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The efficacy of using SIFCON in the strengthening of reinforced concrete beams containing cold joints

ABSTRACT

The Slurry-infiltrated fiber concrete (SIFCON) is a distinctive form of fiber-reinforced concrete known for its exceptional ductility and superior impact resistance, making it as an ideal material for demanding rehabilitation and strengthen applications in civil engineering. The cold joints in concrete represent the planes of weakness that forms due to delays between successive concrete pours. This study experimentally investigates the efficacy of usingSIFCON jackets as a strengthen materials on the performance of beams with horizontal or vertical cold joints at various locations. Two strengthening techniques were adopted: hardened SIFCON jacket or fresh SIFCON jacket, the studied beam specimens were tested by two-point flexural loading to evaluate ultimate load capacity, failure modes, load -deflection behavior, stiffness, ductility, and energy absorption. The results reveal that the presence of cold joints reducing the performance of beamsin comparison to that of reference specimen and such reduction depends on the orientation and location of these joints within the beam. Whereas the experimental results showed that the performance degradation that caused by cold joints addressed by using both fresh or hard SIFCON jackets. Besides, the enhancements of structural properties that achieved by using hard SIFCON jacket are more than that of fresh SIFCON jacket.

Keywords: *RC beams, horizontal cold joint, vertical cold joint,freshSIFCON jacket, hard SIFCON jacket.*

1. INTRODUCTION

Concrete is the most widely used construction material globally, valued due to its workability, and availability of its raw materials. Besides, concrete has high compressive strength, good durability, minimal permeability, and good resistance to fire[1-2]. Achieving the desired concrete quality requires meticulous oversight throughout the production process, from the selection of materials to mixing and placing, to ensure not only target strength but also long-term durability. Although the production process may seem straightforward, the stages of mixing, transportation, and placement are critically important as they directly influence the strength and durability of concrete. A key factor that can compromise concrete quality is the formation of cold joints [3]. The cold joints are the weak planes that occur in concrete due to an interruption or delay in the concreting process.

While continuous casting is ideal to prevent such joints, it is often not feasible due to large site dimensions, complex formwork, shortages of concrete, unexpected delays, and labor constraints [4].

The primary concern with cold joints is the formation of a weak interface where the bond between two concrete placements is inadequate. This imperfection can allow water infiltration and diminish the structural robustness of the concrete, leading to potential vulnerabilities. These joints are particularly problematic in critical structural elements like foundations, where unwavering strength and material continuity are essential [5]. Previous research indicated that cold joints considerably affect the performance of reinforced concrete (RC) structural elements.Abass (2012) [6], conducted an experimental study on nineteen RC beams with different locations (midspan and third-point), and types of cold joints (vertical, inclined) and with or without stirrups. The results showed that inclined cold joints have maximal effect on the flexural performance due to weak transfer of shear across the interface. Also, the study validated that locating the joint at midspan zones provides the most appropriate performance

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of beams. An experimental investigation was conducted to study the flexural behaviour of RC beams with different concrete grades strengths, these beams having vertical cold joints. Charts were provided to predict the decrease in the bending moment of RC beams for strength in the presence of cold joints [7]. Roy and Laskar (2018) [8] stated that the existence of cold joints within the beam column specimens decreased the performance of such specimens, and according to this study, the first crack developed through the cold joint oneself. In 2021 Al-Rifaie et al. [9] studied the behavior of ten RC beams, eight of these specimens had differences in the positions and number of horizontal cold joints (HCJs), and two specimens without cold joints were used as reference beams. The results revealed that presence of HCJs lead to decrease the ultimate load and increase in the measured deflection in comparison to reference specimens.Recent research has conducted on deep beams included horizontal cold joints (HCJs) located at various heights within the depth of the studied specimens. The results of this study demonstrated that the structural behaviour of beam specimens depending on the positions of HCJs and locating the joint in the upper zone of the beam results in the lower impact on performance [10].

Slurry-infiltrated fiber concrete (SIFCON) is a relatively new high-performance material, considered a special type of steel fiber-reinforced concrete (SFRC). The technique of infiltrating layers of steel fibers with a cement-based slurry was first proposed by Haynes (1968). Lankard (1979) later modified this method, demonstrating that increasing the steel fiber volume fraction could produce a material with very high strength properties, which it named as SIFCON. This composerexhibits unique characteristics such as high strength, large ductility, and excellent potential for structural applications subjected to accidental or abnormal loads, such as explosions, during their service life. A key behavioral phenomenon in SIFCON is fiber lock, which is believed to be responsible for its outstanding stress-strain properties [11-13]. The use of SIFCON in strengthening of RC beams has been studied in previous research. Jaafer Abdulkhaliq (2015) [14] experimentally studied the effect of theSIFCON matrix on the flexural response of ferrocement slabs. The results indicated that SIFCON significantly improved flexural strength and energy absorption while reducing crack width. Vijayakumar and Dinesh Kumar (2017) [15], investigated the strength properties of SIFCON with constant cement, sand, and fly ash content, while varying steel fiber content (6%, 8%, 10%, 12%). They found that compressive, tensile, and flexural strengths all increased with higher fiber volumes, with a 12% fiber addition resulting in a 36.2% strength increase. In 2021, SawantSushant and PatilChetan [16] studied the chloride resistance of SIFCON made with steel and polypropylene fibers. They reported that flexural strength was 2.5 times greater, and compressive strength was 1.04 times greater than that of conventional concrete. Ultimate load capacity, stiffness, ductility, and energy absorption were also significantly enhanced. Ali et al (2022) [17], investigated the mechanical properties and performance of SIFCON samples at elevated temperatures under standard and accelerated curing. The study found improvements in compressive strength, splitting tensile strength, flexural strength, Poisson’s ratio, elastic modulus, and ultrasonic pulse velocity with increasing steel fiber ratios under standard curing.The concern is essentially because presence of cold joints within beams represents weak planes that can thereby affect the flexural performance of beams. Therefore, the present study introduces an incoming implementation by investigating SIFCON jacketing specifically for strengthening beams with horizontal or vertical cold joints at various locations.To this end, a comprehensive assessment was performed covering strength recovery, cracks patterns, load deflection relationship, stiffness, ductility, and energy absorption. A comparative of the response of the reference specimen, beam specimens with vertical or horizontal cold joints and beam specimens strengthen with fresh and hardened SIFCON jacketing techniques has been done.

2. EXPERIMENTAL PROGRAMS

The experimental program comprised two phases, in the first phase, thirteen (100 x 150 x 1000) mm beam specimens were cast,this set included one reference beam without a cold joint and twelve beams fabricated with pre-defined cold joints. Such joints were divided equally into vertical and horizontal orientations. For vertical orientation, three beams had the joint at the mid-span and three at the first third of the span. On the other hand, the rest six beam specimens had horizontal joints, three of them had joints in the compression region and three beams had in the tension region. The second phase focused on strengthening the beams using two SIFCON strengthen techniques: a hard jacket and a fresh jacket. All the tested beam specimens were subsequently tested under two-point bending to evaluate their ultimate load capacity, cracking behavior, load -deflection relations, stiffness, ductility, and energy absorption. The following sections detail the constituent materials, specimen preparation, and testing procedures for both the normal concrete and SIFCON.

2.1. The mix proportion and materials properties

The mix proportions for the normal concrete (NC) with a target compressive strength of 30 MPa and for SIFCON with compressive strengthof 110 MPa are summarized in Table 1. The NC mix design for normal concrete was based on ACI211.4R [18] guideline.Regarding the SIFCON mix, trail slurry mixes were carried out to produce the suitable mix that has an ultra-fluid, strong slurry capable of totally infiltrating a pre-placed bed of a high volume of fibers. It is well known that SIFCON does not utilized coarse aggregate, and the proportion of (sand: cement) by weight is recommended by researchers to be equal to (1:1)[19]. The normal concrete mix utilizing Portland cement, fine and coarse aggregate and superplasticizer. The SIFCON mix was developed usingPortland cement, silica fume as a replacement to cement, fine aggregate and with 7% of steel fibers.The selectionsteel fibers volume fraction of 7%follows confirmed the SIFCON mix design principles [19] and optimizations of prior experimental study [15], representing a feasible balance between achieving enhancement of mechanical properties (toughness, ductility, post-cracking strength) and maintaining reliable workability of slurry for complete fiber infiltration without balling issues.Portland cement commercial (42.5R)mark is Al-mass and met the Iraqi Specification (IQS) requirements [20].The physical testing of cement shows that this cement has a fineness of 324m^2/kg and a relative density of 3.15. The SF employed in this experimental investigation, complied with ASTM C1240 [21]. The normal concrete mixes were produced using fine and coarse aggregates with maximum particle sizes of 5 mm and 12.5 mm, respectively. Both aggregates complied with the gradation requirements of IQS No. 45 [22].

Table 1. Mix proportions kg/m^3.

Material	NC	SFCON
Cement	463	850
Silica fume	n.a.	150
Fine sand	750	1000
Coarse aggregate	950	n.a.
Water	199	330
Superplastisizer	0.5	3
Steel fibers	n/a	7%

2.2. Specimens Preparations and Test Set up

The specific gravity values and water absorption of fine and coarse aggregate were (2.66, 2.69) (1.5, 0.52) % respectively. On the other hand, the SIFCON mix incorporated a much finer fine aggregate with a maximum particle size of 0.6 mm. This mix was further enhanced with 25 mm long, hooked-end steel fibers (0.3 mm in diameter), silica fume, and a superplasticizer admixture in compliance with ASTM C494 [23].

A prior stage was conducted to investigate how horizontal or vertical cold joints affect the mechanical properties of concrete, and this was performed by examining two strength grades of concrete (30 MPa and 55 MPa) and two casting delay times (60 and 180 minutes). The results showed that cold joints reduced the mechanical properties of the lower-strength concrete (30MPa). Furthermore, the longer 180-minute delay had a more pronounced detrimental effect than the 60-minute delay. Based on these findings, the current study focused on the worst-case condition by preparing thirteen beam specimens of (100 x 150 x 1000) mm using 30 MPa concrete with a 180-minute casting delay.The 30 MPa concrete strength represents a normal concrete strength for general reinforced concrete construction, while the 180-minute delay, though not ideal, reflects extended interruptions that can occur in real construction due to unexpected site conditions.

The test beam specimens were categorized into reference specimen without a cold joint and twelve beams containing designedly formed cold joints, these beams were divided into two groups based on the orientation of joints (Table 2). The first group consisted of six beams with vertical cold joints, with three cold joints located at the mid-span (maximum flexural stress) and the other three in the shear span (first third of the length) as shown in Fig. 1a. The second group comprisedof six beams with horizontal cold joints; three of such cold joints were positioned in the tension zone and three in the compression zone as shown in Fig. 1b. All specimens shared identical concrete dimensions. The steel reinforcement details that used for flexural and shear are shown in Fig.2, where the beam specimens reinforced with two Ø 8 mm and two Ø10 mm diameter deformed steel bars as the top and bottom reinforcement respectively. While the transverse reinforcement was used steel bars of Ø 8 mm at a spacing of 60 mm along the beam length. To evaluate the strengthening methods, four beams from each group were retrofitted using fresh or hardened SIFCON jacketing and two beams were used to provide a comparison with the strengthened beams (Fig. 3 a and b). The beam specimens had been tested to failure in flexural under two-point loads using testing machine with a maximum capacity of 2500 kNwith rate of loading of 0.1 kN/sec, the test setup and the instrumentations details are shown in Fig.4. To measure the vertical mid-span deflection for each load increment, a dial gage with accuracy of 0.001 mm per deviation was used.

Table 2. Details of the beams with the strengthen methods

Beam symbol	Details of the Beams
BJ0	Beam without a cold joint
BVMJ	Beam with a vertical cold joint at mid-span
BVSJ	Beam with a vertical cold joint at the shear span
BHTJ	Beam with a horizontal cold joint in the tension zone
BHCJ	Beam with a horizontal cold joint in the compression zone
Strengthened Methods	
FS -BVMJ	Fresh SIFCON jacketing of beam with vertical cold joint at mid-span
FS -BVSJ	Fresh SIFCON jacketing of beam with vertical cold joint at shear span
HS-BVMJ	Hard SIFCON jacketing layers of beam with a vertical cold joint at mid-span
HS -BVSJ	Hard SIFCON jacketing layers of beam with a vertical cold joint at the shear zone
FS -BHTJ	Fresh SIFCON jacketing of beam with horizontal cold joint in the tension zone
FS -BHCJ	Fresh SIFCON jacketing of beam with horizontal cold joint in the compression zone
HS -BHTJ	hard SIFCON jacketing layers of beam with a horizontal cold joint in the tension region
HS -BHCJ	hard SIFCON jacketing layers of beam with a horizontal cold joint in the compression region

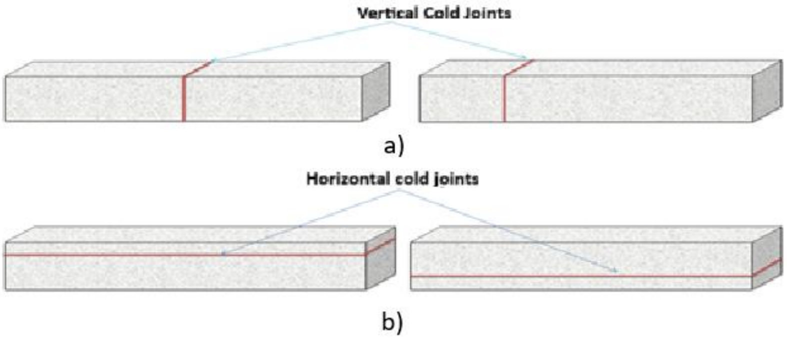
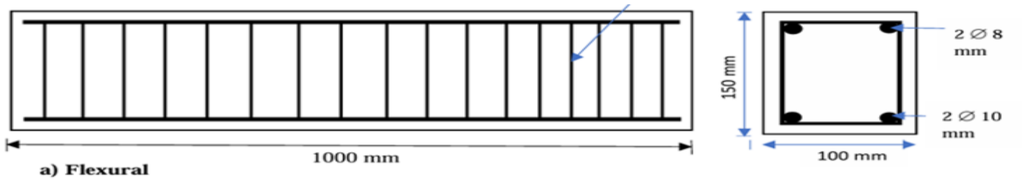


Figure 1. (a) Vertical cold joints, (b) horizontal cold joints of beams



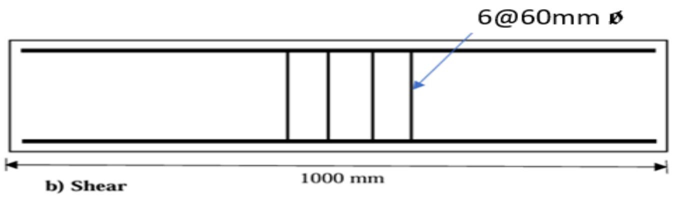


Figure 2. Details of the steel reinforcement (a) flexural, (b) shear, (c) moulds for beam Specimens

(a) (b)

Figure 3. Beam specimens (a) fresh SIFCON (b) hard SIFCON

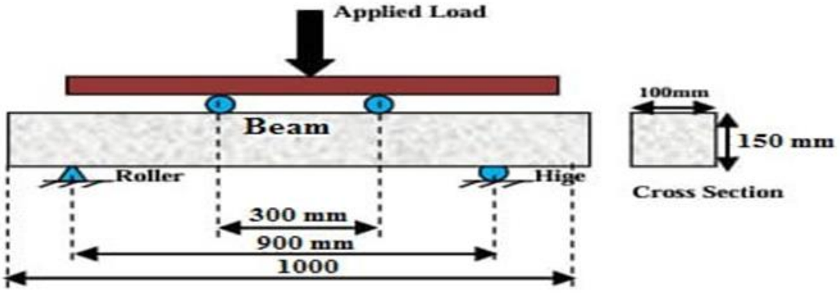


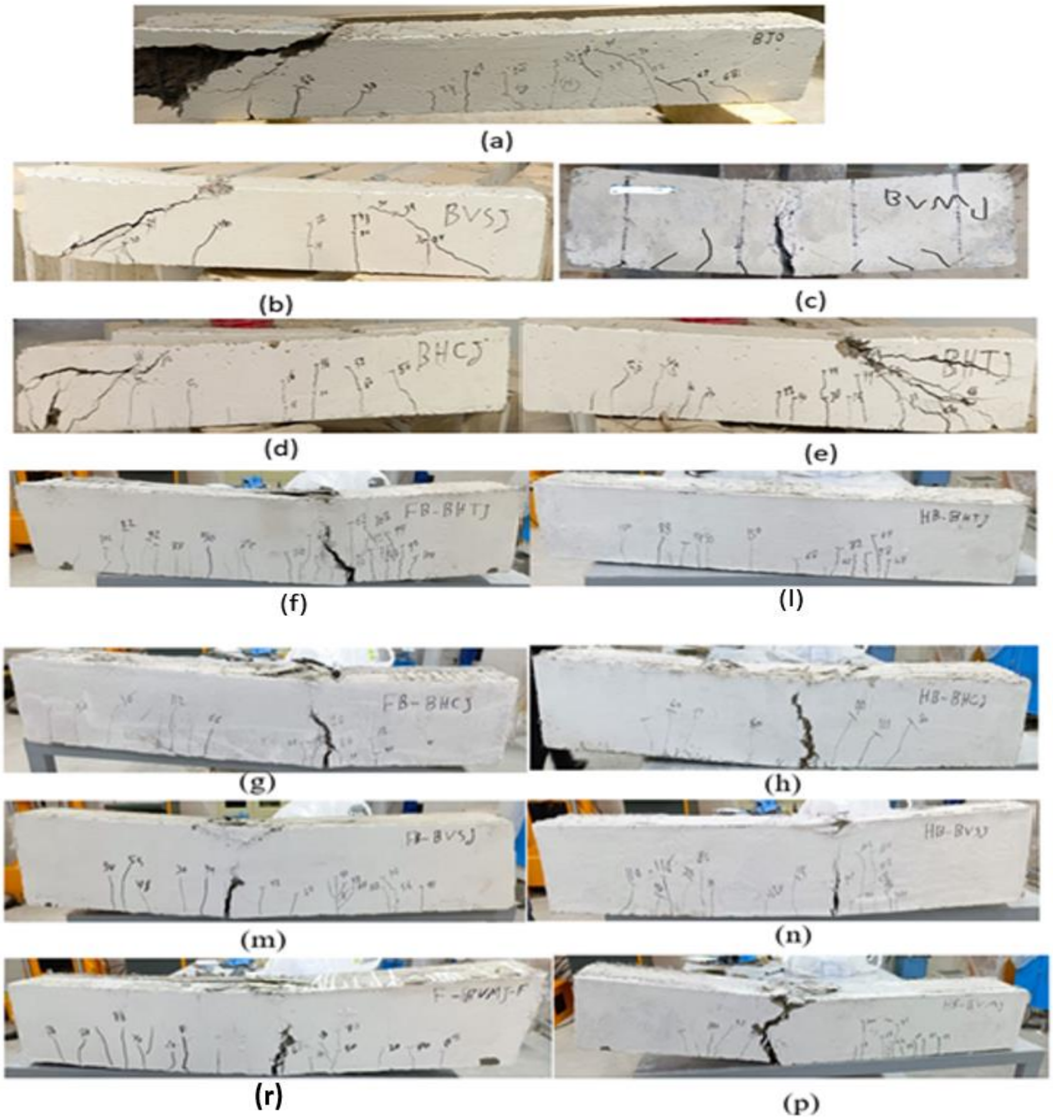
Figure 4. Schematic test setup of beams

3. RESULTS

3.1. The ultimate load carrying capacity and cracking patterns

The values of the ultimate load carrying capacity of the tested beam specimens are detailed in Table 3. Out of the reference specimen (BJ0) and beam specimens that had vertical and horizontal cold joints,BJ0 specimen manifested the higher ultimate load capacity.The beam specimens of vertical (BVMJ, BVSJ) and horizontal (BHTJ, BHCJ) cold jointsshowed reductions in their capacity values, whereBVMJ and BVSJ exhibited 21.1 % and 27.7% lesser capacities than BJ0. The beam specimensBHTJ and BHCJon the other hand showed reductions than those of BJ0by14.7% and 5.1%.It can be noticed that more reductions are pronounced in specimens with vertical cold joints, which can be attributed to the interruption of the main load-transmit path, and this in turn affects both flexural and shear resistance. Conversely, the horizontal joints tend to be more at close with the direction of the main compressive stresses, that way able to maintain partial continuity and providestructural safety. These findings are consistentwith the previous studies [24,25]. Strengthening the beam specimens BVMJ, BVSJ, BHTJ, and BHCJwith fresh (FS) or hard (HS) SIFCON jacketing significantly improved their performance. For example, the FS-BVMJ and HS-BVMJ specimens saw load capacity increases of95.6% and 137.4% over their un-strengthened BVMJ specimen.The specimens FS -BVSJ and HS-BVSJ showed improvements of 97.8% and 184.6% higher than that of BVSJ specimen.On the other hand, strengthening of such specimens that had horizontal cold joints with fresh or hard jacketing SIFCONincreased of loads carrying capacity of FS-BHTJ and HS-BHTJ by 100.7% and 156.1% respectively.Similarly, the percentages of increase of the loads carrying capacity of the specimens FS-BHCJ and HS-BHCJ were 91.3% and 112%, compared to their unstrengthen specimen BHCJ. Besides, the FS- and HS-jacketed beam for all specimens with both vertical and horizontal joints exceeded the capacities of the reference specimen BJ0 by about 42.9–118.5%, confirming that the jacket enhances the structural capacity over the reference specimen. The notable enhancements in the load carrying capacity can be attributed to the dense network of steel fiber and superior confinement of SIFCON layer, which reflects how effective the jacket is in the bridging the weak joint zone and restoring structural continuity due to development of the composite action at the interface [25,26]. Besides, it can be noticed that the values of ultimate load capacity of beams strengthened with hard SIFCON were greater than that of those strengthened with fresh SIFCON. This is mainly due to the stronger interface bond formed by the roughened surface and the applied epoxy layer. Together, these boost lateral restraint and minimize the relative movement between the beam specimen and SIFCON jacket, leading to superior structural performance.

Generally, the initial flexural cracks began to appear within the middle third of span of the reference specimen BJ0at load of 14 kN (about 17% of the maximum load), and as the applied load increased, additional flexural cracks developed and propagated, accompanied by increments in the width of cracks.Thereafter, flexural-shear cracks began to form, followed by the development and propagation of numerous diagonal shear cracks between the points of loading and the supports (Fig.5a). In the case of beams with vertical and horizontal cold joints, the flexural cracks initiated at loads of (14-17) kN, then these cracks propagated along the cold joints interface with wider of the crack’s width. After that the shear cracks typically developed diagonally between the loading and support points. Such interfaces begin to be the preferred path for development of cracks, which can lead to precocious failureas shown in Fig.5(b, c, d, e).



(a)
(b) (c)
(d) (e)
(f) (l)
(g) (h)
(m) (n)
(r) (p)

Figure 5. Cracking patterns of beam specimens (a) BJ0; (b) BVSJ; (c) BVMJ; (d) BHCJ; (e) BHTJ; (f) FS-BHTJ; HS-BHTJ; (g) FS-BHCJ; (h) HS-BHCJ; (m) FS-BVSJ; (n) HS-BVSJ; (r) FS-BVMJ; (p) HS-BVMJJ

The examination of post-failure revealed that the mechanisms behind this improved behavior of SIFCON strengthened beams. In these beams, the micro-cracks throughout the jacket were visibly bridging by multiple steel fibers. Such action of fiber bridging effectively distributes stresses and delays the formation of a dominant failure crack. Furthermore, SIFCON jacketing acts integrally with the tested beam and this in turns, leads to change in failure mode from sudden shear failure along the cold joint interface to ductile flexural failure [26,27].

The first crack loads of beams strengthened with fresh- SIFCON layers were at of range of (30-34)kN, whereas such loads for hard-SIFCON layers were at the range of (60-65)kN.These beams showed cracking behaviour in form of fine cracks with small widths, delay in formation of the major crack, and alteration of the modes of failure away from sudden brittle shear to flexural failure Fig.5 (f, l, g, h, m, n, r, p).This can be attributed to the high volume of steel fibers into SIFCON jacketing that bridge cracks, which in turn lead to improves both the serviceability and toughness [11,27].

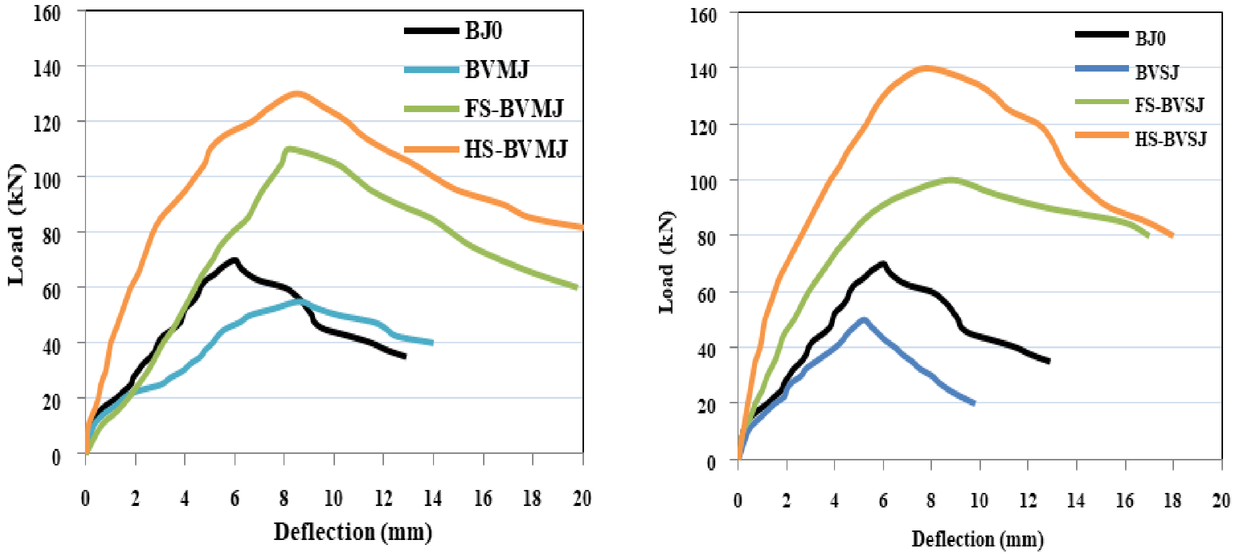
Table 3. Summaries of flexural test results

Beam symbol	First crack load (kN)	Yield load(kN)	Ultimate load (kN)	Deflection at ultimate (mm)	Stiffness kN/mm
BJ0	14	67.15	69.80	6.21	13.73
BVMJ	14	52.25	55.10	8.6	10.30
BVSJ	14	47.45	50.44	5.2	11.31
BHTJ	15	56.23	59.55	7.5	11.75
BHCJ	17	62.33	66.24	6.3	10.78
FS -BVMJ	30	95.22	107.80	8.2	17.50
FS -BVSJ	32	90.45	99.75	8.8	23.53
HS-BVMJ	62	122.10	130.80	8.5	27.32
HS -BVSJ	60	128.35	143.57	7.8	28.04
FS -BHTJ	32	112.35	119.50	7.3	30.65
FS -BHCJ	34	121.32	126.70	8.5	24.71
HS -BHTJ	65	138.65	152.50	7.5	37.25
HS -BHCJ	64	126.45	140.45	15.3	26.88

3.2. Load - deflection and stiffness results

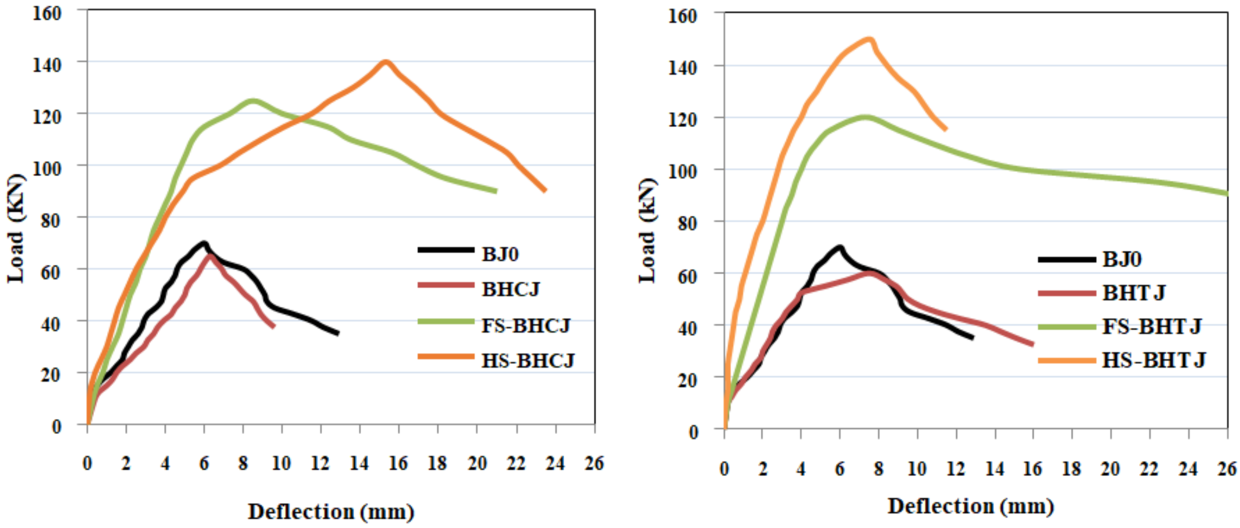
The load–deflection relationships for reference beam, beams with vertical and horizontal cold joints and strengthened beams—both fresh and hard SIFCON jackets are illustrated in Figs6 and 7. The results of load-deflection curves showed that all beam specimens followed a typical three-stage pattern. The initial stage is linear, indicating a linear relation between the applied load and mid span deflection, reflecting elastic behavior of the specimens. This is followed by a nonlinear hardening stage, identified by a gradual reduction in the curve's slope due to initiate and propagate of micro-cracking, causing deflection to increase more rapidly than the load. The third stage is softening, where a rapid increase in deflection occurs after the ultimate load is reached, leading to a descending branch on the curve. As shown in Table 3significant differences were observed in the initial stiffness of these curves. Beams containing vertical or horizontal cold joints exhibited a lower initial stiffness compared to that of reference beam.The reductions in stiffness were (18-25) % and (14.5-21.5) % for beam specimens with vertical and horizontal cold joints respectively, which can be attributed to weaken the tension zone, reduce the effective bond and deactivate the interlock with aggregate [28].

Conversely, beams that were strengthened showed superior initial stiffness. Furthermore, the ascending branch of the curves became nonlinear earlier in beams with cold joints. Whilst the strengthened beams with SIFCON jacketing showed the most enhanced performance, with a prolonged linear ascending branch and greater deflection capacity. The stiffness valuesimproved for FS-BVMJ and HS-BVMJ specimens by 70% and 165.3% compared to the beam BVMJ, while such values increased by 108% and 148% for the FS-BVSJ and HS-BVSJ beam in comparison to BVSJ specimen.Equivalently, the enhancements in the stiffness values for specimens FS-BHTJ and HS-BHTJ were 160% and 217% compared to the stiffness of BHTJ specimen. The increases in the stiffness for the FS-BHCJ and HS-BHCJspecimens were 130% and 149.4% over the stiffness value of BHCJ specimen.This is attributed to an alteration in failure mode at the cold joint from a brittle failure to a more ductile behavior, helped by yielding of steel and the bridging of cracks by fibers and dense cementitious matrix of SIFCON.[24, 29,30].



(a) (b)

Figure 6. Load-deflection relationship of beam specimens (a) BJ0 and beams with vertical cold joints at moment region; (b) BJ0 and beams with vertical cold joints at shear region



(a) (b)

Figure 7. Load-deflection relationship of beam specimens (a) BJ0 and beams with horizontal cold joints at compression region; (b) BJ0 and beams with horizontal cold joints at tension region

3.3. The ductility index

Ductility is a performance indicator for reinforced concrete members, typically evaluated the capacity of such members to sustain inelastic deformations while maintaining their ability of load-carrying. In this study, the ductility was assessed using the displacement-based method, where the ductility index (μΔ) is defined as the ratio between the mid-span deflection at ultimate load (Δu) and the deflection at first yield (Δy) [31]. The ductility index gives a direct indication of degree of deformation the beam beyond yielding of stage. The calculated ductility indices for the tested beams are listed in Table 4. Among reference and the tested specimens that having vertical or horizontal cold joints, the reference beam (BJ0) showed the greatest ductility index, reflecting its continued composite action. In contrast, beams containing either vertical or horizontal cold joints exhibited a decrease in their ductility, the reductions ranging from 14% to 27% when compared to the BJ0 specimen. This is due to the existence of cold joints, which break the continuity of matrix of concrete and appearance of interfacial weaknesses, and this in turn, leads to big inelastic deformations.

Strengthening beam specimens containing vertical cold joints by fresh or hardened SIFCON jacketingproduced to an essential improvement in ductility. The ductility of FS-BVMJ and HS-BVMJ increased by respectively 26.2% and 27.3%, while the FS-BVSJ and HS-BVSJ specimens gained achieves of 22.2% and 42.5% compared to the BVSJ specimen. A similar trend was noticed in specimens with horizontal cold joints. The FS-BHTJ and HS-BHTJ specimens showed ductility increases of 42.6% and 57.4%, respectively, while the FS-BHCJ and HS-BHCJ specimens display enhancements of 38.5% and 84.5% comparative to the BHCJ beam. Such improvements can be attributed to the outstanding mechanical properties of SIFCON, including its high content of fiber, the capacity of crack- bridging, and special energy absorption, which generally magnify the capacity of post-yield deformation [32]. Further, the ductility of FS- and HS-jacketed beam specimens exceeded that of the of the reference specimen BJ0 by about 6.3%–32.5% supporting that the SIFCON jacketing enhances the ductility over the reference specimen.

Table 4. Results of ductility of beam specimens

Beam symbol	Yield deflection (mm)	Ultimate deflection (mm)	Ductility index
BJ0	2.7	6	2.22
BVMJ	4.5	8.6	1.91
BVSJ	2.7	5.2	1.93
BHTJ	4.1	7.5	1.83
BHCJ	3.9	6.3	1.62
FS -BVMJ	3.4	8.2	2.41
FS -BVSJ	3.3	7.8	2.36
HS-BVMJ	3.5	8.5	2.43
HS -BVSJ	3.2	8.8	2.75
FS -BHTJ	2.8	7.3	2.61
FS -BHCJ	4.1	8.5	2.13
HS -BHTJ	2.6	7.5	2.88
HS -BHCJ	5.2	15.3	2.94

3.4. Energy Absorption Capacity

The energy absorption capacity of the tested beam specimens was evaluated by calculating the area under its load–deflection curve [33]. The calculated values of the energy absorption were summarized in Table 5. Firstly, the presence of cold joints caused reductions in the capacity of energy absorption where such reductions ranged between (11-35) % and (4-8.5) % for beams with vertical and horizontal cold joints respectively.This reduction is attributed to the decrease of growths of tension stiffening and accelerates the initiation of crack under bending [28]. All strengthened beams specimens showed obviously higher capacities compared with the reference and other beams with cold joints. Among the hard strengthen jacketing, the HS-BHCJ specimen exhibited the greatest enhancement, reaching value of energy absorption approximately 5.7 times that of the unstrengthen BHCJ specimen. In general, beams strengthened with hardened SIFCON (HS) provided higher energy absorption than those strengthened with fresh SIFCON (FS).

For instance, HS-BVMJ and FS-BVMJ achieved increases of 3.4 and 2.9 times the capacity of the BVMJ beam.Whereas the HS-BVSJ and FS-BVSJ recorded improvements of 4.9 and 3.8 times the capacity of BVSJ, respectively. The improvement was even greater for the HS-BHCJ and FS-BHCJ beams, recording increases of 6 and 3.5 times the capacity of the BHCJ beam, while the HS-BHTJ and FS-BHTJ beams improved by 3.7 and 3.4 times the capacity of the BHTJ beam.The reason behind these improvements is attributed to the distinctive properties of SIFCON, which has a special content of high fiber and superior crack-bridging capability compared to conventional fiber-reinforced concrete. These properties enhance the dissipation of energy, defer the localization of cracks, and boost stable post-peak behavior [32].

Table 5. Results of energy absorption capacity of beamspecimens

Beam symbol	Energy absorption (kN· mm)
BJ0	230.45
BVMJ	205.88
BVSJ	148.50
BHTJ	211.25
BHCJ	221.25
FS -BVMJ	590.25
FS -BVSJ	570.45
HS-BVMJ	698.54
HS -BVSJ	730.22
FS -BHTJ	710.36
FS -BHCJ	742.50
HS -BHTJ	775.56
HS -BHCJ	1320.25

4. CONCLUSIONS

- The presence of cold joints lowers the load beam capacity, the vertical cold joints causing the highest strength loss (21%–26%) compared to horizontal joints (5%–15%) due to interruption of flexural and shear stress paths.
- The development of cracks is untimely of beams containing cold-joint with widen width along the joint interface, often leading to early shear failure. Contrariwise, the strengthened beams show improved of cracking behaviour, which includes slow initiation of cracks, finer cracks, and a change the mode of failure from brittle shear to more ductile flexural failure.
- Using SIFCON jacketing provides recovery of strength, where the load capacity increasing by 91%–184% in comparison to those load capacity of beams with cold joints, and in all cases exceeding the reference beam (BJ0) by 43%–119%. Also, the hardened SIFCON jackets exceed fresh SIFCON due to robust interface bonding achieved by surface roughening and epoxy, producing in higher ultimate loads and enhanced stiffness.
- The Load–deflection relationships are improved by SIFCON jacketing, providing in higher initial stiffness, an expanded linear range, and improved deformation capability in comparison to that of both cold-joint and reference beams.
- The ductility is enhanced through SIFCON strengthening, with increases of 22%–84.5% comparing to unstrengthen cold-joint specimens and even 6.3%–32.5% over the reference beam.
- The energy absorption capacity increases, especially for hardened SIFCON jackets, which reached up to 6 times the capacity of control beams. Also, fresh SIFCON also results well, especially in the behavior of post-peak.
- In construction practice, the experimental parameters represent a realistic scenario, while the efficacy of SIFCON jacketing is expected to be in general applicable, the quantity of improvement may vary with base concrete strength, joint condition, and other environmental factors.

Limitations and Recommendationsfor Future Research

This study provides clear evidence of the effectiveness of SIFCON for cold joint remediation; however, certain limitations should be acknowledged. Each beam configuration was tested with a single specimen; thus,it is recommended to represent each variable with multiple specimens.

To further validate and generalize the proposed approach of strengthening, future studies should concentrate on researching the energy dissipation and ductility of SIFCON-jacketed beams under cyclic and impact loading. It is recommended to represent each variable with multiple specimens Moreover,predicting of the structural behavior on variables that are not covered experimentally, such as different shear span-to-depth ratios (a/d) and varying geometries of jacketing by developing analytical or numerical models.

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IZVOD

EFIKASNOST UPOTREBE SIFCON-A U OJAČAVANJU ARMIRANOBETONSKIH GREDA KOJE SADRŽE HLADNE SPOJEVE

Vlaknasti beton infiltriran slurri-infiltracijom (SIFCON) je poseban oblik vlaknasto armiranog betona poznat po svojoj izuzetnoj duktilnosti i superiornoj otpornosti na udarce, što ga čini idealnim materijalom za zahtevne primene rehabilitacije i ojačavanja u građevinarstvu. Hladni spojevi u betonu predstavljaju ravni slabosti koje se formiraju usled kašnjenja između uzastopnih izlivanja betona. Ova studija eksperimentalno istražuje efikasnost upotrebe SIFCON obloga kao materijala za ojačavanje na performanse greda sa horizontalnim ili vertikalnim hladnim spojevima na različitim lokacijama. Usvojene su dve tehnike ojačavanja: očvrsnuta SIFCON obloga ili sveža SIFCON obloga, proučavani uzorci greda su testirani dvotačkastim savijajućim opterećenjem kako bi se procenila granična nosivost, načini otkaza, ponašanje opterećenja i deformacije, krutost, duktilnost i apsorpcija energije. Rezultati pokazuju da prisustvo hladnih spojeva smanjuje performanse greda u poređenju sa referentnim uzorkom i da takvo smanjenje zavisi od orijentacije i položaja ovih spojeva unutar grede. Dok su eksperimentalni rezultati pokazali da je degradacija performansi izazvana hladnim spojevima otklonjena upotrebom i svežih ili tvrdih SIFCON obloga. Osim toga, poboljšanja strukturnih svojstava koja su postignuta upotrebom tvrde SIFCON obloge su veća nego kod sveže SIFCON obloge.

Ključne reči: *RC grede, horizontalni hladni spoj, vertikalni hladni spoj, sveža SIFCON obloga, tvrda SIFCON obloga.*

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