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INFLUENCE OF USING CONCRETE JACKET ON THE BEHAVIOR OF REPAIRED REINFORCED CONCRETE BEAMS

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ABSTRACT

Reinforced concrete jacketing is one of the widely used repairing techniques for beams and columns. The aim of this research is to evaluate the efficiency of using concrete jackets using different reinforcements and thicknesses. The behavior of repaired reinforced concrete defected beams is investigated under flexural effect. The tested beams are preloaded up to 70 and 90% of their ultimate capacity then, repaired using concrete jackets. The main variables are thickness of concrete jacket (3, 5 cm), diameter of reinforcing steel bars (8, 10 mm) and concrete jacket type. The experimental results showed that, repairing using concrete jackets enhances the load capacity up to 378%. Increasing jacket thickness enhances the structural performance of the tested beams and in the same time increases its weight. It also increases the stiffness compared to the control beam and consequently the repaired concrete beams indicated a brittle manner compared to the ductile failure of the control beams.

استخدام القميص الخرسانى لتدعيم قطاعات الكمرات أو الاعمدة الخرسانية المسلحة هي أحد التقنيات المستخدمة على نطـــاق واسع فى أعمال الإصلاح أو التقوية. الهدف من هذا البحث هو تقييم كفاءة استخدام قمـــيص خرســـانى لإصـــلاح الكمـــرات الخرسانية المسلحة وذلك بإستخدام تسليح مختلف وسمك طبقات خرسانية مختلفة. تم دراسة سلوك الكمرات الخرسانية التى تم اصلاحها حيث تم تطبيق القميص الخرسانى بعد تحميلها بنسبة من حمل الانهيـــار (٧٠% و ٩٠ % مـــن حمـــل الانهيـــار). المتغيرات الرئيسية هي سمك القميص الخرسانى (٣، ٥ سم)، وقطر أسياخ صلب التسليح (٨، ١٠ مـــم) ونـــوع الخرســـانة المستخدمة للقميص الخرسانى. أظهرت النتائج المعملية أن إصلاح الخرسانة باستخدام القميص الخرسانى يعـــزز مـــن قـــدرة التحمل حتى ٣٧٨%. زيادة سمك القميص الخرسانى يعزز من الأداء الانشائى الا انه يزيد مـــن وزن القطـــاع الخرســـانى. القميص الخرسانى يزيد من صلابة القطاع الخرسانى مقارنة بكمرات التحكم بدون قميص خرسانى.

Keywords: Rehabilitation; Beam; Jacketing; Concrete, reinforced; Deterioration.

1. Introduction

The repair and rehabilitation of reinforced concrete members in aggressive weathering conditions or due to over loading cases are the major challenge to civil engineers. The cracking and collapse are the most common defects occur in reinforced concrete elements. Defects, failure and general distress in the structures could be the result of structural deficiency caused by reinforcement corrosion, to chemical and salt, and cracking due to aggressive environmental effects, incorrect design, poor workman shop or overloading. These factors interact with each other to worsen the deterioration processes [1, 2].

The purpose of repairing and strengthening processes is to improve the function and performance of the structure, restore and increase the strength and stiffness of the concrete, improve the appearance of the concrete surface, increase water tightness, prevent access of corrosive materials to the reinforcing, and improve the overall durability of the concrete elements. The proper repair of deteriorating concrete structures based on the evaluation of the causes, extent, and consequences of the deterioration, the repair techniques, procedures and materials necessary to remedy the situation. The cost, ease of application and the efficiency of the repair process are major considerations in choosing the materials and techniques. A damaged or distressed structure can be repaired or retrofitted to a satisfactory level of performance at a reasonable cost by different methods.

Repairing defected beams can be carried out by applying repairing technique on the tension face of the beam (such as using steel plates [2], reinforced concrete layer [3, 4], Ferrocement layer [5, 6] or FRP wrap laminates or sheets [7-10]).

One of the common repairing techniques is concrete jacketing. It considered as one of the common used repairing or strengthening techniques for beams and columns. It is used mainly to achieve the performance of beams to resist the flexural and

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shear effect, while in columns to resist the axial or eccentric load effect. Generally, the concrete member wrapped with a jacket of concrete reinforced with longitudinal steel and ties, or with steel or fiber wire mesh as ferrocement jacketing [11].

The main objectives of using concrete jacketing are to restore, increase the load and seismic capacity of concrete members. Depending on the type of jacketing used an increase in stiffness and strength was obtained [12].

As any other strengthening or repairing technique, the design of the concrete jacket should include the probable extra loads affecting on the member. The compressive strength of the new concrete should be greater than that of the existing member by about 5 MPa [13] but not less than that of the existing structure [14]. Concrete jackets are also good solution for repairing and strengthening of beam-column connections [15, 16].

Given the many benefits of concrete jackets and their increased use in structural applications, it is essential that the fundamental behavior of them be understood to ensure that structural performance will be sufficient. This paper presents test data on the behavior of repaired reinforced beam samples using plain and reinforced concrete jackets.

2. Research Significance

The main objective of this research is to establish the effectiveness of using reinforced concrete jackets as a repair and strengthen techniques for R.C. beams. The main variables in this research are; the concrete jacket thickness, the strength of the concrete jacket, preloading value and the jacket reinforcement.

3. Experimental Program

The experimental program conducted in this study was performed in the laboratory of testing of building materials at the Faculty of Engineering, Menoufia University, Egypt. The flow chart of experimental program is shown in Fig.(1). Thirteen R.C. beams with dimensions of 10x15x100cm were cast and tested in the research as shown in Fig.(2). There are designed according to Egyptian code of practice (E.C.P. 203/2007) [17].

3.1. Materials

The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007) [19], based on the recommendations of manufacture. The chemical and physical characteristics of Polypropylene Fibers 300-e3 are given in Table (1). (E.S.S. 1109/2008) [18]. It was clean and nearly free from impurities with a specific gravity 2.6 t/m^3 and a modulus of fineness 2.7.

The coarse aggregate used was of crushed dolomite, which satisfies the ASTM C33 Specification [19] and the Egyptian Standard Specification (E.S.S. No. 1109\ 2008) [18]. Its specific gravity is about 2.70 t/m^3 and a fineness modulus of 6.64. The shape of these particles was irregular and angular with a very low percentage of flat particles. The delivered crushed dolomite had a maximum nominal size of 12.5 mm.

The cement used was the Ordinary Portland cement, type produced by the Suez cement factory. Its chemical and physical characteristics satisfied the Egyptian Standard Specification (E.S.S. 4657-1/2009) [20].

The water used was the clean drinking fresh water free from impurities used for mixing and curing the R.C. beams tested according to the (E.C.P. 203/2007) [17].

Super plasticizer used was a high rang water reducer HRWR. It was used to improve the workability of the mix. The admixture used was produced by CMB GROUP under the commercial name of Addicrete BVF. It meets the requirements of ASTM C494 (type A and F) [21]. The admixture is a brown liquid having a density of 1.18 kg/litre at room temperature. The amount of HRWR was 2.0 % of the cement weight.

High tensile deformed steel bars use was produced from the Ezz Al Dekhila Steel - Alexandria Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011) [22]. High tensile deformed steel bars (nominal diameters 10 and 12 mm) were used in reinforcing all the concrete beams, there yield stress was 400 MPa and there tensile strength was 600 MPa.

Mild steel bars of 8 mm diameter were used for stirrups with yield strength of 240 MPa and had tensile strength of 350 MPa.

High tensile deformed steel bars (with a diameter of 10 mm) were used in eight repaired concrete beams. Mild steel bars of 6 mm diameter were used for stirrups with yield strength of 240 MPa and had tensile strength of 350 MPa were used in eight repaired concrete beams.

Polypropylene fibres PP 300-e3 was used. It was available in the Egyptian markets. It was used in concrete mixes to produced fibrous concrete jacket to improve the concrete characteristics. The percentage of addition was chosen as 900 gm/m^3

Table 1. Physical and Mechanical Properties of Polypropylene fibers 300-e3. *(as provided by manufacturer)*

Fiber Length	Type/ Shape	Absorption	Specific Gravity	Electrical Conductivity	Acid &Salt Resistance	Melt Point	Ignition Point	Thermal Conductivity	Alkali Resist.
Various	Graded / Fibrillated	Nil	0.91	Low	High	162°C (324 °F)	593 °C (1100°F)	Low	Alkali Proof

Table 2. Proportions of the concrete mixes used.

Proportions / Type of Concrete	Cement *(kg/m³)*	W/C *(kg/m³)*	Sand	Dolomite	Silica Fume /C *(%)*	Fibers *(kg/m³)*	Add./C *(%)*	Main Properties	
								Slump *(mm)*	F_{cu28} *(MPa)*
NSC	350	140	1	2	--------	-------	0.2	25	25.5
HSC	450	180	1	2	15	0.9	0.2	25	60

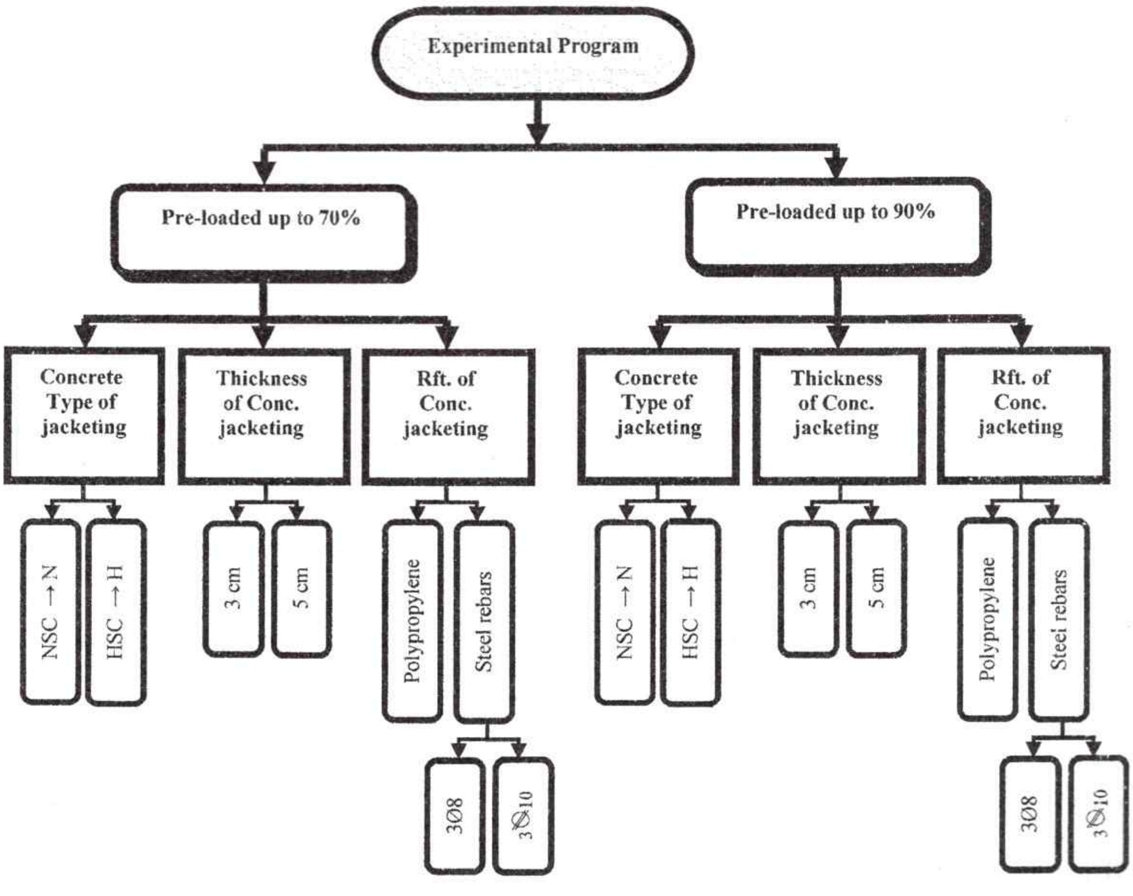
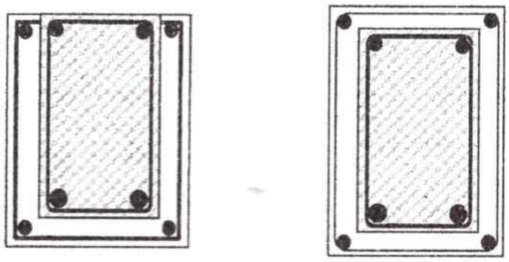


Fig. 1. Flow chart of the experimental work program.

3.2. R.C. Beam Under Investigation

Thirteen beams of dimensions of 10x15x100 cm. They were reinforced with longitudinal main steel rebars of 12 mm diameter and 2 rebars as stirrup hangers of 10mm diameter. The stirrups were 8 rebars of 8mm diameter arranged each 12.5 cm. These beams were cast with normal strength concrete (NSC) of 25.5 MPa compressive strength. The properties of the concrete mix used are shown in Table (2).

The flow chart of the conducted experimental program is shown in Fig. (1). The reinforcement details and dimensions of the reinforced concrete beams are shown in Figs. (2) and (5). Description of the concrete jackets used for repairing the defected reinforced concrete beams are shown in Tables (3) and (4).



a. Three sides concrete jacketing   b. Four sides concrete jacketing

Fig. 3. The concrete jacketing of the tested beams.

The longitudinal reinforcement and stirrups were previously prepared before placing in wooden molds, which were specially made for the beam specimens. The prepared steel cage is carefully placed in the wooden mold after oiling its surface. The molds with the steel cages were placed on the vibration table at a low speed, while the concrete was poured. After casting the specimens were covered with wet burlap in the laboratory at 24°C and 68% relative humidity. The specimens were demalded after 2 days and wrapped with damp cloth for 14 days and left after that in the laboratory at most plan till there were tested.

The control and preloaded beam specimens (preloaded up to 70% and 90% of ultimate load (P_u) were prepared for testing after 28 days after casting. Three beams were loaded up to fracture and the maximum load was recorded under bending test machine as control beams. The other beams were preloaded up to two different percentages of the ultimate load of the control beams (Pu). Preloaded beams were divided in to two groups; "A" group was loaded up to 70% of P_u, while the other group "B" was loaded up to 90% of P_u.

3.3. Repairing Processes

Two beams of each tested group were repaired using plan concrete jacket. Eight beams were repaired using normal strength concrete (NSC)

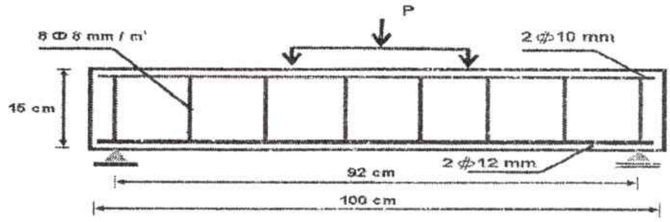


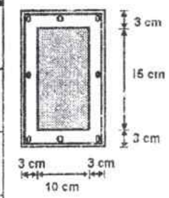
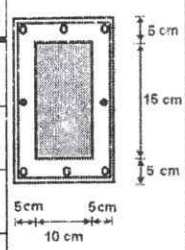
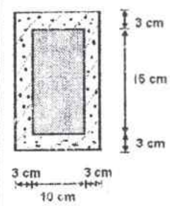
Fig. 2. Detailing of tested beams samples

jackets (compressive strength F_{cu}=25.5 MPa) with two thickness of 3 and 5 cm, two steel reinforcement of 3Ø8 and 3 Ø10 top and bottom and stirrups of 6Ø6/m' & 6Ø8/m' respectively as shown in Table (3). Another two beams were repaired using high strength concrete HSC jackets (with F_{cu} = 65 MPa and proportions as shown in Table (2)) with a thickness of 3 cm. HSC was used as fibrous concrete jacket using polypropylene fibres without steel reinforcement.

The concrete jackets were prepared using two layer thicknesses (3, 5 cm). Steel reinforcement (3Ø8 and 3 Ø10) were placed and covered with a flow able NSC for the first group and HSC jacket for the second group using specially designed molds. The concrete jackets were applied to the preloaded beam specimens after being loaded to 70% and 90% respectively of their ultimate capacity after 28 days from the day of casting. Before applying the concrete jackets all the R.C. beams were sand-blasted to roughen their surfaces for a better bond between the concrete surface and the applied jacket concrete layer. Two rows of demec points were fixed on each of the side faces of the tested beam to measure the top and bottom strain values (compressive and tensile strain values).

The preloaded concrete beams were surrounded with the new jacket reinforcement and placed in new wooden forms with the required jacket thickness. Then the concrete mix was poured around the beam specimens and the sides of the wooden molds were vibrated to ensure the full penetration of the concrete around the new steel jacket reinforcement. The specimen's top surface was finished and covered with damped cloth for two days, and covered with damped cloth for another 14 days after removing the molds. The repaired beams specimens were kept uncovered to dry in the laboratory environment until testing. Figure (3) shows the final form of the beam specimens after applying the concrete jacket. Table (3) shows the different tested beams.

Table 3. Details of beam samples used.

Beams	Preloading load	Repairing layer thickness (cm)	Repairing concrete layer	Reinforcement of repairing jacket					Beam Cross Section
				Beam rft		Stirrups	Side rft	Fiber content	
				Upper rft	Lower rft				
control	-	-	-	-	-	-	-	-	
PJ-1	70%	3	NSC	---	---	---	---	--	
PJ-2	90%	3		---	---	---	---	--	
RJ-1	70%	3	NSC	3 Ø 8	3 Ø 8	6Ø6\m'	---	--	
RJ-2	70%	5		3 Ø 8	3 Ø 8	6Ø6\m'	2Ø8	--	
RJ-3	70%	3		3 Ø 10	3 Ø 10	6Ø8\m'	---	--	
RJ-4	70%	5		3 Ø 10	3 Ø 10	6Ø8\m'	2Ø 10	--	
RJ-5	90%	3		3 Ø 8	3 Ø 8	6Ø6\m'	---	--	
RJ-6	90%	5		3 Ø 8	3 Ø 8	6Ø6\m'	2Ø8	--	
RJ-7	90%	3		3 Ø 10	3 Ø 10	6Ø8\m'	---	--	
RJ-8	90%	5		3 Ø 10	3 Ø 10	6Ø8\m'	2Ø 10	--	
FPJ-1	70%	3	HSC	---	---	---	---	polypropylene fibrous 0.9Kg\m^3 concrete	
FPJ-2	90%	3		---	---	---	---	polypropylene fibrous 0.9Kg\m^3 concrete	

Where: R→ Reinforced J → Jacket P→ Plain concrete F→ Fibrous concrete

3.4. Instrumentation and Testing Procedures

The beam specimen was placed on a steel frame with a hydraulic jack of a capacity of 500 KN as shown in Figure (4). The demec points used to measure the strains were fixed on the side surface of the tested concrete beams. A schematic sketch showing the positions of strain measurement on the specimen is presented in Figure (5). Beams were tested and the deflection values as well as compressive and tensile strain values were determined. Initial crack load and failure loads were recorded and crack patterns are sketched.

4. Analysis and Discussion of the Test Results

4.1. First Cracking Loads and Ultimate Loads

The cracking and ultimate loads of all the tested beams are listed in Table (4). Figure (6) shows the first cracking loads P_{cr} and ultimate loads P_u for all the tested beams. Beams repaired using concrete jacket indicated higher values of first and ultimate loads, which complies with the previous researchers [13, 14]. The increasing in P_{cr} and P_u values may refer to the increase of the section dimensions. The values of increasing depend on jacket thickness and reinforcement type, which agree with earlier researches [12].

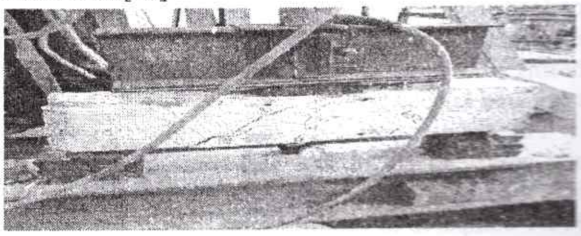


Fig. 4. Flexure test, four lines loading

First cracking loads for beams repaired using normal concrete jacket and preloaded up to 70% of P_u increased by about 733%, 650%, 433% and 375% for beams RJ-4 (∅10 and 5 cm thickness), RJ-2 (Ø8 and 5 cm thickness), RJ-3 (∅10 and 3cm thickness) and RJ-1 (Ø8 and 3cm thickness) respectively beam. For beams repaired using fibrous concrete jacket and preloaded up to 70% of P_u , the initial cracking load increased by about 100% and 58% for beams FPJ-1and PJ-1 compared to control beam. When beams preloaded up to 90% of P_u, the first cracking load increased by about 50% for beam FPJ-

compared to the control beam. In case of repaired beams and preloaded up to 90% of P_u, the first cracking load increased by about 567 %, 483 %, 317 % and 292 % for beams RJ-8 (∅10 and 5 cm thickness), RJ-6 (Ø8 and 5 cm thickness), RJ-7 (∅10 and 3 cm thickness) and RJ-5 (Ø8 and 3 cm thickness) respectively compared to control

2 the first cracking load decreased by about 8% for beam PJ-2 compared to the control beam. That increase may refer to the increase of cross sectional stiffness compared to the span of tested beams (in the range of this study).

Table 4. The ductility indexes of tested beams.

Beam type	Preload as % of P_u	Concrete Jacket			Initial cracking load *(ton)*	Ultimate load *(ton)*	First Ductility Index $\mu_1 = \Delta\mu \backslash \Delta y$	Second Ductility Index $\mu_2 = \Delta\mu_0 \backslash \Delta y$
		Rebar Diameter *(mm)*	Thickness *(cm)*	Concrete Type				
Control	--	--	--	--	1.2	3.45	10.14	3.06
PJ-1	70	--	3 cm		1.9	5	18.33	3.83
PJ-2	90	--	3 cm		1.1	3.5	7.65	2.63
RJ-1	70	Ø 8	3 cm		5.7	12	12.65	4.00
RJ-2	70	Ø 8	5 cm		9	15.5	5.56	1.89
RJ-3	70	∅ 10	3 cm	*NSC*	6.4	13	11.97	10.94
RJ-4	70	∅ 10	5 cm		10	16.5	5.83	2.33
RJ-5	90	Ø 8	3 cm		4.7	10.5	15.06	5.44
RJ-6	90	Ø 8	5 cm		7	13.5	9.54	3.14
RJ-7	90	∅ 10	3 cm		5	11	18.08	5.31
RJ-8	90	∅ 10	5 cm		8	14.5	7.00	2.25
FPJ-1	70	--	3 cm	*HSC*	2.4	6	19.07	4.67
FPJ-2	90	--	3 cm		1.8	5	12.96	3.58

The ultimate loads for beams repaired using normal concrete jacket and preloaded up to 70% of P_u increased by about 378%, 349%, 277% and 248% for beams RJ-4, RJ-2, RJ-3 and RJ-1 respectively compared to the control beam. That may refer to the increase of the ductility of RJ-4 followed by the ductility of RJ-2, RJ-3 and RJ-1 respectively. As they preloaded up to 90% of P_u, the ultimate load increased by about 320%, 291%, 220% and 204% for beams RJ-8, RJ-6, RJ-7 and RJ-5 respectively compared to control beam.

For beams repaired using plane concrete jacket and preloaded up to 70% of P_u, the ultimate load increased by about 45% and 74% for beams PJ-1 and FPJ-1 compared to control beams. The increasing in the ultimate load of beam FPJ-1 is refer to using a fibrous high strength concrete jacket compared to using plane concrete jacket for beam PJ-1. When beams preloaded up to 90% of P_u, the ultimate load increased by about 1% and 45% for beams PJ-2 and FPJ-2 respectively compared to control beam. This reduction in these values is due to high preloading value.

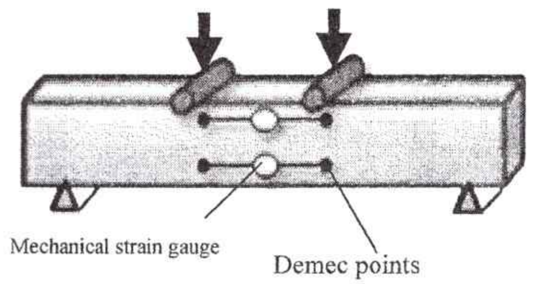


Fig. 5. The positions of demec points and strain gauges on the tested beam.

According to the test results, the highest increasing was recorded as 378% for jacket thickness of 5 cm and reinforcement of Ø10 mm. Based on the test results; it was noticed that the jackets thickness, the diameter of rebars and the type of concrete used as jackets have significant effect on cracking load of the beams. Fibers and longitudinal reinforcement works after first cracking load of concrete. When using longer aspect ratio of steel bars, tend to increase the ultimate load.

Based on discussion above, using fibers and reinforcing rebars for concrete jackets have good positive effect on the first cracking loads and their respective ultimate loads.

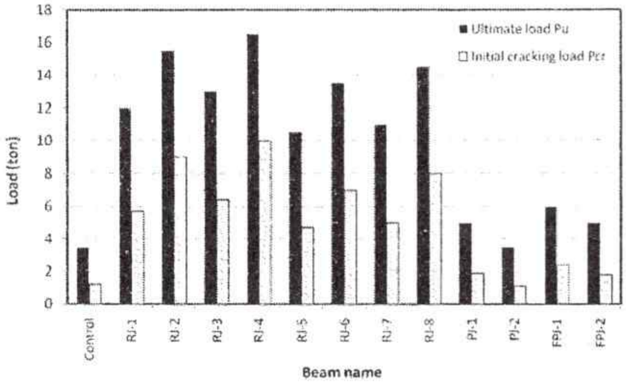


Fig. 6. Initial and failure loads for tested beams.

Using 3 cm thickness concrete jacket increasing the cross section to span ratio by about 124% compared to the control beam and enhances the beam capacity by about 2.5 times. Concrete jacket of 5 cm thickness increasing the previous mentioned ratio by about 233% compared to the control sample and enhances the beam capacity by about 3.5 times. Using a concrete jacket as a repairing or strengthening technique enhances the beam capacity and decreases the deflection values but it depends mainly on the ratio of the cross-sectional area and reinforcement to the span of repaired beam.

4.2. Deflection Values

The load-deflection curves of all beams can be seen in Figures (7) to (15). It can be seen that the load is proportion to the deflection values before cracking of concrete.

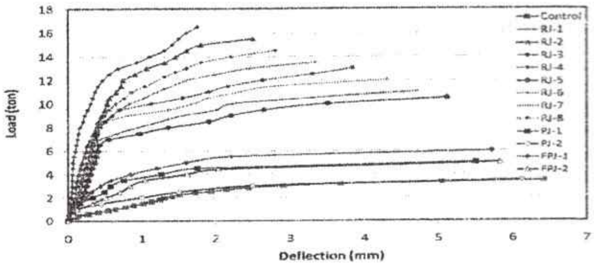


Fig. 7. Load-deflection curves of tested beams.

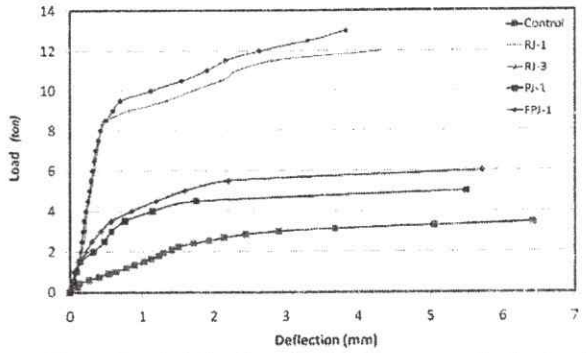


Fig. 8. Load-deflection curves of beams repaired using 3 cm concrete jacket.
(preloaded up to 0.7 P_u)

The mechanical behavior of all beam have three stages. The first stage is elastic stage. The load-deflection relationship is linear (load is proportion to deflection values). It ends once the first crack emerges. The second stage is crack propagation stage. The load-deflection relationship is nonlinear line (curve). The third stage is failure stage.

The deflection values of control beam were the largest deflection values, and the ultimate load of the control beam was the smallest load value compared to repaired beams using concrete jacketing technique. The deflection values were decreasing as the load increased in accordance with the thickness of jacket, the diameter of steel bars, the type of concrete and the preloading which is compatible with satisfies (Teran et al., 1992) [11].

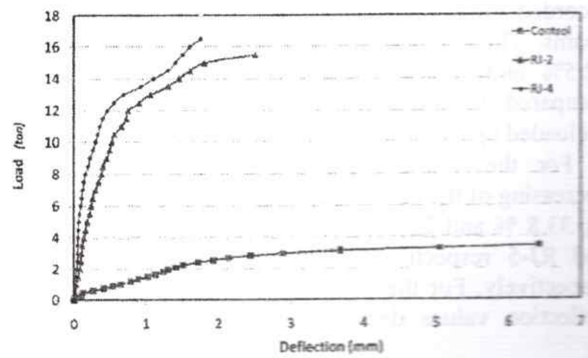


Fig. 9. Load-deflection curves of beams repaired using 5 cm concrete jacket.
(preloaded up to 0.7 P_u)

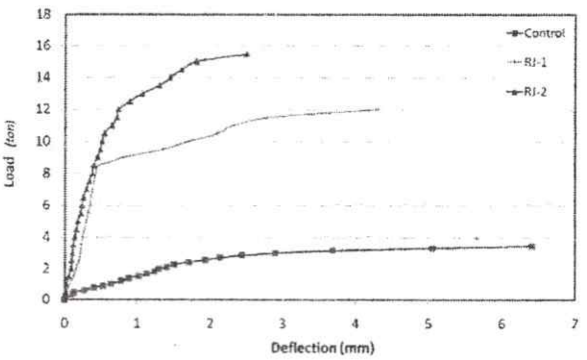


Fig. 10. Effect of jacket thickness on the load-deflection curves of beams repaired using concrete jacket reinforced by Ø8mm rebars.
(preloaded up to 0.7 P_u)

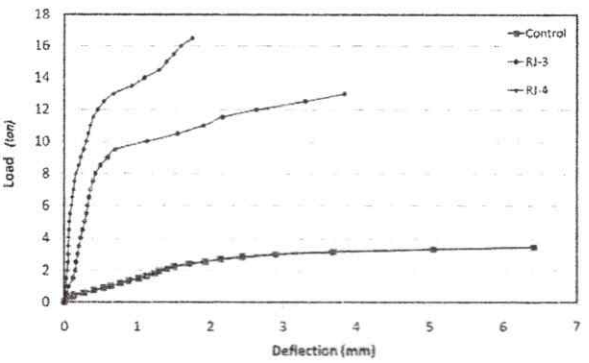


Fig. 11. Effect of jacket thickness on the load-deflection curves of beams repaired using concrete jacket reinforced by Ø 10mm rebars.
(preloaded up to 0.7 P_u)

For beams preload up to 70% of their P_u, the decreasing of the deflection values were 75.35 %, 64.79 %, 46 % and 39.44 % for beams RJ-4, RJ-2, RJ-3 and RJ-1 respectively compared to control beam respectively. The deflection values of the beams repaired using concrete jacket without steel rebars recorded lower deflection values compared to other beams. Their deflection values decreased by about 22.5% and 19.44 % for beams PJ-1 and FPJ-1 compared to deflection of control beams when preloaded up to 0.7 P_u.

For the beams preloaded up to 0.9 P_u, the decreasing of the deflection values were 60.56 %, 53 %, 33.8 % and 27.9 %, for beams RJ-8, RJ-6, RJ-7 and RJ-5 respectively compared to control beam respectively. For the beams preloaded up to 0.9 P_u, deflection values decreased by about 13.8% and 17.9% for beams PJ-2 and FPJ-2 compared to deflection of control beams

4.3. Ductility Ratio

The ductility of the beam can be expressed based on deflection of the beam. According to ACI Committee 363 [23], the first ductility index is defined as $\mu_1 = \Delta\mu \setminus \Delta y$. where $\Delta\mu$ is beam deflection when beam collapsed. Δy is beam deflection when longitudinal reinforcement yielded. According to (Sung et al, 1989) [24], the second ductility index is defined as $\mu_2 = \Delta\mu_0 / \Delta y$. Where, $\Delta\mu_0$ is beam deflection when load is equal to 80% of ultimate load in descending branch of load-deflection curve. The ductility indexes of all beams are listed in Table (5).

Two beams were considered as reference beams. PJ-1 was considered as a reference for repaired beams (as it repaired using plane concrete jacket with 3 cm thickness).

It can be seen that from Table (5), the first ductility index $\mu_1$of reference beam PJ-1 is better than recorded for repaired beams. Increasing the jacket thickness decreases the first ductility index μ_1. It means that the addition of concrete jacket thickness make beam flexural ductility fall down. Using the fibrous concrete jacket enhance the ductility of the repaired beams.

4.4. Strain Values

Figures (16) to (23) shows the compressive-strain values of tested beams. Figures (24) to (31) shows the tensile-strain values for tested beams. Test results indicated that the values effected by the thickness and the type of concrete jacket used. Results indicated also that the values of strain decreased by noticed values due to the increasing in the stiffness values of the repaired beam samples.

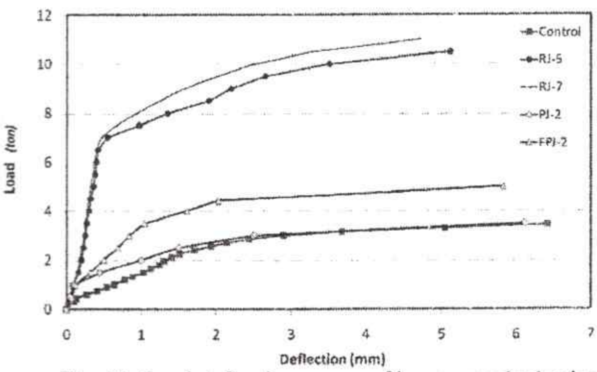


Fig. 12. Load-deflection curves of beams repaired using 3 cm concrete jacket.
(preloaded up to 0.9 P_u)

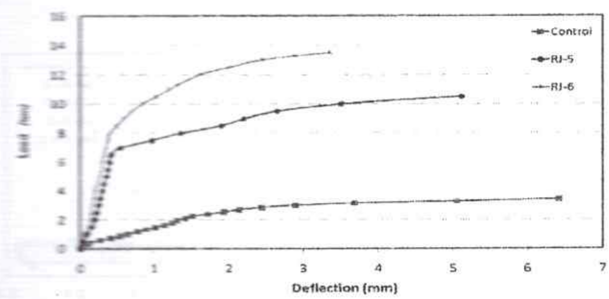


Fig. 14. Effect of jacket thickness on the load-deflection curves of beams repaired using concrete jacket reinforced by Ø8mm rebars.
(preloaded up to 0.9 P_u)

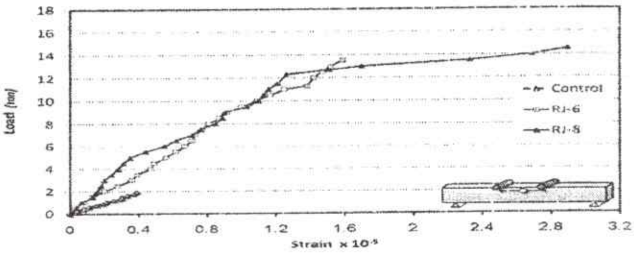


Fig. 15. Effect of jacket thickness on the load-deflection curves of beams repaired using concrete jacket reinforced by Ø 10mm rebars.
(preloaded up to 0.9 P_u)

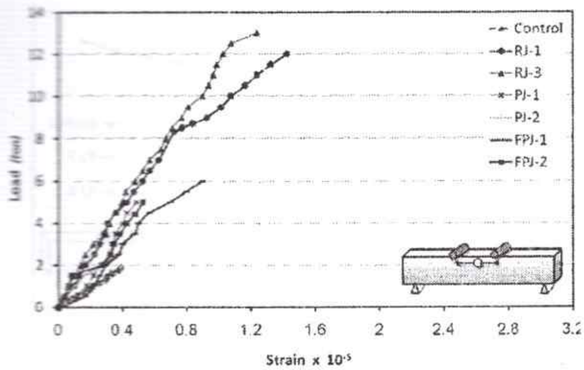


Fig. 16. Load-compressive strain curves of beams repaired using 3 cm concrete jacket.
(preloaded up to 0.7 P_u)

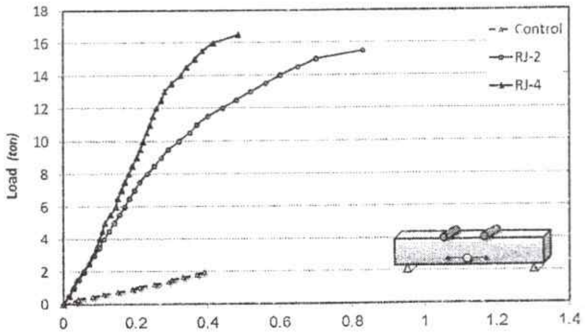


Fig. 17. Load- compressive strain curves of beams repaired using 5 cm concrete jacket.
(preloaded up to 0.7 P_u)

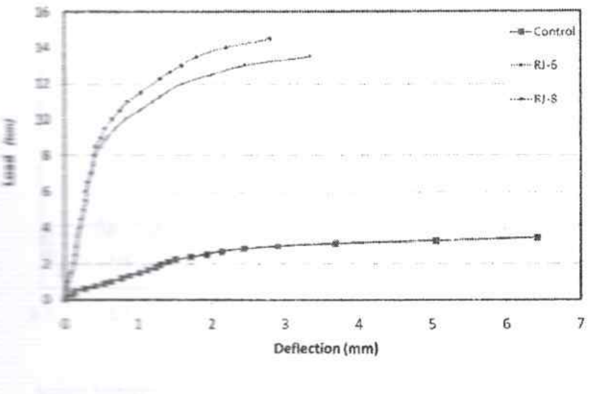


Fig. 13. Load-deflection curves of beams repaired using 5 cm concrete jacket.
(preloaded up to 0.9 P_u)

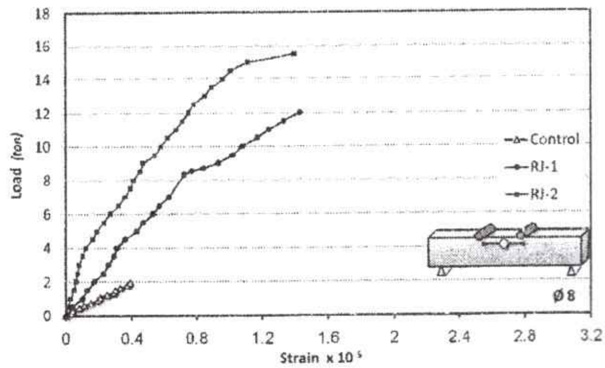


Fig. 18. Effect of jacket thickness on the Load-compressive strain curves of beams repaired using concrete jacket reinforced by Ø8mm rebars.
(preloaded up to 0.7 P_u)

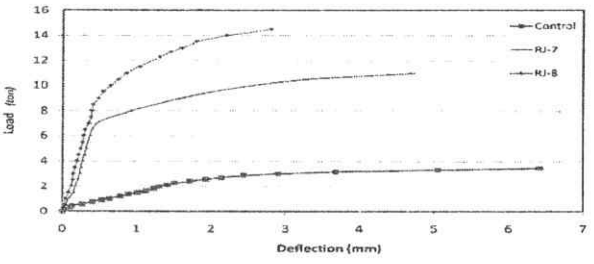


Fig. 20. Load- compressive strain curves of beams repaired using 3 cm concrete jacket.
(preloaded up to 0.9 P_u)

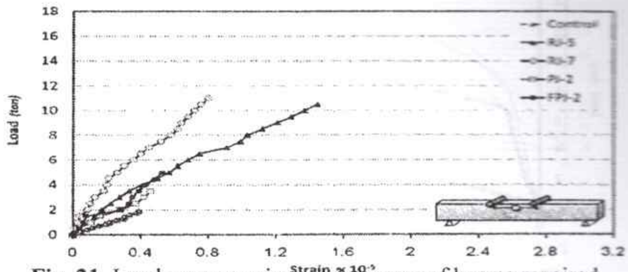


Fig. 21. Load- compressive strain curves of beams repaired using 5 cm concrete jacket.
(preloaded up to 0.9 P_u)

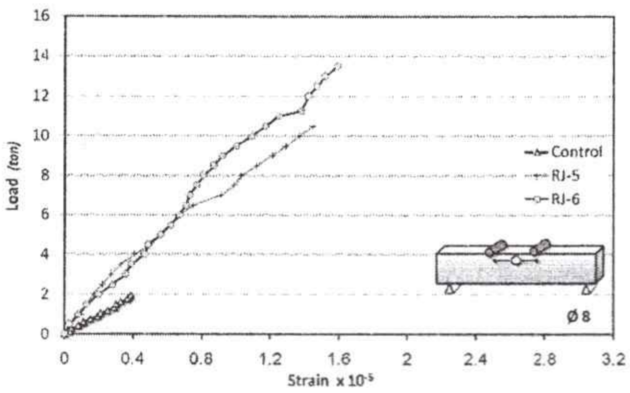


Fig. 22. Effect of jacket thickness on Load-compressive strain curves of beams repaired using concrete jacket reinforced by Ø8mm rebars.
(preloaded up to 0.9 P_u)

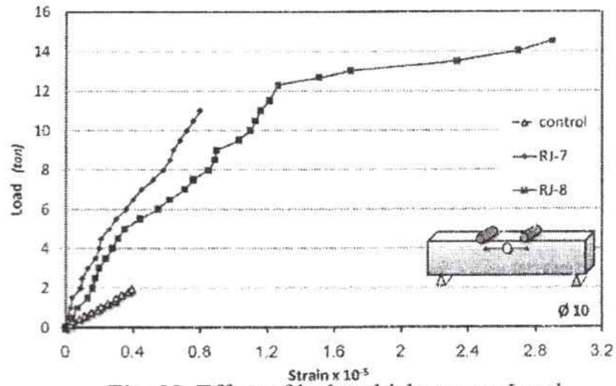


Fig. 23. Effect of jacket thickness on Load-compressive strain curves of beams repaired using concrete jacket reinforced by Ø 10mm rebars.
(preloaded up to 0.9 P_u)

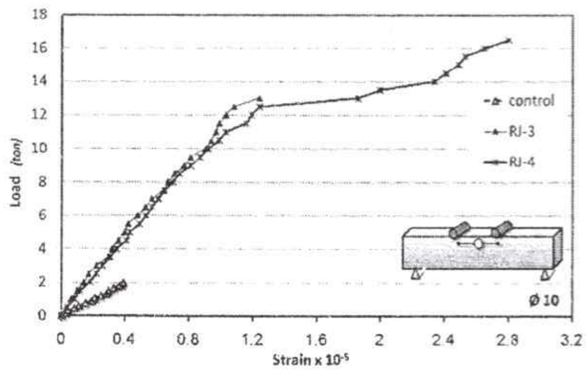


Fig. 19. Effect of jacket thickness on the Load-compressive strain curves of beams repaired using concrete jacket reinforced by Ø 10mm rebars.
(preloaded up to 0.7 P_u)

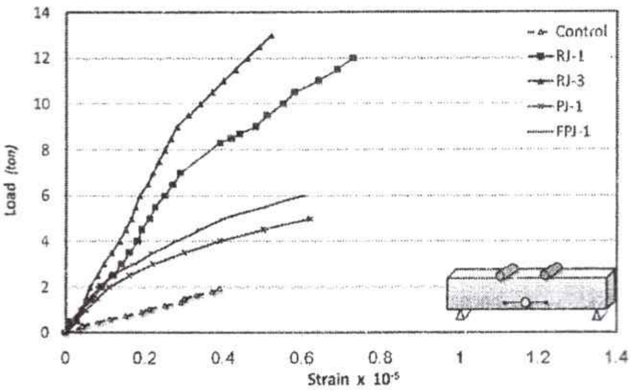


Fig. 24. Load-tensile strain curves of beams repaired using 3 cm concrete jacket.
(preloaded up to 0.7 P_u)

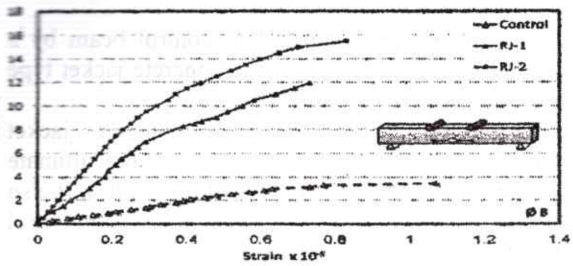


Fig. 26. Effect of jacket thickness on the Load- tensile strain curves of beams repaired using concrete jacket reinforced by Ø8mm rebars.
(preloaded up to 0.7 P_u)

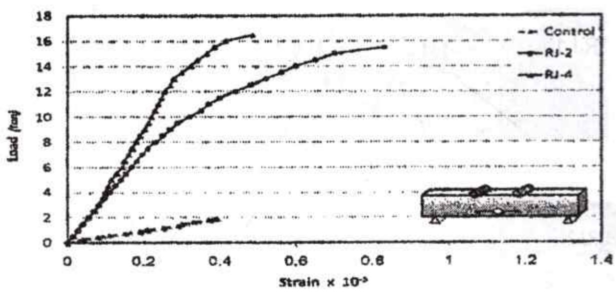


Fig. 27. Effect of jacket thickness on the Load- tensile strain curves of beams repaired using concrete jacket reinforced by Ø 10mm rebars.
(preloaded up to 0.7 P_u)

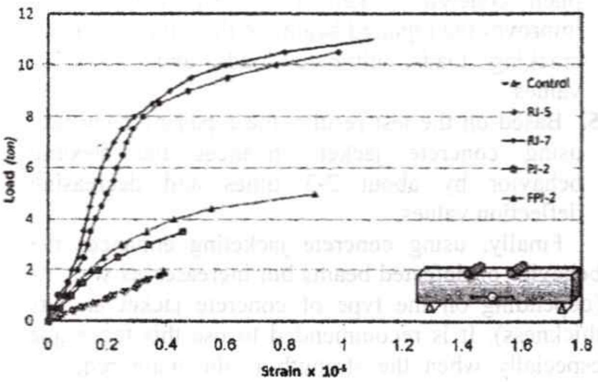


Fig. 28. Load- tensile strain curves of beams repaired using 3 cm concrete jacket.
(preloaded up to 0.9 P_u)

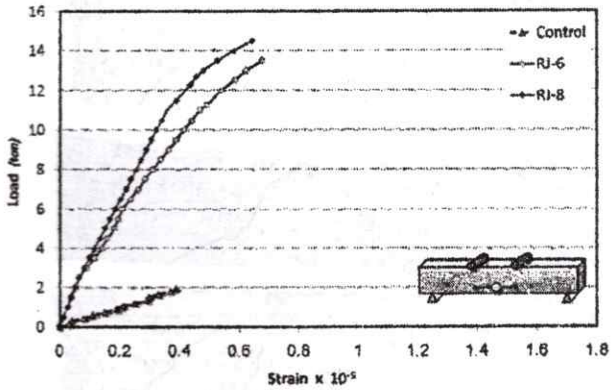


Fig. 29. Load- tensile strain curves of beams repaired using 5 cm concrete jacket.
(preloaded up to 0.9 P_u)

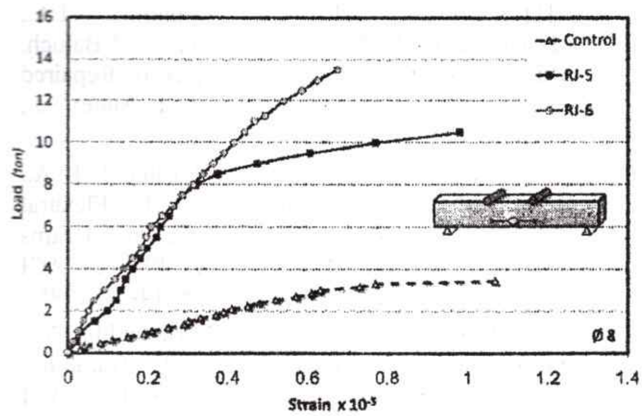


Fig. 25. Load-tensile strain curves of beams repaired using 5 cm concrete jacket.
(preloaded up to 0.7 P_u)

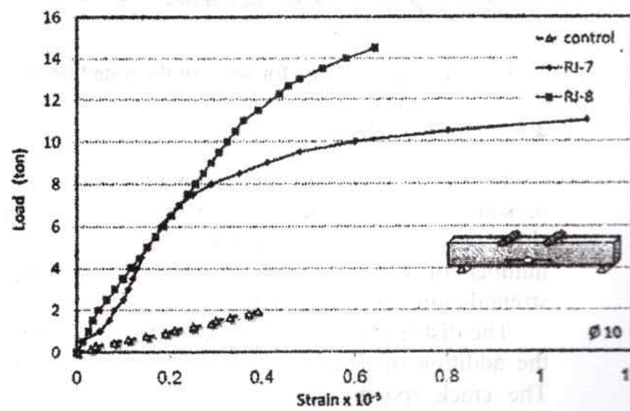


Fig. 30. Effect of jacket thickness on Load-tensile strain curves of beams repaired using concrete jacket reinforced by Ø8mm rebars.
(preloaded up to 0.9 P_u)

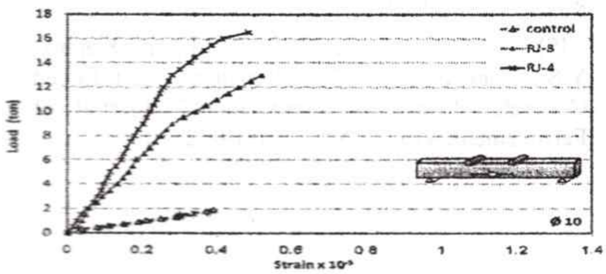


Fig. 31. Effect of jacket thickness on Load- tensile strain curves of beams repaired using concrete jacket reinforced by Ø 10mm rebars.
(preloaded up to 0.9 Pu)

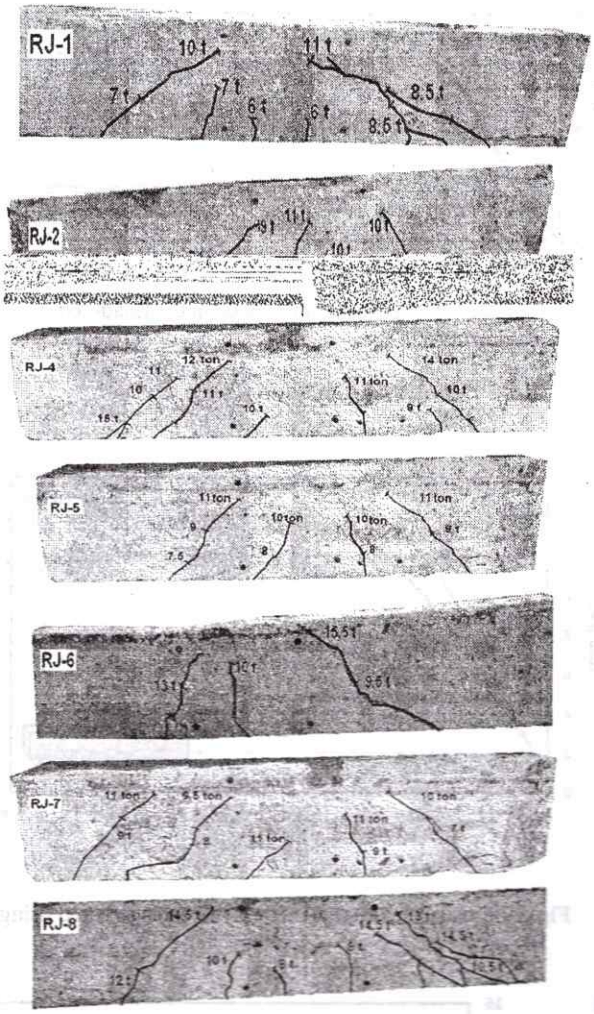


Fig. 32. Crack patterns for some of the tested beams.

4.5. Crack pattern

Figure (32) illustrate an example for crack pattern of some tested beams. Flexural crack and flexural-shear cracks are emerged after beam collapsed. The number of cracks decreased as the thickness of strengthening jacket increased.

The distribution of cracks was more evenly due to the addition of fibers into beams FPJ-1 and FPJ-2. The crack spacing declined. However, the similar phenomenon is not concluded in this test. Flexural shear crack did not emerge in the beam with fibers.

5. Conclusion

The following conclusions are derived based on the conducted experiments:

1. Increasing the reinforcement ratio increases the first cracking load and ultimate load by about 4 times (in rang of this study) and decrease the deflection values compared to control beam by a range of 20-75% based on the concrete jacket type and thickness.
2. Increasing the thickness of concrete jacket enhances the first cracking load and the ultimate load by about 3 times (in rang of this study). It also decreases the deflection values compared to control beam.
3. Ductility decreased as the thickness of the repairing concrete jacket increases (within the limits of this study). Using fibrous concrete and high strength concrete enhance the ductility of the repaired beams.
4. The repairing using reinforced concrete jacket is better than using only the fibrous concrete jacket or plain concrete jacket. The steel reinforcement improves the repaired beams in the values of initial cracking loads, ultimate loads and deflection values.
5. Based on the test results, the repairing technique using concrete jacket enhances the flexural behavior by about 2-3 times and decreasing deflection values.

Finally, using concrete jacketing enhances the behavior of defected beams but increases its weights (depending on the type of concrete jacket and its thickness). It is recommended to use this technique especially when the strength is the main required affecting factor regardless the increasing of concrete element weight.

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