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Behaviour of Uniaxial Reinforced Concrete Columns Strengthened with Ultra-High Performance Concrete and Fiber Reinforced Polymers

A B S T R A C T

This article investigates the behaviour of strengthened concrete columns using jacketing ultra-high-performance fiber reinforced concrete (UHPFRC) and carbon fiber-reinforced polymer (CFRP) under uniaxial loaded. The jacket was connected to the column core using shear connectors and (CFRP) fixed as a strip on the tension zone between the column cores and the jacketing. Seven column samples of square cross-section (120 x120) mm at the midsection with overall length of 1250 mm were cast using normal strength concrete (NSC) and having similar longitudinal and transverse reinforcement. The samples were made and tested under axial load at eccentricity equal to 120 mm up to failure. Test parameters were the thickness of jackets (25 and 35) mm and the width of CFRP (0,8, and 12) cm. Column specimens were tested, one of them was reference without any strengthening, and the other specimens divided into two groups (A, and B), and each group included three specimens based on the parameters. Group (A) has UHPFRC jacket thickness 25 mm and CFRP width (0,8, and 12) cm respectively, and group (B) has UHPFRC jacket thickness 35 mm and CFRP width (0,8, and 12) cm respectively. The outcomes of the article show that increasing the thickness of jacket, and width of CFRP lead to increase in the load carrying capacity about (110.5%,168.4%, and 184.2%) for group A, and (157.9%,226.3%, and 263.2%) for group B compared with the reference column due to delay in the appearance of cracks and their distribution. The mid-height lateral displacement of columns was decreased about (66.6%,42.3%, and 35.9%) for group A, and (46.15%,38.46%, and 32.3%) for group B, also the axial deformation of specimens decreased about (71.7%,60.86%, and 55.86%) for group A, and (65.5%,60.5%, and 53.4) for group B compared with the reference column. The ductility of columns that were strengthened with UHPFRC jacket only was increased about (13.67%,19.66%) for thickness(25,35) mm respectively, because of that UHPFRC jacket was contented on steel fibers, and the percentage decrease of ductility was about (5.1%,and 12%) for group (A), (1%,and 9.4%) for group (B) when bonded CFRP in the tension zone with width (8 ,and 12) cm respectively. The results show improvement in the initial and secant stiffness when, increased the thickness of jacket, and width of CFRP because of increase in the size of columns and improvement in the modulus of elasticity. The toughness increase was about (273.97%,301.55%, and 304.5%) for group A, and (453.69%,511.93%, and 524.28%) for group B compared with the reference column because of increase in the size of specimens and delay the appearance of cracks.

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سلوك الاعمدة الخرسانية المسلحة تحت تأثير احمال احادية المحور والمدعمة بالخرسانة فائقة الاداء والألياف ألمقواة بالبوليمر

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الخلاصة

هذه المقالة تتحرى عن سلوك الاعمدة الخرسانية المسلحة التي يتم تقويتها باستخدام طبقة من الخرسانة عالية الاداء والمدعمة بألياف الحديد والتي تكون ذات سمك متغير تحت تأثير احمال لا محورية. وكذلك تم دراسة تأثير اضافة الياف الكاربون البوليمرية والتي تم تثبيتها بشكل شريط طولي في منطقة الشد وبعرض مختلف لمعرفة مدى تأثيرها على كفاءة طبقة التقوية الخرسانية. وقد تم تثبيت طبقة التقوية الخرسانية مع العمود الاصلي باستخدام قضبان القص والتي يتم تثبيتها اثناء مرحلة الصب للعمود الخرساني وكانت الياف الكاربون تثبت تحت طبقة التقوية الخرسانية. في هذا البحث تم صب سبعة اعمدة من الخرسانة المسلحة الاعتيادية وجميع هده الاعمدة متشابهة في ابعاد ومساحة المقطع العرضي(120*120)ملم ويبلغ طولها الكلي مع النهايتين المعكوفة (1250) ملم .و كمية حديد التسليح كانت ثابتة في الاتجاهين الطولي والعرضي لجميع الاعمدة الخرسانية. وقد تم فحص جميع النماذج تحت تأثير حمل انضغاط لا مركزي يقع على مسافة (120) ملم من مركز العمود حتى يتم الوصول الى الفشل. المتغيرات التي تم دراستها سمك طبقة التقوية الخرسانية (25 او 35)ملم وعرض شريط الياف الكاربون (8 او 12) سم. وقد تم اختيار احد الاعمدة التي تم فحصها ليكون نموذج مرجعي وهو لا يحتوي على اي تقوية اما النماذج الاخرى فقد تم تقسيمها الى مجموعتين هي(A,B) .كل مجموعة تضم ثلاثة نماذج وذلك اعتمادا على المتغيرات . النماذج في مجموعة A كان سمك طبقة التقوية الخرسانية (25)ملم و عرض شريط الياف الكاربون في منطقة الشد هو (0,8,12) سم على الترتيب. مجموعة B كان سمك طبقة التقوية الخرسانية (35)ملم وعرض شريط الياف الكاربون في منطقة الشد هو (0,8,12) سم على الترتيب. أظهرت نتائج البحث أن زيادة سمك السترة الخرسانية ، وعرض CFRP يؤدي إلى زيادة القدرة الاستيعابية للحمل بحوالي (110.5٪ و 168.4٪ و 184.2٪) للمجموعة A و (157.9٪ و 226.3٪ و 263.2٪) للمجموعة B مقارنة مع العمود المرجعي بسبب التأخير في ظهور التشققات وتوزيعها ، وهذا يسبب تقليل التشوه للعينات حيث تم تقليل الإزاحة الجانبية للأعمدة بنسبة (66.6٪ ، 42.3٪ ، و 35.9٪) للمجموعة A ، و (46.15٪ ، 38.46٪ ، و 32.3٪) للمجموعة B مقارنةً بالعمود المرجعي. أيضًا ، التشوه المحوري للعينات انخفض بنسبة (71.7٪ و 60.86٪ و 55.86٪) للمجموعة "A" ، و (65.5٪ و 60.5٪ و 53.4 للمجموعة "B" مقارنة بالعمود المرجعي .وقد ازدادت الليونة للأعمدة الخرسانية التي تم تقويتها فقط باستخدام طبقة من UHPFRC بنسبة (13.67٪ ، 19.66٪) عندما يكون سمك طبقة التقوية (25،35) ملم على التوالي بسبب أن UHPFRC تحتوي على الألياف الفولاذية ، وكانت النسبة المئوية لانخفاض الليونة حوالي (5.1٪ ، و 12٪) للمجموعة (A)،(1٪ ، و 9.4٪) للمجموعة (B) عند لصق CFRP في منطقة الشد بعرض (8 ، و 12) سم على التوالي. أظهرت النتائج تحسن الصلابة الأولية والثابتة عند زيادة سمك طبقة التقوية الخرسانية وعرض CFRP بسبب زيادة حجم الأعمدة وتحسن معامل المرونة. كمية الطاقة الممتصة ازدادت بنسبة (273.97٪ ، 301.55٪ ، و 304.5٪) للمجموعة A ، و (453.69٪ ، 511.93٪ ، و 524.28٪) للمجموعة B مقارنة بالعمود المرجعي بسبب زيادة حجم العينات وتأخير ظهور الشقوق.

INTRODUCTION

Columns are the most important structural elements of the structure. It is the only member responsible for transferring the loads to the foundations. Thus, any failure in a column with a critical location causes a failure in that location and all the adjacent structural parts and can lead to the complete collapse of the structure. It is necessary to pay attention to the strengthening of the columns and to improve their performance in order to be in accordance with the intended purpose. Therefore, many ways have been found to rehabilitate and strengthen these elements and to enable them to resist the stresses and to reach the building at the required planning life. Improvement in the efficiency of the ductility of the column and reorganization of the stiffness of the column can also be maintained by strengthening. Damage of RC columns can result by slight cracks of concrete without damaging the steel, crushing the concrete, buckling the steel or breaking the ties. Depending on the damage, techniques such as removal and replacement of jackets ,and injections can be used. [1,2,3,4].

Several methods are used to strengthen the structural elements to increase the building performance. Some methods of strengthening are listed below:

1. **Strengthening by steel Plates::** This technique has proved to be an effective adaptation and has proved itself several times in practice, however the corrosion of steel in corrosive environments and the need for heavy types of equipment for construction make this technique not economical, [5].
2. **Jacketing RC Columns Using Reinforced Concrete:** this way is economical and does not need special construction procedures, but enlargement of column's size was obtained when the jacket was constructed and longtime of construction leads to make this technique unattractive.
3. **Jacketing RC Columns Using Composite Fiber-reinforced polymer (FRP) :** (FRP), is used for construction of buildings due to its mechanical properties such as, the high tensile strength, light weight, high resistance of corrosion, high fatigue endurance, small heat coefficient, short duration for

installing, simple fixing and low costs for maintenance [6].

Hadi [7] studied and tested 16 specimens, all columns were made from HSC and they had circular cross-section. The 16 specimens was divided into four groups: The first one a control column. The outcomes indicate that an increase in the eccentricity of the applied load leads to a decrease in the load capacity. The use of (CFRP) as external confinement significantly increased the strength of (RC) column considerably , while the ductility increases with the addition of steel fiber to concrete.

Murugadoss et al.[8] ascertain that to achieve efficient and most favorable FRP strengthening using CFRP composite strips. CFRP composite strips with a width of 50 mm were used at two different spacing (20, 40) mm to confine columns. The results of the column confined with spacing (20 mm) showed a significant limitation of the axial deformation of the column and increased the strength capacity to a maximum of 99.20% compared with the reference column. In contrast, the column, which was confined by strips with a spacing (40 mm), failed by crushing the concrete alone, which happened before the CFRP strips even reached the ultimate tensile strength. Based on these results, it is recommended that CFRP strips with a spacing of (20)mm can be used to improve the strength capacity of the RC column; besides, this wrapping technique provides economic benefits more than a column confined with full wrapping.

Recently, a new retrofit technique using UHPFRC jacket was investigated and applied to show the weak points of the current strengthening techniques.

Beschi et al. [9].The ultra-high performance fiber reinforced concrete (UHPFRC) has compressive strength that can reach more than 180MPa and tensile strength more than 10MPa by including fiber. This high compressive and tensile strength can make it possible to exhibit higher strengthening effect than using normal concrete jacket. Also, due to high fluidity of UHPFRC, jacket thickness can be reduced between (30-50)mm, There are other advantages of UHPFRC retrofit such as high durability, good adjustability with various situations and that it can be combined with other materials like wire mesh , textile mesh and CFRP for better performances

Some mechanical properties of UHPFRC studied by Richard and Cheyrezy [10] published the first report on reactive powder concrete. They developed two types of reactive powder concrete RPC: RPC200 and RPC800 .The two types are made up of the materials (cement, very fine sand, silica fume, water, super plasticizer and steel fibers), but there are differences in mix proportions, curing methods, type of steel fibers, steel aggregate and in using compacting pressure during samples preparation. The first-type RPC 200 was produced without compacting pressure and curing the concrete at ambient temperature the compressive strength was least than 170MPa. While curing in hot water or steam at 80-90C for 48 hr. after two days from casting , the compressive strength was more than 230MPa. RPC800 was made by using compacting pressure at setting (50MPa) with heat curing (250 - 400°C).

The reactive powder concrete is an effective material in building and construction works due to the advantages of the high carrying capacity loading compared to the weight, and homogeneous properties, if they are compared with other building materials.[11]

Using of Reactive Powder Concrete (RPC) decreases dimensions, and gives a stronger structural element. It is also classified as a form of Ultra High Performance Concrete (UHPC)[12].

Danha et al.[13] investigate the effectiveness of three variable parameters on several mechanical properties of (RPC). The content of silica fume was (0%, 10%, 15%, 20%, 25%, and 30%), super plasticizer type (Sikament®-163N and PC200) and hooked macro steel fibers volume fraction (0%, 1%, 2% and 3%). The outcomes showed that increasing the content of silica fume from (0% to 30%) leads to increase the compressive strength from (13.54% to 34.17%), while the improvement of tensile strength was (2.63% to 16.89%). The inclusion of steel fibers volume fraction from (0% to 3%) leads to a large increase in direct tensile strength from (59.4% to 238.35%), while the added steel fiber leads to a slight increase in compressive strength from (3.72% to 8.89%). The behavior of RC column strengthening with (UHPFRC) Jacketing was studied by many researchers .

The increase in the fractions volume of steel fibers added to the concrete increases compressive strength and flexural strength .[14]

Tsonos et al. [15]. studied the strengthening of reinforced concrete structures with UHPFRC-jackets (without conventional reinforcement) to resistant earthquake. The results showed that the UHPFRC- jackets were more effective than the normal reinforced concrete jackets (NRC- jackets) and the fiber reinforced polymers jackets (FRP-jackets) when used for strengthening the earthquake-resistant of reinforced concrete structural members.

Menna et al. [16] studied the behavior of RC columns by replacing the present concrete cover with external jacketing made of (HPFRC) to increase the average dimensions of the present column section. Six small square RC columns were cast by using a low performance concrete, to make poor mechanical properties of existing RC members. Then, three of them were strengthened with a (HPFRC) jacketing. The columns were subjected to combined axial load and bending. The results of the test indicated that the use of HPFRC jacketing, increased strength and improved the ductility significantly and can be an effective technique for rehabilitating damages of existing RC columns.

In the present study, an experimental program is used to investigate the behavior of square rectangular columns, which are confined by UHPFRC jackets and a CFRP strip in the tension zone under eccentric loading. Many specimens of normal reinforced concrete columns under eccentric loads with different strengthening layers can give a good indication of the effectiveness of the columns and the strengthening method. The parameter of this study will be of interest to engineers involved in updating and strengthening structures with UHPFRC jackets and CFRP materials.

Koo, et al.[17] focused on strengthening RC columns with (UHPFRC) jacket. For this study, four specimens were manufactured with size (300*300) mm. After casting and curing for two weeks, one column left un strengthened, three columns were jacketed with UHPFRC in different thickness. Before strengthening the surface of columns treatment with sand blasting was applied to get cohesive between columns and (UHPFRC) jackets; the first one was strengthened with 30mm jacket, the second one was strengthened with 50mm jacket and third specimen was strengthened with 50mm jacket plus stirrups(D10@150) mm inside UHPFRC jacket. The details of specimens are summarized in Plate (2.3). UHPFRC jackets were cured in high temperature(90°C) for 3 days. The result shows that the (UHPFRC) jacketing change failure mode from shear to flexural shear failure ,improves ductile behavior of columns and shows high strengthening effects . The (UHPFRC) jacketing could be a good alternative for RC column retrofit.

Bassam, et [18]. studied the repairing and strengthening of square RC columns by applying two concrete jacketing types: using ultrahigh-performance fiber-reinforced self-compacting concrete (UHPFRSCC) and normal strength concrete (NSC) as jacketing materials with three methods of surface roughening, mechanical wire brushing, mechanical scarification, and using shear studs. The results showed that using NSC as a jacketing material was effective, UHPFRSCC was more effective than NSC due to the use of steel fibers. It also reduces the total strengthened column sections UHPFRSCC can flow better NSC in narrow sections without segregation or honeycombing problems, so to bind column cores and their jackets reveals that using shear studs is the best among the three methods.

2. EXPERIMENTAL PROGRAM

2.1. Materials

***2.1.1*.Cement:** Al-Mas ordinary cement (ASTM Type I) made in Iraq has been used for concrete mixes in this research. The chemical analysis and physical properties satisfied the specification of Iraqi standard No.5/1984 [19].

***2.1.2.*Fine Aggregate:** Al-Ekhaider natural sand of 4.75mm maximum size was used as fine aggregate in normal concrete. However, for UHPFRC very fine sand with maximum size 600µm was used. The grading of the sand and sulfate content were according to the requirements of the limits of the Iraqi Specification (IQS 45/1984)[20].

***2.1.3.*Coarse Aggregate**: Crushed gravel from Samarra region was used for casting specimens with maximum size of 12.5mm. Results indicate that grading of this material was within the requirements of the Iraqi specification No.45/1984 [21].

***2.1.4.*Water:** Tap water was used in all mixes and in the curing of the specimens

***2.2.5.*Superplasticizer S.P**: To improve the workability and strength concrete, high range water reducing admixture used in this study which is known commercially as (Mega Flow3000). This type of superplactisizer was imported from Sika Company.

***2.1.6.*Silica Fume:** In the present investigation, micro silica (Mega Add) was used which was imported from CONMIX company. Chemical composition and pozzolanic activity of micro silica are shown in Table 1 which satisfies the requirements of ASTM C1240-03 [22].

Table 1

Shows the chemical composition and pozzolanic of micro silica in this research. It conforms to the (ASTMC1240-03)

Pozzolanic activity	Limit of ASTM C1240-03	Chemical composition		Limit of ASTM C1240-3
		Oxide	Result%	
		SiO2	91.7	85% Min
122.3%	105%	AL2 O3	4.02	----
		Fe2O3	0.31	----
		SO3	0.74	----
		L. O. I	3.21	6% Max

***2.1.7.*Micro Steel Fibers:** Straight and brass-coated short steel fibers were used in this study. The properties of the used steel fibers are presented in Table 2.

Table 2

Micro steel fiber properties.

Property	Specifications
Surface	Brass coated
Relative Density	7800 Kg/m3
Tensile Strength	Minimum 2600MPa
Form	Straight
Melting Point	1500°C
Average Length	15 mm
Diameter	0.2 mm
Aspect Ratio (Lf/Df)	75
Type	WSF0213

***2.1.8.*Steel Reinforcement:** Two sizes of deformed steel bars of nominal diameter (6)mm for closed stirrups and (12) mm for longitudinal reinforcement. The tension test of all these bars gave the properties listed in Table 3**.**

Table 3
Specification and test results of steel reinforcing bars.

Nominal diameter (mm)	Measured diameter (mm)	Yield stress (MPa)	Ultimate Stress (MPa)	Elongation %
10	9.8	611	700	9.8
6	5.75	395	454	16

***2.1.9.*Carbon Fiber Reinforced Polymer(CFRP):** The (Sika Wrap®-301 C) is a unidirectional woven carbon fiber fabric that was used for strengthening jacketing of UHPFRC in the tension zone of the concrete in the longitudinal direction of the tested columns. All information related to this CFRP is shown in Table 4.

Table 4
properties of CFRP at 25oC.

Property	Grade
Fiber weight (g/m2)	300
Fiber density (g/cm3)	1.80
Design thickness (mm/ply)	0.168
Composite thickness (mm/ply)	0.60
Tensile strength of fiber (N/mm2)	4800
Tensile strength of CFS(N/mm2)	4000
Tensile modulus (N/mm2)	230000
Ultimate elongation (%)	1.8

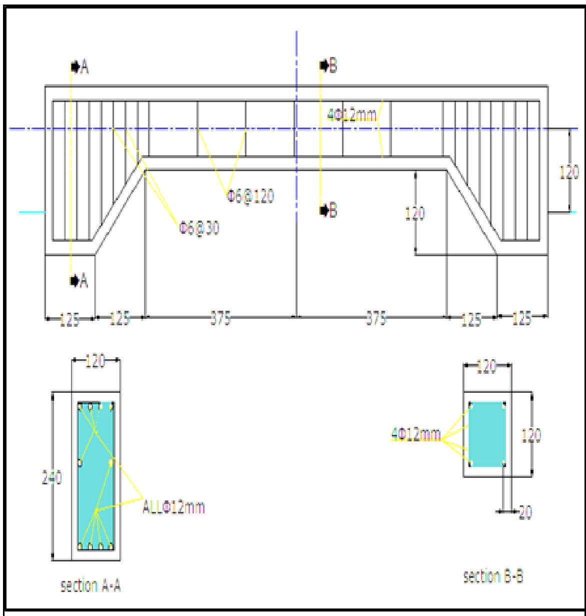
***2.1.10.*Epoxy Resin:** The (Sikadur ® -330) that included two-parts, was used in this study. The mixing ratio of the epoxy consists of four parts resin of component A (white paste) to one-part hardener component B (grey paste) by weight.

2.2. Specimens

A total of seven RC specimens were designed with a square section (120 *120)mm, and a total length of (1250 mm). The length between corbels is (750 mm) and each corbel head had a height of 240 mm. All specimens were tested under compression eccentric loading up to failure. Fig. 1 and Fig. 2 show the geometry of the specimens. The columns were performed with NSC , with 4Ø12 mm as main reinforcement and the transvers reinforcement with Ø6@ 120 mm., One of which was proposed as control specimen. And other specimens are strengthened with jacketing form (four) faces using a layer of UHPFRC having different thicknesses(25,35)mm and longitudinal strip of CFRP fixed in tension zone by epoxy with width (8,12) cm. The jacketing fixed with specimens by using shear connectors with Ø6 mm. The experimental variables investigated were: (the thickness of (UHPFRC) jacketing (25,35) mm and, width of (CFRP) a strip in longitudinal direction that fixed in tension zone between the layer of (UHPFRC) and core of specimens (8,12) cm.

Table 5
Specimen design detail

No.	Specimens Symbols	Thickness of UHPFRC (mm)	Width of CFRP (cm)	Details
1	R	-	-	Reference .
2	C-25	25	-	Column Strengthening with (UHPFRC) jacketing has thickness 25 mm.
3	C-25-CF8	25	8	Column Strengthening with (UHPFRC) jacketing has thickness 25 mm. and (CFRP) has width (8 cm).
4	C-25-CF12	25	12	Column Strengthening with (UHPFRC) jacketing has thickness 25 mm. and (CFRP) has width (12 cm)
5	C-35	35	-	Column Strengthening with (UHPFRC) jacketing has thickness 35 mm
6	C-35-CF8	35	8	Column Strengthening with (UHPFRC) jacketing has thickness 35 mm. and (CFRP) has width (8 cm).
7	C-35-CF12	35	12	Column Strengthening with (UHPFRC) jacketing has thickness 35 mm. and (CFRP) has width (12 cm)



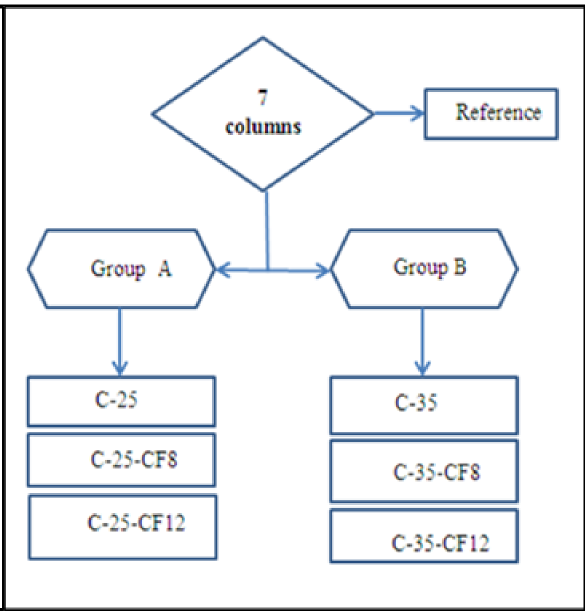


Fig. 1: The dimensions of column in (mm).

Fig. 2: Schematic plan of columns groups.

2.2.1. Normal Strength Concrete (NSC)

NSC mix is designed in accordance with ACI-211[23]. Mixture details are given in Table (6). The used mixture produces good workability and uniform mixing of concrete without segregation .

2.2.2 Ultra- High Performance Fiber Reinforced Concrete (UHPFRC)

Ultra- high performance fiber reinforced concrete mixes were used in the present research as listed in Table 6. In the present work, mixing was performed by using 0.125 m3 capacity horizontal rotary mixer The mixing procedures in this study are described below:

1. Adding the sand to the mixer.
2. Silica fume and cement were mixed in dry to disperse the silica fume particles throughout the cement

particles, then the (silica fume +cement) are added to the mixer and the mixture was mixed for (5) minutes.

3. Super plasticizer was added to the water and stirred, then the liquid was added to the dry mix during the mixing procedure and all were mixed for (5) minutes.
4. The mixer was stopped and mixing was continued manually especially for the portions not reached by the blades of the mixer.
5. The mixer then operated when the flow achieved consistency the steel fiber added slowly during the operation of the mixer to insure the uniformly dispersion for(5) minutes to attain reasonable fluidity.
6. The whole mixing process takes about (15) minutes.

Table 6
concrete Mixture details

Material	**Unite**	**NSC**	**UHPFRC**
Cement	Kg/m3	525	900
Sand	Kg/m3	675	1000
Gravel	Kg/m3	975	-
Silica fume	Kg/m3	-	100
Steel fiber	Kg/m3	-	156
Superplsticezer	Kg/m3	-	20
Water	Kg/m3	220	240
w/c	%	0.42	0.24

2.2.3. Mechanical Properties of Concrete

2.2.3.1. Properties of fresh concrete

The slump test of conventional concrete was performed in accordance with ASTM C143/C 143M [24]. The equipment for the slump test was a truncated cone and a tamping rod. The truncated cone has 30 cm height, 20 cm diameter at the bottom and 10 cm in diameter at top. It is filled with concrete at three equal layers, with each layer being stroked 25 times uniformly by standard steel rod and then slowly lifted. The difference in height from the average concrete level after concrete being slumped down by its own weight to the top of the mold, is called the slump. The slump values ranged from (75-100) mm, as it is designed.

The workability of the UHPFRC was determined using the flow table. The test was conducted according to ASTM C1437-01[19]directly after mixing to get the desired workability. The specification limit of the flow must be (110±5) % and it calculated from the Eq. 1.

$$\text{Flow} = \frac{Dave-Do}{Do} * 100 \quad \text{------------------------------ Eq. 1.}$$

Where:

Dave: Average Dia. of the spread concrete (mm) measured in four directions.

Do: Original inside base Dia. of the test cone (mm).

2.2.3.2. Properties of hardened Concrete

The test program included the casting of many samples (cubes, cylinders, and prisms) for each normal concrete, and ultra-high-performance fiber concrete depending on the ideal proportion of the material mixtures used for this research. The samples cured for 28 days. The results of the hardened properties of the concrete were listed in the following Table 7.

Table 7
Hardened properties of concrete.

Type	Sample	Compressive strength of cubes (MPa)	Compressive strength of cylinders (MPa)	Modules of rupture (MPa)	Modules of splliding (MPa)
NCS	Sample 1	47.81	36.78	4.8	4.17
	Sample 2	50.46	39.12	4.54	4.1
	Sample 3	45.6	34.29	5.82	3.68
	average	47.95	36.73	5.05	3.98
UHPFRC	Sample 1	119.5	--------	30.4	14.9
	Sample 2	120	-------	32.2	14.1
	Sample 3	120.5	-------	31.6	14.5
	average	120	-------	31.4	14.5

2.2.4. Samples preparation

2.2.4.1 Casting and Curing

Before casting, the selection materials were prepared and weighed according to the volume of the mix . The reinforcement and shear connector was placed in the right position carefully inside of all column steel molds with the required bottom and sides cover being accurately maintained and all molds were filled with concrete in three layers with compaction by using vibrator. The upper surface of conventional concrete was smoothly finished after completing the casting by using hand trowel. Then, the specimens were removed from their molds, within 24 hours and kept in a tap water basin for 28 days.

2.2.4.2. Application of CFRP Strips

After casting and curing the samples then, CFRP–strips were applied on columns. The following steps were followed:

1. Cutting CFRP according to the length of column and required width of strips.
2. Specify area of concrete surface to make it rough by using steel brush and cleaned with a normal brush to remove all dirt and dust according to ACI Committee 440[25] to avoid failure at the adhesion.
3. Two parts of epoxy adhesives A, B Sikadur-330 are mixed by ratio(4: 1) respectively, until the color is uniform. Then epoxy is applied to the column with a thickness about 1.5 mm.
4. Putting CFRP-strip on columns surface that coated by epoxy and pressure subjecting by a rubber roller to fix the strip.
5. after curing for 4 days at laboratory temperature 25o C the columns be ready to cast the jacket of(UHPFRC). Fig.3 shows some these steps.

2.2.4.3. Casting the Jacketing of column's using UHPFRC

Before casting, all steel molds were well cleaned and their internal surfaces were lightly oiled to prevent the adhesion with hardened (UHPFRC). Steel molds were manufactured with very accurate dimensions based on the required jacket thickness(25,35) mm . The column cores were provided with shear connectors (fixed during casting) to connect with jacketing. After that putting the columns in steel molds and casting the jacket finally the surface was smoothed by troweling. All the above mentioned steps were repeated again to cast the jackets for the groups A and B of column cores. Fig.4 shows the thickness of jacketing for groups .

2.2.4.4. Curing jacketing of UHPFRC

Curing of the jacketed column specimens is as follows:

1. After 24 hours Of casting. The specimens were taken off the molds.
2. Next the specimens were submerged in curing water basin full with hot water temperature about 90^0 for 28 days for the enhancement of the microstructure of UHPFRC jackets .

After (28) days, they were taken out of the water and left in the laboratory till the time of testing.

2.2.4.5. Painting the specimens after jacketing with (UHPFRC)

Usually, one day before testing, the column specimen surface was cleaned and coated with white emulation to simplify the spread of cracks and make the crack viewing, easier.

2.2.5. SUPPORT AND LOADING CONDITION

The columns were tested in a (250) ton capacity universal testing machine model (AVERY) with hydraulic jack and dial gauge for detecting the load. Fig. 5 shows a general view of the testing machine. Columns were placed vertically and eccentrically with respect to the vertical axis of the testing machine. To apply a proper axial compression loading and transmit it to the column with accurate eccentricity, arrangement of a new loading cap was manufactured based on a loading cap designed by Hadi [26]. The loading cap has rectangular section (120×240) mm, thickness 20mm and can be provided with values of eccentric loading, see Fig. 6. However, in the present work, one eccentricity distance of 120mm was used. The loading caps were made of high strength steel and provided with screws and each end of the columns was covered with loading cap. The lower end of the column was attached to the actuator of the machine, while the upper end was supported on the steel reaction cap of the machine. Both end supports were designed as hinged connections with predefined eccentricity by using these loading caps see Fig. 7.

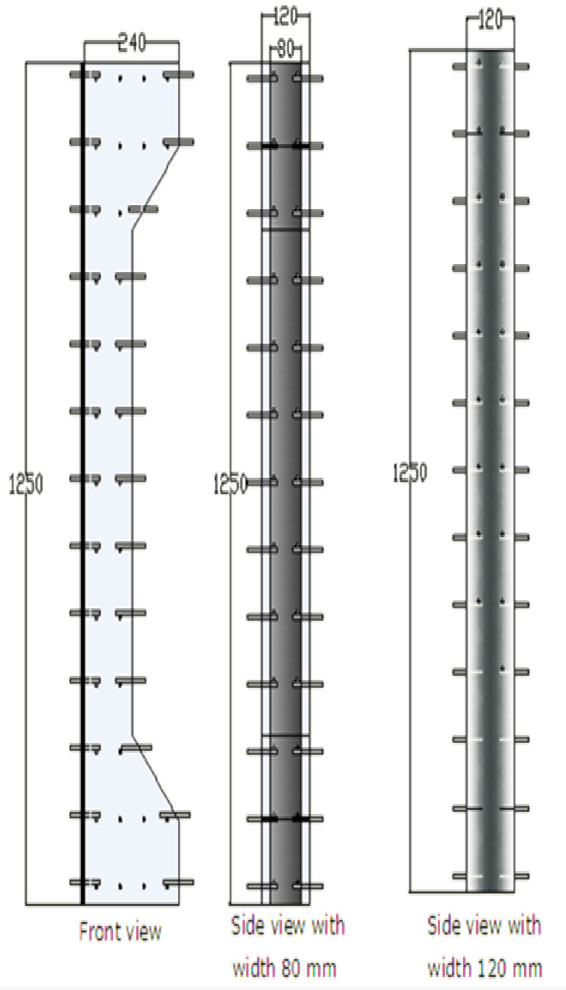


Fig. 3: apply CFRP –strips on columns.

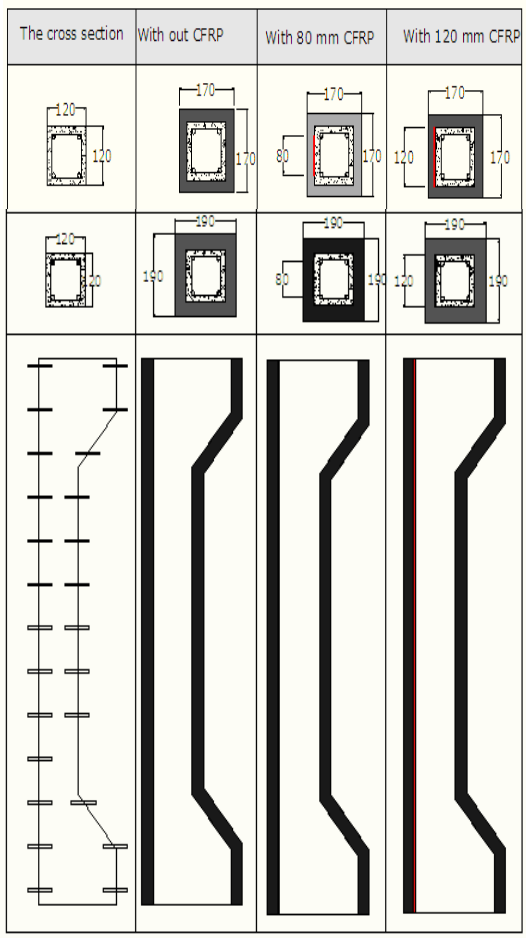


Fig. 4: Thickness of jackets for groups A, B

Fig. 5: Electro-hydraulic testing machine

Fig. 6: Loading cap with eccentricity distance.

Fig. 7: Columns placed inside testing machine..

3. RESULTS AND DISCUSSION

3.1. Load Carrying Capacity of RC Columns

The load carrying capacity reflected the ultimate applied load that can be subjected to the tested column specimens, after that a drop in machine reading appeared with a rapid deformation on column, which termed as failure. The results showed that the control column had less load capacity than the others specimens. the load carrying capacity for the Confined column was increased about (110.5,168.4,184.2)% and (157.9,226.3,263.2)% for (group A) and (group B) respectively compared with the control column due to the change in the thickness of jacketing and width of CFRP layer in the tension zone as shown in Fig. 8 and Fig. 9 below..

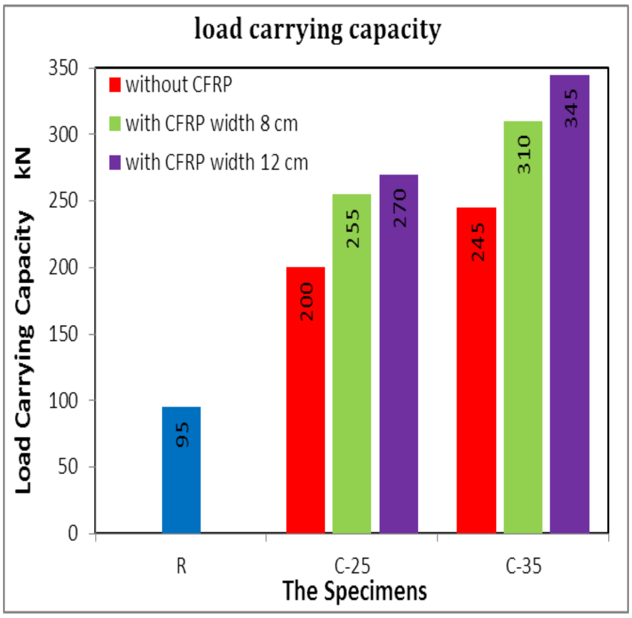


Fig. 8: The load carrying capacity for specimens.

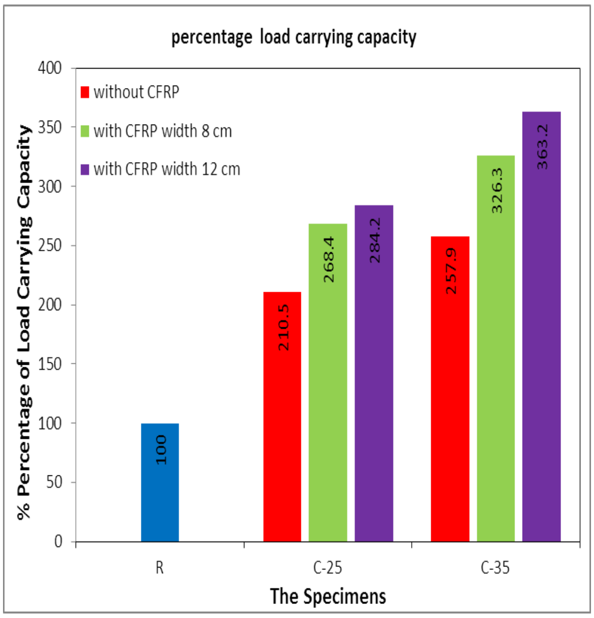


Fig. 9: The change in percentage load carrying capacity for specimens.

3.2. Mid-Height Lateral Displacement of RC Columns

The load versus mid-height lateral displacement relationship of reinforced concrete column specimens loaded at eccentricity of 120 mm for group A and B are presented in Fig. 10 and Fig. 11. The decreasing percentage of lateral displacement of these column specimens was about (66.6%,42.3%,and 35.9%) for group A and about (46.15%,38.46%,and 32.3%) for group B with CFRP width (0,8,12) cm respectively compared with the reference, which occurred immediately when they were loaded. The values of mid-height lateral displacement were decreased due to increase the size of columns and improvement the modulus of elasticity of concrete that leads to reduce the effect of cracking. So, CFRP reduces the lateral displacement of the

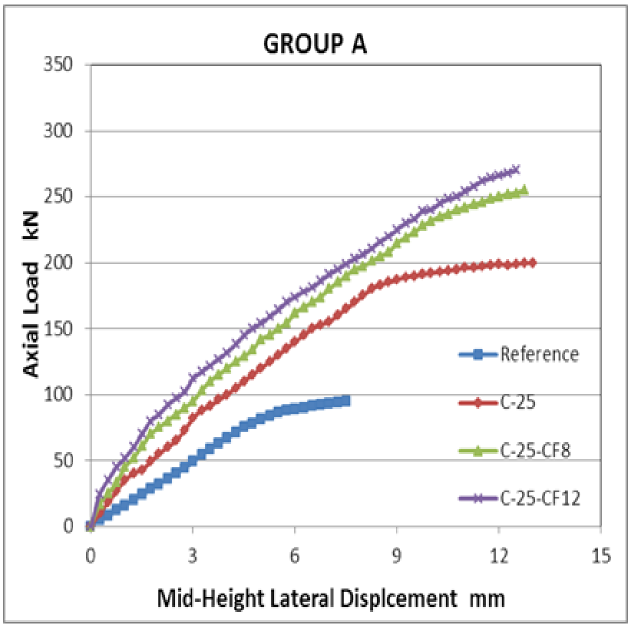


Fig. 10: Axial load carrying capacity VS the mid-height lateral displacement for group(A).

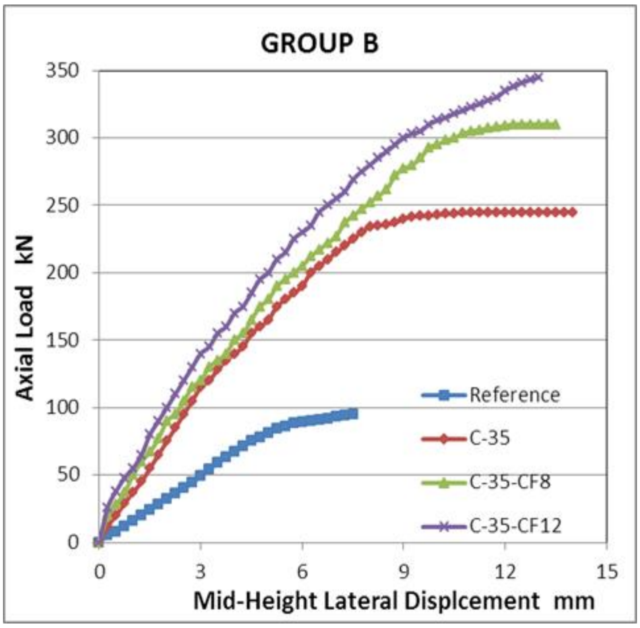


Fig. 11: Axial load carrying capacity and the mid-height lateral displacement for group(B).

strengthened column compared with specimen without CFRP because , it delays the presence of cracks and increases the strength of columns. The value of lateral displacement is taken from all strengthening specimens at same load 66.5 kN (service load about 0.7 of ultimate load of control specimens suggested by Ibrahim [27].

3.3. Axial Deformation of RC Columns

The strengthening specimens with (UHPFRC jackets, and CFRP) effected on the characteristics of axial deformation for columns with eccentric loading are presented in Fig. 12 and Fig. 13. The dial gauge was fixed on the bottom plate to measure the vertical displacement of these columns. The percentage decreasing of axial deformation was about (71.7%,60.86 %,and 55.86 %) for group (A), and about (65.5%,60.5%,and 53.4%) for group (B) compared with reference. The results clarify that specimens strengthening with thickness 25 mm (group A) has large value of axial deformation compared with columns strengthening with thickness 35 mm (group B).Also, result shows that the increasing width of CFRP leads to reduction of the axial deformation. The improvement on behavior of axial deformation of strengthened specimens is satisfying by increasing thickness of jacket and width of CFRP where that causes increase in the flexural stiffness.

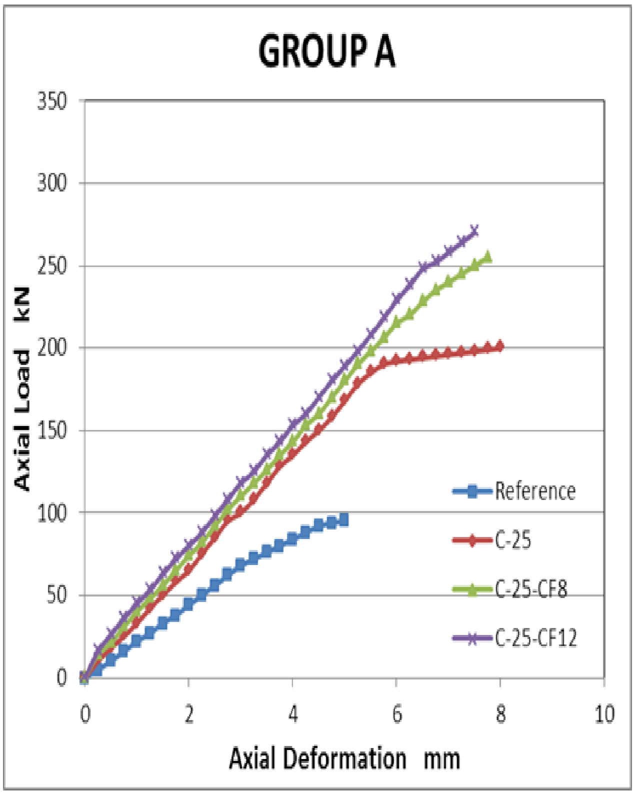


Fig. 12: Axial load carrying capacity VS the axial deformation for group(A).

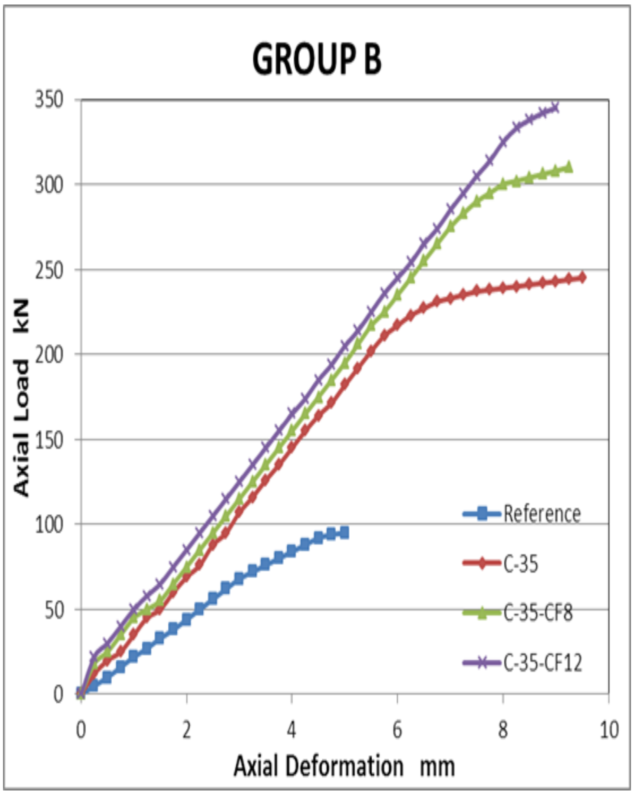


Fig. 13: Axial load carrying capacity VS the axial deformation for group(B).

3.4. Ductility of RC Columns

The ductility of the tested columns were computed using the approach developed by priestly and park[28]. They defined the displacement ductility as the ratio between the displacement at peak load (Δu) and the yield displacement (Δy), the notional yield displacement (Δy) is defined as the intersection of a line passing through a point on the load-displacement curve corresponding to 75% of the maximum applied load on the specimen (0.75Pu) is extended to intersect with the horizontal line at (Pu). The results of ductility index of columns were listed in Table 8 . (Δμ) = Δu / Δy. The results showed that increasing of UHPFRC jacketing thickness improved the ductility because the UHPFRC contented steel fibers. and using CFRP as strip in the longitudinal direction of columns in the tension zone led to reduction of the ductility as shown in Fig. 14 and Fig. 15 below.

Table 8
Ductility index test results of column specimens

Specimens Symbols	Δy	Δu	Δμ
R	4.28	5	1.17
C-25	6	8	1.33
C-25-CF8	7	7.75	1.11
C-25-CF12	7.25	7.5	1.03
C-35	6.75	5.9	1.4
C-35-CF8	8	8.25	1.16
C-35-CF12	8.5	9	1.06

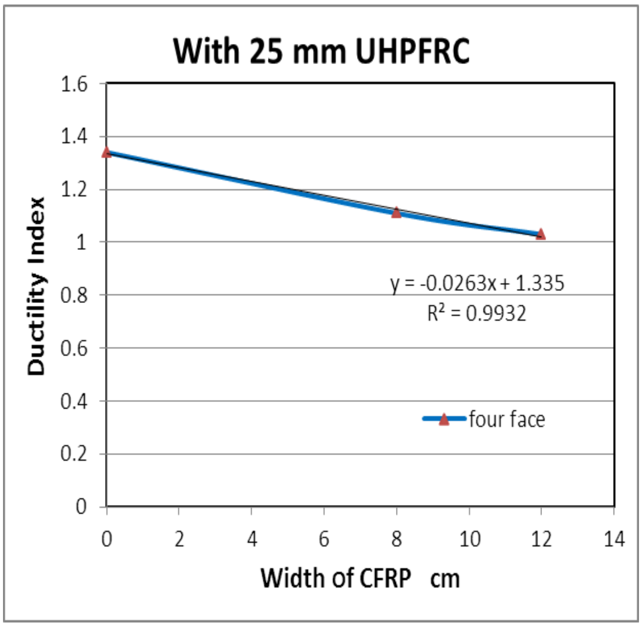


Fig. 14: Ductility index VS CFRP.

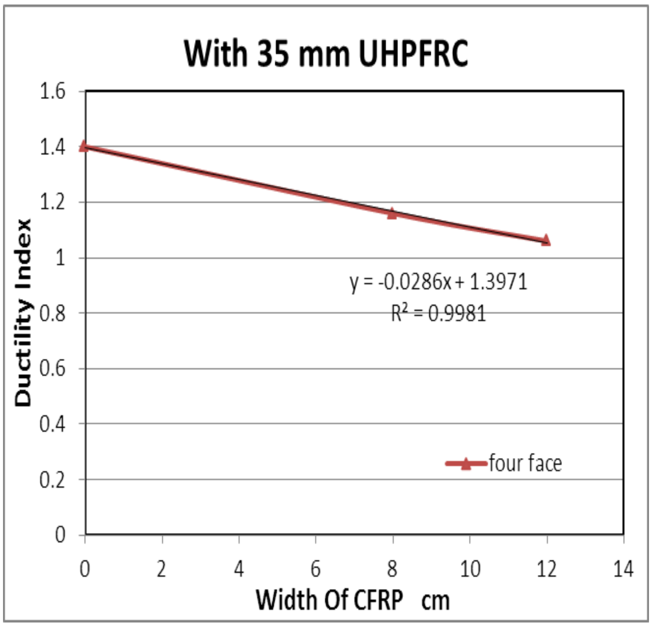


Fig. 15: Ductility index VS CFRP.

3.5.Stiffness of Column Specimens

Sullivan et al.[29] proposed two procedures that are commonly utilized to determine the stiffness of (RC) columns, secant stiffness (Ks) and initial stiffness (Kin). Secant stiffness of RC columns, is defined as the ratio of the maximum applied load on the specimen (Pu), to the maximum displacement (Δu), while initial stiffness determined by simple approach, in which a secant passing through a point on the load-displacement envelope corresponding to 70% of the maximum applied load on the specimen (0.7Pu) is extended to intersect with the horizontal line at (Pu). The results of the secant and initial stiffness columns were listed in Table 9.

The results showed that increasing the thickness of UHPFRC jacketing led to increase in the initial and secant stiffness because the section became large and improved the modules of elasticity. So, the use of CFRP in the tension zone cause increased the initial and secant stiffness because of the higher resisted of CFRP to the tension stresses that lead to reduce the cracks as shown in Fig. 16 and Fig. 17:

Table 9
Initial Stiffness and Secant Stiffness test results of columns.

Columns	Initial Stiffness				Secant Stiffness			
	Pu	*yΔ*	Kin kN/mm	Increase Kin%	*Pu*	*uΔ*	KS kN/mm	Increase Ks%
R	95	4.2	22.62	0	95	5	19	0
C-25	200	5.9	33.9	49.87	200	8	25	31.58
C-25-CF8	255	7.1	35.9	58.7	255	7.75	32.9	73.16
C-25-CF12	270	7.15	37.8	67.1	270	7.5	36	89.47
C-35	255	6.85	35.8	58.3	255	9.5	25.8	35.79
C-35-CF8	310	7.75	40	76.84	310	9.25	33.5	76.32
C-35-CF12	345	8.4	41	81.26	345	9	38.33	101.74

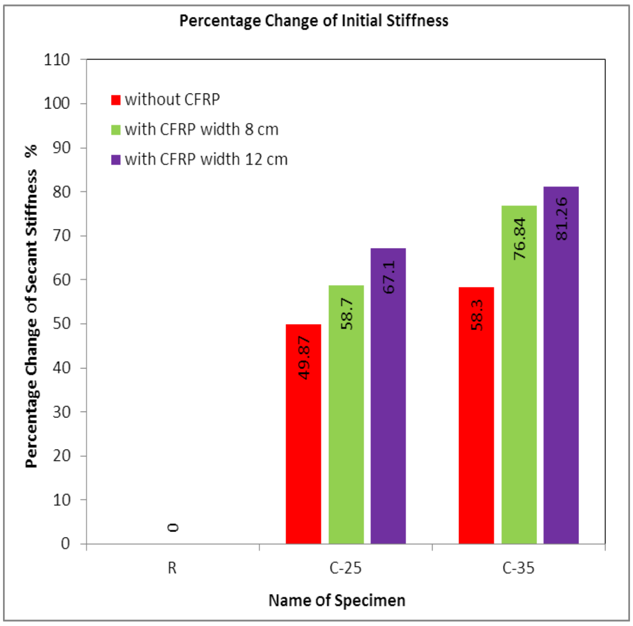


Fig. 16: Initial Stiffness

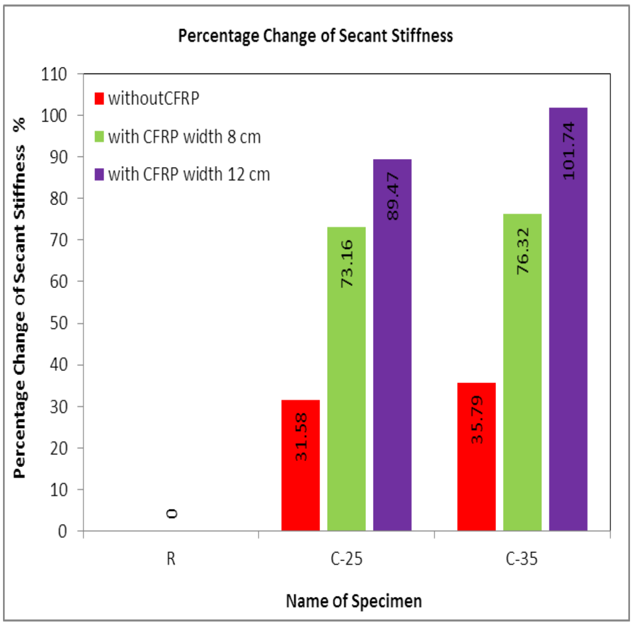


Fig. 17: Secant Stiffness

3.6.Toughness of Column Specimens

The toughness of the RC column is defined as the area surrounded by load-displacement curve till the maximum load is reached, which represents the energy absorption of the RC column that could be sustained before a significant drop in the load- capacity can be recorded Kumar et al.[30]. The results of the energy absorption of the columns are shown in Table 10 . It is obvious that the thickness of jacket and width of cfrp affect the energy absorption capacity of column specimens by increasing the energy absorption capacity as shown in Fig. 18 and Fig. 19.

Table 10
The energy absorption capacity test results of Columns.

Specimens Symbols	Energy Absorption Capacity (kN.mm)	Increasing Energy Absorption Capacity%
R	266.125	0
C-25	995.25	273.97
C-25-CF8	1068.625	301.55
C-25-CF12	1076.5	304.5
C-35	1473.5	453.69
C-35-CF8	1628.5	511.93
C-35-CF12	1661.375	524.28

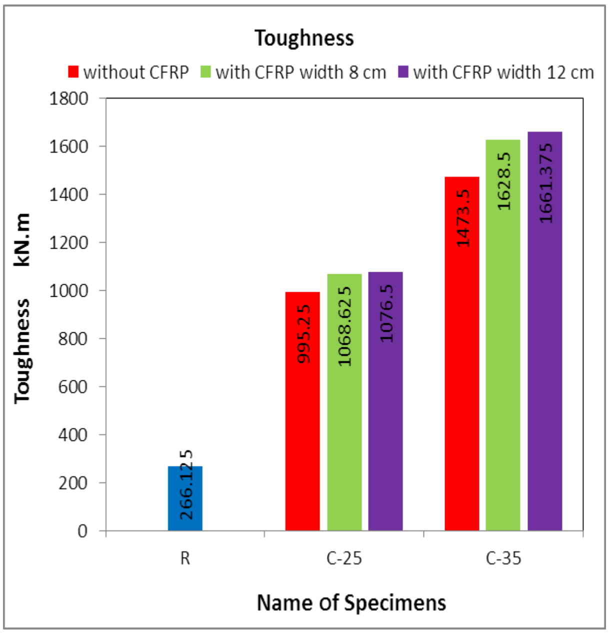


Fig .18: Toughness of Specimens

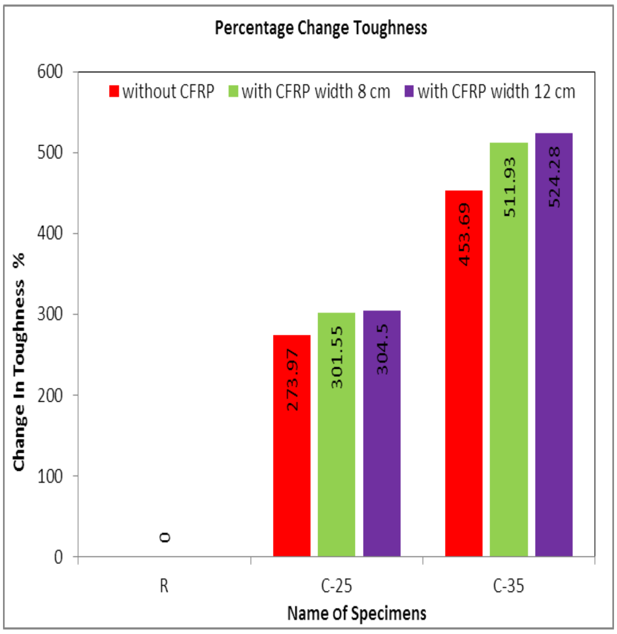


Fig. 19: Change in Toughness of Specimens

3.7. Mode of Failure

The columns were tested with eccentric load by (e/h) equal to (1) The columns tested with such type of loading often have compression failure. The side which the load shifting forward of it, exposed to compression stress, while the other opposite side has tension stresses. The failure began gradually with presence cracks in tension side and progressive spread to compression side passing through the other sides. The failure of control specimens which have in addition to cracks, crushing in compression area and yield in steel reinforcement. For specimens of group (A), the failure of the column(C-25) occurs at the tension zone, and cracks were focused in the middle third of column and occurred perpendicular to the column axis, finally, the concrete was crushed, and steel reached to the yield strain. Because, the UHPFRC jacked lead to raise the neutral axis forward the compression area of block stresses, , while for the columns (C-25-CF8,and C-25-CF12) the bonded CFRP in tension zone caused descent of the neutral axis in compression area of block stresses, and reduced the stress in tension reign, but the failure occurred in tension zone of columns as shown in Fig.20. The failure of specimens of group (B) was similar to the failure of group (A) but, the failure occurred under a larger loading, because of increasing the thickness of jacket.

Fig.20: modes of failure for specimens

4. *CONCLUSIONS*

This experimental study proposed a new strengthening technique for square RC columns that subjected to axial loaded with eccentricity. The new strengthening technique included strengthened of the square RC column with a strip of CFRP fixed in the tension zone by epoxy on the original columns, then casting jacketing of the UHPFRC with different thickness .The jackets connected with original columns by using shear connectors and curing with hot water for 28 days. Based on the experimental results of this study, the following conclusions can be drawn:

1. Using UHPFRC jacket with thickness (25, and 35)mm, increase the ultimate loading capacity about(110.5%157.9%) respectively, compared with the reference column.
2. Using UHPFRC jacket reduces the lateral displacement and axial deformation of columns because, it reduces the appearance of cracks and distributed it. Also ,it increases the ductility, stiffness and toughness of columns compared with the reference column.
3. The efficiency of UHPFRC jacket was more effective when the thickness of jacket is increased, compared with the reference column
4. Using CFRP with width (8 ,and12) cm in the tension zone between the original columns and UHPFRC jacket increases the ultimate loading capacity about (55%, and 70%), for group (A),and (65%, and 100%) for group (B), compared with the reference column .
5. Using the CFRP improves the efficiency of UHPFRC jacketing because of increasing the ultimate load carrying capacity, toughness, stiffness. And decreases the lateral displacement, axial deformation compared with reference column.
6. The experimental results showed that the technique of strengthening columns with UHPFRC jacketing and a strip of CFRP in the tension zone can be used effectively for strengthening square RC columns Under eccentric axial loads.

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