete (SIFCON) as shear strengthening and repairing materials for normal strength reinforced concrete (RC) beams, finally (Jerry et al, 2022) [8] Investigation the effect of fiber type on the apparent density of SIFCON and on performance under impact load. Hook-end steel fiber and polyolefin fiber were used.

2. Research significance

The main objective of the current study is to give data and information for the enhance structural behavior of corbels made from slurry infiltrated fiber concrete (SIFCON), and this focused on effect of shear span-to-effective depth ratio, type of fiber, volume fractions of steel fiber, and reinforcement steel bars. The object also focused on strength, as outlined by ACI Committee 363, the strength should be above 55 MPa [9]. The mechanical characteristics of high strength steel fiber reinforced concrete (HSSFRC), such as compressive strength, flexural strength, splitting tensile strength, and modulus of elasticity also investigated in this paper.

3. Test program

The test program consisted of testing a total of twelve specimens, which are cast in the Basra university of civil engineering laboratory. All specimens are subjected to fresh and hardened concrete tests. The specimens were labeled in the test matrix according to their shear span-to-effective depth ratio was (0.4, 0.5, and 0.6), type of fiber (Hooked end and Micro), volume fractions of steel fiber (5, 6, and 7%), and reinforcement steel bars (2Ø12, and 3Ø12mm).

4. Details of test specimens

The test specimens were comprised of a double-sided corbel that was integrated with a column, as depicted in Figure 1. The corbel specimens in the study had a trapezoidal shape with a depth of 300mm. The projection length was 200mm, while the thickness was 150mm at the end that was free and 300mm at the column face. The dimensions of the corbel columns are 200 mm in width and 400 mm in length, with a depth of 200 mm. The majority of corbel specimens exhibit reinforcement consisting of four longitudinal deformed steel bars of 10 mm in diameter, positioned at the corners of the column. Additionally, four closed ties of 8 mm in diameter are present, with a spacing of 100 mm. In contrast, the implementation of corbel reinforcement was chosen as a viable option, wherein two primary steel bars with a dimension of 12 mm were employed on the side that was in tension for certain models, while three primary steel bars were utilized for others. The details of SIFCON corbel specimens are listed in Table1, C: Corbels, S: SIFCON, and R: Reinforcement bars, while the numbers (5, 6, and 7) and (1,2, and 3) represent the volume fractions of steel fibres and shear span-effective depth ratio, respectively.

Table1: Details of SIFCON corbels specimens

Specimen	Steel fiber content Vf(%)	a/d ratio	Steel reinforced	Fiber mixed
CS5-1	5	0.6	-	Hooked-end
CS6-1	6	0.6	-	Hooked-end
CS7-1	7	0.6	-	Hooked-end
CS5R-1	5	0.6	2Ø12 mm	Hooked-end
CS6R-1	6	0.6	2Ø12 mm	Hooked-end
CS7R-1	7	0.6	2Ø12 mm	Hooked-end
CS6R-2	6	0.5	2Ø12 mm	Hooked-end
CS6R-3	6	0.4	2Ø12 mm	Hooked-end
CS6R-2	6	0.5	3Ø12 mm	Hooked-end
CSM6R-2	6	0.5	3Ø12 mm	Micro
CSM3R-2	6	0.5	3Ø12 mm	3%Micro 3%Hooked-end
CSM1.5R-2	6	0.5	3Ø12 mm	1.5%Micro 4.5%Hooked-end

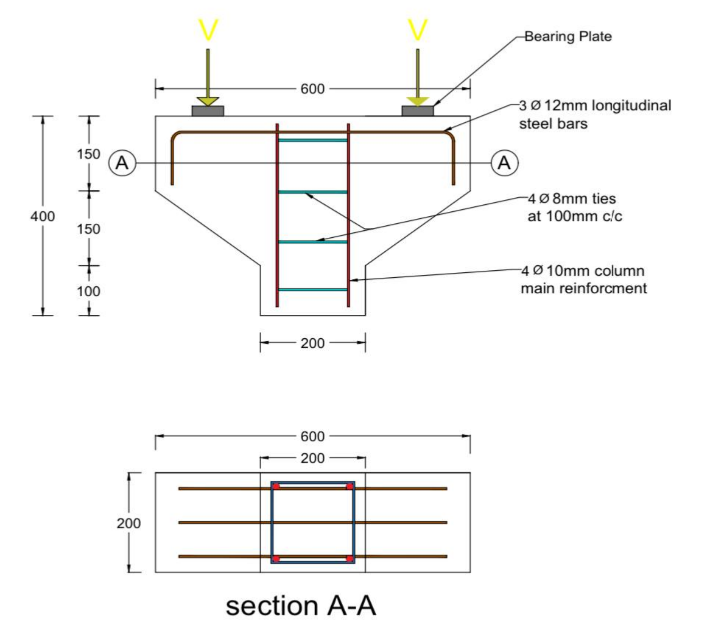


Fig. 1: The SIFCON corbel details (all dimensions in mm)

5. Material properties

5.1. Cement

Cement that used is (Karasta cement), is one of the common varieties, this type is of grade 42.5R and it produced from natural materials and using sustainable production techniques, it was stored well to be protected from the different atmospheric conditions, this cement conforms to the Iraqi standard specification IQS 5/1984 requirements [10].

5.2. Fine aggregate

As a fine aggregate, natural sand was utilized which adhered to the specified standards set by Iraq [11], it should go without saying that the sand used to create the SIFCON slurry needs to be tiny and fine enough to easily penetrate the steel fibre bed without. Because of this, the SIFCON mortar is made using only 1.18 mm sieved sand, which removes the larger particles. the specific gravity, absorption, density, and sulphate content of the material were recorded as 2.6, 2.2%, 1630, and 0.34, respectively.

5.3. Water

For mixing and curing SIFCON specimens tap water has been used.

5.4. Silica fume

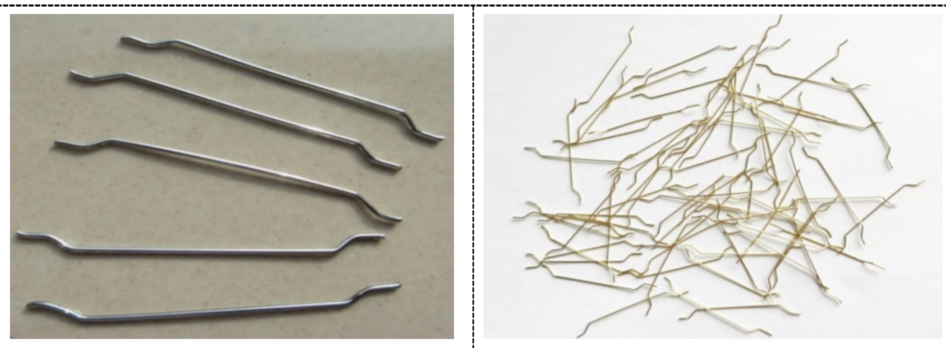
This paper utilized densified silica fume obtained from BASF Company, commercially referred to as MEYCO/MS610, having a specific surface area of 21000m²/kg, as a substitute for a portion of the cement. The statement adheres to the specifications outlined in ASTM C1240-05 [12]. The normal quantity of silica fume used in practice is approximately 10% of the total mass of cementations material.

5.5. High range water reducing (HRWR)

The second additive that used was HRWR. Water lowering admixtures are employed in the construction industry to decrease the water-to-cement ratio, hence facilitating the production of concrete with enhanced strength properties. In order to ensure thorough penetration amidst the densely packed steel fibers and to effectively hinder the development of voids often referred to as honeycombs, the utilization of a high range water reduction admixture (HRWR) is of utmost importance. The current research employed a high-range water reduction admixture (HRWR) called GLENIUM 54, which is a super plasticizer manufactured by BASF Construction Chemicals Company. The admixture in question demonstrated compliance with the specifications given in ASTM C494 type F [13].

5.6. Steel fiber

At present, the global market consists of over 30 prominent manufacturers engaged in the production of steel fibers, which are utilized for the purpose of enhancing the properties of concrete. These manufacturers collectively provide a diverse range of over 100 distinct fiber variations. The most ancient and fundamental form of steel fibers consists of straight fibers that are derived from the cutting of smooth wire. Regrettably, the utilization of steel strength is not fully ensured by these fibers due to the absence of suitable anchorage inside the concrete matrix. Shaped fibers constitute more than 90% of the fibers now being produced. The morphology of fibers is modified in a manner that enhances the adhesion of fibers within concrete. Over the past four decades, a variety of steel fibers have been manufactured, including bent, crimped, flattened, spaded, coned, hooked, surface-textured, and melt-cast variants. The steel fibers exhibited cross-sectional shapes that were either round, square, rectangular, or irregular. The various varieties were further differentiated based on their respective diameters and lengths [14].
Micro and hooked-end steel fibers with varying volume fractions (5%, 6%, and 7%) were used. The dimensions of the steel fibers used in the micro variant are 12 mm in length and 0.2 mm in diameter, while the hooked variant has dimensions of 35 mm in length and 0.55 mm in diameter see Figure 2. The product adheres to the specifications given in ASTM C1609/C1609M-05 [15].



(a) (b)

Fig. 2: (a) Hooked end steel fibers (b) Micro steel fibers

6. Experimental work

6.1. Trail mix

A group of experimental mixtures were conducted to find the appropriate quantities of materials. Based on previous research conducted on SIFCON mixtures, it was found that the cement quantity should range between (800 and 1000kg/m³) the trail mixes are performed for 16 SIFCON cubes (100mm X 100mm X 100mm) as shown in figure 3. Where previous research was relied upon to find the values of the materials (silica fume content, w/b ratio, value of super plasticizer, and steel fiber content), two values of silica fume (SF) to replace 10 and 15% of the cement weight, two values of water/binder materials (cement and silica fume) ratios (0.3 and 0.4), and two values of super plasticizer 2.4% and 3.7% by weight of cement. Also, three different volume fraction percentages 5%, 6% and 7% by volume of the SIFCON specimen are used. The mixing ratio of sand to cement is constant (1:1).

Fig. 3: Cubes of trial mixes

6.2. Test of fresh concrete flow table and V-funnel test

Testing of SIFCON in its fresh state is of serious importance for the production of SIFCON. Its matrix must be liquid enough and have sufficient fineness to flow through the dense fiber bed see Figure 4. The mini slump flow and V-funnel test, according to EFNARC [14]. The flow test is a method used to assess the flow-ability, segregation resistance, and homogeneity of a slurry. The SIFCON mortar necessitates a spread diameter value ranging from 320 to 380 mm. Another method used to evaluate the consistency of the slurry is the V-funnel test. According to reference [16], a flow duration ranging from 7 to 11 seconds is deemed suitable. The specifics of these two examinations can be located in numerous sources [16, 17, 18]. Table 2 and 3 show the result of these tests and the details of SIFCON mix proportion respectively. The mixing method that led to this result was to start by mixing the dry materials (cement, sand, and silica fume) together well in order to homogenize them and that take around 5 minutes. On the other hand, water was mixed with the plasticizer and then added to the dry materials gradually.

If cement bulges are observed, the mixing time should be sufficiently extended until a homogeneous slurry is attained. It is also possible to re-mix the slurry during the pouring period for 1/2 minute each time to avoid sand settling to the underside of the mixer.

(a)V-funnel device

(b) V-funnel test

(c) Flow table device

(d) diameter of slurry by flow table test

Fig. 4: Test of fresh concrete

Table 2: Test of Fresh Concrete

Mix No.	Test of Fresh Concrete: Result of Flow Table mm	Test of Fresh Concrete: Result of V-Funnel sec.	The infiltration of SIFCON slurry through the fiber bed
1	300	13.5	Bad
2	295	16	Bad
3	380	12	Bad
4	332	5	Bad
5	389	8	Bad
6	350	9	Good
7	280	19	Bad
8	396	7.8	Bad

Table 3: Details of SIFCON Mix proportion

Mix	Fibers Vf (%)	Cementite's: Cement kg/m^3	Cementite's: SF kg/m³ 10% rep.	Sand kg/m³	Water Kg/m^3	w/b	HRWR (%) by wt. of cement
MS5	5						
MS6	6	895.5	99.5	995	298.5	0.3	3.7
MS7	7						

7. Test measurements for SIFCON corbels

The corbel samples were arranged in an inverted orientation, see Figure 5b. wherein a vertical load was applied to induce failure. This was achieved by utilizing the Universal Hydraulic Testing Machine Figure 5a, which has a maximum capacity of 3000 KN. The deflection was determined by positioning a mechanical dial measurement device accurate to within 0.01 mm at the tested corbel's central column see Figure 5c.

(a)

(b) (c)

Fig. 5: (a) The testing machine (b) Set up of corbel specimen (c) Dial gauge

8. Experimental results and discussion

8.1. Compressive strength

The mechanical parameters of SIFCON mixture are summarized in Table 4, where the compressive strength values of MS5, MS6, and MS7 are in the range of 132.4 MPa, 140.5 MPa, and 147.3 MPa, respectively and failure of cylinder is shown in figure 6. The addition of steel fiber to SIFCON composites increases the compressive strength by approximately 6.1%, 4.8%, and 11.3% as the fiber volume fraction increases from 5-6%, 6-7%, and 5-7%, respectively as shown in the Figure 7.

Table 4: Test results of SIFCON Mix

Mix	Compressive strength (f´c) MPa	Splitting Tensile Strength (ft) MPa	The modulus of Rupture (fr) MPa	The modulus of Elasticity (Ec) GPa
MS5	132.4	15.9	29.4	49.7
MS6	140.5	18.7	32.7	52.7
MS7	147.3	21	36	55.7

Fig. 6: Failure of cylinder

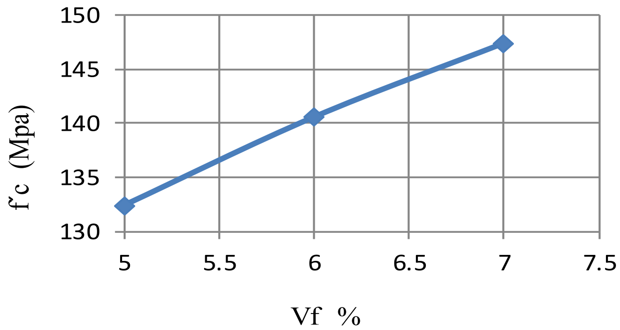


Fig. 7: Effect of fiber content on the compressive strength

8.2. The modulus of elasticity (Ec)

The stiffness of concrete is measured by its modulus of elasticity, which is an excellent indicator of strength. Compressive testing on concrete cylinders can provide it. The results of the experimental test revealed that as the content of steel fibers increased from (5-6) %, (6-7) %, and (5-7) %, so did the modulus of elasticity in the order of 5.9%, 5.7%, and 12% see Figure 8.

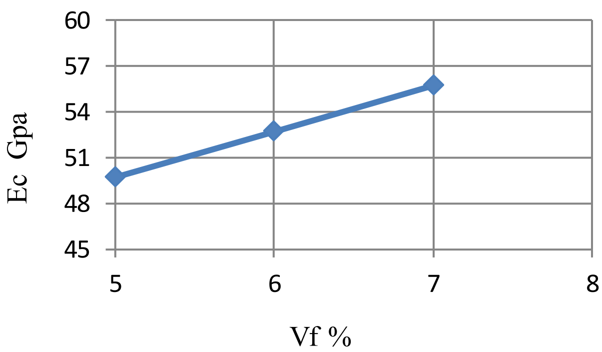


Fig. 8: Effect of fiber content on the modulus of elasticity

8.3. Splitting tensile strength (ft)

Tensile stress is the main reason for the formation of cracks in concrete. Therefore, the splitting tensile strength should be taken into consideration as shown the crack patterns in figure 9. From the results of the test, it can be noticed that the increase in steel fiber volume fraction from (5-6) %, (6-7) %, and (5-7) % leads to an enhancement of the splitting tensile strength by about 18%, 11.8%, and 32% see Figure 10.

Fig. 9: Splitting tensile crack patterns

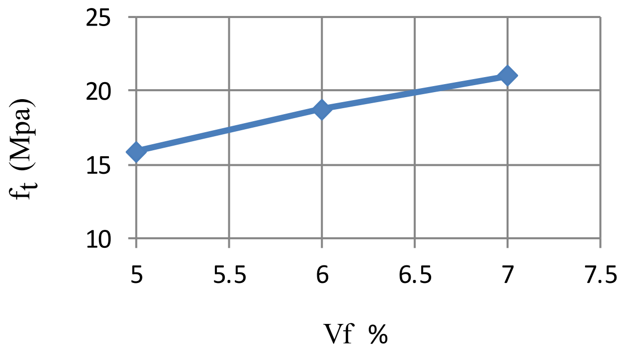


Fig. 10: Effect of fiber content on the splitting tensile strength

8.4. The modulus of rupture (fr)

Flexural strength refers to the maximum tensile stress of concrete being tested in flexural as shown the prism failure patterns in figure 11. Due to the results of the tested prisms, the increase in the fractional volume of steel fibers from (5-6) %, (6-7) %, and (5-7) % leads to an increment in the flexural strength of 11.3, 9.9, and 22.4 % see Figure 12.

Fig. 11: Prism failure patterns

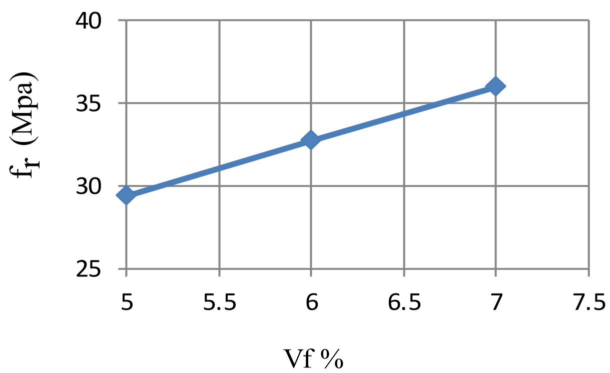


Fig. 12: Effect of fiber content on the Flexural strength

9. Specimens behavior

The experimental results of SIFCON corbels are listed in Table 5, including the values of first crack loads (Pcr) and ultimate loads (Pu) and their corresponding amounts of deflection (Δcr) and (Δu).
In the beginning, when the vertical load was applied to all the SIFCON corbels, it was noticed that they give the same reaction in terms of the absence of any cracks. The first crack appears when the load is gradually increased. Some models may be similar in terms of the location of the crack and the way it appears. In most models, this crack appears as shown in figure 13.
The first crack to form in most models were shear crack, CS5R-1, CS6R-1, CS7R-1, CS6R-2, CS6R-3, CSM6R-2, CSM3R-2, CSM1.5R-2 the propagation occurred at the point of junction between the column face and the horizontal face of the corbel. Subsequently, diagonal stress cracks manifested in the corbels. The observed cracks exhibited a general alignment that approximately followed a trajectory originating from the point of junction between the inclined surface of the corbel and the surface of the column. As the magnitude of the applied load was progressively augmented, the length of the diagonal tension cracks exhibited a corresponding increase. Initially, this elongation occurred at a rapid rate, but as the ultimate load was approached, the rate of crack propagation decelerated significantly. The classification of failure in these models presents challenges, although it can be categorized as a form of flexural failure.
In the case of the corbels without reinforcement steel bar, CS5-1, CS6-1, CS7-1. The failure of these corbels was easy classified as a flexural failure, since it was characterized by wide opening of the flexural cracks, while the diagonal tension cracks remained fine.

Table 5: Experimental results of SIFCON corbels

Corbelname	Vf (%)	a/d	Steel reinforcement	Pcr (kN)	Pu (kN)	Δcr (mm)	Δu (mm)	Pcr/Pu(%)
CS5-1	5	0.6	-	250	1000	0.135	0.65	25
CS6-1	6	0.6	-	380	1240	0.159	0.52	30.645
CS7-1	7	0.6	-	400	1370	0.09	0.5	29.197
CS5R-1	5	0.6	2Ø12 mm	320	1150	0.11	0.54	27.826
CS6R-1	6	0.6	2Ø12 mm	490	1370	0.21	0.48	35.766
CS7R-1	7	0.6	2Ø12 mm	600	1620	0.15	0.37	37.037
CS6R-2	6	0.5	2Ø12 mm	750	1460	0.16	0.41	51.369
CS6R-3	6	0.4	2Ø12 mm	1250	1900	0.20	0.31	65.789
CS6R-2	6	0.5	3Ø12 mm	1000	1800	0.19	0.70	55.556
CSM6R-2	6	0.5	3Ø12 mm	700	1250	0.18	0.65	56
CSM3R-2	6	0.5	3Ø12 mm	860	1560	0.13	0.62	55.128
CSM1.5-2	6	0.5	3Ø12 mm	1100	1740	0.31	0.56	63.218

10. Failure mechanism

Various varieties of failure exist, encompassing Shear Failure, Flexural stress, and compression Failure, among others. Failure can be defined as a phenomenon characterized by a rise in deflection accompanied by a drop in the load. In the context of this study, the SIFCON corbels exhibited a specific mode of failure, namely flexural tension failure. This particular failure mode manifests at the interface where the column and corbel intersect, subsequent to the extraction of fibers from the concrete matrix. Additionally, the observed cracks exhibit significant depth and vertical propagation, resulting in a pronounced widening of the aperture, as depicted in Figure 13.
The most important experimental parameters that affect the model in this thesis are:
1.Cracking and Ultimate load
2.Load-deformation behavior

10.1. Cracking and ultimate load

The initial occurrence of a crack on the SIFCON corbels is denoted as the cracking load Pcr, which is the load value recorded at the time of crack initiation. While the term "ultimate loads Pu" pertains to the external forces that result in the structural failure of SIFCON corbels. These loads are specifically represented by the vertical load that is imparted to the corbels.

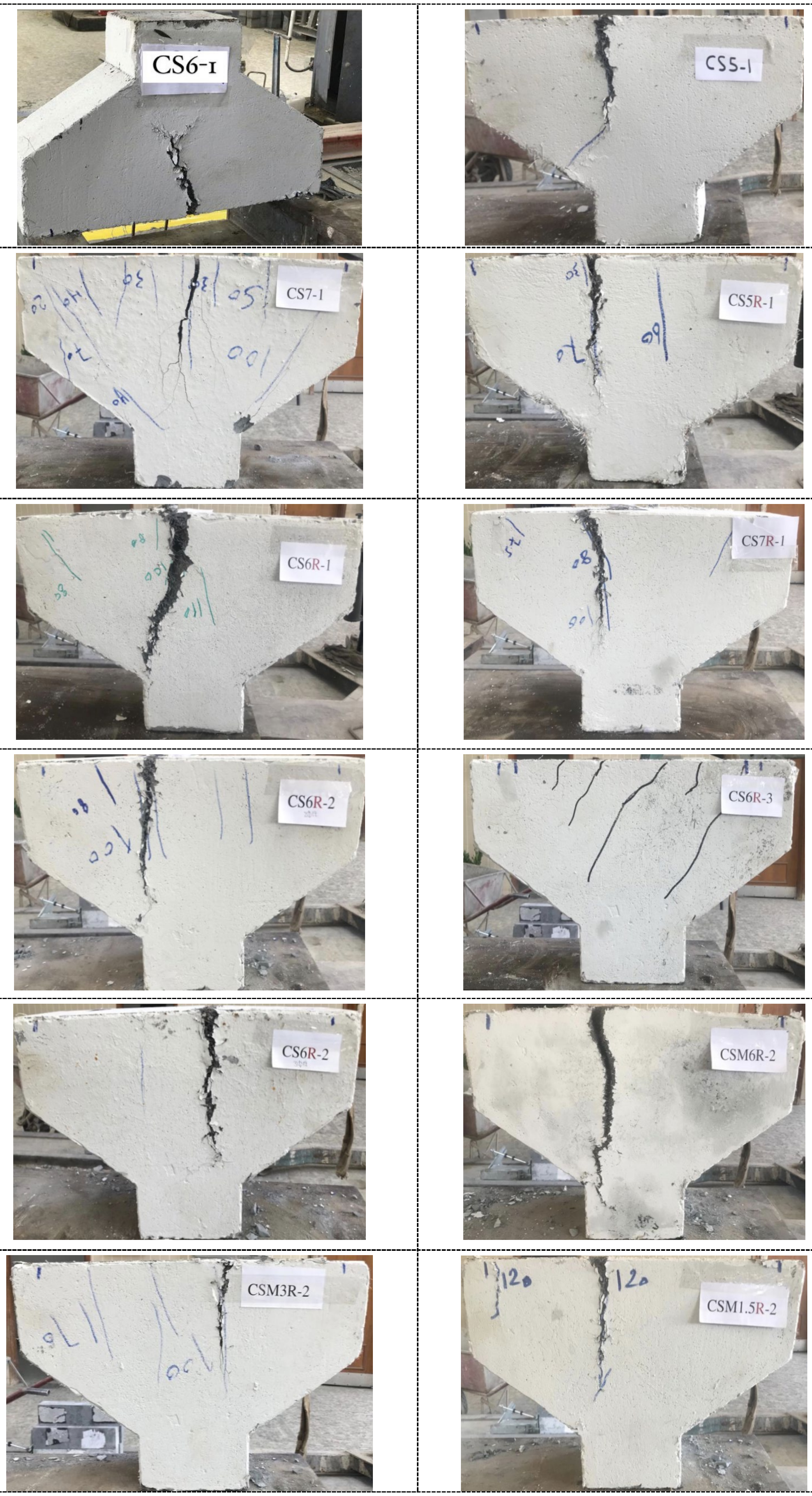


Fig. 13: Failure of SIFCON corbels

10.1.1. Effect of the ratio between shearing span and effective depth (a/d)

In the SIFCON corbels CS6R-1, CS6R-2, and CS6R-3, when the fiber percentage is constant at 6%, as the shearing span-effective depth ratio falls from 0.6 to 0.5, 0.5 to 0.4, and 0.6 to 0.4, the cracking load improves by 53.1%, 66.6%, and 155.1%, respectively, as shown in table 6. Also, there is improvements in ultimate load such 6.5%, 30.1%, and 38.6% respectively, see Figures 14 and 15.

Table 6: The effect of Ratio Between Shearing Span and Effective Depth (a/d)

Vf 6%	Decrease in a/d		
	0.6 to 0.5	0.5 to 0.4	0.6 to 0.4
Increase Pcr %	53.1	66.6	155.1
Increase Pu %	6.5	30.1	38.6

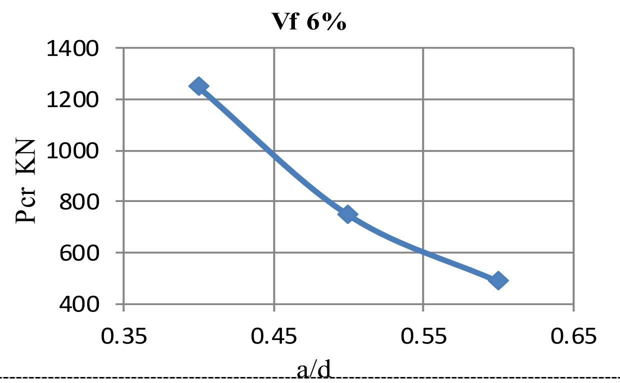


Fig. 14: Effect of shearing span to effective depth ratio (a/d) on cracking load

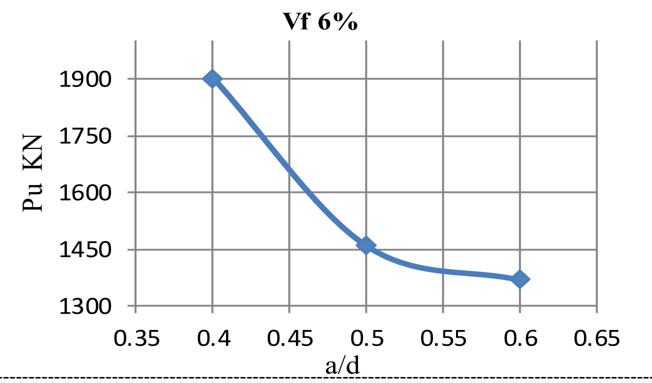


Fig. 15: Effect of shearing span to effective depth ratio (a/d) on ultimate load

10.1.2. Effect of fiber content and reinforcement

Based on the findings of the conducted tests, it is evident that the incorporation of steel fibers in SIFCON corbels leads to an enhanced resistance against the formation of initial cracks as shown in table 7. This effect is observed when the value of (a/d) remains constant. The observed improvement can be attributed to two significant mechanisms exhibited by the fibers, namely crack bridging and crack arrest. These mechanisms effectively delay the occurrence of initial cracks in the corbels. The utilization of steel fibers in concrete mixtures has proven to be an efficient method for enhancing the structural integrity by mitigating fracture propagation inside the material. This particular fiber exhibits the capacity to maintain the integrity of the matrix as a cohesive entity during the entirety of the loading procedure, see Figures 16 and 17.

Table 7: The effect of Fiber content and reinforcement

	a/d	Increase in Steel Fiber Content %		
		5 to 6%	6 to 7%	5 to 7%
Increase Pcr %	0.6*	52	5.2	60
	0.6	53.1	22.4	87.5
Increase Pu %	0.6*	24	10.4	37
	0.6	19.1	18.2	40.8

*Corbel without reinforcing

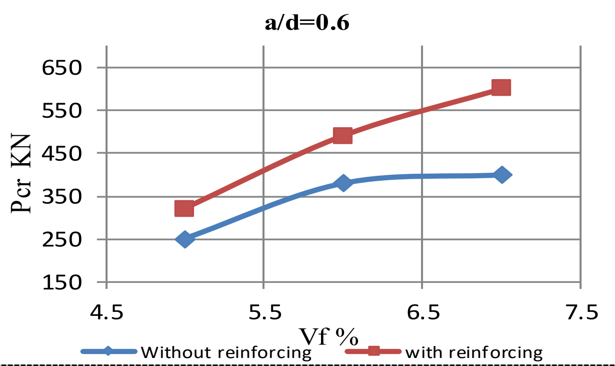


Fig. 16: Effect of steel fiber volume fraction on cracking load

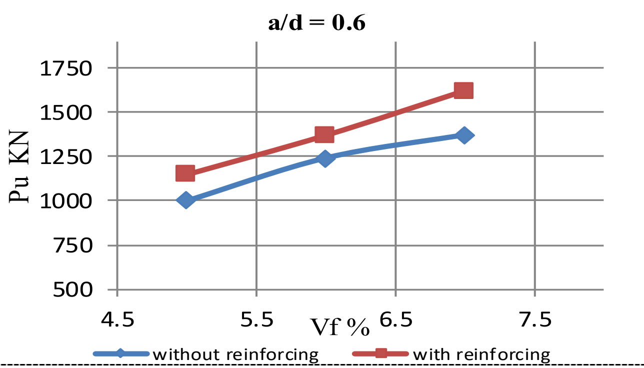


Fig. 17: Effect of steel fiber volume fraction on ultimate load

10.1.3. Effect of mixed fiber (Micro and Hooked end)

The incorporation of steel fiber in SIFCON corbels CSM6R-2, CSM3R-2, and CSM1.5R-2 does not yield a favorable outcome in terms of the ultimate load. Similarly, the cracking load is adversely affected by a rise in the micro proportion of steel fiber injected to the SIFCON corbels, resulting in a reduction in the cracking load, and this may be due to the formation of gaps inside the SIFCON corbels because the micro does not allow the slurry to permeate through it, but in the case of the hook, he built a solid model that acts as one to resist the load (table 8 and figures 18 and 19).

Table 8: The effect of mixed steel fiber

	a/d 0.5		
	Decrease in Micro steel Fiber		
	6 Micro	3 Micro	1.5 Micro
Increase Pcr %	22.8	27.9	57.1
Increase Pu %	24.8	11.5	39.2

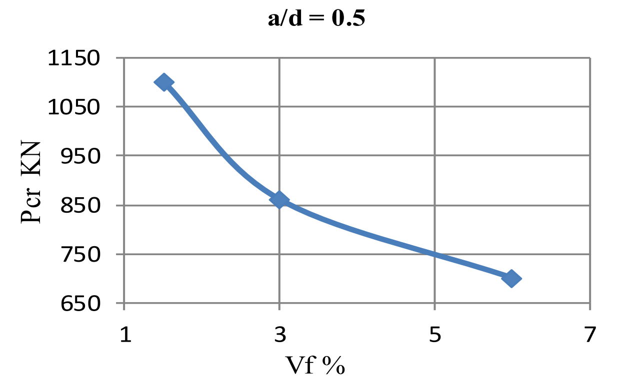


Fig. 18: Effect of mixed fiber on cracking load

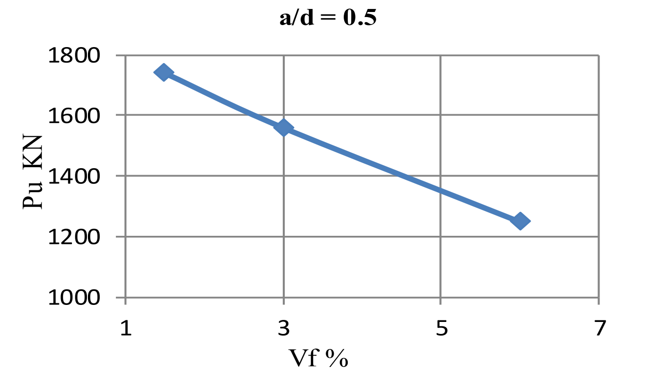


Fig. 19: Effect of mixed fiber on cracking load

10.2. Load-deflection response

By studying the curves of load-deflection, all the tested SIFCON corbel specimens, whether reinforced with steel bars or not, were submitted to three phases.

- In the first phase, the load-deflection curve is almost linear and the cracks have not formed yet. At this stage, the matrix and the fibers share and sustain the applied load and stresses, and work together to restrain the formalization of the first crack. In general, the SIFCON has significant crack resistance, which is responsible for the first crack postponement. This stage is known as the first cracking strength or the elastic stage, where the structure attains its original shape once the applied load is removed.
- In the second phase, where the first crack forms, the matrix is no longer capable of undergoing more stresses, thus it begins to transfer the tensile stresses gradually to the fibers. Here, the fibers begin their vital role in holding and controlling the tensile stresses.
- In the third phase, with the increment of the applied load, the fibers tend to pull out of the matrix and the strength shows its lowest values and the deflection reaches its highest amount until the corbel fails completely.

10.2.1. Effect of shearing span and effective depth on the load-deflection curve

The models incorporated three different ratios (0.4, 0.5, and 0.6) between the shear span and effective depth as variables. In Figure 20, the relationship between the variable and the models is elucidated. It is evident that as the ratio (a/d) grows, the deflection values of the SIFCON corbels employed in this investigation also increase. This may be attributed to the rise in the bending moment.

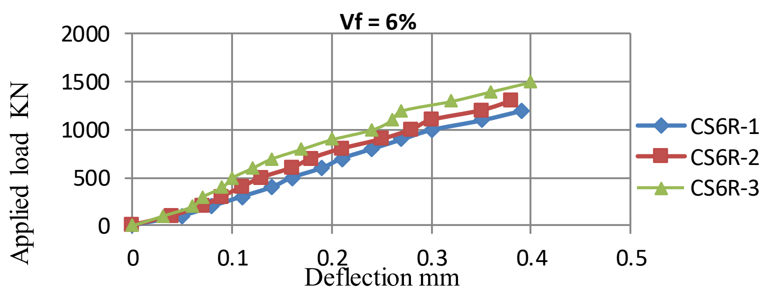


Fig. 20: Effect of (a/d) value on load-deflection curve of SIFCON corbels with (Vf= 6%)

10.2.2. Effect of fiber content on the load-deflection curve of SIFCON corbels

The observed behavior can be attributed to the significant concentration of steel fibers (figures 21 and 22). This finding supports the notion that steel fibers possess the capacity to effectively span and obstruct cracks, thereby playing a prominent role in augmenting deflection and impeding a sudden decline in the load-deflection curve following the attainment of the ultimate load. Furthermore, enhance the resilience of the concrete to cracking. Furthermore, when considering the reinforcement of the models, it was observed that at a consistent ratio of shear span to effective depth, the models exhibited significant resistance to crack propagation and a prolonged failure process. This observation highlights the impact of reinforcement on the model's behavior.

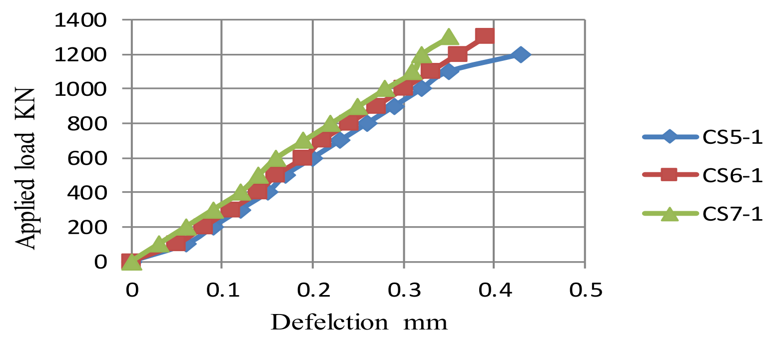


Fig. 21: Effect of fiber ratio on load-deflection

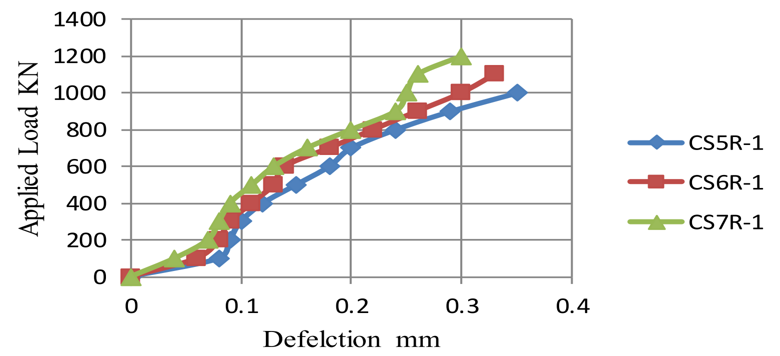


Fig. 22: Effect of fiber ratio with reinforcing on load-deflection

10.2.3. Effect of reinforcement steel bars on the load-deflection curve

This study employed reinforcement in all of the models, with the exception of three models that did not incorporate reinforcement. The disparity lies in the existence or nonexistence of reinforcing steel in relation to every volume fraction of steel fibers. The utilization of steel bars has demonstrated a favorable impact on the deflection values. During the load application process, it was observed that deflection of corbels CS5R-1, CS6R-1, and CS7R-1 was lower compared to deflection of the reference SIFCON corbels CS5-1, CS6-1, and CS7-1, respectively (figures 23, 24 and 25), while maintaining the same value of (a/d).

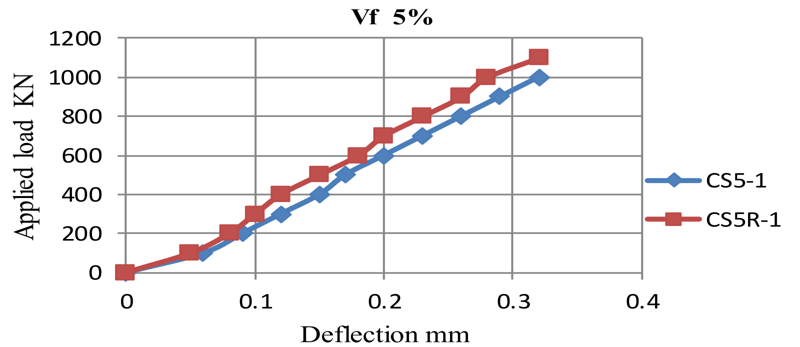


Fig. 23: Effect of Reinforced Steel Bar on load-deflection

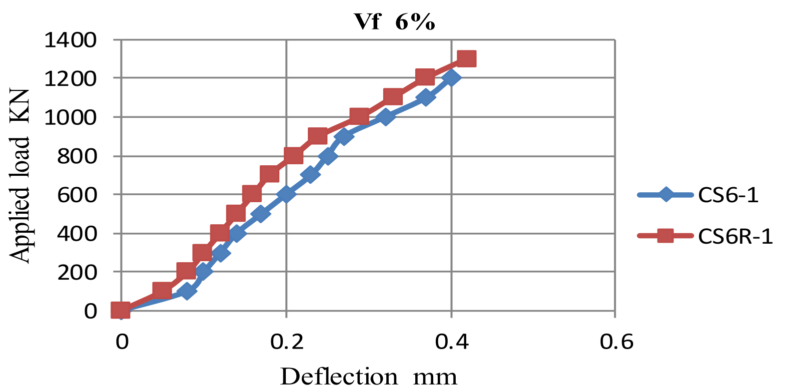


Fig. 24: Effect of Reinforced Steel Bar on load-deflection

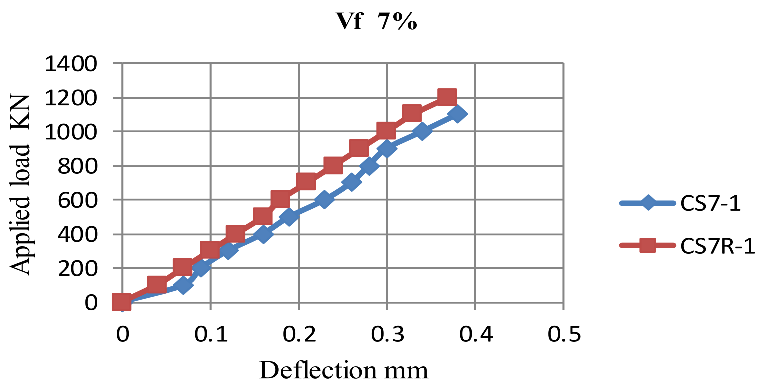


Fig. 25: Effect of Reinforced Steel Bar on load-deflection

10.2.4. Effect of mixed steel fibers on the load-deflection curve

Two types of fibers were used for the last three models, (hook end and micro steel fiber). It can be seen from figure 26 that there is no good effect on the SIFCON corbels when the two types are used together in different proportions or just micro used in terms of resistance to the applied load and the delay in the failure process. However, in practice, the use of the micro type was not easy, as it showed difficulty in terms of allowing the slurry to permeate through it, due to its small size.

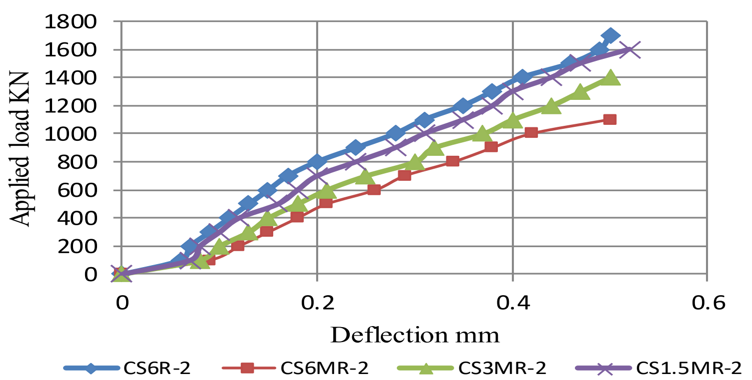


Fig. 26: Effect of Mixed Steel Fibers on load-deflection

11. Conclusions

1. When adding fiber to the mixtures, there is an increase in the compressive strength, as by increasing the fiber from 5 to 6, from 6 to 7, and from 5 to 7, the compressive strength increased by an amount 6.1 %, 4.8 %, and 11.3% respectively.

2. In the calculations of the modulus of elasticity in the case of adding fiber in proportions of 5 to 6, 6 to 7, and 5 to 7, there is an improvement in this coefficient, and the increase was for mixtures MS5, MS6, and MS7 was 5.9%, 5.7%, and 12% respectively.
3. The ascending values of steel fibers added to SIFCON mixes resulted in a notable enhancement in splitting tensile strength of approximately 18%, 11.8%, and 32% when the percentage content of steel fiber increased from (5-6) %, (6-7) %, and (5-7) %, respectively.
4. There is an increase in the flexural strength by increasing the fiber, as for each mixture MS5, MS6, and MS7, the percentages of increase were 11.3 %, 9.9 %, and 22.4 %, respectively.
5. The ultimate load and crack load increase as the shear span/effective depth ratio decreases with constant in the percentage of fiber.
6. With the shear span to effective depth ratio constant, the ultimate and cracking load increase with the fiber percentage.
7. The presence of steel reinforcement in the model in addition to fiber significantly improves the performance of concrete, including ultimate and cracking load.
8. The use of mixed fibers did not have a clear effect on the performance of concrete, but it certainly did not give a noticeable increase in the ultimate and crack load, as well as on the load-deformation curve.
9. In general, SIFCON exhibits notable fracture resistance as a result of its elevated steel fiber content. These steel fibers play a crucial role in facilitating crack-bridging and crack-arresting mechanisms, which effectively impede the formation of initial cracks and avert abrupt structural collapse.
10. The deflection of SIFCON corbels has a positive correlation with the shear span to effective depth ratio, indicating that an increase in the ratio leads to a greater degree of deflection.
11. The presence of SIFCON corbels exerts a notable influence on the deflection values. It is evident that the degree of deflection escalates in proportion to the volumetric ratio of steel fibers.
12. The deflection values exhibited by SIFCON corbels reinforced with steel bars are found to be lower than the deflection values observed in SIFCON corbels with the same aspect ratio (a/d).

References

[1] M. Vijayakumari and P. Dineshkumar “STUDY ON STRENGTH PROPERTIES OF SIFCON” International Journal of Innovative Research in Science, Engineering and Technology, vol. 4, No. 1, January 2017.

[2] A. Beglarigale, and Ç. Yalçınkaya, “Flexural Performance of SIFCON Composites” ELSEVIER Journal Construction and Building Materials, vol. 104, pp. 99-108, February 2016

[3] A. M. Gilani, "Various durability aspects of slurry infiltrated fiber concrete" Ph.D. Thesis, The Graduate School of Natural and Applied Sciences of Middle East Technical University, Turkey, September 2007.

[4] Y. Farnam, M. Moosavi, and M. Shekarchi “Behaviour of Slurry Infiltrated Fibre Concrete (SIFCON) under triaxial compression” Construction Materials Institute, School of Civil Engineering, College of Engineering, University of Tehran,Iran June 2010.

[5] Y. Shafaei, "Influence of Hooked-End Steel Fibers on Some Engineering Properties of SIFCON" Ph.D. in Civil Engineering Thesis, requirement of the Eastern Mediterranean University, April 2012.

[6] D. Elavarasi, "Performance of Slurry Infiltrated Fibrous Concrete (SIFCON) With Silica Fume " ACI Structural Journal, vol.14, no.4, pp.2710-2722, Department of Civil Engineering, Sastra University, 2016

[7] R. Z. Al-Rousan and M. J. Shannag “Shear Repairing and Strengthening of Reinforced Concrete Beams Using SIFCON” Ph.D. thesis Department of Civil Engineering, Jordan University of Science and Technology, Irbid, Jordan Department of Civil Engineering, King Saud University, Riyadh, Saudi Arabi May 2018

[8] A. H.Jerry, and N. M. Fawzi, “The Effect of Type of Fiber in Density and Splitting Tensile Strength of SIFCON” Ph.D. Thesis, University College of Engineering University of Baghdad 2022.

[9] American Concrete Institute - ACI. ACI 363R-92. State of the art report on High-Strength Concrete. In: ACI Manual of Concrete Practice (MCP), Part 5. Farmington Hills: American Concrete Institute; 2002.

[10] European Standard EN BS 197-1, “Cement - Part 1: Composition, specifications and conformity criteria for common cements”, European committee for standardization,2011.

[11] Iraqi standard Specification No.5/1984, “Aggregate from Natural Sources for Concrete and Construction”, Central Organization for Standardization and Quality Control, Baghdad-Iraq

[12] ASTM C1240-20, “Standard Specification for Silica Fume Used in Cementations Mixtures”, ASTM International, West Conshohocken, PA, USA 2020.

[13] ASTM C494/C494M, “Standard Specification for Chemical Admixtures for Concrete”, ASTM International, West Conshohocken. (2017).

[14] J. Katzer “Steel Fibers and Steel Fiber Reinforced Concrete in Civil Engineering”, The Pacific Journal of Science and Technology, vol.7, no.1, May, 2006.

[15] ASTM C1609/C1609M-05, (2005) “Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)”, ASTM International, West Conshohocken, PA, USA, 2005.

[16] EFNARC, “Specifications and Guidelines for Self Compacting Concrete”, EFNARC, UK, pp. 1-32, 2005.

[17] S. Salih, Q. Frayyeh, and M. Ali, “Fresh and some mechanical properties of SIFCON containing silica fume”, MATEC Web of Conferences, vol.162, 2018.

[18] H. Yazici, S. Aydın, H. Yiğiter, M. Y. Yardımc , G. Alptuna, “Improvement on SIFCON Performance by Fiber Orientation and High-Volume Mineral Admixtures” journal of material in civil engineering, no.22 , pp.1093-1101, 2010.