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# The Effect of Using New Techniques of Glass Fiber Laminates (GFRP) and Ferrocement Jacket on the Behavior of Strengthened RC Columns

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## ملخص البحث :

يتناول البحث دراسة معملية تهدف الى دراسة تأثير استخدام أساليب وطرق تدعيم مختلفة لتقوية الاعمدة الخرسانية المسلحة بغرض رفع مقاومتها وتحسين ممطوليتها , حيث يتناول البرنامج العملى للبحث اختبار ١١عينة من الاعمدة الخرسانية مقسمة الى خمسة مجموعات مختلفة طبقا لطرق التدعيم المختلفة, المجموعة الاولى تضم عينة وحيدة غير مدعمة وتعتبر عينة مرجعية لباقى عينات الاختبار, كما تم استخدام الالياف الزجاجية المسلحة فى المجموعتين الثانية والثالثة بنفس عدد طبقات رقائق الالياف الزجاجية بالاضافة الى استخدام غطاء خرسانى من المونة الاسمنتية البوليمرية بسمك ١٥مم فى المجموعة الثالثة فقط, اما المجموعة الرابعة فقد شملت اضافة (الفيروسمنت) الى عينات الاختبار بطبقات مختلفة من الشبك الحديد المسلح بسمك ١مم لجميع العينات, اما المجموعة الخامسة فهى تشمل عينة وحيدة بطريقة تدعيم جديدة حيث تم اضافة الالياف الزجاجية المسلحة والفيروسمنت معا. وقد أظهرت النتائج أن الالياف الزجاجية المسلحة أكثر كفاءة من الفيروسمنت فى زيادة المقاومة القصوى للاعمدة, كما أن مقاومة الاعمدة لقوى الضغط المحورية تزداد بزيادة عدد طبقات الالياف الزجاجية وأيضا بزيادة عدد طبقات الشبك الحديد المسلح. كما أظهرت النتائج دور استخدام الغطاء الخرسانى من المونة الاسمنتية لعينات الالياف الزجاجية, حيث انها تزيد من مقاومة الاعمدة لقوى الضغط بمقدار ٢٠% بالمقارنة بالعينات بدون اضافة الغطاء الخرساني كما انها تزيد من ممطوليتها, وتعتبر العينة المزودة ب ٣ طبقات من الالياف الزجاجية ومزودة بالغطاء الخرسانى هيا الاعلى مقاومة لقوى الضغط المحورية بالمقارنة بباقى عينات الاختبار.

## Abstract

Many old structures became structurally insufficient to carry the new loading conditions requirements. Moreover, they suffer structural degradation, high temperature affection, reinforcement steel bars corrosion, and bad weather conditions. The fiber reinforced polymer (FRP) materials and Ferrocement jacketing strengthening techniques established a good position among all other techniques. This paper presents the performance of the glass fiber (GFRP) lamination and Ferrocement jacket. The new techniques depended on the combination between (GFRP) and Ferrocement together, and the (GFRP) lamination with cement polymer mortar for RC columns under axial compression load (ACL). Thirty three specimens with eleven models were tested after using the strengthening techniques. This paper aims to achieve two main targets. First, it aims to examine the effect of applying GFRP laminate and Ferrocement jacketing. The second target lies in using new techniques, which study the effect of using cement-polymer mortar as an outer coating on the behavior of the (GFRP) lamination specimens, and the combined technique between GFRP laminate and Ferrocement jackets for RC columns. The studies include 1, 2, and 3 number of the wrapped layers of the (GFRP), and wire mesh for the Ferrocement jacketing. The results showed that (GFRP) technique is more efficient than Ferrocement technique. They also showed that the composite technique is the most effective technique compared with the models in the same case. On the other hand the outer coating of (GFRP) specimens increased the ultimate failure load by 20% comparing with specimens without coating.

**Key Words:** Ferrocement jacketing, glass fiber reinforced polymer (GFRP), laminate, reinforced concrete, cement-polymer mortar, strengthening, new techniques,

# 1. Introduction

Reinforced concrete structures often require strengthening to increase their capacity to sustain loads. This strengthening may be necessary due to the change in use that resulted in additional live loads, deterioration problems of the load carrying elements, high temperature resulted from fire exposure, and design errors. These situations may require additional concrete elements or the entire structure to be strengthened, repaired, or retrofitted.

Common methods of strengthening columns include fiber reinforced polymer (FRP), concrete jacketing, steel jacketing, or Ferrocement jacketing. All these techniques have shown the effective increase in axial load capacity of columns, [1]

Little attention was paid to the effect of applying outer coating from cement plaster to the strengthened columns with (GFRP) laminates, so in this research outer coating was added to the (GFRP) in addition to using new technique which consisted of 1 layer of wire mesh added to the outer coating.

# 2. Background

Over the last two decades, many researchers initiated studies to determine the effect of different techniques in strengthening concrete columns. Some of these studies focused at using Ferrocement, CFRP, and GFRP as a technique of strengthening for RC columns. Few researchers studied the effect of adding an outer cover to the GFRP technique as a protection material, and no one spotted using GFRP laminate and Ferrocement jacketing together in the same specimen as a technique of strengthening.

Researches of Ferrocement technique studied the behavior of strengthened RC columns with different parameters; (shear, shear connectors, load capacity, stiffness, and ductility). K.Alenezi. [2] studied the behavior of shear connectors of the composite columns assembled together as a precast member. He came to the conclusion that the shear connector with 12mm diameter showed the highest shear capacity. On the other hand, Mohamed Taghi Kazemi et al. [3] studied seismic shear strengthening of R/C columns with Ferrocement jacket, and they concluded that using Ferrocement jacket had a great effect for

For strengthen shear deficient. Kaish et al [4] studied Ferrocement jacketing as a strengthed technique for square short column. He concluded that using additional wire mesh for the corner of the square cross-section decreased the concentration of stresses in this area. Xiong.[5] Studied strengthening the plain concrete columns with Ferrocement technique including steel bars. Ahmed M. El-Kholy et al. [6] studied the improving confinement of reinforced concrete columns. The results showed that the columns, confined with proposed lateral reinforcement, revealed significant improvement in the strength and ductility.

In the same way, researches of GFRP and CFRP technique focused on the performance of the strengthened RC columns under different conditions, Niloufar Moshiri et al. [7] studied the effect of strengthening RC columns by longitudinal CFRP sheets. They achieved that CFRP sheets postponed the buckling, subsequently the load capacity of the specimens. Amer M. Ibrahim et al. [8] studied the behavior and strength of bearing wall strengthening by CFRP. The results showed the efficiency of using CFRP as strengthening technique, subsequently increased the bearing load and the stiffness. P.Sangeetha.[9] studied the behavior of the GFRP wrapped concrete columns under uniaxial compression, the results of the study showed that confinement increased the strength of the concrete columns loaded axially. Qais F.Hasan et al.[10] studied NSM rebar and CFRP laminate strengthening for RC columns subjected to cycle loading. The results of this paper showed enhancement of the overall behaviors of columns like, crack pattern, yield and ultimate cyclic load capacities, and ductility ratios.

Finally, Hossam Z. el-karmoty. [11] studied the thermal protection of reinforced concrete columns strengthed by GFRP laminate and he achieved that confining reinforced concrete columns with GFRP laminates increase the ultimate failure load up to 19%. Lila M. Abdel-Hafiz et al. [12] studied the behavior of RC columns retrofitted with CFRP exposed to fire under axial load. The results showed that CFRP materials were still confined with the column for more than 70min with temperature. Fahmy A. Fathelbab et al. [13] studied strengthening of RC bridge slab using CFRP sheets. The results showed that attaching FRP sheets to the RC slab increased its capacity and enhanced the ductility.

The purpose of this paper is to determine the effect of using Ferrocement jacketing with different numbers of wire meshes, GFRP laminate with different layers, and the combined technique between them as a strengthening techniques at reinforced concrete columns.

## 3. Experimental work

### 3.1. Materials

Different materials were used in this research, such as concrete with its different components in addition to the strengthening materials from Ferrocement jacketing to GFRP laminate. The properties of different materials were listed in **Table (2).**

## 3.1.1 Concrete materials

The reinforced concrete for columns specimens consisted of fine, and coarse aggregate, cement, water, and steel. The used fine and coarse aggregate in this research were natural sand from 6 October quarries and basalt from Sinai quarries. They were tested according to Egyptian standard specifications. In the same way, the cement that was used in this research was Ordinary Portland Cement (OPC) ,and it was tested according to Egyptian standard specification.

There are two types of the steel reinforcement were used in this research. The first type was high tensile steel with yield strength Fy = 360 N/mm$^2$ for the longitudinal bars with diameter 10mm. The second type was mild steel with yield strength Fy = 280 N/mm$^2$ for the stirrups, with diameter 6mm.The mechanical tests were performed on the two types of steel. Finally, the water that was used in this research was ordinary tap portable water.

## 3.1.1.2 Concrete Mix Design

The achieved compressive strength of the mixing concrete was 25Mpa. Table (1) showed the concrete mix for one cubic meter.

**Table 1:** Concrete mix content by weight for one cubic meter of concrete.

| Mix. No. | Cement(Kg) | Water (lit). | Fine Agg.(Kg.) | Coarse Agg.(Kg.) |
|---|---|---|---|---|
| 1 | 350 | 175 | 650 | 1300 |

A standard cubes with dimensions 150×150×150 mm were casted and curing, mixing was performed in a horizontal pan mixer. The fine and coarse aggregates were blended in the mixer, and then the mixer was rotated to provide a uniform distribution of aggregates. Cement was then added followed by water. The contents were then thoroughly mixed mechanically for a period of three minutes.

## 3.1.2 GFRP laminates

### 3.1.2.1 Sika-wrap Hex 430G

The GFRP laminated (Sika-wrap Hex) was about fibers with thickness 0.173 mm, and width 500mm. the density of the material was 2.54gm/cm$^3$. Tensile strength was 22760 kg/cm$^2$. **Figure (1)** showed the used laminated material.

### 3.1.2.2. Epoxy resin (Sikadur-330)

This material was divided into two components (A, and B) with ratio (4:1). The weight of the two component 4 kg, 3.2 for component A, and 0.80 kg for component B. density of the composite material is 1.31 kg/lt. Tensile strength is 300 kg/cm$^2$ for the epoxy resin.

## 3.1.3 Ferrocement jacket

### 3.1.3.1 Steel Anchors

Steel anchors of nominal diameter 8 mm and length 70 mm were used for fixing the steel wire mesh to the concrete specimens before mortar.

### 3.1.3.2 Steel wire meshes

One type of steel wire mesh was used in this paper. The type was expanded wire mesh with closely hexagonal openings showed in **Figure (2).**

**Table 2:** properties of used materials

| Materials | Parameter | Properties | values |
|---|---|---|---|
| **Sikadur-330** | | Tensile strength(kg/cm$^2$) = | 300 |
| | | Elongation (%) = | 0.90 |
| **Sikawrap-Hex430 G** | | Tensile strength (kg/cm$^2$) = | 22760 |
| | | Elongation (%) = | 4.0 |
| **Silica fume** | | Bulk Density(kg/m$^3$) = | 660 |
| **Addicrete (BVF)** | | Density(kg/m$^3$) = | 1.18 |
| **Addibond(kg/m$^3$)** | | Density(kg/m$^3$) = | 1.02 |
| **Cement** | | Strength after 3 days(kg/cm$^2$) | 210 |
| | | Strength after7 days(kg/cm$^2$) | 290 |
| **Steel** | 10mm | (Tensile strength kg/cm$^2$) | 4998 |
| | 6mm | (Tensile strength kg/cm$^2$) | 5410 |

## 3.1.4 Ferrocement and GFRP Cement Plaster

The mix proportion of the cement-polymer plaster was 1:2 by weight of cement and sand, respectively. The water to cement ratio was 0.40.The ratio of the Silica fume

(SF) was 10% from the weight of the cement. Super-plasticizer (Addicrete BVF) was 1.50% from the weight of the cement. The Addibond (65) ratio was about 1:3 from the weight of water. The compressive strength of mortar was achieved 42.5Mpa at 28 days of curing. **Table (3)** showed the mix proportions for six cubes of cement plaster.

**Table 3:** The mix proportions for the six cubes of cement plaster

| Mix.No | Cement (kg) | Sand (kg) | Water (lit) | Silica-fume kg) | Addicrete BVF(lit) | Addibond (lit) | W/C | Fcu ($kg/cm^2$) 28 days |
|---|---|---|---|---|---|---|---|---|
| **Mix.1** | 1.5 | 3 | 0.60 | 0.150 | 0.015 | ------- | 0.40 | 310 |
| **Mix.2** | 1.5 | 3 | 0.60 | 0.150 | 0.015 | 0.200 | 0.40 | 425 |
| **Mix.3** | 1.5 | 3 | 0.60 | 0.150 | ------- | 0.200 | 0.40 | 360 |
| **Mix.4** | 1.5 | 3 | 0.60 | 0.150 | ------ | -------- | 0.40 | 275 |

From the results of **table (3),** the mix 2 with polymer addictive had the highest compressive strength comapred with the other mixes. These results refered to the role of adding polymer material (Addibond65) to the cement plaster, as we reached cement mortar with high strength up to 425 $kg/cm^2$ after 28 days from casting and curing.

**Figure1:** GFRP Laminate (Sikawrap)

**Figure 2:** Hexagonal steel wire mesh

## 3.2. Preparations of test specimens

A total number of 33 reinforced concrete column specimens with height of 1000 mm, and initial cross-section 100×120 mm were constructed and tested under axial compression. Each type of specimen had 3 samples to get the average results. The test specimens were divided into five series (CC, CG, CGW, CF, and CFG) based on their technique of strengthening. **Table (4)** showed the details of the specimens.

### 3.2.1 Classification of the test models

Series C consisted of one column with cross-section 100×120 mm, without any strengthening technique. Four deformed steel bars with 10-mm diameter were used as internal reinforcement providing a longitudinal steel ratio "$\mu$= 2.50%"

Series CG included 3 columns with rectangular cross-section 100×120 mm. The internal steel bars as the same of CC series. The (GFRP) was applied with 1, 2, and 3 layers for specimens CG1, CG2, and CG3, respectively.

Series CGW were the same as series CG, beside of adding a coating material from a cement-polymer plaster with 15 mm from all side of the specimen's cross-section. The final cross section of the series CGW reached 130×150 mm.

Series CF included 3 columns specimens with initial cross-section 100×120 mm. the Ferrocement jacketing was applied with 1, 2, and 3 layers of hexagonal wire mesh with thickness 1mm for specimens CGW1, CGW2, and CGW3, respectively. Cement – polymer plaster was applied to the specimens with thickness 15mm from all side of the cross-section, so the final cross-section was to 130×150 mm.

Series CFG included one specimen, strengthened with 1 layer of (GFRP), and 1 layer of hexagonal wire mesh, then, cement plaster was applied with thickness 15mm from all side of the cross-section, so that, the final cross-section was 130×150 mm.

**Table 4:** Details of the research specimens:

| Series | Specimen | Cross-section(cm) | Length (cm) | Slenderness ratio | RFT | Parametric study |
|---|---|---|---|---|---|---|
| **CC "Control"** | C | 10×12 | 100 | 10 | 4Φ10 | **Control-specimen** |
| **CG "GFRP"** | CG1 | 10×12 | 100 | 10 | 4Φ10 | **One layer GFRP** |
| | CG2 | 10×12 | 100 | 10 | 4Φ10 | **Two layers GFRP** |
| | CG3 | 10×12 | 100 | 10 | 4Φ10 | **Three layers GFRP** |
| **CGW "GFRP with Coating"** | CGW1 | 13×15 | 100 | 7.7 | 4Φ10 | **One layer GFRP with coating** |
| | CGW2 | 13×15 | 100 | 7.7 | 4Φ10 | **Two layers GFRP with coating** |
| | CGW3 | 13×15 | 100 | 7.7 | 4Φ10 | **Three layers GFRP with coating** |
| **CF "Ferrocement"** | CF1 | 13×15 | 100 | 7.7 | 4Φ10 | **One layer wire mesh** |
| | CF2 | 13×15 | 100 | 7.7 | 4Φ10 | **Two layers wire mesh** |
| | CF3 | 13×15 | 100 | 7.7 | 4Φ10 | **Three layers wire mesh** |
| **CFG "GFRP &Ferrocement"** | CF1G1 | 13×15 | 100 | 7.7 | 4Φ10 | **One layer GFRP +one layer wire mesh with coating** |

## 3.3. Instrumentation and testing

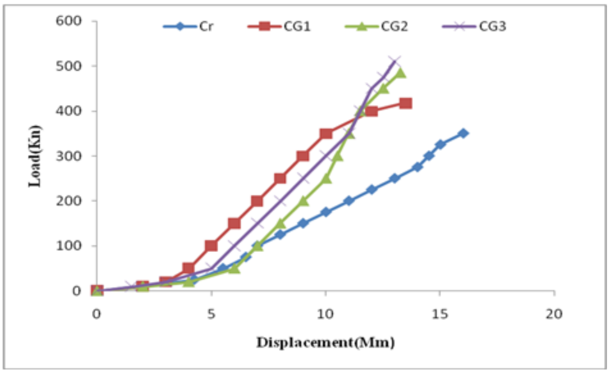
The specimens were subjected to axial compressive loading. Tests were executed using hydraulic loading machine of 1000 KN capacity. All series specimens were placed on the rigid two RC blocks that was rested on the rigid steel floor of the machine. Rigid steel plates were fitted under and above the ends of the column specimens. Vertically of column specimen was carefully examined and adjusted to ensure perfect centric loading on the column. Steel jackets were clamped and bolted together with high strength bolts to provide enough confinement at loading and supporting ends. One vertical displacement transducers was used at top of the column specimen in vertical direction to measure the axial deflection. The load and displacement were monitored and logged using an automatic data acquisition system.

## 4. Experimental results and discussion

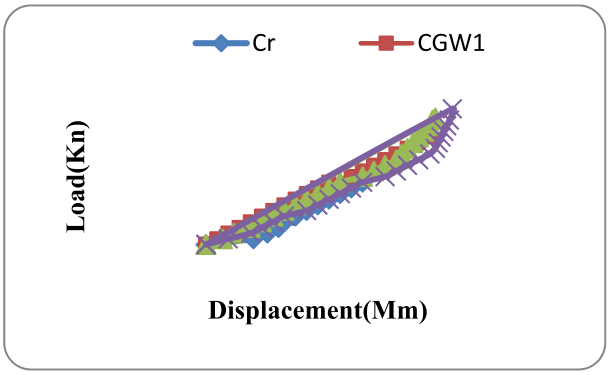
All specimens were tested up to failure. The load and displacement data were collected using the data logger connected to the compression machine. The test results of all series are presented in **Table 5.**

**Table 5:** Test results of all specimens

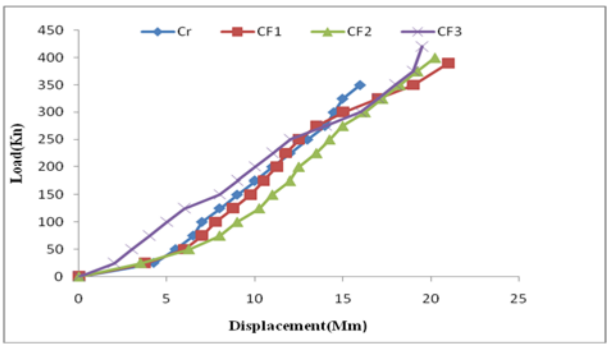
| Series | Specimen Code | $P_{ult}$ (kN) | (P/Pc) % | Displacement (mm) at ( $P_{ult}$) | (D/ Dc) % | Energy ($E_{ult}$) (KN.mm) | ($E_{ult}/E_c$) % |
|---|---|---|---|---|---|---|---|
| **CC** | C | 340 | 100% | 16 | 100% | 2156 | 100% |
| **CG** | CG1 | 418 | 123% | 13.50 | 84% | 2695 | 125% |
| | CG2 | 485 | 143% | 13.25 | 83% | 2875 | 133% |
| | CG3 | 510 | 150% | 13.00 | 82% | 3225 | 149% |
| **CGW** | CGW1 | 475 | 140% | 20 | 125% | 3415 | 158% |
| | CGW2 | 560 | 165% | 20.50 | 128% | 4778 | 221% |
| | CGW3 | 600 | 176% | 22.00 | 137% | 5400 | 250% |
| **CF** | CF1 | 390 | 115% | 21 | 131% | 3780 | 175% |
| | CF2 | 400 | 118% | 20.25 | 126% | 4120 | 191% |
| | CF3 | 420 | 124% | 19.50 | 122% | 4536 | 210% |
| **CFG** | CF1G1 | 500 | 147% | 14.25 | 89% | 4720 | 219% |



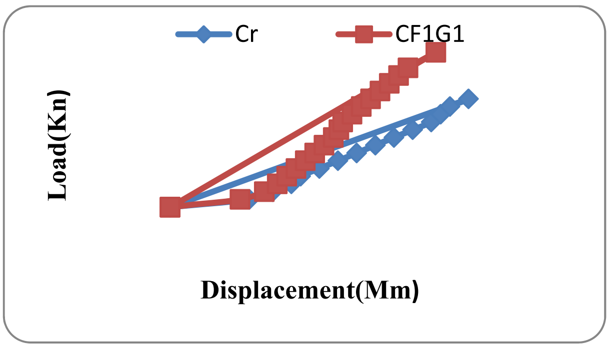

A) Series (CG)




B) Series (CGW)




C) Series (CF)




D) Series (CFG)

**Figure 3:** Load-displacement curve for series "CG, CGW, CF, CFG"

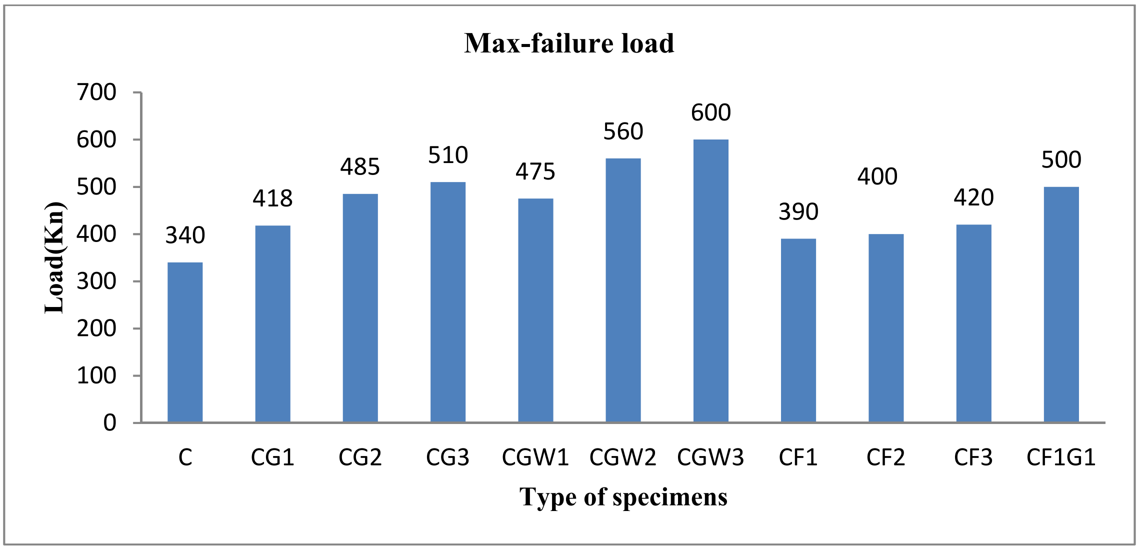



**Figure 4:** Maximum failure load of all specimens.

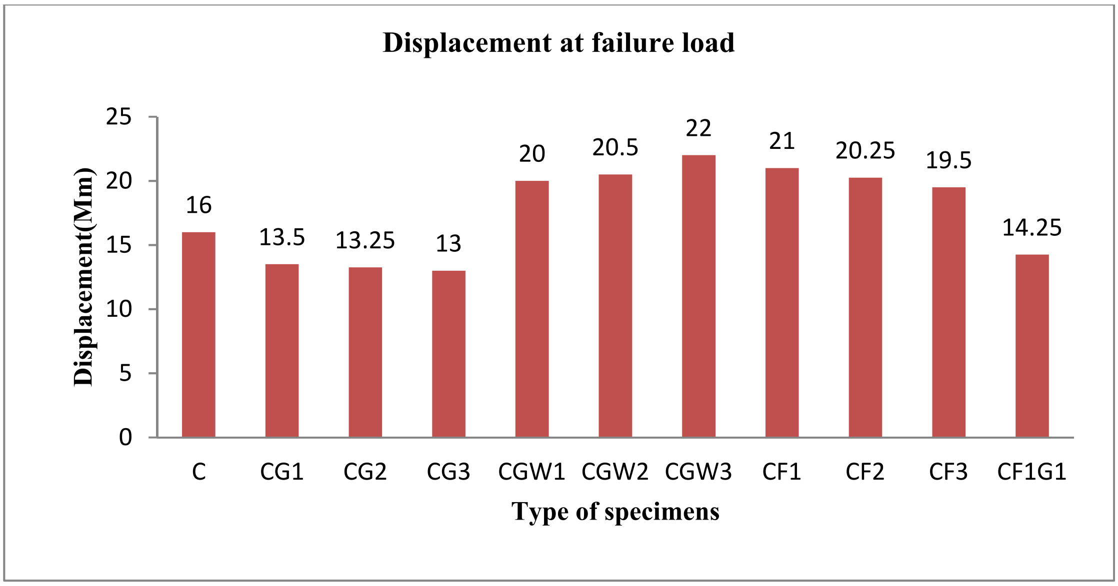



**Figure 5:** Load-Displacement curve for all specimens.

## 4.1. Series CC (Control)

The results of the test program show that the maximum load capacity and the vertical displacement at this load were 340 KN, 16mm, respectively.

## 4.2. Series CG (GFRP)

The percentage of increasing in the maximum failure load corresponding to the control specimen for columns model CG1, CG2, and CG3 were 123%, 143%, and 150% respectively. In the same way, the percentage of decreasing in vertical displacement, compared with the control specimens for columns model CG1, CG2, and were 84%, 83%, and 82% respectively.

The energy absorption increased by the increase in GFRP lamination layers with percentage 125%, 133%, and 149% for 1, 2, and 3 layers, respectively.

The column models with 3 GFRP layers had the highest value of ultimate failure load, and the lowest value of the vertical-displacement comparing with the control model, and the other models in the same series.

## 4.3. Series CGW (GFRP with Coating)

The percentage of the increase in the maximum failure load compared with the control specimen for columns model CGW1, CGW2, and CGW3 were 140%, 165%, and 177%, respectively , In the same way, the percentage of the increase in vertical displacement compared with the control specimens for columns model CGW1, CGW2, and CGW3 were 125%, 128%, and 137%, respectively.

The difference between series CGW, and CG was the coating that was applied after applying GFRP Technique, so the results of the maximum ultimate load for CGW series specimen were about 115% comparing with CG series specimen for each case.

The energy absorption was increased by the increase in GFRP lamination layers with percentage ١٥٨%, ٢٢١%, and ٢٥٠% for 1, 2, and 3 layers, respectively.

The column models with 3 GFRP layers with coating had the highest value of ultimate failure load, and the highest value of the vertical-displacement comparing with the control model, and the other models in the same series.

## 4.4. Series CF (Ferrocement)

The percentage of the increase in the maximum failure load about the control specimen for columns model CF1, CF2, and CF3 were 115%, 118%, and 124%, respectively. In the same way, the percentage of the increase in vertical displacement about the control specimens for columns model CF1, CF2, and CF3 were 131%, 126%, and 122%, respectively.

The energy absorption was increased by the increase in GFRP lamination layers with percentage 175%, 191%, and 210% for 1, 2, and 3 layers of wire mesh, respectively.

The column models with 3 wire mesh layers had the highest value of ultimate failure load, the lowest value of the vertical-displacement comparing with the control model, and the other models in the same series.

## 4.5. Series CFG (GFRP and Ferrocement)

The percentage of the increase in the maximum failure load about the control specimen for column model was 147%, and 89%.

The maximum load capacity of CF1G1 specimen considered the highest result comparing with the specimens with the same case, such as CG1, CGW1, and CF1.

## 4.6 Failure modes

**Figure 6** showed the failure modes of all specimens. It was observed that the failure mode crushed in most specimens at mid-height, in some specimens at top of specimens, and the others were at the bottom of the specimens.

From the crack patterns of specimens, it was showed that Ferrocement jacketing specimens were more ductile than GFRP techniques; on the other hand, GFRP laminate specimens were more brittle, it is result to the effect of epoxy resin in GFRP.

Using a polymerized cement mortar as a coating or in Ferrocement mortar helped to make a failure mode more ductile.

**6. (a)**

Control Specimen's failure "C"

**6. (b)**

Specimen "CG"

**6. (c)**

"CG2" Specimen

**6. (d)**

"CG3" Specimen

**6. (e)**
”CGW1” Specimen

**6. (f)**
”CGW2” Specimen

**6. (i)**

"CGW" Specimen

**6. (j)**

"CF1" Specimen

**6. (k)**

"CF2" Specimen

**6. (l)**

"CF3" Specimen

**6. (m)**

"CF1G1" Specimen

**Figure 6**: Modes of failures for all the test specimens

## 5. Conclusion

This research has presented many different techniques used to enhance the behavior of the RC column under axial compression load; different parameters were used in this, and the major conclusions derived from this study can be summarized as follows:

1. The used of polymer cement mortar coating over 3 layers of GFRP was effective more than using GFRP only. In the same way, the increasing of ultimate load and energy absorption were 76 % and 150%, respectively comparing with the control specimen.
2. A combination between 1 layer of GFRP and 1 layer of Ferrocement increase the ultimate load and energy absorption by 47 % and 119% respectively more than the unstrengthened columns. This technique had a great bearing under the effect of the axial compression load, as it was compared with the specimens at the same case. The wire mesh had a great benefit for the confinement of the coating with the any surface of column, as it made a great cohesive between coating and the old concrete or coarse GFRP surface , as the failure of the specimens occurred for the coating and the reinforced concrete specimens at the same time.
3. New techniques had a great effect on the load capacity, energy absorption and it was more low cost than using GFRP only. it was increased the ductility of reinforced concrete columns.
4. The cement plaster that was applied for the series CGW, CF, and CFG had a compressive strength after 7 days reached to 273 $Kg/Cm^2$, and 425 $Kg/Cm^2$ after 28 days from casting, so these results referred to the effect of adding polymer materials to the cement mortar.
5. Adding polymer materials to the cement mortar, helped to increase the cohesive between coating and the old concrete or GFRP laminates. It was effect on the mode of failure and increases the ultimate column load capacity.
6. The maximum load capacity between the test columns was for "CGW3" specimen with 600 KN, and CGW2 became in the second place with 560 KN, and the lowest specimen was C the control specimen with ultimate load equal 340 KN, and CF1 became at the second place with ultimate load equal to 390 KN.
7. Applying GFRP technique to the reinforced concrete columns increased the maximum load capacity by 123%, 143%, and 150% for 1, 2, and 3 layers respectively comparing with columns without strengthening.
8. Applying Ferrocement jacketing to the reinforced concrete columns increased the maximum load capacity by 115%, 118%, and 124% for 1, 2, and 3 layers of wire mesh respectively, comparing with columns without strengthening
9. The effect of applying GFRP technique was greater than the effect of the Ferrocement jacketing on the axial compressive bearing of the concrete columns, but it was more cost than the Ferrocement technique.
10. From modes of failure of the test specimens, it was observed that Ferrocement jacketing specimens were more ductile than GFRP technique; on the other hand, GFRP specimens were more brittle than other specimens.

11. Used a polymer cement mortar coating over the layers of GFRP increase the ductility of GFRP lamination system.

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