



Effects of Fiber Type and Shape on the Shear Behavior of Reinforced Concrete Corbels without Hoop Re-bars

Ihab S. Saleh ^{1*}, Saddam Kh. Faleh ¹, Muthana Sh. Mahdi ¹

¹ Civil Engineering Department, Engineering College, University of Basrah, Basrah, Iraq.

Received 20 November 2021; Revised 18 February 2022; Accepted 26 February 2022; Published 01 March 2022

Abstract

In this research, the structural behavior of reinforced concrete brackets cast with concrete containing different types of fibers was studied. Seven samples of reinforced concrete corbels were cast and tested. One specimen was cast without fiber as a reference, and the other samples were made with six different types of fibers at a constant volume fraction (1% of the total concrete volume). The fibers used in the research were made of two different materials: steel and polyolefin. One specimen was cast with polyolefin fiber, and in the five remaining samples, steel fiber was used. Straight, crimped, and three different dimensions of hooked fiber were used. The results showed that the corbels with straight and hooked end steel fiber (6, 5, and 3 cm length), crimped steel fiber sized 3 cm, straight steel fiber sized 12 mm, and straight polyolefin fiber sized 6 cm showed 69.2%, 57.7%, 38.5%, 61.5%, 92.3%, and 100% higher cracking loads than the control corbel made with normal concrete, respectively, as well as exhibiting (51.7%, 48.3%, 31.0%, 24.1%, 12.1%, and 3.4%) higher ultimate loads than the control corbel. From these results, it can be concluded that the shape of the steel fiber clearly affects the ultimate load. For the same length, and despite the lack of aspect ratio, steel fibers gave an increase in the maximum load of 46.6% when compared with polyolefin fibers.

Keywords: Concrete; Corbel; Polyolefin Fiber; Steel Fiber; Shear Strength, Shear reinforcement.

1. Introduction

According to ACI-318M-19, corbels are “short cantilevers that operate more like simple trusses or deep beams” for ratio (a/d) values up to unity, the shear friction method can be used, and for values less than two, the strut and tie model can be used [1]. These elements, along with their supports, are cast in one piece. They are designed to sustain large shear stresses under bending in a minimal amount of time [2]. Shearing along the column-corbel interface, tension tie yielding, compression strut crushing or splitting, and localized bearing or shearing failure under the loading plate are all possible failure modes for corbel. A corbel is a shear-critical structure and is dominated by disturbed regions (D-regions), as shown in Figure 1. ACI 318-19 [1] provides a typical steel reinforcement distribution (Figure 2) for resisting the customary disturbed stress distribution that is compatible with the strut-tie model (Figure 3).

Reinforced concrete corbels carry horizontal and vertical loads from beams to columns. In these elements, the shear span-to-depth ratio (a/d) is generally less than one, and they are subjected to forces in support locations. Several research studies have consisted of attempts to determine the influencing factors on the structural response of reinforced concrete corbels. An experimental and analytical program was used to determine the strength of such members under transfer

* Corresponding author: ihab.sabri@uobasrah.edu.iq

 <http://dx.doi.org/10.28991/CEJ-2022-08-03-08>



© 2022 by the authors. Licensee C.E.J, Tehran, Iran. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).

and vertical forces and to explain the effects of variables on the response of concrete brackets; these variables included the shape and dimensions of the concrete brackets, the shape and proportions of the corbels, the amounts of main and shear reinforcement, and the concrete strength [3, 4].

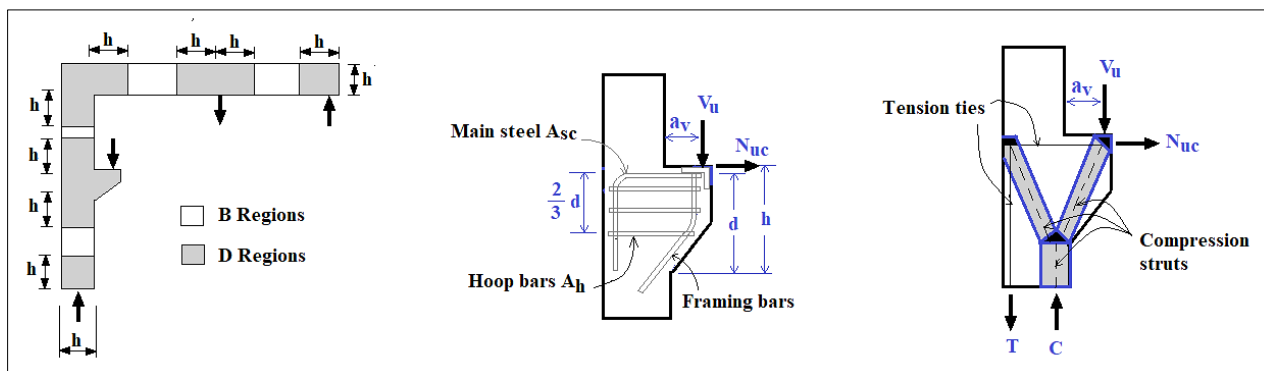


Figure 1. Corbel D-regions

Figure 2. ACI typical reinforcement

Figure 3. Strut-tie model

Steel fiber-reinforced concrete (SFRC) is manufactured using cement with aggregates and individual steel fibers. The steel fibers for SFRC have short, discrete lengths with an aspect ratio (length-to-diameter ratio) varying between 20 and 100. The steel fibers are small enough to be spread randomly in the unhardened concrete mix in the concrete mixing process [5]. The influence of longitudinal reinforcement and stirrups, as well as steel fibers, on the behavior of RC corbels has been investigated [6, 7]. Many researchers have examined the behavior of steel fiber-reinforced concrete corbels; a series of experimental programs were carried out on normal strength SFRC corbels by Fattuhi and Hughes [8-14]. Fattuhi and Hughes studied the effects of adding steel fiber on the shear strength of corbels. The authors used various variables were concrete compressive strength, fiber content, shear span, fiber dimensions, depth, and longitudinal reinforcement amount and observed the structural behavior of SFRC corbels. Fattuhi (1994) [15] also considered the mechanical behavior of trapezoidal normal strength SFRC corbels. Campione et al. (2007) [16] experimentally investigated the flexural behavior of corbels cast with fibrous reinforced concrete and recommended simple analytical expressions for bearing capacity considering the contribution of steel reinforcements and fibers in shear resistance. Campione (2009) [17] carried out two experimental studies on SFRC corbels, the first, the performance of SFRC corbels under the combined influence of horizontal and vertical loads was investigated. In another investigation, the flexural response of SFRC brackets was determined. However, few studies have been performed on the response of corbels made with fiber-reinforced concrete containing many types of fibers, in particular, polyolefin fibers.

Atif et al. [18] studied the shear response of steel fiber-reinforced concrete corbels made with high strength concrete. The fiber volume fraction, concrete compressive strength, a/d ratio, main tensile steel reinforcement ratio, and stirrup inclusion were the test parameters. The results show that adding horizontal stirrups or steel fibers enhances the ductility and shear strength of the tested corbels, resulting in a more ductile mode of failure. The load-carrying capacities calculated from the test results was compared to those calculated from the ACI 318-08 equations and those calculated using proposed equations by other researchers. Mohammed et al. [19] investigated the strength of RC corbels (self-consolidating) with different steel fiber volume fractions, compressive strength, and subjected them to concentrated vertical loading only. The addition of steel fibers delayed the initiation and propagation of cracking in FRC corbels compared with corbels without steel fibers, increasing the first cracking and ultimate loads by 31.5 and 25.3 %, respectively, as the fiber content fraction increased from 0 to 0.4 %. Qasim [20] investigated the behavior of high-strength R.C. corbels made of commercially available rolled steel (W-shape). It was discovered that raising the a/d ratio from 0.7 to 1.0 for the control specimens reduced the capacity by 27, 29 and 21% for composite T-shaped and W-shaped encased beams. Using finite element analysis, nonlinear constitutive models for SFRC under compression and tension were proposed [21]. The ultimate shear capacity of RC corbels with extra steel fibers was predicted using the truss analogy method [22]. Zin et al [23] studied experimentally the influence of secondary reinforcement with different types of high-performance reinforced concrete containing fibers with a/d equal to 0.75 and 1.00, they found that the corbels performed with high-performance steel fiber-reinforced composite exhibited much more ductility and deformation capacity versus another specimens. Also, it clearly could be concluded that the influence of existing secondary reinforcement for strength of view point was decreased with a/d ratio 1.0. Presence of closed secondary reinforcement or steel fibers and their effect on performance of high strength corbels were explored by Faleh et al [24], they observed that the closed stirrups may be alternated by steel-fibers for high strength concrete corbels.

The present study is attempted to explore of using of fibers in concrete corbels fabrication because fiber concrete is characterized by a relatively high tensile strength and more toughness, it can be utilized as a tie instead of transverse reinforcement (hoop bars) in the proportioned strut-tie model that forms within the strut element (as shown in Figure 3).

Several studies have been conducted on each type of fiber in terms of the effects of the dimensions, aspect ratio, and fiber content relative to the volume of concrete on the properties of hardened concrete, as well as the structural behavior of reinforced concrete members (s reinforced concrete corbels), but only a few studies have examined the presence of different types of fiber on the properties of reinforced concrete corbels. Recent research is examined the effects of each of different types of fibers on corbel behavior, such as cracking and ultimate load, load deflection response and crack pattern.

The main interest is to demonstrate the effects of variable types of fibers on the structural behavior of reinforced concrete corbels without stirrups. On the other hand research has focused on the effect of the fiber percentage on the behavior of concrete corbels but has overlooked the impacts of different types of fibers, particularly novel fibers such as polyolefin fibers are depicted in this study.

2. Experimental work

2.1. Specimen Description

Seven corbels were cast and tested to failure under vertical loading. One of these corbels was a control corbel made with concrete without fibers, and the other six corbels were made with concrete containing fibers (1% of the concrete volume). Figure 4 shows the six types of fibers used in this study. The dimensions and the primary reinforcement of the corbels were constant, as illustrated in Figure 5. The width b of all corbels was 200 mm, the height h was (300) mm, the effective depth was 275 mm, and the depth at the far edge was 150 mm. The $200 \times 200 \times 400$ mm column that supported the two corbels on opposite sides was reinforced with four $\Phi 12$ mm bars and $\Phi 10$ mm @ 87.5 mm ties. The primary steel was made up of three 12 mm distorted bars. The yield strength of the primary steel was $f_y = 570$ MPa, while the yield strength of the stirrups was $f_y = 520$ MPa. The corbel notations, as well as the fiber type employed in each of them, are shown in Table 1.

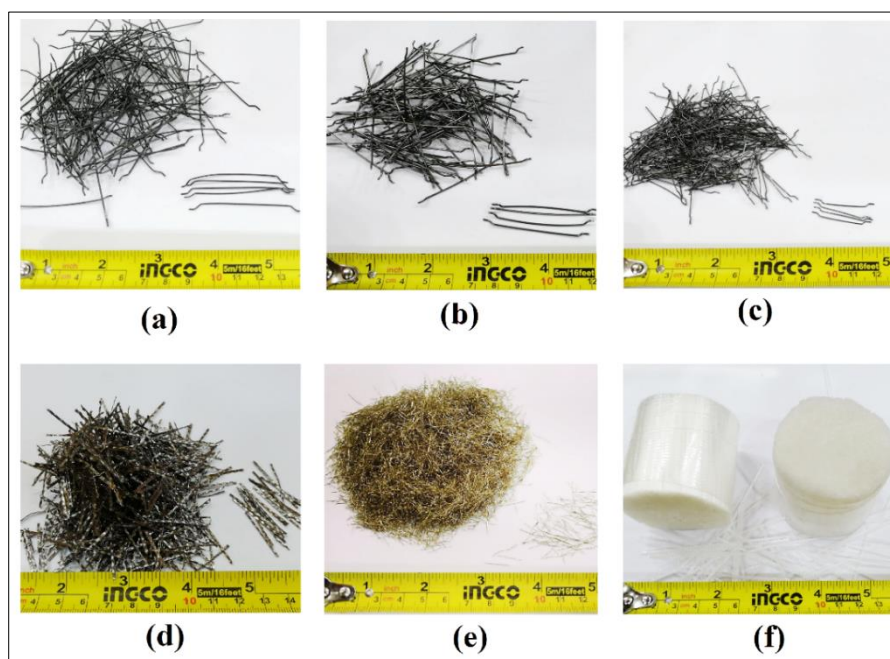


Figure 4. Types of fiber used: (a) hooked steel fiber 60 mm, (b) hooked steel fiber 50 mm, (c) hooked steel fiber 30 mm, (d) crimped steel fiber 30 mm, (e) straight steel fiber 12 mm, and (f) straight polyolefin fiber 60 mm

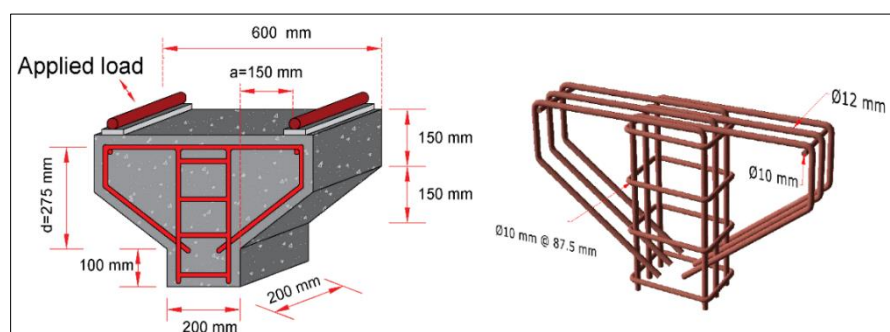


Figure 5. Reinforcement and details of the corbels

Table 1. Corbel notations and the types of fiber used

Corbel Notation	Fiber	
	Type	Amount (Volume Fraction)
C1	No fiber	0%
C2	Hooked steel fiber 60 mm	1%
C3	Hooked steel fiber 50 mm	1%
C4	Hooked steel fiber 30 mm	1%
C5	Crimped steel fiber 30 mm	1%
C6	Straight steel fiber 12 mm	1%
C7	Straight polyolefin fiber 60 mm	1%

2.2. Materials

3.2.1. Cement

The ordinary Portland cement used in this research conformed to the requirements of ASTM C150-13 [25]. Table 2 lists the chemical components and mechanical properties of the cement used.

Table 2. Physical test results and chemical components of the cement used

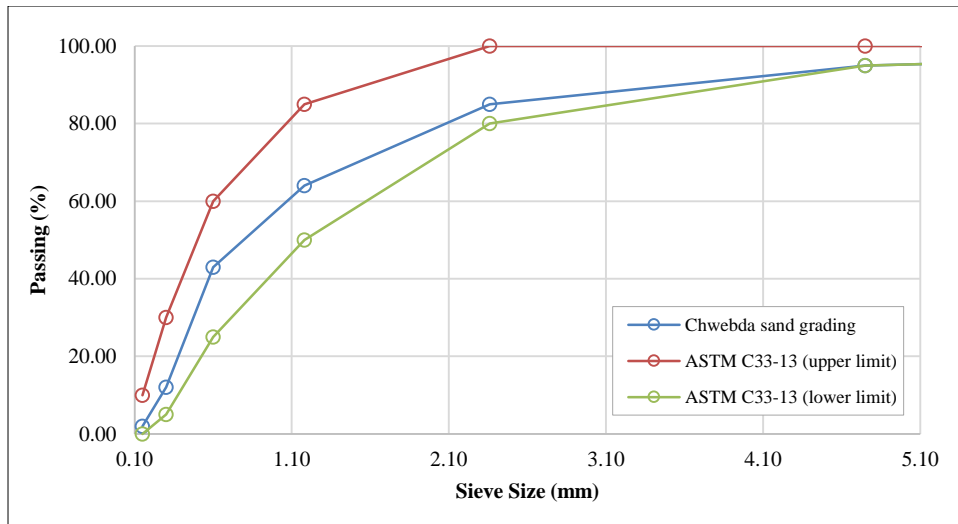
Physical properties		Specification limits-ASTM C150
Compressive strength (MPa)		Setting time (min)
7 days	14.9	12 min
28 days	21.4	19 min
Blaine fineness (cm ² /g)	3100	
Chemical components (%)		
Magnesia (MgO)	2.45	
Lime (CaO)	60.12	
Iron oxide (Fe ₂ O ₃)	2.77	
Alumina (Al ₂ O ₃)	5.20	
Silica (SiO ₂)	22.5	Less than 6
Sulfate (SO ₃)	2.2	Less than 3
Insoluble residue (I.R.)	0.57	Less than 0.75
Loss on ignition (LOI)	0.72	Less than 3
Lime saturation factor (L.S.F.)	0.74	

3.2.2. Sand

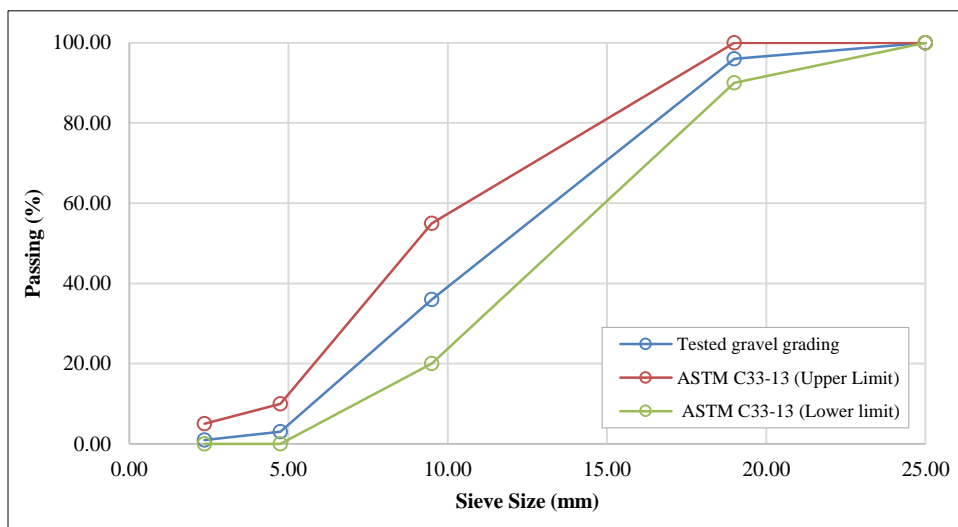
Natural sand from the Al-Zubair (Chwebda) region was used. The fine aggregate fineness modulus was 2.78. The sand was tested in accordance with ASTM C33-13 [26], and its grading was within the specification's limitations, as shown in Table 3 and Figure 6.

Table 3. Grading of the sand and gravel

Gravel			Sand		
Sieve (mm)	Passing (%)	ASTM C33-13-Permissible Limits (%)	Sieve (mm)	Passing (%)	ASTM C33-13-Permissible Limits (%)
25	100	100	9.5	100	100
19	96	90-100	4.75	95	95-100
9.5	36	20-55	2.36	85	80-100
4.75	3	0-10	1.18	64	50-85
2.36	1	0-5	0.6	43	25-60
			0.3	12	5-30
			0.15	2.0	0-10



(a) Sand grading



(b) Gravel grading

Figure 6. Sieve analysis of adopted aggregate

3.2.3. Gravel

The crushed gravel used was from the Al-Zubair region and was 19–4.75 mm in size. Table 3 and Figure 6 expressed the aggregate grading according to ASTM C33-13 [26].

3.2.4. Steel Reinforcement

Deformed steel rebar 12 mm in diameter was used as the main reinforcement, and for the ties of the column, a 10 mm diameter bar was used. The properties of the reinforcing bars used in this study are presented in Table 4; these steel reinforcements conform to ASTM A615-15[27].

Table 4. Reinforcement bars properties

Diameter (mm)	Yield stress (MPa)	Ultimate strength (MPa)	Elongation%
10	570	675	18
12	520	650	20
ASTM C615 limits	More than 420	More than 620	More than 9

3.2.5. Fibers

Six types of fibers were used in this study: five of these fibers were steel fibers with different shapes and dimensions, and one was polyolefin fiber. The dimensions and details of all types of fibers used are illustrated in Table 5.

Table 5. The details of all types of fibers used

Type	Shape	Length (mm)	Diameter (mm)	Aspect ratio	Tensile strength (MPa)
Hooked steel fiber	Hooked ends and straight middle	60	0.75	80	>1000
Hooked steel fiber		50	0.90	55	>1000
Hooked steel fiber		30	0.50	60	>1000
Crimped steel fiber	Wavy	30	0.55*	55	>700
Straight steel fiber	Straight	12.5	0.25	50	2850
Polyolefin fiber	Straight, white, embossed	60	0.84*	71	465

* Equivalent fiber diameter

3.2.6. Water

The water used in this study for the preparation of the concrete mixes and specimen curing was tap water.

3.2.7. Superplasticizer (S.P.)

To produce concrete with suitable workability with a percent of fibers, a copolymer-based superplasticizer (SIKA VISCOCRETE F180G) was used in this study. It fulfilled the requirements of ASTM C494 [28], type F, and type G. It reduced the consumption of water and maintained the slump value.

2.3. Material Quantities

In recent study, the first mix did not include fiber, but a different type of fiber was contained in each other mix at a constant content (1% of the concrete volume). Table 6 presents the details of the fiber type of all mixes. The constant mix proportions used for all mixes 445 kg/m³ cement, 178 kg/m³ water, 667 kg/m³ sand and 1112 kg/m³ Gravel with superplasticizer dosage 2 % of cement weight.

Table 6. Details of the fiber used

Mix	Fiber	
	Type and shape	Aspect ratio
C1	No fiber	---
C2	Hooked steel fiber 60 mm	80
C3	Hooked steel fiber 50 mm	55
C4	Hooked steel fiber 30 mm	60
C5	Crimped steel fiber 30 mm	55
C6	Straight steel fiber 12 mm	50
C7	Polyolefin fiber 60 mm	71

2.4. Specimen Preparation

The mixes were prepared using a rotary mixer with a capacity of 0.1 m³. First, the cement, sand, and gravel were thoroughly mixed. Then, water and superplasticizer were gradually added to the mixture, and the fiber was gradually added to the fresh concrete. The fibers were homogeneously distributed within three to four minutes in the mixer. The mixing of steel fibers required special attention. A volume of each mixture sufficient to cast one specimen of corbels and three specimens of cylinders, prisms, and cubes was prepared. Immediately after the concrete was completely mixed, tests on the properties of the fresh concrete mixtures were performed, and corbels were cast in prepared steel forms. Two layers of concrete were poured into the formwork, compacted using a poker vibrator, and then trowel finished for smooth top surfaces. To test the compressive strength, splitting strength, and modulus of rupture, 150 mm cubes, (150×300) mm cylinders, and (100×100×350) mm prisms were cast and cured under the same conditions as the related corbels. Twenty-four hours after casting, the molds were removed, and the specimens were wet cured under polythene sheets for seven days and then air cured until the date of testing. At 28 days of age, all corbels, cubes, and cylinders were tested.

2.5. Testing Method of Fresh and Hardened Concrete

The qualities of the fresh and hardened concrete are shown in Table 7. The classic slump test was performed in accordance with ASTM C 143 [29]. ASTM C 496 [30] was used to measure the splitting tensile strength (f_t) of (300×150) mm cylinders, while ASTM C78 [31] was used to test the flexural strength of a prism (100×100×350) mm. Cubes with sides dimension of 150 mm were tested to estimate the compressive strength (f_{cu}) according to EN12390-3 [32].

Table 7. Properties of fiber-reinforced concrete mixtures

Corbel No.	Fiber type	f_{cu} * MPa at age (days)		f_r (MPa)	f_s *** (MPa)	Slump (mm)
		7	28			
C1	No fiber	41.76	44.30	4.41	2.87	220
C2	Hooked steel fiber 60 mm	48.37	53.90	10.42	6.63	150
C3	Hooked steel fiber 50 mm	47.67	49.40	9.42	5.52	170
C4	Hooked steel fiber 30 mm	48.66	50.71	8.57	5.00	190
C5	Crimped steel fiber 30 mm	60.42	62.12	7.85	4.10	160
C6	Straight steel fiber 12 mm	52.00	55.08	6.84	5.10	170
C7	Polyolefin fiber 60 mm	46.27	49.62	7.36	4.16	140

* f_{cu} compressive strength; ** f_r modulus of rupture; *** f_s splitting tensile strength

2.6. Test Set-Up, Loading Procedure, and Instrumentation

Specimens were tested using a measuring machine with a 2000 kN maximum capacity. Figure 7 depicts the loading scheme that was carried out. The tested corbels were symmetrically supported by two steel rollers located ($a=150$ mm) from the interior face of the column, as described in Figure 7. The central vertical deflection for the bottom surface of the column was measured by a dial gauge with 0.01 mm per division accuracy at each load incensement. The cracking load and ultimate load were also recorded for all corbels, while crack propagation patterns were observed.

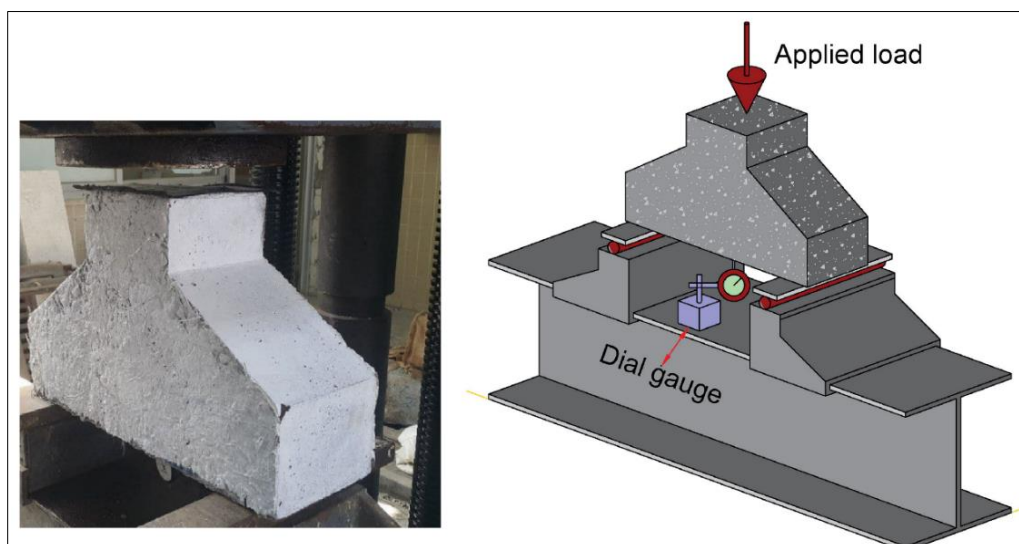


Figure 7. Test setup of the tested corbels

3. Results and Discussion

The experimental work in this study is divided into two parts: the first is an examination of the influence of the fiber type on the properties of fresh and hardened concrete, and the second is an examination of the effect of fiber type on the structural performance of fiber-reinforced concrete corbels, as well as the establish of composition change.

3.1. Properties of Fresh and Hardened Fiber-Reinforced Concrete

Table 7 illustrates the properties of the fresh and hardened concrete mixtures. From the values of the slump in this table, it can be observed that the presence of fibers leads to reduced workability of concrete. This means that introducing fibers can change the workability and slump of the mixture depending on the dimensions and type of these fibers.

From the obtained results, it can be noted that the type of fiber is important and that polyolefin fibers can reduce the slump more than steel fibers. Since polyolefin fibers are lightweight, mixes can often have lower slump, thus affecting the workability. Polyolefin fibers with a length of 6 cm compared to steel fibers with hooked ends with the same length (60 mm), the decreasing in slump values are 36 and 32%, respectively. These values are somewhat similar, the reason for this may be having same length inspect of decreasing in inspect ratio.

From Table 7, it can be noted that the dimensions of fibers in a mix significantly affect the slump and consistency. The surface area of the fibers can be explained as an influencing factor. The mortar must coat the fibers in addition to

the coarse aggregate. The slump and workability are worse if the mortar fraction of the mix is insufficient. Table 7 shows that the length of fibers affects the slump. It can be concluded that longer fibers reduce the slump to a greater degree than shorter fibers. It is noted that 60 mm-long fibers reduce the slump more than 30 mm-long fibers of the same type at the same dose level.

Table 7 shows that adding fibers of all types to the concrete mixture results in a clear increase in compressive and tensile strengths, albeit at varying percentages. The increase in tensile strength is greater than the compressive strength increase, which is primarily attributed to the higher continuous bridging effect of steel fibers, providing high fracture energy until failure. Crimped steel fiber sized 30 mm most affects the compression strength, which can be attributed to the distribution of waves and ripples along its length. The longest fibers of the fibers used (60 mm hooked steel fiber) are the most influential fibers in terms of increasing the tensile strength. The influence of polyolefin fibers on the compressive strength is similar to that of hooked steel fiber sized 50 mm, while their effect on the tensile strength is similar to that of crimped steel fiber sized 30 mm.

3.2. General Behavior of Corbels under Loading

During the early stages of stress, all of the examined corbels evident like elastic members; they are free of flexural and shear cracks, and the deflection is minimal. Cracks begin to appear as the applied load increases. The cracks begin as a few shear cracks on the supports, followed near the column face by a lengthy shear crack at one or both ends of the supports. These shear cracks spread along a line traced from the application load's midpoint to the supports. Figures 8 and 9 illustrate the crack patterns of all corbels evaluated. The control corbel collapses with a single large inclined crack, but the fiber corbels fail with multiple narrow cracks around the main crack, as seen in Figure 9. As the applied load increases, the inclined cracks propagate, leading to a new sudden inclined cracks formation. The principal diagonal shear crack grows increasingly wider as the corbel fails, and in all specimens, this crack separate between the supports and the column-corbel intersection at the inclined face, break one of the double corbels from the withstanding column, as seen in Figure 10. All the corbels fail with the same pattern, but the corbels with fibers are more ductile than the control corbel

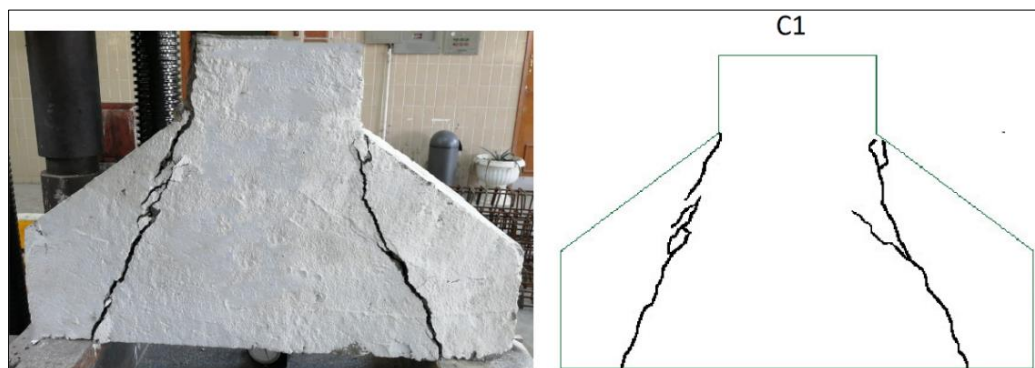


Figure 8. The failure mode of the control corbel

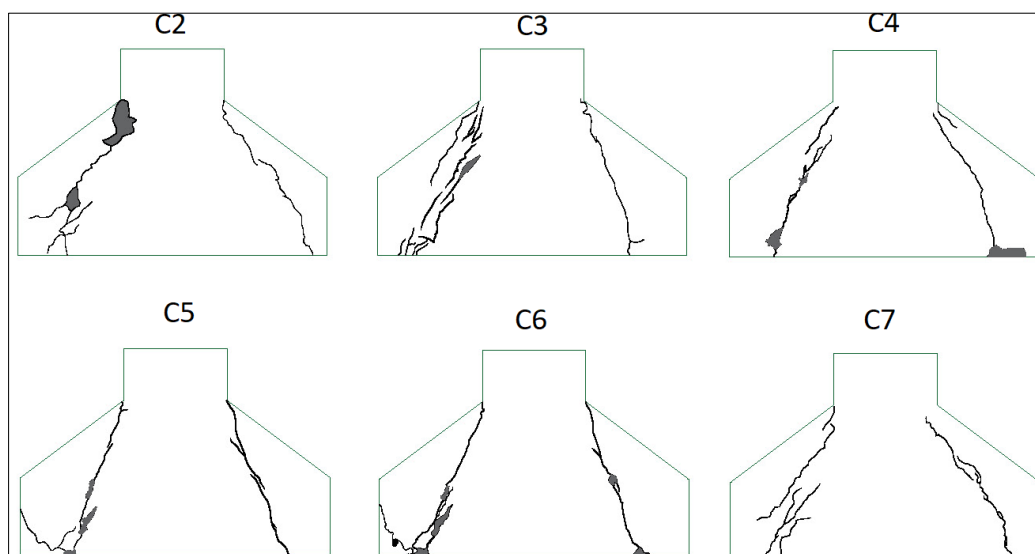


Figure 9. The typical failure mode for the tested corbel specimens

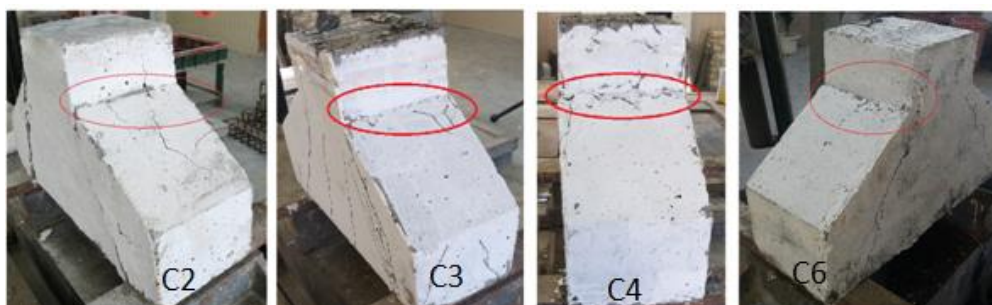


Figure 10. The typical failure mode for the different tested corbel specimens (side perspective)

3.3. Cracking and Ultimate Loads

Table 8 shows incline cracking and ultimate loads. The load at which the first visible crack appears in the corbel body is defined as the inclined cracking load. The ratios of inclined cracking to ultimate load are 44.8 and 86.7 % for the control corbel C1 and the corbel containing polyolefin fiber C7 and range from 47.4 to 76.9 % for the corbels containing steel fibers C2, C3, C4, C5, and C6. The corbels have a reserve in shear strength above which diagonal stress cracks occur, and adding fiber to the concrete mix increases this gain in shear strength. Additionally, the gain in shear ultimate load above the shear load causing diagonal cracks increases by decreasing the concrete compressive strength. This has been attributed to the decrease in the tensile strength of normal strength concrete corbels leading to the appearance of diagonal cracks at lower shear forces than those necessary in high-strength concrete corbels.

Table 8. Results of first crack and ultimate loads

Corbel Notation	Load (kN)		Deflection (mm)		(Cracking/Ultimate) Load Ratio %
	Cracking	Ultimate	Cracking	Ultimate	
C1	260	580	2.60	6.0	44.8
C2	440	880	1.78	8.1	50.0
C3	410	860	1.91	7.8	47.7
C4	360	760	1.77	7.5	47.4
C5	420	720	1.95	6.9	58.3
C6	500	650	2.50	6.4	76.9
C7	520	600	3.60	6.3	86.7

The corbels C2, C3, C4, C5, C6 and C7 with fibers show 69.2%, 57.7%, 38.5%, 61.5%, 92.3% and 100% higher cracking loads than the control corbel C1 made with normal concrete. It can be seen, for corbels with small length fiber (steel or polyolefin) exhibited a significant increase the cracking load capacity. This has been attributed to the bridging of large number of microcracks in the composite due to a much uniform distribution of short fibers in the mix [33].

From Table 8, the ultimate loads of fiber-reinforced corbels C2, C3, C4, C5, C6 and C7 are 51.7%, 48.3%, 31.0%, 24.1%, 12.1%, and 3.4% higher than that of the control corbel C1. Obviously, from these results, it can be concluded that the ultimate load increases as the steel fiber aspect ratio and length (with similar aspect ratio) increase. This may be because increasing the length of the fiber leads to bridges discrete macrocracks at higher loads [33]. With the same length of fiber (30 mm), the corbel made with hooked steel fiber C4 (with aspect ratio of 60) exhibits an ultimate load greater than that of the corbel made with crimped steel fiber C5 (with aspect ratio of 55). For the corbel made with fibers with a length of 60 mm, the ultimate load of the hooked steel fiber corbel C2 (with aspect ratio of 80) is higher than that of the polyolefin fiber corbel C7 (with aspect ratio of 71). This may be attributed to the many of the fibers may break before they dissipate energy by sliding out polyolefin fiber with cement matrix in contrast the tensile strength of steel is greater than that of polyolefin fibers. The straight short steel fibers corbel C6 exhibits a lower ultimate load than all corbels made with steel fibers C2, C3, C4, and C5. Referring to the fiber is the shortest and is not hooked at the ends or twisted along its length but it is not long enough to bridge cracks after formation and propagation. The typical inclined crack patterns for all tested specimens are shown in Figures 8 and 9. All the tested corbels fail in inclined shear; the comparison is performed with the first cracking load for the control C1, fiber-reinforced concrete corbels made with steel fibers of different lengths and shapes C2, C3, C4, C5 and C6, furthermore, corbel made with concrete containing polyolefin fiber C7.

3.4. Load – Deflection Response

Figure 11 demonstrates the load-deflection curves for the tested RC corbels. The load-deflection curve can be divided into two stages, the first of which appears to be a straight line and begins at the initial points and ends at the developed crack, representing the linear behavior of the tested specimens. The second segment is usually represented by a curve

that depicts the nonlinear behavior of the concrete corbels and runs from the developed first visible crack to the final failure stage. From Figure 11, it is clear that the addition of fiber to concrete increases the stiffness in the elastic stage and the ductility in the plastic stage. Additionally, it can be innovated that the corbel, which contains steel fibers sizes 50 mm and 60 mm in length exhibits high stiffness in the pre-cracking phase and after cracking. For the steel fibers sized 30 mm and 12 mm in length and the polyolefin fibers, the opposite trend is observed. In the plastic stage, the corbels with long steel fibers exhibit higher ductility than the other corbels, which means more toughness. It seems that the stiffness of specimens after initiations of cracking becomes larger than that of the first stage. This performance is revealed to that after inclined crack formation, the behavior of the corbel converts to arch action behavior instead of flexural performance.

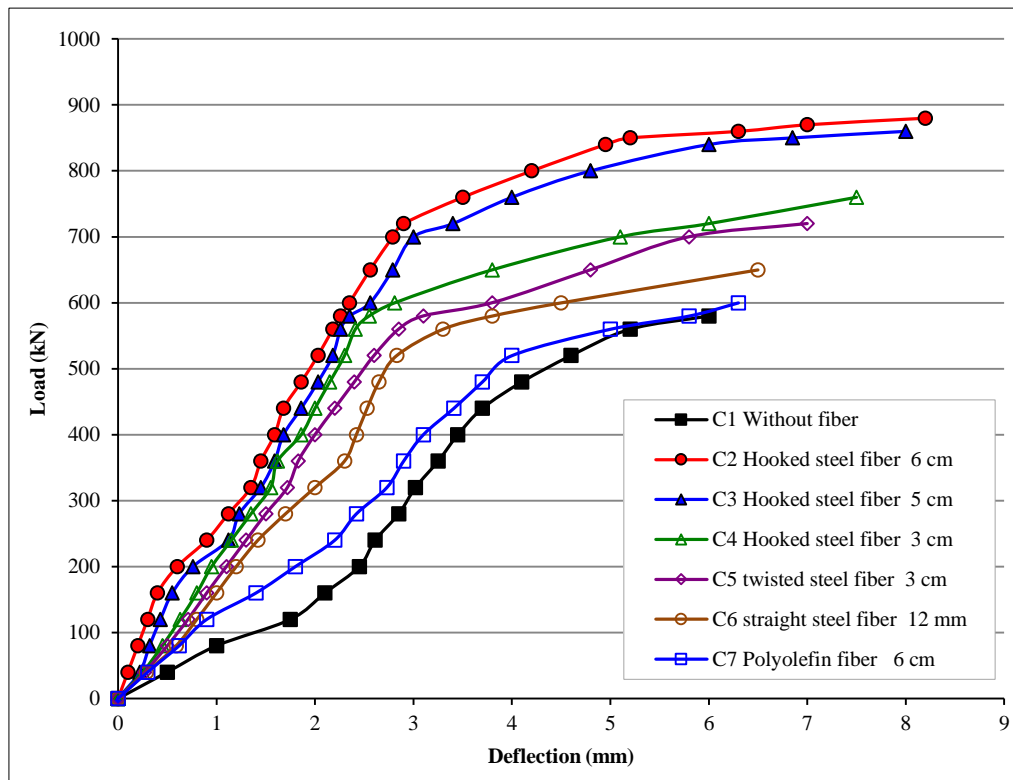


Figure 11. Load deflection relationships of corbels

4. Conclusions

The important observations that can be made based on the findings of this experimental study are as follows:

- The length and aspect ratio of the fiber and the presence of a hook at the ends or twisting along the length of the fiber affect the properties of the fresh and hardened concrete. So optimization or hybrid fibers must be considered because the role of fiber size, strength, and bond is remarkable. The corbel with the greater length and aspect ratio steel fibers yields an ultimate load greater than those with all other types of fiber used in this study. It also has good cracking load compared with concrete corbels, which have no fibers. Therefore, it can be concluded that a corbel with long steel fiber has an excellent reserve of strength compared to the other corbels.
- The corbel has small length fibers that demonstrate a cracking load more than the others. Because of the bridging of micro-cracks at the pre-cracking load stage. The corbels with longer steel fibers have greater stiffness in the first stages of loading (elastic stage) than those containing short steel fibers and the control corbel.
- The yield strength of fibers affects the shear behavior of RC corbels. It is clear that in corbels containing polyolefin fiber, where exhibited ultimate load, gain in strength, and stiffness lower than those of steel fiber, which had the same length and diameter.
- It can be noticed that polyolefin fiber concrete corbels without hoop bars collapse shortly after the generation of cracks compared to steel fiber concrete corbels.
- The best corbels are fabricated with hooked steel fibers C2 and C3, due to much more gain in strength and the ability of the corbel to sustain deformation plastically before fracture.
- Studying the presence of hybrid long and short steel fibers on the behavior of high strength corbels with and without closed stirrups is recommended for future work.

5. Declarations

5.1. Author Contributions

Conceptualization, M.M.; methodology, S.F.; formal analysis, I.S.; investigation, M.M.; resources, I.S.; data curation, I.S.; writing—original draft preparation, I.S., S.F., and M.M. ; writing—review and editing, S.F. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

An expression of gratitude is presented to the staff of the construction materials laboratory for their assistance in preparing this work.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

- [1] ACI 318. (2019). Building Code Requirements for Structural Concrete. American Concrete Institute (ACI), Michigan, United States.
- [2] Yassin, L. A. G., & Hasan, Q. A. M. (2015). Reinforced Concrete Corbels—State of the Art. *Journal of Materials and Engineering Structures*, 2(4), 180-205.
- [3] Araújo, D. L., Azevedo, S. A., Muniz, E. D., Silva, E. O., & Oliveira Júnior, L. A. (2017). Strength evaluation of concrete corbels cast in a different stage from the column. *Revista Ibracon de Estruturas e Materiais*, 10(2), 509-546. doi:10.1590/s1983-41952017000200011.
- [4] Othman, Z., & Aziz, O. Q. (2010). Ultimate shear strength of reinforced high strength concrete corbels subjected to vertical load. *Al-Rafidain Engineering Journal (AREJ)*, 18(1), 1-12. doi: 10.33899/rengj.2010.27981.
- [5] ACI 544.1R-96 (2002), State-of-the-Art Report on Fiber Reinforced Concrete, reported by ACI Committee 544, American Concrete Institute, Michigan, United States.
- [6] Campione, G., La Mendola, L., & Papia, M. (2004). 101. Strength and ductility of fiber reinforced concrete corbels subjected to vertical loads. 6th International RILEM Symposium on Fibre Reinforced Concretes. RILEM Publications SARL, Paris, France.
- [7] Abdul-Razzak, A. A., & Mohammed Ali, A. A. (2011). Modelling and numerical simulation of high strength fibre reinforced concrete corbels. *Applied Mathematical Modelling*, 35(6), 2901–2915. doi:10.1016/j.apm.2010.11.073.
- [8] Fanella, D. A., & Naaman, A. E. (1985). Stress-Strain Properties of Fiber Reinforced Mortar in Compression. *Journal of the American Concrete Institute*, 82(4), 475–483. doi:10.14359/10359.
- [9] Fattuhi, N. I., & Hughes, B. P. (1989). Ductility of reinforced concrete corbels containing either steel fibers or stirrups. *ACI Structural Journal*, 86(6), 644–651. doi:10.14359/2660.
- [10] Fattuhi, N. I. (1987). Sfrc Corbel Tests. *ACI Structural Journal*, 84(1), 119–123. doi:10.14359/2802.
- [11] Fattuhi, N. I., & Hughes, B. P. (1989). Reinforced steel fiber concrete corbels with various shear span-to-depth ratios. *ACI Materials Journal*, 86(6), 590–596. doi:10.14359/2243.
- [12] Fattuhi, N. I. (1990). Strength of SFRC Corbels Subjected to Vertical Load. *Journal of Structural Engineering*, 116(3), 701–718. doi:10.1061/(asce)0733-9445(1990)116:3(701).
- [13] Fattuhi, N. I. (1990). Column-Load Effect on Reinforced Concrete Corbels. *Journal of Structural Engineering*, 116(1), 188–197. doi:10.1061/(asce)0733-9445(1990)116:1(188).
- [14] Fattuhi, N. I. (1994). Reinforced corbels made with plain and fibrous concretes. *ACI Materials Journal*, 91(5), 530–536. doi:10.14359/4166.
- [15] Fattuhi, N. I. (1994). Strength of FRC Corbels in Flexure. *Journal of Structural Engineering*, 120(2), 360–377. doi:10.1061/(asce)0733-9445(1994)120:2(360).

- [16] Campione, G., La Mendola, L., & Mangiavillano, M. L. (2007). Steel fiber-reinforced concrete corbels: Experimental behavior and shear strength prediction. *ACI Structural Journal*, 104(5), 570–579. doi:10.14359/18859.
- [17] Campione, G. (2009). Performance of Steel Fibrous Reinforced Concrete Corbels Subjected to Vertical and Horizontal Loads. *Journal of Structural Engineering*, 135(5), 519–529. doi:10.1061/(asce)0733-9445(2009)135:5(519).
- [18] Ahmed, M. M., Diab, H., & Drar, A. A. M. (2012). Shear Behaviour of High Strength Fiber Reinforced Concrete Corbels. *JES. Journal of Engineering Sciences*, 40(4), 969–987. doi:10.21608/jesaun.2012.114468.
- [19] Salman, M. M., Al-Shaarbaf, I., & Aliewi, J. M. (2014). Experimental study on the behavior of normal and high strength self-compacting reinforced concrete corbels. *Journal of Engineering and Development*, 18(6), 17-35.
- [20] Shakir, Q. M. (2020). Response of innovative high strength reinforced concrete encased-composite corbels. *Structures* (Vol. 25, pp. 798–809). doi:10.1016/j.istruc.2020.03.056.
- [21] Beshara, F. B. A., Mustafa, T. S., Mahmoud, A. A., & Khalil, M. M. A. (2020). Constitutive models for nonlinear analysis of SFRC corbels. *Journal of Building Engineering*, 28, 101092. doi:10.1016/j.job.2019.101092.
- [22] Iliyas, S. S., Wadekar, A. P., & Kakade, D. N. (2016). Investigation of Steel Fiber Reinforced Concrete Corbels by Experimental and Analytical Method. *International Journal of Concrete Technology*, 2(2), 23-29.
- [23] Zin, N. M., Al-Fakih, A., Nikbakht, E., Teo, W., & Gad, M. A. (2019). Influence of secondary reinforcement on behaviour of corbels with various types of high-performance fiber-reinforced cementitious composites. *Materials*, 12(24), 1–16. doi:10.3390/ma1224159.
- [24] Faleh, S. K., Chkheiwer, A. H., & Saleh, I. S. (2022). Structural behavior of high-strength concrete corbels involving steel fibers or closed stirrups. *Periodicals of Engineering and Natural Sciences*, 10(1), 239–252. doi:10.21533/pen.v10i1.2604.
- [25] ASTM C 150. (2012). Standard specification for Portland cement. ASTM International, Pennsylvania, United States.
- [26] ASTM C33/C33M. (2016). Standard Specification for Concrete Aggregates. ASTM International, Pennsylvania, United States.
- [27] ASTM A615/A615M. (2020). Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement. ASTM International, Pennsylvania, United States.
- [28] ASTM C494/C494M. (2017). Standard Specification for Chemical Admixtures for Concrete. ASTM International, Pennsylvania, United States.
- [29] ASTM C143C/143M. (2017). Standard Test Method for Slump of Hydraulic Cement Concrete. ASTM International, Pennsylvania, United States.
- [30] ASTM C496/C496M. (2017). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. ASTM International, Pennsylvania, United States.
- [31] ASTM C78/C78M. (2015). Standard Test Method for Flexural Strength Of Concrete (Using Sample Beam with Third-Point Loading). ASTM International, Pennsylvania, United States.
- [32] BS EN 12390-3. (2009). Testing hardened concrete- Part 3: Compressive Strength of test specimens. British Standards Institution, London, United Kingdom.
- [33] Mehta, P. K. A. M., & Monteiro, P. (2006). *Concrete: Microstructure, Properties, and Materials*. (3rd Ed.). McGraw-Hill Education, New York, United States.