

Strengthening RC Columns Using Carbon Fiber Reinforced Epoxy Composites Modified with Carbon Nanotubes

Mohammad R. Irshidat, Mohammed H. Al-Saleh, Mahmoud Al-Shoubaki

Abstract—This paper investigates the viability of using carbon fiber reinforced epoxy composites modified with carbon nanotubes to strengthening reinforced concrete (RC) columns. Six RC columns was designed and constructed according to ASCE standards. The columns were wrapped using carbon fiber sheets impregnated with either neat epoxy or CNTs modified epoxy. These columns were then tested under concentric axial loading. Test results show that; compared to the unwrapped specimens; wrapping concrete columns with carbon fiber sheet embedded in CNTs modified epoxy resulted in an increase in its axial load resistance, maximum displacement, and toughness values by 24%, 109% and 232%, respectively. These results reveal that adding CNTs into epoxy resin enhanced the confinement effect, specifically, increased the axial load resistance, maximum displacement, and toughness values by 11%, 6%, and 19%, respectively compared with columns strengthening with carbon fiber sheet embedded in neat epoxy.

Keywords—CNT, epoxy, Carbon fiber, RC columns.

I. INTRODUCTION

STRENGTHENING of concrete structural members like columns may be required on many cases such as deterioration of structure due to environmental effect, damage caused by accidents, upgraded loading requirements, revision in loading standard, and seismic retrofitting. The most conventional method to strengthening RC columns is by using fiber reinforced polymers (FRP) materials. FRP are suitable for strengthening RC columns due to their excellent resistance to corrosion, high strength and stiffness-to-weight ratio, good mechanical properties, quickly and easily applied, and minimal effect on columns geometry [1], [2]. During the last two decades, many studies were carried out to investigate the behavior of RC columns strengthening by CFRP sheets. It was found that the level of strengthening of RC columns using CFRP depends on many factors: concrete strength, the columns' cross-section and slenderness ratio, the number of CFRP layers, fiber orientation, type of matrix, and the bond at the interface between the concrete and the composite sheet [3]–[8]. On the other hand, nanocomposites have superior mechanical, thermal, electrical, magnetic, and electromagnetic properties, which can be utilized for best substitution of FRP

M. R. Irshidat and M. Al-Shoubaki are with the Civil Engineering Department, Jordan University of Science and Technology, Irbid 22110, Jordan (e-mail: mrrshidat@just.edu.jo).

M. H. Al-Saleh is with the Chemical Engineering Department, Jordan University of Science and Technology, Irbid 22110, Jordan (e-mail: mhsaleh@just.edu.jo).

as retrofitting materials. In order to take advantage of the new generation of nanocomposites, CNTs modified epoxy was used during this research in the process of strengthening RC columns. Six RC columns were casted then strengthening using carbon fiber sheets impregnated in neat and CNTs modified epoxy. The columns were tested under concentric load to investigate the efficiency of using these materials to enhance their axial load resistance, stiffness and toughness.

II. TEST SPECIMENS

Six rectangular RC column specimens were constructed with a length of 1.5m and cross section of 150x200 mm. All columns reinforced with four steel rebars of 10mm diameter in the longitudinal direction and 6mm diameter stirrups every 10cm. Moreover, a corner radius of 10 mm was used for the current test. General layout and reinforcement details of the test specimens are shown in Fig. 1.

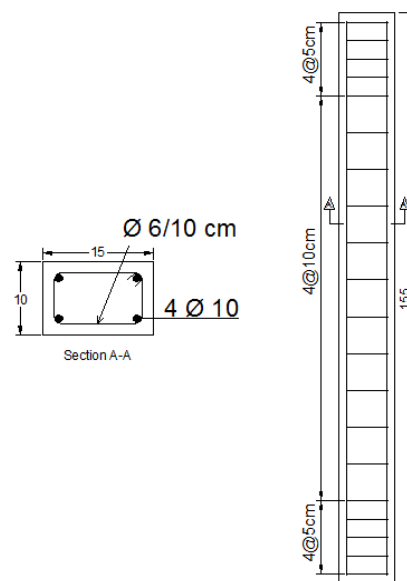


Fig. 1 Column layout and reinforcement details of test specimens

Different schemes were used to investigate the effectiveness of using MWCNT on the confinement effect of CFRP sheet strengthening RC columns as follows: Two columns were designed as unwrapped control specimens, eight specimens were fully wrapped using a single layer of carbon fiber sheet (two with neat epoxy resin, two with MWCNT pregrenat

epoxy resin, two with neat epoxy resin and MWCNT pregnant sizing agent, and two with MWCNT pregnant epoxy resin and MWCNT pregnant sizing agent), and four specimens were partially wrapped using a single layer of unidirectional CFRP sheet with MWCNT pregnant epoxy resin (two with 37cm-strip at the middle third of the column and two with 15cm strips spaced at 10cm through the length of the column).

III. MATERIALS PROPERTIES

Ordinary Portland cement (Type I), crushed coarse limestone aggregates with a maximum size of 12.5mm, and a mixture of silica sands and crushed fine limestone (20% silica and 80% fine aggregate) were used to prepare the concrete mix for columns. Physical properties of aggregate used in the study are listed in Table I. Concrete mix details are shown in Table II using w/c ratio of 0.47.

TABLE I
PHYSICAL PROPERTIES OF AGGREGATES

Property	Coarse Limestone	Fine Limestone	Silica Sand
Bulk Specific Gravity (SSD)	2.23	3.11	2.65
Fineness Modulus	-	3.1	1.6
Water absorption	4.8 %	4.8%	0.55 %
Unit Weight (compacted)	1500 kg/m ³	-	-

TABLE II
DETAILS OF THE CONCRETE MIX

Ingredient	Quantity
Cement	490 kg/m ³
water	230 kg/m ³
Coarse Limestone	817 kg/m ³
Fine aggregate	468 kg/m ³
Silica sands	117 kg/m ³

TABLE III
PROPERTIES OF CARBON FIBER SHEET

Aral weight	600 g/m ²
Thickness	0.34 mm
Sheet width	500 mm
Ultimate tensile strength	4900 MPa
Elastic modulus	230 GPa
Strain at break	2.1%

Steel rebars with 10mm and 6mm diameter were used as longitudinal and transverse reinforcement with average yield stress of 414 MPa and 290 MPa, respectively. Unidirectional carbon fiber sheet, MBrace Fibre CF 230/4900, impregnating epoxy resin, MBrace Saturant, was used to strengthen concrete columns in this study. The properties of the carbon sheet as provided by the manufacturer are summarized in Table III. Liquid Bisphenol-A epoxy resin enriched with high concentration of carbon nanotubes (EPOCYL™ NC R128-02) manufactured by Nanocyl was used as a master batch.

IV. TEST SETUP

In this study, all columns were tested under a concentric axial loading using a testing machine with a capacity of 2000 kN in the structural laboratory at Jordan University of Science

and Technology. Three linear variable displacement transducers (LVDT) were used to record the axial and lateral displacement of the columns.

V. RESULTS AND DISCUSSION

A. Strengthening RC Columns Using Carbon Sheets Impregnated with Neat Epoxy

The typical axial load-displacement response for control unwrapped columns and columns fully wrapped with CFRP sheet is plotted in Fig. 2. The figure clearly shows that full wrapping with CFRP sheets did not affect the initial stiffness of the column. On the other hand, compared to unwrapped column, full wrapping with CFRP sheet resulted in an increase of about 12%, 96%, and 180% in axial load resistance, maximum displacement, and toughness values, respectively.

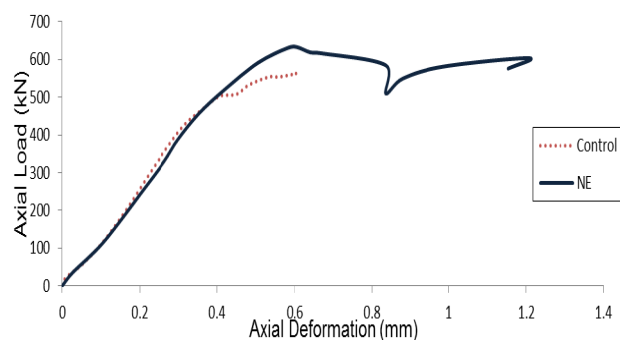


Fig. 2 Axial load-displacement curve for control and CFRP wrapped columns



Fig. 3 Failure of control specimen

The control unwrapped specimens were failed in a brittle manner as shown in Fig. 3. During the loading process, crackle sounds were heard due to cracks initiation and then splitting of concrete cover was noticed. As load increase, crushing of concrete at the middle height of the columns along its short side was observed accompanied by sudden loss of axial resistance. On the other hand, crackle sounds and ripples in the upper third of columns fully wrapped with single layer of CFRP sheet were heard during the loading as shown in Fig.

4. Then, snap sound was heard accompanied by significant increase in the buckling as the axial resistance dropped. After that, the specimen undergoing increasing axial resistance until the wrapping system failed at about 633 kN. At failure, straining of the FRP laminate and cracking of the epoxy resin in a direction parallel to the fiber orientation were observed at the middle height of the column while the FRP was still intact with concrete.



Fig. 4 Failure of CFRP wrapped specimen (NE)

B. Strengthening RC Columns Using Carbon Sheets Impregnated with CNTs Modified Epoxy

In this set of experiments, the epoxy resin was modified using CNTs before it was applied to the carbon sheet. Fig. 5 shows the axial load-displacement response of unwrapped column and columns fully wrapped with a single layer of carbon fiber sheet embedded with neat epoxy (NE) and CNT modified epoxy (CNTE). Compared to the unwrapped specimen, wrapping concrete columns with carbon fiber sheet embedded in CNTs modified epoxy resulted in an increase in its axial load resistance, maximum displacement, and toughness values by 24%, 109% and 232%, respectively. These results reveal that adding CNTs into epoxy resin enhanced the confinement effect, specifically, increased the axial load resistance, maximum displacement, and toughness values by 11%, 6%, and 19%, respectively compared with columns strengthening with carbon fiber sheet embedded in neat epoxy. The enhancement in the axial resistance may be attributed to the good interfacial bonding achieved by CNT-epoxy resin which leads to improve the shear capacity of the epoxy matrix thus improving the mechanical properties of the carbon fiber nanocomposite. The enhancement in the toughness may be assigned to the CNTs ability to bridge the micro-cracks of the matrix which leads to increase the capacity of the whole composite to absorb more energy before rupturing. On the other hand, reinforcing epoxy by CNTs does not have any effect on the modulus of elasticity of the

composites. This may be attributed to the fact that the modulus of elasticity of FRP material is governed by the modulus of the fiber rather than the modulus of the matrix.

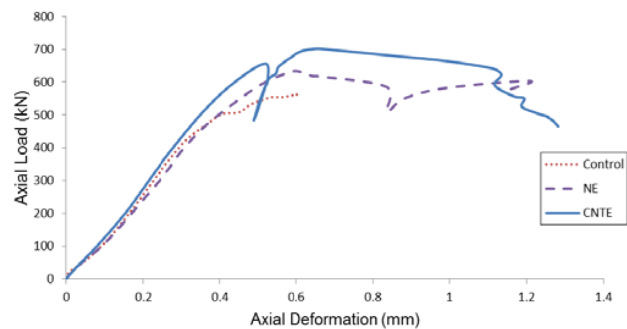


Fig. 5 Axial load-displacement curve for control, NE, and CNTE specimens

During the loading, debonding of CFRP wrap, ripples throughout the column surface, and buckling of the column were observed. At about 94% of the maximum resistance (F_u), snap sound was heard accompanied by significant increase in the buckling as the resistance dropped to about 68% F_u . After that, the specimen undergoing increasing axial resistance until the wrapping system failed at 702kN. At failure, straining of the FRP laminate and cracking of the epoxy resin in a direction parallel to the fiber orientation were observed at the middle height of the column while the FRP was still intact with concrete as shown in Fig. 6.



Fig. 6 Failure of CNTE specimen

VI. CONCLUSION

Based on the experimental results, the following conclusions could be drawn:

1. Wrapping concrete columns with carbon fiber sheet embedded in CNTs modified epoxy resulted in an increase in its axial load resistance, maximum displacement, and toughness values by 24%, 109% and 232%, respectively, compared with unwrapped specimens

2. Wrapping concrete columns with carbon fiber sheet embedded in CNTs modified epoxy resulted in an increase in its axial load resistance, maximum displacement, and toughness values by 11%, 6%, and 19%, respectively, compared with columns strengthening with carbon fiber sheet embedded in neat epoxy.

ACKNOWLEDGMENT

The work presented in this article was funded by the Scientific Research Support Fund at the Ministry of Higher Education and Scientific Research in Jordan.

REFERENCES

- [1] Belouar A, Laraba A, Benzaid R, Chikh N. Structural Performance of Square Concrete Columns Wrapped with CFRP Sheets. *Procedia Eng* 2013;54:232–40. doi:10.1016/j.proeng.2013.03.021.
- [2] Gambarelli S, Nisticò N, Ožbolt J. Numerical analysis of compressed concrete columns confined with CFRP: Microplane-based approach. *Compos Part B Eng* 2014; 67: 303–12. doi:10.1016/j.compositesb.2014.06.026.
- [3] Trapko T, Musiał M. The effectiveness of CFRP materials strengthening of eccentrically compressed reinforced concrete columns. *Arch Civ Mech Eng* 2011;11:249–62. doi:10.1016/S1644-9665(12)60187-3.
- [4] Nisticò N. R.C. square sections confined by FRP: A numerical procedure for predicting stress–strain relationships. *Compos Part B Eng* 2014;59:238–47. doi:10.1016/j.compositesb.2013.12.004.
- [5] Rocca S, Galati N, Nanni A. Review of Design Guidelines for FRP Confinement of Reinforced Concrete Columns of Noncircular Cross Sections. *J Compos Constr* 2008;12:80–92. doi:10.1061/(ASCE)1090-0268(2008)12:1(80).
- [6] Mirmiran A, Shahawy M, Samaan M, Echary HE, Mastrapa JC, Pico O. Effect of Column Parameters on FRP-Confined Concrete. *J Compos Constr* 1998;2:175–85. doi:10.1061/(ASCE)1090-0268(1998)2:4(175).
- [7] Wang L-M, Wu Y-F. Effect of corner radius on the performance of CFRP-confined square concrete columns: Test. *Eng Struct* 2008;30:493–505. doi:10.1016/j.engstruct.2007.04.016.
- [8] Wu Y-F, Wei Y-Y. Effect of cross-sectional aspect ratio on the strength of CFRP-confined rectangular concrete columns. *Eng Struct* 2010; 32: 32–45. doi:10.1016/j.engstruct.2009.08.012.