BEHAVIOUR OF STEEL REINFORCED CONCRETE COLUMNS STRENGTHENED WITH CARBON FIBRE REINFORCED POLYMER (CFRP)

M, Abbas[1], J, M. Kaura[2], A Ocholi[3] N. and A. Lawan[4]
[1]*Nigerian Building and Road Research Institute, Plot 5 Old Katsina Road, Kano, Nigeria*
[2,3,4]*Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria*
[1]mabbas@yahho.com, [2]jdanbala@yahoo.co.uk, [3]aocholi@abu.edu.ng, [4]bnlawan@yahoo.co.uk
Corresponding author: *jdanbala@yahoo.co.uk (+2348023583817)*

Abstract
This paper investigated the use of Carbon Fibre Reinforced Polymer for increasing strengthening of Reinforced Concrete Columns. Squared Reinforced Concrete Columns were selected for the study, being them more frequently used in building, The performance of the columns wrapped with CFRP were compared to non-wrapped column (control). Twelve columns with cross-sectional dimensions 100mmX100mmX375mm with constant corner radius of 15mm, were tested under axial loading. Three columns each were wrapped with one and two layer of CFRP respectively, and the remaining three columns were not wrapped as they served as the control columns. Experimental results showed increased ductility from 17% and 22.6% respectively for column specimens wrapped with one and two layers of CFRP compared to the control specimens. Also, increase in axial load-carrying capacity up to 60% and 129% were respectively achieved for column specimens wrapped with one and two layers of CFRP compared to the control specimens.

Keywords: CFRP, ductility, confined column, epoxy resin

1.0 Introduction

Reinforced concrete structures are durable, strong and perform well under its service lifetime. However, RC structures deteriorate over time when exposed to certain conditions. The deterioration may be due to ageing, increase in higher live loads, poor maintenance, corrosion, poor initial design or construction and accidental situations like gas explosion. Therefore, rehabilitating existing structures that suffered from partial loss of load carrying capacity due to deterioration has been identified as an important issue to be addressed (Carse et al, 2002).

There are a number of approaches for rehabilitation of reinforced concrete structures. These include steel jacketing, concrete jacketing, use of polymer concrete and use of Fibre Reinforced Polymer (FRP). This research is mainly on the effectiveness of the use of Carbon Fibre Reinforced Polymer (CFRP) for strengthening of reinforced concrete column with squares cross section. There were some research efforts in that direction. For example, Raval and Dave (2013) studied the effectiveness of the use of Glass Fibre Reinforced Polymer (GFRP) for external strengthening of RC Columns of circular, square and rectangular sections. The results shown that, the axial load carrying capacity of the GFRP wrapped circular, square and rectangular columns increased by 159%, 79% and 76%, compared to the respective control specimens. Also, Abdel-Hey (2014) investigated the overall behavior of reinforced concrete square columns with poor concrete at upper part, strengthened with CFRP. The wrapped part of column was the upper part only. The main parameters in his research were the compressive strength of the upper part, the height of the upper poor concrete part, and the height of CFRP wrapped part of column. The test result showed that partial strengthening of square column using CFRP can be permitted and gives good results of the column carrying capacity. Widiarsa and Hadi (2013) assessed the performance of square RC columns wrapped with CFRP subjected to eccentric loading. The influence of two parameters was studied including the number of the CFRP layers and the magnitude of eccentricity. Compression testing was conducted on twelve short square ($200mm \times 200mm \times 800mm$) RC columns with 34mm corner radii, wrapped with CFRP composites. From the results, it was concluded that wrapping the square RC columns under eccentric loading with CFRP enhanced their performance by providing higher load carrying capacity and ductility compared to unwrapped RC columns.

Previous studies on the effectiveness of CFRP strengthening of RC columns paid little or no attention to the ability of the columns to undergo large deformation (ductility) before failure. The specific aim of this study is to assess the effectiveness of CFRP strengthening of squared reinforced concrete columns in terms of strength and ductility.

1 Materials and Methods

1.1 Materials

The materials used in this research are ordinary portland cement, coarse and fine aggregate, water, reinforcing steel, Carbon Fibre Reinforced Polymer (CFRP) and epoxy resin bonding agent.

1.1.1 Cement, aggregate and water

The ordinary portland cement used in this study conforms to BS EN 197-1 (2011). The coarse and the fine aggregates were graded according to BS EN 12620 (2013). Also, potable tap water suitable for drinking was used.

1.1.2 Reinforcing Steel

The longitudinal reinforcements used are high yield steel bars with 10mm diameter. The stirrups used are 10 mm diameter mild steel bars; all obtained from steel suppliers in.

1.1.3 The Carbon Fibre Reinforced Polymer (CFRP) Shhets

The carbon fiber reinforced polymer sheets used in this work was Tianjin BinJin CXS-200 I (China) unidirectional CPRP. The characteristics of the CFRP obtained from the manufacturers are shown on Table 1.0.

Table 1.0: Properties of the CFRP (CXS-200)

Tensile strength (MPa)	Modulus of Elasticity (MPa)	Density (g/cm^3)	Thickness (mm)	Ultimate strain (%)	Width (mm)
3400	240	1.76	0.11	1.7	200

1.1.4 Epoxy Resin

Araldite GY Epoxy Resin bonding agent obtained from Super Floors Company, Lagos, Nigeria, was used. The properties of the Epoxy Resin are presented in Table 2.0. It is is made up of two part, resin base (Type A) and resin hardener (Type B).

Table 2.0: The Properties of the Epoxy Resin Bonding Agent

Colour	Pot Life @ 30° C (mins)	Tensile strength, 7 days (N/mm^2)	Compressive strength, 7 days (N/mm^2)	Flexural Strength (N/mm^2)
Brown	± 30-40	10.4	60	28.1

1.2 Methods

2.1 Preparation of the Test Column Specimens

Nine reinforced concrete columns of 100mm width, 100mm depth and 375 heights were prepared in accordance with British standard specifications at the concrete laboratory of the Department of Civil Engineering, Ahmadu Bello University, Zaria. The specimens are in three groups. The first group is the control, while the second and the third group are the CFRP nstrengthened specimens. The first group of three specimen denoted as 'U_1, U_2 and U_3' are each reinforced with 4 number 10 mm diameter bars as longitudinal reinforcement and 10 mm diameter stirrup spaced at 125 mm as transverse reinforcement. The second of three specimens denoted as 'US_1, US_2 and US_3' are similar to the first group but wrapped with one layer of 0.11mm thick CFRP sheet. The third group also of three specimen denoted as 'UD_1, UD_2 and UD_3' is similar to the second group but wrapped with two layer of 0.11mm thick CFRP sheet. Each of the specimens satisfied the minimum design requirements set by ACI 318-11 (2002) and ACI Committee 440 (2002) for short columns and CFRP strengthened concrete structures.

To achieve the best bond between the CFRP wrap and concrete for each specimen, the surface of the specimens were first prepared by smoothened and made free from dust. The Epoxy resin bonding agent was then prepare by mixing of the resin base (type A) and resin hardener (type B) in the ration of 2:1. The bonding was then applied on the surface of each specimen using a paint brush. The CFRP was then wrapped around the specimens. Finally a roller was then rolled on the column until the bonding agent has fully saturated the wrap for hidden air to be driven away.

1.2 Compressive Strength Test

Each of the Specimens was subjected to uni-axial compressive strength test after 28 days curing age. The load was applied using Avery Denison universal testing machine with a vertical load capacity of 2500 kN, at the concrete research laboratory, Ahmadu Bello University, Zaria. The aim of the compressive strength test is to determine the maximum compressive load that will cause rupture of each column. The compressive strength test setup for the columns is shown in Figure 1.0.

Figure 1.0: Column Test Setup

3.0 Results and Discussion

The results obtained from the laboratory experiments were used to generate the failure pattern and the load deformation of each of the six control and the six CFRP wrapped columns. The results are presented as follows:

3.1 The Ultimate Load Capacity of the Columns

Ultimate failure load is the maximum load that causes the rupture. This was obtained for each test specimen and the percentage contribution of CFRP to the load carrying of the strengthened columns were determined and presented in Table of all the columns and percentage increment of the confined and unconfined columns is presented in Table 3.0.

Table 3.0: Compressive Strength Test Results

Test Specimen	Ultimate Load (kN)	Average Ultimate Load (kN)	Percentage Increment (%)
U1	260		
U2	245	245	-
U3	230		
US1	400		
US2	385	392	60
US3	390		
UD1	545		
UD2	540	562	129
UD3	600		

It is clear from Table 3.0 that Carbon Fibre Reinforced Polymer (CFRP) considerably increase the load carrying capacity of squared reinforced concrete columns. From the table, strengthened column with one layer of the 0.11mm thick CFRP wrap (US) lead to 60% increase in its load carrying capacity Also, 129% increased in the load carrying capacity was obtained when strengthened with two layers of 0.11mm thick CFRP wrap (UD).

3.2 Ductility Response

The determination of ductility of the CFRP wrapped RC columns specimens are based on the load deformation behavior of the specimens as shown in Table 4.0. Ductility indices for column US (specimen wrapped with single layer CFRP) and column UD (specimen wrapped with double layer CFRP) were determined and presented in Figure 2.0. The ductility of the 'US' and the 'UD' specimens increased by 18% and 24% respectively, compared to the 'U' specimen (control specimen). This indicated that the introduction of CFRP wrap to the squared RC columns has improved the ductility of the columns.

Table 4.0: Ductility of the Test Specimens

Specimen Type	Applied Load (kN)	Strength Increase (%)	Ultimate Deformation Δu (mm)	Yield Deformation Δy (mm)
U	245	-	1.29	1.24
US	332	35.51	2.697	2.22
UT	562	129	2.80	2.17

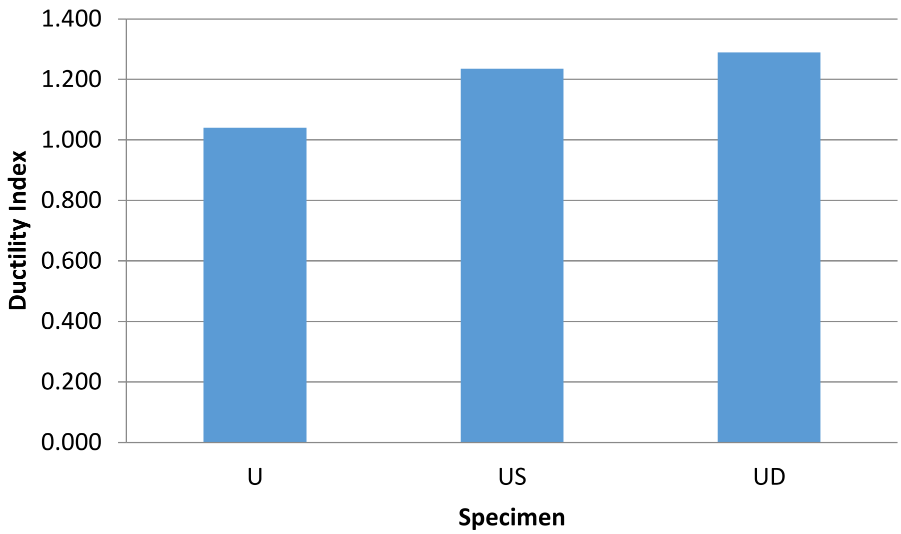

Figure 2.0: Ductility Indices of the U, US and UD Columns Specimen

3.3 Failure Patterns

The failure patterns of the CFRP wrapped RC columns specimens were observed. Generally, concrete crushing was evident at or close to the column ends coupled with the CFRP wraps rupture around that region. White patches were also noted before the column failed which is an indication of yielding of the CFRP and the Epoxy Resin bonding agent composite. The Failure modes of some of the samples are shown in Figures 3.0 and 4.0.

Figure 3.0: Typical Failure mode of Control specimens

Figure 4: Typical Failure mode of the CFRP Wrapped Specimen

2 CONCLUSIONS

In this paper, the effectiveness of CFRP strengthening of squared reinforced concrete columns is presented. From the experimental results on compressive and ductile capacities of the columns were assessed and the following conclusions are drawn.

i. The study established that the introduction of external confinement of CFRP effectively improved the axial compressive strength capacity of squared RC columns. It was established from the results that strengthened column with one layer of 0.11mm thick CFRP wrap (US) lead to 60% increase in its axial load carrying capacity. Also, 129% increases in the axial load carrying capacity was obtained when strengthened with two layers of 0.11mm thick CFRP wrap (UD).

ii. There was improvement of 17% and 22.6% in ductility when the columns were wrapped with one and two layers of CFRP respectively as compared to the control column specimen.

References

Abdel-Hay, A. S. (2014). Partial strengthening of R.C square columns using CFRP. *HBRC Journal*, *10*(3), 279–286. https://doi.org/10.1016/j.hbrcj.2014.01.001

ACI Committee 440. (2002). *Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures, Technical report*.

British Standard Institution. (2011). *BS EN 197-1, Cement: composition specifications and conformity criteria for common cement*. London, England.

British Standard Institution. (2013). *BS EN 12620: Aggregate for concrete*. London, England.

Carse, A., Spathonis, M. J., Chandler, M. L., Gilbert, M. D., Johnson, M. B., Uws, A. J., & and Pham, L. (2002). Report 2002-005-C-01: Review of Strengthening Techniques Using

Externally Bonded Fiber Reinforced. *CRC for Construction Innovation*, Brisbane.

Grigg, N.S. (1988) I*nfrastructure Engineering and Management*. John Wiley and Sons, New York.

Raval, R., & Dave, U. (2013). Behavior of GFRP wrapped RC columns of different shapes. *Procedia Engineering, 51*, 240–249. https://doi.org/10.1016/j.proeng.2013.01.033

Widiarsa, I. B. R., & Hadi, M. N. S. (2013). Performance of CFRP wrapped square reinforced concrete columns subjected to eccentric loading. *Procedia Engineering*, *54*, 365–376. https://doi.org/10.1016/j.proeng.2013.03.033