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Experimental Study on Shear Strengthening of Reinforced Concrete Beams Using Different Techniques of Concrete Jacketing

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Abstract

A large number of RC structures or at least some of their members need strengthening or rehabilitation. Among the typical failure modes, the shear failure is more dangerous and less predictable, because of usually brittle behavior and sudden collapse. Therefore, there are necessities for upgrading the shear capacity and the local ductility of reinforced concrete beams. In this study, four different techniques of concrete jacketing were used to improve the behaviors of the shear deficiencies beams. The four techniques used in this study to enhance the behavior of the beams were by using a Self-Compacted Fiber Reinforced Concrete jacket without stirrups (S.-J. + Steel Fiber), a concrete jacket of Self Compacted Concrete with stirrups (S.-J. + Stirrups), a concrete jacket of ferrocement jacket (S.-J. + Ferrocement), and a concrete jacket of ferrocement jacket with external steel reinforcing bars (S.-J. + Ferrocement + R). These techniques contributed to enhancing the load-carrying capacity and delaying the appearance of the first crack in tested beams compared with the control beam by a percentage of (35, 59, 30, 6) % and (18, 35, 81, 80) %, respectively. The specimen (S.-J. + Stirrups) showed the best performance in comparison with the other used strengthening techniques used in this study in terms of stiffness and the ultimate load-carrying capacity. The ferrocement jacket (S.-J. + Ferrocement) was found to be the most suitable jacketing system used to enhance the shear capacity in terms of cracking load.

Keywords: Shear, Reinforced Concrete Beam, Strengthening, Jacketing, Ferrocement, Steel Fiber, Self-Compact Concrete.

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1. Introduction

A lot of structural members require strengthening or repairing. The urgent need for upgrading or repairing the existing structures is because of design or construction errors, change in the dead and live loads to achieve the change of the structure use, or to achieve the continuous increase in the demand of design codes and specifications, to treating the deterioration or damage output from overloading or environmental conditions and neglecting of maintenance and durability problems, also in some time it is necessary to control the deflection and cracking load.

The typical failure modes in reinforced concrete beams are shear and flexure. The shear failure is more dangerous and less predictable than the flexural one, because of usually brittle behavior and sudden collapse. The RC beams must be designed to develop their entire flexural failure in the case of overloading to ensure a ductile flexural failure. Thus, there are usually necessities for upgrading the shear capacity and the local ductility of reinforced concrete beams [1], [2].

The technique that will be used in the strengthening must be appropriate with the nature of the project, satisfied the architectural requirements, and must resist the environmental conditions surrounding the structure to get the durability approaching the project's life, it should also be acceptable in terms of time and cost.

Several researchers studied the behavior of different RC members strengthened or retrofitted by using a concrete jacket. The behavior of RC columns rehabilitated using concrete jacketing was investigated by several researchers [3]-[7]. Shaaban and Seoud [8] reported the behavior of exterior beam-column space joints repaired by ferrocement jacketing. Sabbaghian and Kheyroddin [9] evaluated the behavior of one-way slabs strengthened by using high-performance fiber-reinforced cementitious composite laminates as a jacket. There is also much research investigated the feasibility of concrete jacketing in upgrading the flexural [10]-[14], torsional [15], [16], and shear [17]-[22] capacity of beams.

One of the most critical parameters that the previous studies focused on was the type of concrete used in the jacketing. Bahraq et al. [18] reported the behavior of shear strengthened RC beams by using Ultra-High-Performance Concrete (UHPC) jacket. Chalioris et al. [23] evaluated the repaired RC beam's behavior using Self-Compacting Concrete (SCC) for jacketing. Ruano et al. [19] studied the use of steel Fiber Reinforced Concrete (SFRC) to rehabilitate RC beams damaged in shear failure. Al-Rousan and Shannag [20] used Slurry Infiltrated Fiber Concrete (SIFCON) and shang et al. [21] used Engineered Cementitious Composites (ECC) for shear strengthening and repair of RC beams.

Other factors that previous studies focused on were the type, shape, aspect ratio, and volume fraction of the used fiber in the jacket concrete, which is an essential part of the aforementioned concrete types. Previous studies also focused on other parameters, such as shear span to depth ratio, the amount of added shear reinforcement, thickness, and configurations of the concrete jacket. In previous research, the concrete jacket has been used in the tension zone or on the two web faces or three sides of the beam as a U shape for shear strengthening or retrofitting.

The use of concrete jackets for strengthening and repair of damaged members has some exceptional advantages. Some of the most prominent features that are considered to be the positive aspects of this method are substantially strength upgrading, good bonding, compatibility between the new and old concrete, fire resistance, delamination and debonding resistance, long term durability, resistance to weather, and environmental conditions, ease of assessment and crack control [18], [19], [21].

Unlike other traditional methods that depend on bonding different materials on the concrete surface, the jacketing technique can be used to strengthen the members with either undamaged or deteriorated concrete surfaces. Especially the concrete jacketing is a good option in structures that are exposed to fire, and the damage occurred in the concrete near the surface [18].

When a fire breaks out in concrete structures, the probability of the RC beam damage due to shear failure is more than the failure in bending. The reason behind it is that the steel reinforcement that plays the main role in flexural behavior will recover its mechanical properties after the fire. Still, the destructive concrete that plays the primary role in the shear strength of RC beams remains useless [21].

The use of concrete jacketing has shortcomings, such as enlargement of member size and an increase in weight. Its completion is somewhat more complicated than traditional methods and thus is more expensive and requires more time for implementation.

There is a special type of jacket is called a ferrocement jacket used by researchers in the strengthening and repairing of different concrete members [6]-[8], [12], [15], [17], [24]-[27]. Some of the characteristics of this type of jacket are that it is a composite material with a thin wall consist of rich cement mortar reinforced with closely spaced layers of wire mesh. The ferrocement composite possesses some important desired properties, for example, it is low self-weight because of its thinness (normally in between 10 mm to 40 mm), does not cause a significant enlargement in the dimensions of members, show high resistance to the occurrence, and development of cracks.

In this study, the structural behaviors of reinforced concrete beams that are designed to be shear deficiencies were investigated after strengthening by using different techniques of concrete jacketing. The techniques used in this study to enhance the behavior of the beams were by using self-compact, steel fiber reinforced concrete, and ferrocement jacketing. The salient feature of this study is that various approaches to upgrading the shear capacity of RC beams are conducted on the same reference shear deficient beams. This study allows easily to compare different strategies of strengthening. All the specimens were designed to undergo shear failure even after upgrading to estimate each strengthening system's contribution to increasing the shear capacity.

2. Experimental program

2.1. Summary of the experimental work

A total of five RC beams were fabricated and tested using a normal concrete mixture. The beam dimensions and reinforcement details of all the beams were the same. The beam's cross-sectional dimensions were 200 (b) × 250 (h) mm with a total length of 1700 mm and 1500 mm clear span. All the beams were tested beneath four-point bending, considering a shear span to depth ratio equals two, as shown in Fig. 1.

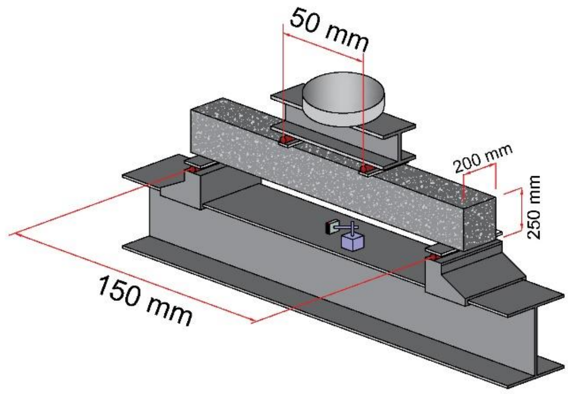

Fig. 1 Beams layout and test setup.

Depending on ACI 318-14 [28], the beams were designed to ensure shear failure. Two deformed bars of 16 mm (D16) diameter were used in the compression zone and three bars of the same size used in the tension zone. Internal stirrups were not used in the clear span of the beam. Two stirrups of (D10) deformed bars were provided on each side of the beam and outside of the clear span for prevention of anchorage failure and to manufacture the reinforcement cage. The concrete cover was 20 mm on each side. The reinforcement details of the beams are shown in Fig. 2. The properties of steel reinforcement bars are presented in Table 1.

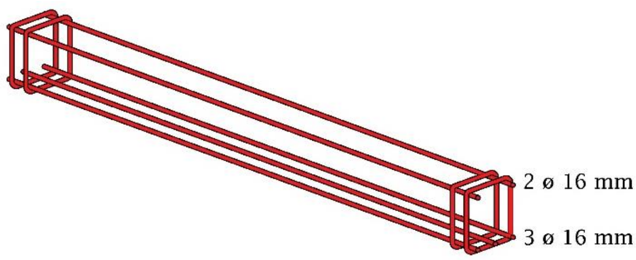

Fig. 2 Reinforcement details.

Table 1. Mechanical properties of steel reinforcement.

Bar Diameter (mm)	Yield Strength (MPa)	Ultimate Strength (MPa)	Modulus of Elasticity (GPa)
16	510	680	199.9
10	490	635	199.7

The ingredients of the 1 m^3 the Normal Concrete (NC) mixture used in this study is presented in Table 2. The beams were covered by a wet burlap for three days after cast finishing. Then the specimens were detached from their forms and stored in the laboratory. Six concrete cubes, beams, and cylinders were prepared from the same shear deficiencies beams mixture and cured in the water to evaluate the concrete mechanical properties. All the specimens were tested at the age of 28 days.

Table 2. Mix proportion of the Normal Concrete (NC).

Material	Properties	Mix proportions	Weight in 1 m^3 volume (kg)
Cement	Ordinary Portland Cement Type (I)	1	385.2
Fine aggregate	Normal sand (From Al-Zubair Area)	1.9	731.9
Coarse aggregate	Crushed Gravel (From Al-Zubair Area)	2.8	1079
Superplasticizer	Sika ViscoCrete ® F180 G	0.005	1.9
Water	Tap water	0.53	204.2

The concrete compressive, flexural, and tensile strength were evaluated according to BS EN 12390-3:2019 [29], ASTM C78/C78M-16 [30], and ASTM C496/C496M-17 [31] respectively. The average results of concrete compressive strength, modulus of rupture, and splitting tensile strength are given in Table 3.

One beam without strengthening was tested as a control. The other four remaining beams were strengthened by using different techniques of concrete jacketing. The beam's designation and a brief description of the used strengthening strategy are presented in Table 4.

Table 3. Concrete mechanical properties of (NC).

Compressive strength (MPa)	Modulus of rupture (MPa)	Splitting tensile strength (MPa)
34.0	4.1	2.6

Table 4. Beam's designation.

Beam Designation	Description of the strengthening system
Control	Without strengthening.
S.-J. + Steel Fiber	A Self-Compacted Fiber Reinforced Concrete (SCFRC) jacket without stirrups.
S.-J. + Stirrups	A concrete jacket of Self Compacted Concrete (SCC) with stirrups.
S.-J. + Ferrocement	A concrete jacket of ferrocement jacket.
S.-J. + Ferrocement + R	A concrete jacket of ferrocement jacket with external steel reinforcing bars.

2.2. Characteristics of Strengthening Beams.

2.2.1. The beam (S.-J. + Steel Fiber)

This beam was strengthened by using a U-shape jacket as shown in Fig. 3. A 60 mm Self Compacted Fiber Reinforced Concrete (SCFRC) jacket was applied to the two web faces of the beam and the bottom side. A particular wooden mold was prepared to achieve the jacket covering the three sides of the beam. The (SCFRC) was prepared by using a one percent (1 %) volume fraction of straight steel fiber. The aspect ratio (fiber length/fiber diameter) of the straight steel fiber was (14 mm/1.2 mm) 11.6, and its tensile strength was 1180 MPa. The mix proportion and the mechanical properties of the hardened (SCFRC) mixture are presented in Table 5 and Table 6, respectively.

The process of strengthening began when the beam reached 28 days of age. The steps that have been taken to strengthen this beam can be divided into six phases:

1. Preparation of the concrete substrate by grinding its face using a rotary diamond grinder to get a rough surface and enhancing the bond between the old and new concrete.
2. The beam surfaces cleaned using compressed air.
3. A 1 mm layer thickness of the Sikadur®-32 LP was applied on the concrete surfaces to get structural bonding between the fresh and hardened concrete. Sikadur®-32 LP is a two-part structural bonding agent and based on special fillers and epoxy resins combination. The mechanical and physical properties of the Sikadur®-32 LP are presented in Table 7.
4. The beam was remolded.
5. The (SCFRC) jacket was cast.
6. The beam was cured for 28 days by a wet burlap cover.

Table 5. Mix proportion of (SCFRC).

Material	Properties	Mix proportions	Weight in 1 m^3 volume (kg)
Cement	Ordinary Portland Cement Type (I)	1.0	450
Fine aggregate	Normal sand (From Al-Zubair Area)	1.78	800
Coarse aggregate	The normal size of (12.5 – 4.75) mm (From Al-Zubair Area)	1.82	820
Limestone powder	Grinded Limestone	0.33	150
Steel Fiber	Straight Steel Fiber	0.174	78.5
Superplasticizer	Sika ViscoCrete® F180G	0.0233	10.5
Water	Tap water	0.433	195

Table 6. Concrete mechanical properties of (SCFRC).

Compressive strength (MPa)	Modulus of rupture (MPa)	Splitting tensile strength (MPa)
64.3	7.39	5.57

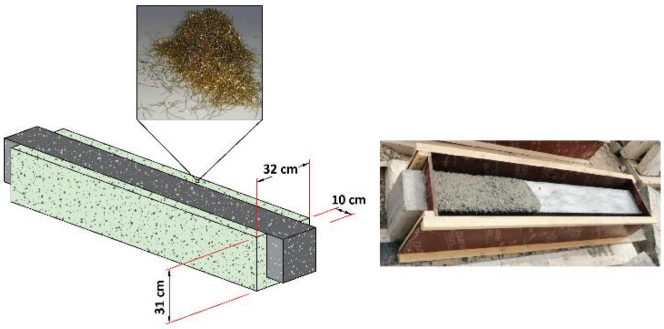

Fig. 3 Details of the beam (S.-J. + Steel Fiber).

Table 7. Technical data of Sikadur®-32 LP.

Property	Description (Range or Value)	Illustration of the product
Mixing and colors	Component A (white), Component B (dark grey) = 2:1 by weight (concrete grey)	
Density	1.4 kg/l (Component A + B mixed at 23 °C)	
Compressive Strength	(39-56) MPa, 14 days curing at (23 °C, 40 °C)	
Tensile Adhesion Strength	Concrete failure (> 3 MPa), 7 days curing at a dry concrete substrate at 23 °C	
Shrinkage	Hardness without Shrinkage	

2.2.2. The beam (S.-J. + Stirrup)

As shown in Fig. 4, the dimensions of the concrete jacket were the same as the previous one. The difference between the strategy used to strengthen this beam and the previous one is in the details of the concrete mixture and the addition of stirrups instead of using steel fiber. The concrete jacket was cast by Self Compacted Concrete (SCC) after adding stirrups. Details of the added shear reinforcement in the concrete jacket are shown in Fig. 4. The mixture proportion and the mechanical properties of the hardened (SCC) mixture are presented in Tables 8 and 9, respectively. The mix design used in (SCC) is the same as (SCFRC) that used in the beam (S.-J. + Stirrup) with the difference of cancellation the steel fiber, which led to a decrease in the proportion of water and plasticizers necessary to obtain fresh mixture within the self-compacted concrete requirements.

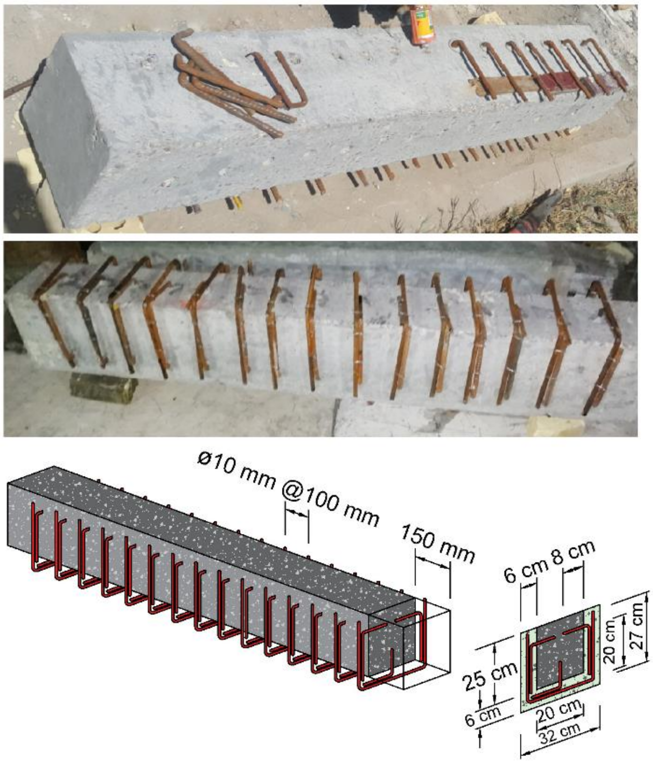

Fig. 4 Details of the beam (S.-J. + Stirrup).

Table 8. Mix proportion of (SCC).

Material	Properties	Mix proportions	Weight in 1 m^3 volume (kg)
Cement	Ordinary Portland Cement Type (I)	1.0	450
Fine aggregate	Normal sand (From Al-Zubair Area)	1.78	800
Coarse aggregate	The normal size of (12.5 - 4.75) mm (From Al-Zubair Area)	1.82	820
Limestone powder	Grinded Limestone	0.33	150
Superplasticizer	Sika ViscoCrete® F180G	0.0144	6.5
Water	Tap water	0.40	180

Table 9. Concrete mechanical properties of (SCC).

Compressive strength (MPa)	Modulus of rupture (MPa)	Splitting tensile strength (MPa)
55.3	5.83	3.81

When the beam (Jac. + Stirrup) reached 28 days' age, the following steps were taken to strengthen it. The first step was to prepare the concrete substrate by grinding its face using a rotary diamond grinder. Then holes of 8 cm deep and 12 mm diameters were made by an electric drill. The holes were made on the concrete surface in the locations specified to add anchors. Steel reinforcement of 10 mm diameters (D10) with angle shape was used as a shear connector. The details and the dimensions of the anchors are presented in Fig. 4. The beam surfaces and the drill holes were cleaned using compressed air. Then the shear connectors were installed by using Sika AnchorFix®-2 + Tropical epoxy resin. Then, after the end of the five-hours curing period, the stirrups were bonded to the anchors. The mechanical and physical properties of the Sika AnchorFix®-2 + Tropical epoxy resin are summarized in Table 10. Then after completing the process of adding shear reinforcement, the beam was cleaned and remolded. A 1 mm layer thickness of the Sikadur®-32 LP was applied to the concrete. Finally, the (SCC) jacket was cast and cured for 28 days by a wet burlap cover.

Table 10. Technical data of Sika AnchorFix®-2 + Tropical.

Property	Description (Range or Value)	Illustration of the product
Mixing and colors	Component A (grey), Component B (off-white) = 10:1 by volume (light grey)	
Density	(1.65-1.75) kg/l (Component A + B mixed)	
Modulus of Elasticity in Tension and Compression	(3800 and 7000 MPa) respectively, 7 days curing at 20 °C	
Compressive Strength	70 MPa, 7 days curing at 20 °C	
Tensile Strength	15 MPa, 7 days curing at 20 °C	
Tensile Strength at Flexure	29 MPa, 7 days curing at 20 °C	
Long Term Service Temperature	- 40 °C min. / 50 °C max.	
Curing Time	15 °C - 20 °C, 5 hours	

2.2.3. The beam (S.-J. + Ferrocement)

This specimen was strengthened by using a 20 mm thick U-shape ferrocement jacket. Six layers of steel wire mesh have been used in the strengthening of this beam. The mechanical properties of the used wire mesh were determined according to ACI 549.1 R-93 [32]. For this purpose, three tensile coupons were prepared and testes as shown in Fig. 5. The properties of the steel wire mesh are presented in Table 11.

Table 11. Properties of the wire mesh used in the ferrocement jacket.

Wire diameter (mm)	Opening shape	Opening dimensions (mm)	Fy (MPa)	Full (MPa)	Modulus of Elasticity (MPa)
1	Square	12 × 12	410	635	92200

In this technique, due to the presence of wire mesh, it is not possible to paint the concrete surface with epoxy. Three steps were taken to avoid getting debonding failure and achieve an acceptable connection between the surface of the beam and the ferrocement jacket. The first one was by using mechanical fasteners. The second step was by using a synthetic rubber emulsion (Sika Latex) old-new bonding agent material. The third step was by using high-quality adhesive mortar as a plaster by using the same material. The high-quality adhesive mortar was prepared by using the mix proportion proposed in the datasheet of the Sika Latex. The amount of the mixed materials and the results of its cube compressive strength at age 28 days are presented in Table 12.

Table 12. Details of the adhesive mortar used in the ferrocement jacket.

Portland Cement (kg)	Quartz Sand (kg)	Sika Latex (Liter)	Water (Liter)	Compressive Strength (MPa)
50	125	7	12	55.3

When the age of the beam becomes 28 days, the sample was prepared for strengthening. The concrete surface was roughened by a grinder, many holes were drilled randomly on the concrete surface, the holes and concrete surface cleaned using compressed air, then the plastic fisher screws were inserted inside the holes (see Fig. 6 (1-3)). The pre-prepared six layers of U wrap steel wire mesh was applied on the three sides of beam faces (the web and the tension zone) and mechanically fixed by using bolts and washers (see Fig. 6 (4)). The pre-prepared bonding bridge liquid was applied to the concrete surface (see Fig. 6 (5)). Finally, the beam was plastered with a 20 mm thick high-quality adhesive mortar and cured for 28 days by a wet burlap cover as shown in Fig. 6 (6).

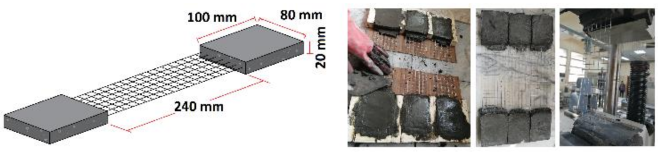

Fig. 5 Details of wire mesh tensile coupons.

Fig. 6 The steps involved in the strengthening of the beam (S.-J. + Ferrocement).

2.2.4. The beam (S.-J. + Ferrocement + R)

This specimen was strengthened in the same way and the details used in the previous one, with the difference that external steel reinforcing bars were added and mechanically connected on the surface of the beam before the wire mesh wrapping. As shown in Fig. 7 twelve deformed bars of 10 mm (D10) were used on each side of the beam web. The added steel bars were distributed at a distance of 80 mm center to the center and were arranged to be perpendicular on the path connecting the loading point and the beam support.

Fig. 7 The configuration of the externally bonded steel rebars used in the strengthening of the beam (S.-J. + Ferrocement + R).

2.3. Test setup and instrumentation

A loading frame with 2000 kN capacity was used to test the specimens under a 4-point bending setup as shown in Fig. 1. The distance between the applied point loads and the clear span was 300 mm and 500 mm respectively. The gap between the support and the end of the beam was 100 mm. The load was applied at a rate of 0.3 mm/min. A laser dial gauge was used to measure the deflection in the midspan.

3. Results and Discussions

The results of all the studied beams will be discussed in this section. The results include the total ultimate failure load (P_{UF}), the ultimate deflection that corresponds to the ultimate failure load (Δ_U), cracking load (P_{crack}), midspan deflection, crack propagation, and the final failure mode. The results of all the studied beams are summarized in Tables 13 and Figs. 8 and 9.

Table 13. Summary of the results for all the studied beams.

Beam Designation	P_{crack} (kN)	P_{UF} (kN)	Δu (mm)	$\frac{P_{UF}}{P_{UF(control)}}$	$\frac{P_{crack}}{P_{UF}}$	$\frac{P_{crack}}{P_{crack(control)}}$	Failure Mode
Control	80.0	136.0	4.87	1.00	0.59	1.00	Shear
S.-J. + Steel Fiber	94.4	184.0	5.63	1.35	0.51	1.18	Explosive
S.-J. + Stirrups	108.0	216.0	6.30	1.59	0.50	1.35	Shear
S.-J. + Ferrocement	145.0	176.3	5.13	1.30	0.82	1.81	Debonding & Shear
S.-J. + Ferrocement + R	144.2	144.2	3.04	1.06	1.00	1.80	Debonding & Shear

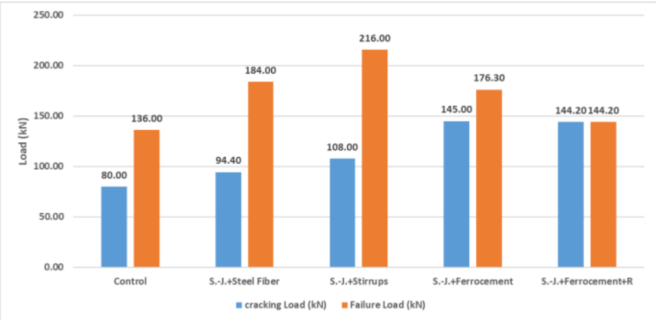

Fig. 8 The cracking and failure load for all the studied beams.

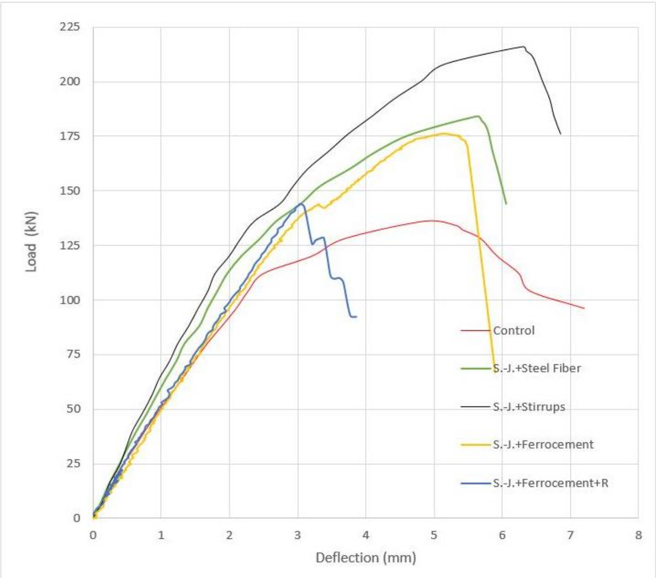

Fig. 9 The Load-deflection Curves in the Mid-span of Overall Studied beams.

3.1. Control Beam

The control beam displayed a shear failure by forming a major diagonal crack. The first crack appears at a total applied load of 80 kN. The crack was initiated near the support and then propagated to the load application point as the load continues to increase. The complete collapse occurred at a total applied load of 136 kN, and the corresponding ultimate mid-span deflection (Δ_U) was 4.87 mm. Fig. 10 shows the control beam (a) before the test and (b) after the failure.

(a) **(b)**

Fig. 10 The control beam **(a)** before the test and **(b)** after the failure.

3.2. The beam (S.-J. + Steel Fiber)

As presented in Table 13 the specimen (S.-J. + Steel Fiber) contributed to increasing the load-carrying capacity of the unstrengthen beam by 35 %. The specimen failed due to a significant diagonal crack. The shear crack was initiated under the edge of the loading plate at 94.4 kN applied load, then propagated toward the support point. The beam failed at a 184 kN load with a 5.63 mm corresponding deflection. Fig. 11 shows the two web faces of the (Jac. + Steel Fiber) specimen after failure.

Fig. 11 The (S.-J. + Steel Fiber) beam after the failure.

3.3 The beam (S.-J. + Stirrup)

The initial and ultimate failure load of the specimen (Jac. + Stirrup) was 108 kN and 216 kN, respectively. In comparison with the unstrengthen beam, there is a 59 % increase in the load-carrying capacity and a 35 % delay in the initial failure occurrence. The deflection was Δ_U = 6.3 mm at the ultimate load. The beam demonstrates a considerable increase in the shear capacity and the stiffness of the original beam. It was found through the study that the strategy used to strengthen this beam is considered the best approach among all the methods used to enhance the rest of the specimens. Fig. 12 shows the (Jac. + Stirrup) specimen after testing.

The failure mechanism started with the appearance of a vertical crack at the end of the concrete jacket. The crack was initiated on the surface of the original beam and above the edge of the support plate. The crack extended until it arrived at the top surface of the specimen. As shown in Fig. 12, when the applied load approached the ultimate failure load, some cracks appeared on the cover of the concrete jacket. At the final failure load, the beam failed in explosive mode, and widespread cracks appeared on the upper surface of the original specimen.

Fig. 12 The (S.-J. + Stirrup) beam after the Testing.

3.4 The beam (S.-J. + Ferrocement)

The ferrocement jacket contributed to enhancing the initial and ultimate failure load by 81 % and 30 %, respectively. The technique used in strengthening this beam significantly improved the shear capacity in terms of cracking load. The first shear crack appeared when the applied load reached 82 % of the ultimate failure load. When the applied load became 145 kN a narrow crack appeared near the support plate on the jacket surface. With the increase in applied load, the crack began to expand towards the loading point until the applied load reached the ultimate failure load at 176.3 kN. Debonding of the ferrocement layer occurred at the ultimate failure load, which was accompanied by a sudden shear failure. Fig. 13 shows the specimen S.-J. + Ferrocement after the failure.

Fig. 13 The (S.-J. + Ferrocement) beam after the failure.

3.5 The beam (S.-J. + Ferrocement + R)

Based on the experimental results and as shown in Fig. 9, it was observed that the structural behavior of the beam (S.-J. + Ferrocement + R) was very similar to (S.-J. + Ferrocement) until initial failure load. Compared to the results of the specimen (S.-J. + Ferrocement), the addition of externally bonded steel bars slightly contributed to increasing the rigidity of the strengthened beam. When the applied load has reached 144.2 kN, the beam suddenly failed by debonding the ferrocement jacket, and a large crack was formed connecting the points of support and loading. The shear crack did not appear on the ferrocement jacket but rather was observed after removing the jacketing layer. This type of failure occurred due to the presence of externally bonded steel bars which caused a gap between the surface of the beam and the ferrocement jacket. For this reason, there was a decrease in the adhesive force exist to resist the shear flow. Fig. 14 shows the specimen (S.-J. + Ferrocement + R) after the failure.

Fig. 14 The (S.-J. + Ferrocement + R) beam after the failure.

4. Conclusions

This paper studied the shear behavior of RC beams strengthened with four different concrete jacketing systems. The techniques used in this study to improve the shear behavior of the beams were by using a Self Compacted Fiber Reinforced Concrete jacket without stirrups (S.-J. + Steel Fiber), a concrete jacket of Self Compacted Concrete with stirrups (S.-J. + Stirrups), a concrete jacket of ferrocement jacket (S.-J. + Ferrocement), and a concrete jacket of ferrocement jacket with external steel reinforcing bars (S.-J. + Ferrocement + R).

From the experimental results of this study the following conclusions can be drawn:

1. These techniques contributed to enhancing the load-carrying capacity and delaying the appearance of the first crack in comparison with the control beam by a percentage of (35, 59, 30, 6) % and (18, 35, 81, 80) %, respectively.
2. The concrete jacket of Self Compacted Concrete with stirrups (S.-J. + Stirrups) performed better than the other used strengthening techniques in terms of stiffness and the ultimate load-carrying capacity.
3. The ferrocement jacket (S.-J. + Ferrocement) was found to be the most suitable jacketing system used to enhance the shear capacity in terms of cracking load.
4. The addition of the externally bonded steel bars under the wire mesh layers has shown an unfavorable effect on the behavior of the strengthened beam in comparison with the case of a ferrocement jacket without steel bars.
5. The use of an epoxy bonding bridge (Sikadur®-32 LP) showed a better ductility performance than the synthetic rubber emulsion (Sika Latex) old-new bonding agent material.

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