Repairing of Circular Reinforced Concrete Columns Damaged By Heat Using Carbon Fiber Reinforced Polymers (CFRP) (Rope) Technique

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Abstract. This study investigated the behavior of repaired circular reinforced concrete RC columns exposed to temperature considering effect of spacing between CFRP ropes, number of layers of carbon fiber reinforced polymers CFRP and degree of temperature. Six circular RC specimens divided into two groups with diameter of 185 mm and length of 800 mm were tested. First and second groups consisted of three RC columns exposed to temperature degree of 400°C and 600°C, respectively. In each group, the first column used as control specimen, the second and third RC columns were repaired using one layer and two layers of CFRP ropes, respectively. The results showed that the repaired RC columns damaged by heated up to (400 °C and 600 °C) with one layer of spacing 100 mm and two layers of spacing 200 mm exhibited load capacity about (140% and 188%) and (123% and 164%), respectively as control specimen. Hence, one layer of CFRP rope at spacing of 100 mm was more effective than two layers at spacing of 200 mm. In addition, as the exposure temperature of fire increases, the regained capacity of the repaired column increase.

1. Introduction

The RC column can be damaged due to several reasons such as: blasts, short-term exposure to temperature (heat), earthquakes, and preloading. As such the RC column may be demolished or repairing according the cost. Recently, the studies used CFRP near surface mounted (NSM-CFRP ropes) on strengthening or repairing the RC elements due to low costs and save time compared to demolishing. The effect of heat level on load-displacement behavior of circular RC column was investigated in this study. The concrete modes failure by fire exposure depends on the fire nature, duration and types of structure. The failure occurred by exposed to temperature may lead to reduce of bending or tensile, or shear or torsional strength. If the damage is not severe and can be repaired, the strengthening and repairing of the structural element are often more economic because the demolishing is required a huge investment.

Using CFRP material is considered a preferable material on strengthening and repairing RC column due to its significant performance [1]. Columns are needed to strengthening in order to increase the shear, axial, and flexural capacities due to eccentric loading, lack of confinement, seismic loading, and corrosion [2]. Using FRP materials on repairing RC elements showed an increase in ductility, compressive load capacity and compared to unconfined RC element [3-8]. The RC element can be bonded by FRP to the outer face
using high strength epoxy [9]. FRP reinforcement can be installed in the required grooves in any directions cut into the RC element. This type of FRP is known as near surface mounted which is a promising technology (NSM) [10]. The NSM technique showed an increase in the flexural strength more than the externally bonded FRP [11-12].

In this study a flexible NSM is developed to strengthening and repairing the circular RC columns. The columns repaired or strengthened with NSM-CFRP ropes exhibited more efficiently than ones repaired or strengthened with CFRP sheet [13]. The purpose of this study is to investigate experimentally the effect of heat levels and effectiveness of NSM-CFRP ropes for strengthening columns tested under axial compression on the behavior of damaged circular RC column.

2. RC circular columns construction and design

To achieve the objective of this study, a total of 6 full-scale RC circular columns were constructed. These specimens were divided into two main groups of three specimens (Table 1). All columns had dimensions with 185 mm diameter cross section and 800 mm in height. All six specimens were constructed with 23 MPa of concrete strength. They had longitudinal reinforcement of ø10 mm deformed bars with 450 MPa yield strength and transverse reinforcement of ø8 mm bars, at spacing of 95 mm center to center with 248 MPa yield strength. The side concrete cover to the longitudinal bars was 30 mm and a cover of 20 mm between the top of column to the first tie. The designation of the specimens was as follows: the first letter, DC, represents the damaged column. The second letter, H, denotes a temperature degree. The third letter, L, denotes a number of layers. Finally, fourth letter, S, represents a spacing between cords. The reinforcement cage was first prepared and fixed in a wooden base that fabricated with six holes in the center. A 5.9 mm thickness of special PVC pipes was used in casting the specimens. The PVC pipe were with external diameter 200 mm, inner diameter 185 mm and with height of 800 mm.

Finally, all six column specimens were placed in electric furnace. First group and second group were exposed to heat temperature of 400°C and 600°C, respectively for three hours.

| Group | Specimen | RC Specimen ID | Concrete Strength (MPa) | Temperature (°C) | CFRPFX layers |
|-------|----------|----------------|------------------------|-----------------|---------------|
| 1     | 1        | DC-H400-Control | 23                     | 400             | -             |
|       | 2        | DC-H400-L1-S100 | 23                     | 400             | one           |
|       | 3        | DC-H400-L2-S200 | 23                     | 400             | Two           |
| 2     | 1        | DC-H600-Control | 23                     | 600             | -             |
|       | 2        | DC-H600-L1-S100 | 23                     | 600             | one           |
|       | 3        | DC-H600-L2-S200 | 23                     | 600             | Two           |

3. Repairing of specimens using CFRP ropes

The groove with 20 mm depth in the concrete cover was produced in order to install the CFRP ropes. Figure 1 shows the steps of preparing grooves. Finally, the grooves were cleaned from dust using a vacuum cleaner "hoover". Thereafter, volatile liquid was used to reduce moisture content to achieve better bond with CFRP ropes (Figure 1).

First and second specimens in each group were repaired using (CFRP) SikaWrap® FX-50 C (NSM-CFRP rope), one rope at 100 mm and two ropes at 200 mm, respectively. Meanwhile, third specimen was not repaired and used as control specimen. The sikadurl® 52 LP adhesive was used to fill the grooves. The ends of all specimens were strengthened using SikaWrap®-230 C (sheet) manufactured by SIKA that glued by sikadur® 330 LP. The Physical and Mechanical Properties of SikaWrap® FX-50 C Ropes and SikaWrap® -230 C Sheet is listed in Table 2. Installing the CFRP ropes was carried out as follows: Cut the CFRP ropes; fill the grooves by the resin Sikadur®-52; adding a suitable amount of Sikadur-52 epoxy resin
to the CFRP ropes until it reaches at saturation phases; filling the groove with Sikadur®-52 adhesive using a plastic blade; inserting the CFRP ropes carefully into the grooving using the plastic blade to reach the bottom of the groove; In the case of adding two layers we repeated the previous steps (Figure 2). Figure 3 shows repaired and control column specimens after exposing to heat temperature of 400 °C and 600 °C.

**Figure 1.** Grooving of specimens and preparation of concrete surface.

**Table 2.** Physical properties of SikaWrap® FX-50 C ropes and -230 C sheet.

| Product Data | NSM-CFRP rope | CFRP sheet |
|--------------|---------------|------------|
| **Technical Data** | | |
| Areal Weight | 50 g/m² (carbon fibers only) | 304 g/m² + 10 g/m² (carbon fibers only) |
| Fabric Thickness | 2.98 mm (based on fiber content) | 0.167 mm (based on fiber content) |
| Fiber Density | 1.82 g/cm³ | 1.82 g/cm³ |
| **Mechanical / Physical Properties (Dry Fiber)** | | |
| Tensile Modulus | 240'000 N/mm² | 230'000 N/mm² |
| Tensile Strength | 4'000 N/mm² | 4'000 N/mm² |
| Elongation at break | 1.6 % | 1.7 % |
| **Mechanical / Physical Properties (ropes)** | Mechanical / Physical Properties |
| Tensile Modulus | 230'000 N/mm² | 225'000 N/mm² |
| Tensile Strength | 2100 N/mm² | 3500 N/mm² |

**Figure 2.** CFRP-NSM Cords Installations.
4. Testing of column specimens
All specimens were tested using Universal Testing Machine (2000 kN capacity in compression), shown in Figure 4. Two linear variable displacement transducers (LVDT) were installed face to face on specimen to measure the vertical displacement.

5. Results and discussion
The results of experimental work including the stress-strain behavior and failure modes of all tested column specimens are presented and discussed in this section.

5.1. Test observation and failure modes
Figures 5(a) and 5(b) show the failure modes of DC-H400-Control and DC-H600-Control specimen. The failure of these specimens initiated by vertical hairline cracks which become visible at 80% to 90% of ultimate strength following by increasing of number and width of cracks until failure load.

Finally, the DC-H400-Control and DC-H600-Control specimens failed by spalling of the concrete cover following by buckling of steel reinforcement in the failure region, when the load recorded 594.5 kN and 398 kN, respectively. DC-H400-L1-S100 failure started by initiated a vertical crack then failed by crushing of concrete when the maximum load reached 832.5 kN. Whereas, DC-H600-L1-S100 column specimen failure mode was similar to DC-H400-L1-S100 specimen mode, however, when the load reached to 749.3 kN, the crushing of unconfined zone concrete located between CFRP ropes was occurred (Figures 5(c) and 5(d)). It can be concluded that there was a good contact between the CFRP cords and concrete since there was not deboning happened, as well as no fracture happened in CFRP ropes. Finally, specimens DC-H400-L2-S200 and DC-H600-L2-S200 failure started by developing vertical cracks at the unconfined zone located...
between CFRP ropes following by buckling of longitudinal bars in the both columns (see Figures 5(e) and 5(f)). Failure mode of DC-H400-L2-S200 occurred by crushing of concrete when the load reached to 730 kN. Whereas, the failure mode of DC-H600-L2-S200 specimen was similar to DC-H400-L2-S200 specimen, however, the failure occurred when the load reached to 654 kN.

![Cracks and failure mode of damaged specimens.](image)

**Figure 5.** Cracks and failure mode of damaged specimens.

### 5.2. Stress-strain curves of tested column specimens

The axial stress-strain curves of the tested specimens, maximum load, maximum stress, and maximum strain are presented in Figure 6 and Table 3.

| Specimen Designation | Max-Load (kN)(%) | Max-Stress (MPa) | Max-Strain (%) |
|----------------------|------------------|-----------------|---------------|
| DC-H400-Control      | 594.5            | 22.12           | 0.0039        |
| DC-H400-L1-S100      | 832.5 (140%)     | 31              | 0.0081 (208%) |
| DC-H400-L2-S200      | 730 (123%)       | 27.16           | 0.0021 (54%)  |
| DC-H600-Control      | 398              | 14.81           | 0.0031        |
| DC-H600-L1-S100      | 749.3 (188%)     | 27.9            | 0.0058 (187%) |
| DC-H600-L2-S200      | 654 (164%)       | 24.34           | 0.35 (3%)     |

### 5.3. Effect of heating level on stress-strain behavior of damaged column specimens

Figure 6 shows that as the heat level increased, the compressive strength decreased. The DC-H400-Control exhibited compressive strength of 22.12 MPa and the DC-H600-Control exhibited compressive strength of 14.81 MPa recording decreasing in strength about 33% compared to DC-H400-Control specimen. However, the repaired DC-H400-L1-S100 specimen exhibited a decrease in strength about 10% compared to DC-H600-L1-S100 specimen. Finally, the specimen DC-H600-L2-S200 exhibited decrease in compressive strength about 10% compared to the compressive strength measured in specimen DC-H400-L2-S200. This can be attributed to more evaporating of water in concrete due to exposed to heat up to 600°C. Hence, expand the concrete and reinforcement steel causing appearance of cracks and the core became weaker as the temperature degree increases which lead to resulting a reduction in maximum stresses.

Figure 6 shows the effect of heat level on stress-strain behavior of tested specimens. It can be seen that the stiffness increased as decreased the heat level in control specimens and the specimens repaired by two ropes at spacing of 200 mm. Meanwhile the specimens repaired by one-layer rope at spacing of 100 mm were not exhibited any change in stiffness. This can be attributed to small space between CFRP cords which generates a high transverse pressure which lead to prevent crushing in core at the beginning stage.
5.4. Effect of rehabilitation confinement techniques on stress strain behavior of heat damaged column specimens

After exposed the specimens to heat up to 400°C and 600°C, the specimens were repaired by CFRP using two techniques: one layer of CFRP rope at spacing of 100 mm and two layers of CFRP rope at spacing of 200 mm. The largest stress values carried by specimens (DC-H400-L1-S100 and DC-H600-L1-S100) and (DC-H400-L2-S200 and DC-H600-L2-S200) were (31 MPa and 27.9 MPa) and (27.16 MPa and 24.34 MPa), respectively, as shown in Figure 7.

It can be seen that the most effective technique of repairing RC column is the technique using one layer of CFRP rope at spacing of 100mm since it has exhibited most carrying capacity of the column. This can be attributed to the increasing the confinement area by decreasing the spacing between CFRP ropes which decrease the arched between the ropes. This means that the spacing between the ropes plays an important role in the effectiveness of the CFRP. Moreover, the DC-H400-L2-S200 and DC-H600-L2-S200 exhibited (87% and 87%), respectively, of the (DC-H400-L1-S100 and DC-H600-L1-S100) capacity, respectively. The maximum strain for the specimens (DC-H400-L1-S100 and DC-H600-L1-S100) and (DC-H400-L2-S200 and DC-H600-L2-S200) were about (208% and 187%) and (54% and 113%) respectively, higher than the (DC-H400-Control and DC-H400-Control) respectively. The increase in maximum strain is due to the increase in CFRP confinement which in turn increases the strength and axial deformation capacity of the columns.
6. Conclusions

This study aims to investigate the effect of changing heat levels and the type of rehabilitation technique in terms of spacing and number of CFRP rode layers on the damaged RC circular column stress-strain behavior by testing six RC column specimens. The following conclusions are drawn based on the test results obtained:

- The unrepaired column specimens failed suddenly in brittle manner. Whereas, the repaired column specimens failed suddenly however they exhibited more ductility especially with column specimens repaired with one CFRP rode at 100 mm spacing.
- Failure has showed that there was a good contact between the cords and concrete since there was no debonding and rupture in CFRP rope.
- Decreasing the exposed heat level decreased the reduction of RC column strength capacity. The heat decreased from 600°C to 400°C, the peak load of unrepaired or control specimen increased

Figure 7. Effect of rehabilitation confinement techniques on stress strain behavior of damaged column specimens by heat up to (400°C and 600°C).

- a) Heat damaged at 400°C
- b) Heat damaged at 600°C
33% since the DC-H400-Control and DC-H600-Control specimens reached maximum load of 594.5 kN and 398 kN, respectively. On the other hand, the column specimens (DC-H400-L1-S100 and DC-H400-L2-S200) exhibited peak stress of 10% higher than (DC-H600-L1-S100 and DC-H600-L2-S200), respectively. Hence, the restoration of the strength of the fire damaged columns depends on the intensity of the applied heat.

- The result showed that the columns damaged at 400°C and repaired using NSM-CFRP one layer rope and two layer ropes recovering about 140% and 123%, respectively. Whereas the columns heated up to 600°C and rehabilitation by using NSM-CFRP one layer rope and two layer recovering about 188% and 164%, respectively.
- It can be concluded that repairing of column specimens by either one layer or two layers subjected to 600°C recovered load capacity more than the ones subjected to 400°C. It can be attributed that more evaporated occurred when column subjected to 600°C which lead to extend the cracks in core and losing some component more than ones subjected to 400°C. Hence, repairing the specimens with one layer or two layers were enough to a lateral pressure to prevent the failure in core early.
- Decreasing the spacing between the CFRP ropes, increased the load capacity of RC column since decreasing the spacing resulted a better effective lateral confining pressure and the effectiveness of CFRP increases. This can be attributed to the increasing the confinement area by decreasing the spacing between CFRP ropes which decrease the arched between the ropes.
- It can be concluded that the spacing between the ropes plays an important role in the effectiveness of the CFRP. Moreover, the DC-H400-L2-S200 and DC-H600-L2-S200 exhibited (87% and 87%), respectively, of the (DC-H400-L1-S100 and DC-H600-L1-S100) capacity, respectively.

7. References

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