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Repairing of Rubberized Reinforced Concrete Knee Joints with CFRP Sheets

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Abstract*:*

This paper presents the results of experimental study on strength and behavior of repairing rubberized reinforced concrete knee joints with carbon fiber reinforced polymer (CFRP)sheets under bending moment tend to open the angle. A total of eighteen specimens with square cross section legs (150 mm×150mm) and length of legs (550 mm) were prepared and tested up to failure.

Test parameters were the percentages of rubber aggregate by weight of coarse aggregate (5, 15 ,25)%, length of rubber aggregate (1,2,4,6)mm, types of reinforcement details in corner region(simple or loop) and method of repairing with CFRP (U or L shape). The effects of these parameters on strength and behavior of knee joints are studies ,The results of the study demonstrated a decrease in cracking and ultimate moment strength of specimens with increase percentage and length of rubber aggregate, and significant increase on the strength of repaired knee joints compared with its original.

تصليح وصلات الخرسانة الحاوية على المطاط المسلحة قائمة الزاوية بشرائح الكاربون البوليميرية

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الخلاصة :

يقدم هذا البحث دراسة عملية لمقاومة و سلوك نموذج يمثل وصلة اتصال عمود مع عتبة خرسانية مسلحة حاوية على المطاط قائمة الزاوية تم تصليحها بأستعمال مادة الايبوكسي الصمغية ولدائن الكاربون البوليمرية معرضة الى عزم يؤدي إلى فتح الزاوية. ثمانية عشر نموذج استخدمت في هذه الدراسة ذات مقطع عرضي مربع بأبعاد (150×150) ملم وطول الساق (550) ملم تم تحميلها لحد الفشل.

المتغيرات المستخدمة في هذه الدراسة هي نسبة مطاط مفروم الاطارات المستهلكة (5، 15، 25) % كنسبة وزنية من وزن الركام الخشن ، طول شرائح المطاط (6,4,2,1) ملم ، نوع تفاصيل حديد التسليح في منطقة الزاوية (تسليح بسيط أو حلقي) وطريقة التصليح بشرائح الكاربون البوليميرية (على شكل حرف U أو L) .تم دراسة تأثير هذه المتغيرات على مقاومة وسلوك الوصلات الخرسانية القائمة الزاوية . أظهرت النتائج نقصان في مقاومة عزم التشقق والأنحناء للنماذج مع زيادة نسبة وطول شرائح المطاط ، وزيادة كبيرة بمقاومة عزم التشقق والأنحناء للنماذج المصلحة مقارنة مع النماذج الأصلية.

1. Introduction :

The joint formed from meeting of two adjacent members usually refers to the "corner". Knee joint is a reinforced concrete corner formed by the joining; at 90^{o}, of the ends of two flexural members . The terms "opening" and "closing" the corner are used to describe the increase and decrease of this right angle [1]. Concrete corners are found in wide variety of structures such as retaining walls, bridges, gable frames, liquid storage tanks, and box culverts[2].

Concrete is the most popular construction material, it has some limited properties, low ductility, low energy absorption, low insulation and shrinkage and cracking associated with hardening and curing [3], some of these properties can be improved by using plastic materials, on the other hand , hazardous waste materials are being generated and accumulated in vast quantities causing an increasing threat to the environment, and in order to prevent the environmental problem from growing, recycling tire is an innovative idea or way in this case. Recycling tire is the processes of recycling vehicles tires that are no longer suitable for use on vehicles due to wear or irreparable damage. Rubberized concrete is an infant technology, when concrete mixed with waste rubber added in different volume proportions is called rubberized concrete [4]. In constructions that are subject to impact effects the use of rubberized concrete will be beneficial due to the altered state of its properties. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are designed, joints are severely damaged. Repairing damaged joints is difficult, and so damage must be avoided [5].

One of the materials which are used for rehabilitation of structures in recent years has been Fiber Reinforced Polymer (FRP) composite. Employment of FRP composites to repair and retrofit concrete elements has been steadily increasing.

2. Research Objectives :

The main objective of the present study is to investigate experimentally the behavior of repaired rubberized reinforced concrete knee joints subjected to bending moment tending to open the angle. This research also aims to satisfying the following objectives:

1. Using consumer waste tire on construction materials industry to produce light weight concrete having suitable properties, and then investigate the feasibility of this material in knee joints subjected to bending moment tending to open the angle
2. To estimate experimentally the effect of rubberized concrete strength and type of reinforcement details on the strength and behavior of knee joints .
3. Saving the environment from waste tire, avoiding the dangerous effect of toxic chemical gases produced by burning, like toxic SO_2 which pollutes the environment.
4. Encourage the industrials recycle waste tire to improve waste management and using clean production techniques to produce friendly environmental buildings.
5. Investigate the efficiency of CFRP sheets for repairing rubberized concrete knee joints with two repairing method .

3. Experimental Program :

3.1. Specimen Layout

Eighteen concrete knee joint specimens are tested in this research, The nominal dimensions of the tested specimens are (550 mm) in overall length of legs , the cross section of the leg is square (150 × 150 mm) and made rectangular (212.1×150 mm) in base as shown in **Figure (1)** , these specimens are divided into five groups . G1 contains four specimens with loop bars details in corner region , G2 contains four specimens with simple reinforcement details in corner region as shown in **plate (1)** , the parameters in these two groups are percentage of rubber chips (5,15, 25) % added as a weight percentage of the coarse aggregate. The specimens in (G1 and G2) are loaded up to failure and repaired with CFPR Sheets by repairing method (A) then re-tested in the same way to compare it with original specimens. The other three groups (G3, G4, G5) include nine specimens in addition to reference specimens, three percentage and three length of rubber strips are used in these specimens, tested earlier by Kaabi [6] and repaired by repairing method (B) .

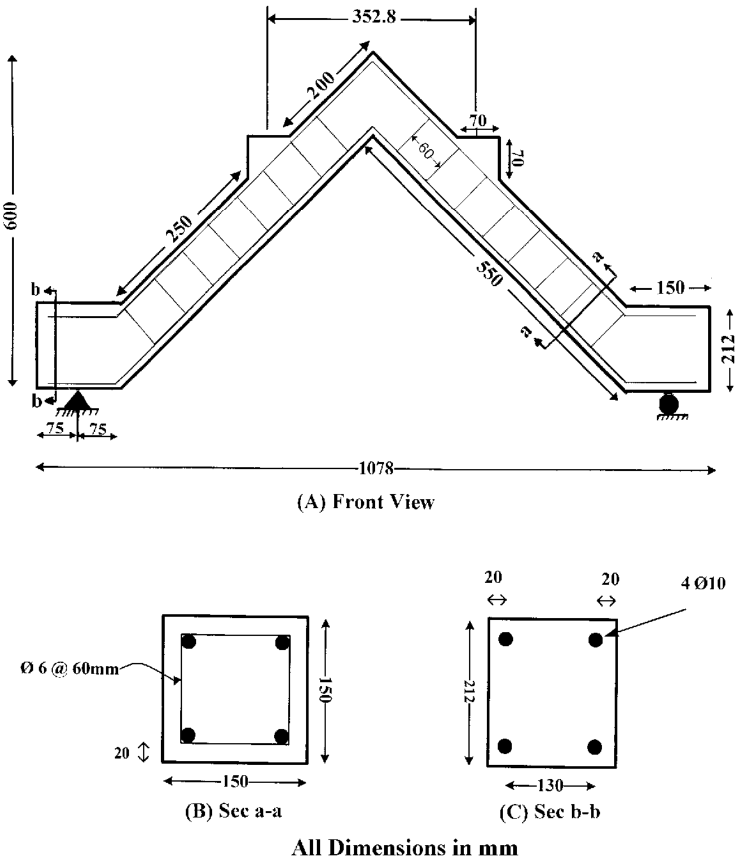


Fig. (1) Details of Tested Knee Joints

(a) Loop Details

(b) Simple Details

plate (1) Types of Reinforcement Details of Knee joints

3.2. Material Properties

3.2.1. Cement

Ordinary Portland Cement **(Type-I)** produced by United Cement Company (Tasluga-Bazian), Sulymania-Iraq, was used throughout this work. To avoid any differences between various batches, the whole quantity was brought and stored in a dry place. The chemical and physical properties of such cement are presented in **Tables (1 and 2)** respectively. Test results indicate that the adopted cement conforms to the Iraqi Standard Specifications IQS No.5/1984[7].

Table (1),Chemical Composition of Cement

No.	Oxide Composition	Abbreviation	Content (percent)	Limit of Iraqi Specification NO.5/1984
1	Lime	CaO	62.33	---
2	Silica	SiO_2	22.01	---
3	Alumina	Al_2O_3	5.49	---
4	Iron Oxide	Fe_2O_3	3.93	---
5	Magnesia	MgO	0.86	≤5.0%
6	Sulfate	SO_3	2.54	≤2.8%
7	Loss on Ignition	L.O.I.	2.1	≤4.0%
8	Insoluble residue	I.R.	0.71	≤1.5%
9	Lime saturation Factor	L.S.F.	0.88	0.66-1.02
10	Tricalcium Aluminates	C_3A	10.01	---

Table (2), Physical Properties of Cement

Physical properties	Test result	Limit of Iraqi Specification NO.5/1984
Specific surface area (m^2/kg)	407	≥230
Setting time (Vicat's apparatus) Initial setting time, (hrs: min.) Final setting, (hrs: min.)	 3:35 5:05	 ≥ 0:45 ≤10:0
Compressive strength 3days, MPa 7days, MPa 28days, MPa	 27.5 35.8 41.6	 ≥15 ≥23 ----

3.2.2. Fine Aggregate

Normalweight natural sand from Al-Akhaider region was used as fine aggregate. Before its incorporation into the concrete mix, sand was sieved on 9.5 mm sieve. Grading of the sand is shown in **Table (3).** Physical test on sand used throughout this work is shown in **Table(4).** The obtained results indicate that the fine aggregate grading and the sulfate content within the requirements of IQS No.45/1984 [8] Specifications.

Table (3), Grading of Fine Aggregate

Sieve size (*mm*)	Cumulative Passing %	Limits of Iraqi specification No.45/1984 , zone 3
4.75	94	90-100
2.36	87	85-100
1.18	83	75-100
0.600	68	60-79
0.300	25	12- 40
0.150	6	0-10

Table (4), Physical Properties of Fine Aggregate

Physical properties	Test results	Limits of Iraqi specification No.45/1984
Specific gravity	2.63	-
Sulfate content	0.09%	≤0.5%
Absorption	0.73%	-

3.2.3. Coarse Aggregate

Crushed gravel with maximum size of (14mm) is used throughout the tests. The crushed river coarse aggregates are washed, then stored in air to dry the surface and then stored in a saturated dry surface condition before using. The specific gravity and absorption are (2.66) and (0.66%) respectively. The grading of the coarse aggregate is shown in **Table (5).** The obtained results indicate that, the coarse aggregate grading is within the requirement of the Iraqi specification No. 45/1984[8].

Table (5), Grading of Coarse Aggregate

NO	Sieve size	%Passing	
		%Coarse Aggregate	Iraqi specification No. 45/1984
1	14*mm*	97	90-100
2	10*mm*	73	50-85
3	5*mm*	9	0-10
4	pan	-	-

3.2.4 .Rubber Aggregate

Fiber rubber worn-out tires of small cars are used. Tires were cut by hand, into small fiber with different sizes (10 * 7 * 10) mm , (10 * 7 * 20) mm, (10 * 7 * 40) mm,(10 *7 *60)mm, as shown in plate(2), added by weight of coarse aggregate with percentage (5%, 5%,25%).**Table(6)** describe percentages and dimensions worn-out tires rubber used.

(a) 10*7*10 mm (b) 10*7*20 mm (c) 10*7*40 mm (d) 10*7*60 mm

plate (2) Rubber Strips and Chips Dimensions

Table (6), Percentages and Dimensions of Worn-out Tires Rubber Used

Groups No.	Specimen Symbol	Rubber ratio by Weight of Coarse aggregate. (%)	Rubber Dimensions (mm)		
			Length	Thickness	width
1	CRL*	-	-	-	-
	1CL5**	5%	10	7	10
	1CL15	15%	10	7	10
	1CL25	25%	10	7	10
2	CR1*	-	-	-	-
	1C5	5%	10	7	10
	1C15	15%	10	7	10
	1C25	25%	10	7	10
CR	CR*	-	-	-	-
3	2C5***	5%	20	7	10
	2C15	15%	20	7	10
	2C25	25%	20	7	10
4	4C5	5%	40	7	10
	4C15	15%	40	7	10
	4C25	25%	40	7	10
5	6C5	5%	60	7	10
	6C15	15%	60	7	10
	6C25	25%	60	7	10

** CRL is the reference corner for G1, CR1,is the reference corner for G2, CR, is the reference corner for groups G3,G4 and G5*
***1CL5 ,refer to corner specimen contains chips rubber aggregate (1 cm) with percentage 5 % and loop bar details in corner region.*
****2C5 , refer to corners contains rubber strips length 2 cm and percentage 5% with simple details in corner region.*

3.3 Concrete Mixing ,Casting and Curing

Concrete without rubber aggregate is used as the reference concrete. Three mixes are designed according to the recommendations of the ACI 318M-11[9] to achieve cylinder compressive strength of (30MPa) at (28) days.

Mixing procedures were the same for all of the concrete batches (1: 1.5: 3) and W/C ratio 0.45. As for the rubberized concrete mixtures, coarse and fine aggregate in saturated surface dry state and cement were loaded in the mixer and mixed for 3 minutes. Rubber aggregate was then added gradually to the mix for a period of 2 minutes to allow the rubber aggregates to mix thoroughly. Water was then added gradually to the mix for a period of 2 minutes and followed by mixing , The total mixing time is (8-10 minutes) to produce a uniform mix.

The concrete is poured in the steel mold in three layers, and each layer is vibrated on a table vibrator which gives adequate compaction. The surface of the concrete is leveled off. Then, the specimens are covered with a nylon sheet.

All specimens are left in the laboratory for 24 hours, and then placed in water bath for (28) days with almost constant laboratory temperature. After (28) days, they are taken out of water and left to dry for (24) hours and then tested in accordance with the standard specifications.

3.4 CFRP Installation

The most crucial part of any rehabilitation application is the bond between CFRP and the surface to which the CFRP is bonded. Proper bond insures that the force carried by the structural member is transferred effectively to the CFRP. Poor bond resulting from unsatisfactory preparation can render the strengthening application completely useless. The quality of the surface preparation is related to the surface texture.

1- The specimens are cleaned by washing with water and allowing to dry prior to composite application.

2- The surface of specimens is prepared by cutting off machine. This procedure removes (0.5-1mm) of surface to ensure removal of all loose particles and contaminations from the specimen's surface.

3- Just before composite application, the knee joints are wire brushed and vacuumed as well, as shown in Plate (3a).

4- Application of the mixed resin Sikadur-330 to the prepared substrate using a trowel or brush in a quantity of approximately (0.7 to 1.2 kg/m^2), depending on roughness of substrate, as shown in Plate (3 b).

5- The SikaWrap Hex-230C fabric was cut by scissors to strips at (50 mm and 150 mm) width and for the required length for all the specimens. The SikaWrap Hex-230C fabric was carefully put into the resin with gloved hands and smoothed out any irregularities or air pockets, and allow the resin to squeeze out between the roving's of the fabric, as shown in Plate (3 c).

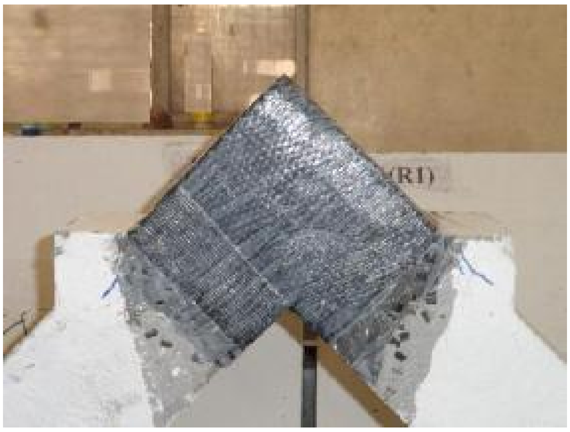
6- As a coating layer, an additional resin layer of approximately (0.5 kg/m^2) broadcast with the brush is added to the exposed surface, as shown in Plate (3 d).

7- After allowing the laminate to cure for a couple of days in dry air, the specimens will be ready to test. All apparent concrete surface knee joints are painted white so that crack propagation can be easily detected.

(a)Surface Preparation

(b) Resin Applied to the knee joint

(c) CFRP Installation



(d) Coating Layer

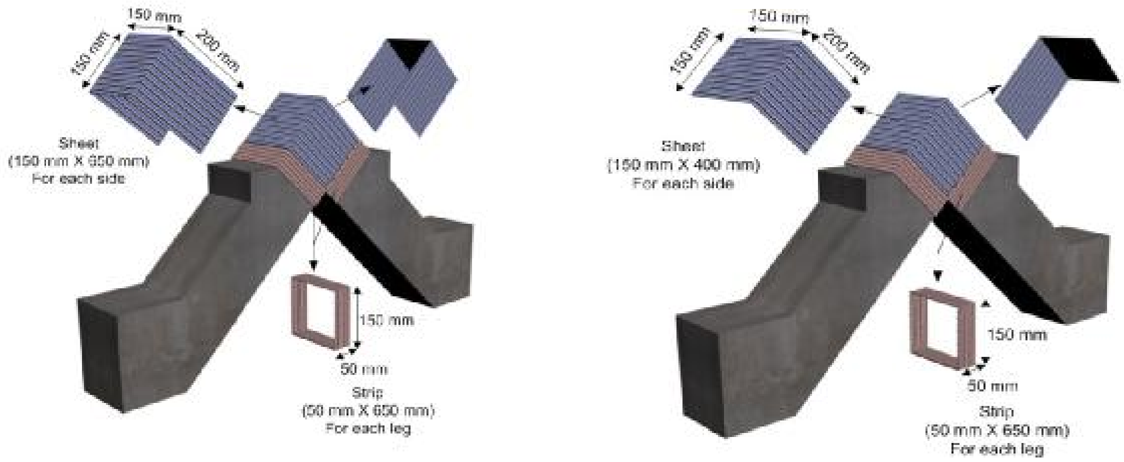
Plate (3) CFRP Sheets Installing Procedures

3.5 Repairing Schemes

Eighteen concrete knee joints are tested in this study. Two repairing methods are used in this study characterized by repairing method **(A) and (B)** .**Table (7)** show the description of CFRP sheets for repaired specimens , the repairing schemes of the tested knee joints are shown in **Figures (2) .**

Table (7), Repaired Methods Details

Repairing Methods	Details of CFRP	Repairing Groups
A	Two sheets installed (150 mm width, 550 mm length) making double layers at corner region as form of (U) shape . And one strip (50mm width, 650mm length) wrapped around each leg.	G1 G2
B	Two sheets installed (150 mm width, 400 mm length) making single layer at corner region as form of (L) shape. And one strip (50mm width, 650mm length) wrapped around each leg.	CR G3 G4 G5



(a)Repairing Method A **(b)Repairing Method B**

Fig. (2) Repairing Methods Schemes

3.6 Test Setup

All knee joint specimens are tested by using the universal testing machine (MFL system) under monotonic loads to ultimate states. According to the circumstances of this test, the specimen (concrete knee joint) is supported to be hinged at one leg and rolled in the other leg upon this apparatus, using two hooks in one side to achieve the hinged situation. The upper and lower parts of concrete knee joints are modified to make the applied loads act as a coupled situation on each side, this leads to open the corner at center, as shown in **Plate (4).**

Plate (4), Knee joint Set Up

4. Experimental Results and Discussions :

4.1 Cracking Moment ,Ultimate Moment and Efficiency

As the applied load increases, the opening moment on the knee joint increases and tending to open the inner angle. Due to the increasing moment, cracks initiate and progress until failure. Cracking moment is the moment at which first visible crack appears on the surface of the specimen, and ultimate moment is the maximum moment which could be carried out by the tested knee joint specimens.

Efficiency of repairing is defined as the ratio of the repaired knee joint specimen strength to it strength before repairing (in percentage). **Table (8)** shows the cracking moment and ultimate moment for repaired specimens and corresponding control specimens, the repairing efficiency also shown in this table.

Original specimens repaired by method (A) have suffered from cracking moment due to cracks initiated in corner region (diagonal cracks), and flexural cracks in legs .Thus, it could be noticed that the cracking moment efficiency ranging between (120.9 %) to (283 %), this increasing refers to the double CFRP sheets that cover both faces of corner region and resist formation of new cracks or re-opening of repaired cracks. Furthermore, high increase in strength is achieved by method A , where the repairing efficiency ranges between (154.54%) to (225%).

In General ,the previously preview on the behavior of specimens repaired by method A verify the expectation for this method in recording best repairing results, whereas, all repaired corners develop cracks adjacent to the CFRP belts, as shown in **plate (5)** furthermore, there is no pulling out in the compression zone. This is due to the confinement effect of the double sheets of CFRP in opposite direction which prevent re-opening the control cracks, that make the repaired specimens more capable of resisting opening moments than the control specimens this indicate full composite action between concrete and CFRP sheets.

Table(8)Cracking Moments, Ultimate moments and Efficiency for All Specimens

Group No.	Original specimens			Repairing Method	Repaired specimens			Cracking Efficiency $\left(\frac{Mcr,r}{Mcr,o}\right)$ %	Total Efficiency $\left(\frac{Mu,r}{Mu,o}\right)$ %
	Specimen Designation	Mcr* KN.m	Mu* KN.m)		Specimen Designation	Mcr KN.m	Mu KN.m		
1	CRL	6.19	15.84	A	RCRL	7.48	24.48	120.9	154.54
	1CL5	6.05	14.68		R1CL5	7.48	23.76	123.63	161.8
	1CL15	5.76	12.67		R1CL15	8.35	22.61	145	178.4
	1CL25	5.18	11.22		R1CL25	7.92	19.87	152.89	177.1
2	CR	3.2	8.64		RCR1	6.91	17.57	215	203.35
	1C5	2.7	8.21		R1C5	6.05	16.56	224.1	201.7
	1C15	2.01	7.2		R1C15	4.75	15.84	236.4	220
	1C25	1.51	5.76		R1C25	3.6	12.96	238	225
	CR	3.44	7.60	B	RCR	3.40	14.11	156.7	185.65
3	2C5	1.22	6.02		R2C5	2.88	11.66	236	193.68
	2C15	1.08	5.30		R2C15	2.59	10.79	239.8	203.58
	2C25	1.0	4.30		R2C25	2.44	8.5	244	197.67
4	4C5	1.08	5.30		R4C5	2.16	9.43	200	178
	4C15	1.0	4.87		R4C15	1.94	9.14	194	187.68
	4C25	0.86	4.01		R4C25	1.94	8.64	225.5	215.46
5	6C5	1.15	5.16		R6C5	1.87	9.36	162.6	181.39
	6C15	1.08	4.73		R6C15	1.87	9.14	173.1	193.23
	6C25	0.86	3.87		R6C25	1.8	8.06	209.3	208.27

* *Mcr: Cracking Moment, Mu: Ultimate Moment*

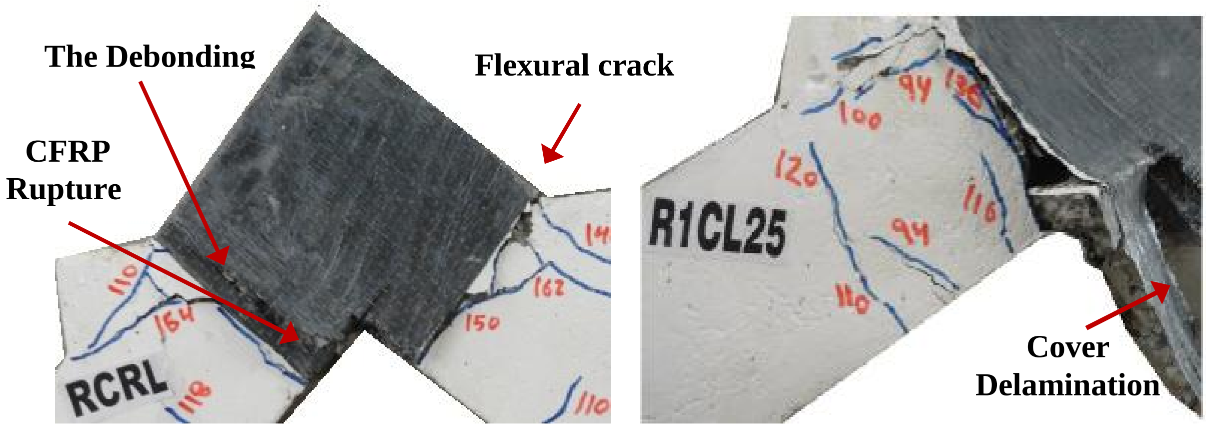
Note: (r) Refers to Repaired Knee joint and (o) Refers to Original Knee joint.

Also, test results showed that the repaired specimens by method A in G2 presented the higher cracking and ultimate moment efficiency compared with specimens in G1 ,because the specimens in G2 are weaker than those in G1 before repairing , therefore the cracking and ultimate moment efficiency of repaired specimens are greatly depends on the strength of original specimens, which affected by reinforcement details and percentage of rubber added as a coarse aggregate, as percentage of rubber increase, the ability of concrete to resist formation cracks decrease causes decrease in cracking and ultimate moment for original specimens and cracking and ultimate moment efficiency.

The cracking pattern of the knee joints repaired by method (B) is approximately similar to each other . The cracking developed in the vicinity of CFRP belt or between CFRP sheet and belt illustrated the high efficiency of CFRP to resist initiation of new cracks or re-opening the old cracks that refers to full composite action between concrete and CFRP sheets.

Since the reinforcement details and repairing manner are constant for all specimens repaired by method B , therefore the variation in cracking and ultimate moment results beyond to the strength of concrete itself in corner region. The concrete contains rubber as form of strips in different percentages and lengths lead to decrease in tensile strength of concrete , and reduce the bond between concrete and CFRP , as the percentages and lengths of rubber strips increase , the tensile strength and bond will decrease .

Also, the repairing method B show a good cracking and repairing efficiency , but cracking and ultimate moments are still less than those recorded by repairing method A , which consist of double layer of CFRP sheets .



(a) (b)

Plate (5), Mode of Failure for Specimen (RCRL and 1CL25)

4.2 Deflection

The behavior of original and repaired specimens in terms of load–deflection in inner angle and explaining the stiffness and serviceability provided after repairing are shown in **figures (3).** Deflection, resulted at ultimate load (Pu) of original specimens (Total deflection for knee joint specimens), is compared with those of the repaired specimens, as shown in **Table (9).** several load- deflection curves are identical and the tested specimens exhibit linear behavior, at the beginning. In the second part, it appears that, the variation in the slope of these curves ,due to increase percentage of rubber aggregates and decrease in ultimate load. that means the specimens in this stage have low flexural rigidity.

Also the rubberized concrete specimens for these five groups show increase in ultimate deflection as compared with its reference specimens ,due to increase percentages of rubber chips and percentages and lengths of rubber strips that lead to decrease in ultimate load.

Specimens repaired by method A have the most satisfactory results due to the confinement effect which is provided by double CFRP sheets. The load-deflection behavior is generally similar to the corresponding specimens repaired by method B , but with little decreases in deflections.

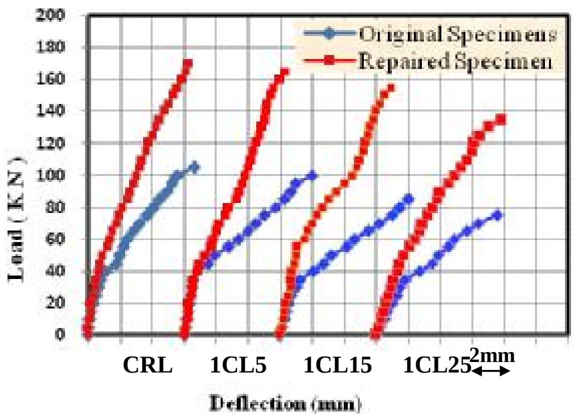
Tables (9), Total Deflection for Tested Knee Joint Specimens

Repairing method A					
G1			G2		
Specimens	Δ_c* mm	$\frac{\Delta_{c,r}}{\Delta_{c,o}}$ ** %	Specimens	Δ_c* mm	$\frac{\Delta_{c,r}}{\Delta_{c,o}}$ ** %
CRL	6.65	94.7	CR1	5.6	131.4
RCRL	6.3		RCR1	7.36	
1CL5	8	78.1	1C5	8.26	93.2
R1CL5	6.25		R1C5	7.7	
1CL15	8.06	85.6	1C15	7.8	116.6
R1CL15	6.9		R1C15	9.1	
1CL25	7.55	103.3	1C25	7.46	112.6
R1CL25	7.8		R1C25	8.4	

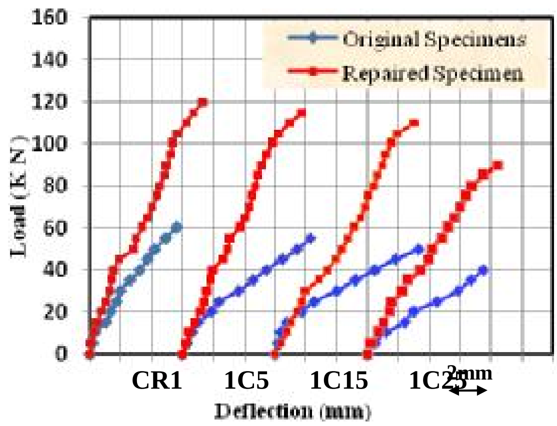
Repairing method B											
CR			G3			G4			G5		
Speci mens	Δ_c* mm	$\frac{\Delta_{c,r}}{\Delta_{c,o}}$ %	Speci mens	Δ_c mm	$\frac{\Delta_{c,r}}{\Delta_{c,o}}$ %	Speci mens	Δ_c mm	$\frac{\Delta_{c,r}}{\Delta_{c,o}}$ %	Speci mens	Δ_c mm	$\frac{\Delta_{c,r}}{\Delta_{c,o}}$ %
CR	8.5	99.3	2C5	18.5	49.4	4C5	14.5	65.5	6C5	9.0	123.3
			R2C5	9.14		R4C5	9.5		R6C5	11.1	
RCR	8.36		2C15	12.0	71.0	4C15	8.3	127.7	6C15	8.5	150.5
			R2C15	8.52		R4C15	10.6		R6C15	12.8	
			2C25	10.0	128.7	4C25	7	181.4	6C25	7.0	210
			R2C25	12.8		R4C25	12.7		R6C25	14.7	

* Δ_c *Total deflection for knee joint specimens*

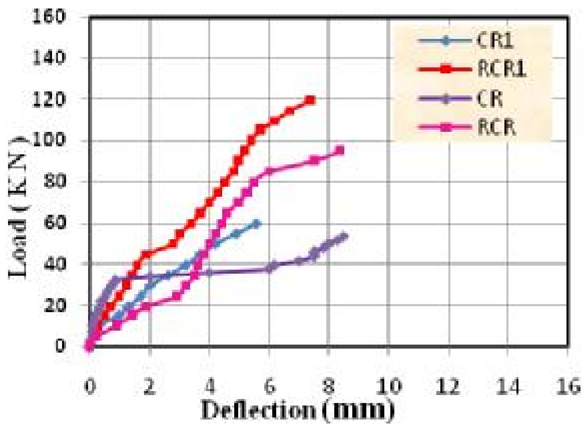
** *r and o refer to repair and origin knee joint respectively*



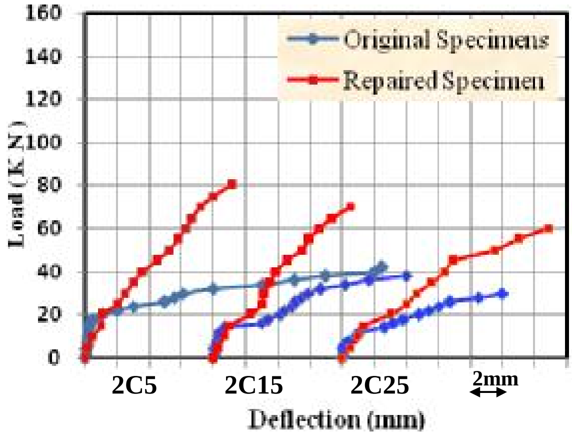
(a) Deflection Curve for (G1)



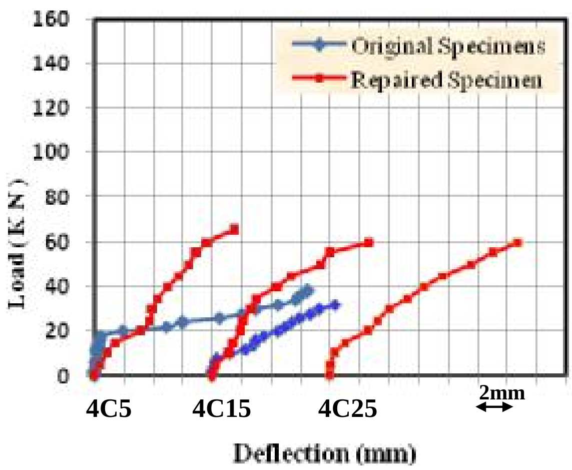
(b) Deflection Curve for (G2)



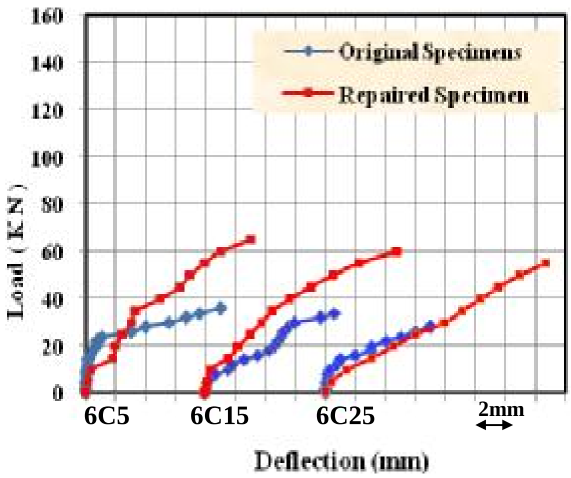
(c) Deflection Curve for Reference Specimens



(d) Deflection Curve for (G3)



Deflection Curve for (G4)



(f) Deflection Curve for (G5)

Fig. (3) Load – Deflection Curve for Original and Repaired Specimens

5. Conclusions :

Based on evidence from the experimental results reported in this work, the following conclusions can be drawn.

5.1 Effect of Rubber Aggregates on Properties of Concrete Specimens

The following conclusions are drawn from the specimens with different percentages and lengths of rubber aggregate:

1- The addition of rubber strips or chips in concrete mix decreases the strength of concrete and the reduction in strength is proportional with increase in percentages of rubber chips or strips and length of strips, because reduced the homogeneity of mix and reduced the rubber strips surface area coated with cement paste.

2- Since cracking and ultimate strength in corner blocks are greatly affected by the strength of concrete which depends on the strength of its components, therefore the addition of rubber strips or chips in corner blocks concrete decreases the cracking and ultimate moment which proportional with increase in percentages of chips and strips and lengths of strips.

3- The rubberized concrete samples showed acceptable workability in terms of ease mixing, handling, placement and finishing. Nevertheless, the results show that increasing the percentage of rubber aggregate reduces the workability of concrete.

4- A more gradual failure was observed in rubberized concrete specimens under compression and splitting tensile loading ,therefore this specimens did not exhibit the brittle failure mode typical of plain concrete .

5- The deflection curves for original specimens show that the values of deflection increase with increase the percentage of rubber aggregates and length of rubber strips ,due to presence of rubber that makes the rubberized concrete more flexible . It is thus absorbing a lot of plastic energy and resisting large deformation without full disintegration. Maximum deflection belongs to specimen (6C25).

5.2. Effect of Types of Details on the Knee joint Specimens

The following conclusions are drawn from the two types of corner details performed in this studies:

1. When the applied load is opening the corner, reinforcement detailing has important effects on strength, and its effects on cracking moment, cracking pattern are obvious.
2. The cracking and ultimate moment of specimens in G1, with looped bars in corner block has been the higher than the other groups , because the loop bar of main steel resists the cracks in all directions.
3. Flexural cracks have been appeared in legs for original specimens with loop details (CRL and 1CL5) , while the original specimens with simple details developed diagonal cracks on corner block, this indicated the high strength of corner blocks in case of loop bar details.
4. The deflection curves for original specimens showed that the values of deflection of specimens with looped bar details were less than corresponding specimens with simple details.

5.3 Effect of Repairing on Knee joint Strength

From the test results of repaired specimens the following conclusion can be drawn:

1- it can be seen that the two repaired methods have considerable increasing effect on the cracking and ultimate moment on repaired specimens compared with original specimens.

2- The both repairing methods showed no pulling out in the compression zone. This is due to the confinement effect of the CFRP sheets in corner blocks which prevent re-opening the control cracks, that make the repaired specimens more capable of resisting opening moments than the original specimens

3- The specimens repaired by method A successful in restoring the full capacity of failing specimens with average increasing of 125%, and max ultimate strength reaches to 24.48 kN.m, also the deflection of repaired specimens is lower than the original specimens.

4- It should be notes that the repairing method B show the high repairing efficiency with average increasing of 144 % , but cracking and ultimate moments are still less than those recorded by repairing method A , which consist of double layer of CFRP sheets .

5- Method A is recording best repairing results and, whereas, all repaired specimens develop cracks adjacent to the CFRP belts that indicate full composite action between concrete and CFRP sheets.

6- Flexural failure has been appeared on repaired specimens legs , repairing by method A , which mean that the corner blocks are become stronger than the legs

7- Repairing by CFRP materials offers enhancement to the corner, by resisting the stresses produced from the applied opening moment. The degree of this resistance would depend on the area of CFRP in corner region.

8- In addition to CFRP area in corner region, the ultimate strength of repaired specimens are greatly depends on the concrete strength of original specimens, hence the specimens with high percentage of rubber aggregates provided low tensile concrete strength and weak bond with CFRP sheets .

9- The reinforcement details in corner blocks are still active even after failure of original specimens , thus the repaired specimens with loop details showed cracking and ultimate moment higher than corresponding specimens with simple details.

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