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"Review Article on Assets of Carbon Fiber Reinforced Polymers"

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Abstract : Carbon fibers were the most attractive fibers to researchers, engineers and scientists as an alternative reinforcement for fibre reinforced polymer (FRP) composites[4]. Due to their high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. Reinforced concrete columns have an important function in the structural concept of many structures. Often these columns are helpless to loads due to impact, explosion or seismic loads and also sensitive to corrosion of steel reinforcement. Confinement has proven to be very efficient in increasing concrete strength and ductility of members. Wrapping by means of FRP reinforcement enhances the structural behavior of concrete column considerably. This paper is a review on the properties of carbon fiber reinforced polymer composites and a detailed study had been made with the available literature on the usage of FRP composites in the strengthening of reinforced concrete columns.
Keywords : Mechanical properties, Thermal properties Carbon Fiber Reinforced Polymers (CFRP).

1.0 Introduction

In recent years, the composite materials, by their non-corrodibility, high stiffness and strength-to-weight ratios, have quickly appeared as advanced solutions adapted to the strengthening and the repair of civil engineering structures[1]. Over the last few years, there has been a worldwide increase in the use of composite materials for the rehabilitation of reinforced concrete structures. One important application of this composite retrofitting technology is the use of fiber reinforced polymer (FRP) jackets or sheets to provide external confinement to reinforced concrete columns. Fiber Reinforced Polymers (FRP) composites were first developed during the 1940s, primarily for military and aerospace engineering applications. In the case of a seismic event, energy dissipation allowed by a well-confined concrete core can often save lives[2]. FRP is a relatively new class of composite material manufactured from fibers and resins has proven efficient and economical for the development and repair of new and deteriorating structures in civil engineering. Compared to steel and concrete, FRP composites are about 1.5 to 5 times lighter. FRP composites provide only a nominal increase in stiffness so they are generally useful for increased structural strength instead of deflection control. Strengthening and increased durability against steel corrosion can be achieved in a RC structure by wrapping them with fiber reinforced polymer.

Advantage of FRP Over steel straps as external reinforcement is its easy handling. Thus, minimal time and labour are required for Implementation. The application of FRP in the construction industry can eliminate some unwanted properties of high-strength concrete, such as its brittle behavior. FRP is particularly useful for strengthening columns and other unusual shapes. There is a growing interest in the use of FRP for strengthening of concrete structures such as buildings, bridges, chimneys, as well including load bearing and infill panels, pressure pipes, tank liners, roofs, bridge repair and retrofit, mooring cables, structural strengthening, etc. This is mainly due to their performance characteristics, ease of application, and low life cycle costs[5,7].Carbon Fiber Reinforced Polymer (CFRP) has a tensile strength much higher than the tensile strength of steel reinforcement. Carbon fiber is a material, which is usually used in combination with other materials to form a composite. It is also called graphite fiber or carbon graphite, carbon fiber consists of very thin strands of the element carbon. The properties of carbon fiber, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion makes them one of the most popular material in civil engineering possessing strength up to five times that of steel and being one-third its weight, as it is called as, 'the superhero' of the material world. Carbon fibers have high elastic modulus and fatigue strength than those of glass fibers[3]. Considering service life, studies suggests that carbon fiber reinforced polymers have more potential than agamid and glass fibers. They also have high chemical resistant and have high temperature tolerance with low thermal expansion and corrosion resistance. Carbon fiber-reinforced composite materials are used to make aircraft and spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, sailboat masts, and many other components where light weight and high strength are needed[6]. Carbon fiber's high strength, light weight and resistance to corrosion make it an ideal reinforcing material. Carbon fiber plates are thin, strong and flexible, they can be designed and installed to provide a cost effective solution[3]. The carbon FRP (CFRP) composites, as unidirectional laminates, are ideal materials for confining existing concrete columns. When the FRP-wrapped concrete is subjected to an axial compression loading, the concrete core expands laterally. This expansion is resisted by the FRP; therefore the concrete core is changed to a three-dimensional compressive stress state. In this state, performance of the concrete core is significantly influenced by the confinement pressure. The confinement pressure provided by the FRP increases continuously with the Lateral strain of concrete because of the linear elastic stress-strain behaviour of FRP, in contrast to steel confined concrete in which the confining pressure remains constant when the steel is in plastic flow. Failure of FRP-wrapped concrete generally occurs when the hooprupture strength of the FRP is reached.

Table 1 - Mechanical properties of CFRP

Characteristic	**Values**
Modulus of elasticity	2380000 kg/cm^2
Tensile strength	43000 kg/cm^2
Ultimate strength	1.8%
Thickness	0.131mm
Weight of CFRP	230±10g/m^2

The use of Carbon Fiber Reinforced Polymer (CFRP) materials has increased significantly in the last decade. Fully or partially wrapping concrete circular columns with wet lay-up CFRP sheets can significantly increase the load carrying and energy absorption capacities of these elements[8]. The effectiveness of this CFRP-based confinement strategy depends on several parameters such as: concrete strength, CFRP percentage, geometric confinement arrangement, column aspect ratio, disposition and percentage of existing steel reinforcement. Some properties of CFRP sheets like low weight, high strength and easy installation make these composites highly suitable for concrete confinement. In this article let us study about the various properties of carbon fiber with the reference of various literature based study.

2.0 Review of Literatures

Wrapping columns with CFRP enhanced the performance of the columns by increasing their displacement at failure, meaning more ductility, maximum load of the columns. FRP jackets prevent premature failure of concrete cover and buckling outwards of steel bars, leading to significant improved performance of FRP concrete column composite. The CFRP strips used to externally wrap the columns were specified to have a width of 75 mm. The whole external load was determined including the contributions of confined core and longitudinal bars, taking into account the strength and buckling conditions of the reinforcement[9]. The moment capacity of strengthened columns can be computed analytically by using the well-known fiber method based on the discretization of the cross-section. At ultimate load, when confinement action was no longer provided due to FRP fracture, the internal steel started buckling and the crushed concrete fell down between the fractured FRP.

This indicates that the concrete core is significantly damaged (but yet confined) even before reaching ultimate load. The following parameters of CFRP were evaluated from different literatures.

2.1 Compressive Strength

To measure the compressive strength of confined concrete, strain in lateral failure is considered. Increasing the amount of CFRP sheets produce an increase in the compressive strength of the confined column. The stiffness of the columns has decreased because of the cracking and the expansion of the confined concrete. At this stage, the confining effect of FRP wraps starts to increase the compressive strength of the columns.

S.no	**Name Of The Author and Year**	**Specimen Detail (L×D or a×a×L)**	**Wrapping detail**	**Methods adopted**	**Remarks**
1.	N. Chikh et al., 2011.	(320×160)mm, (1000×197)mm circular column and (140×140×280)mm square column with 50Mpa grade concrete.	Specimens were wrapped under a monotonic uni-axial compression load up to failure unidirectional wrap with 1and 3 layers.	The load was applied at a rate of 0.24 MPa/s and recorded with an automatic data acquisition system. Axial and lateral strains were measured using extensometers.	Increasing the amount of CFRP sheets, increase in the compressive strength of the confined column and decrease the deformation capacity.
2.	K. olivová et al., 2008.	4columns with (250x250x1500)mm and 3 numbers of (100x100x400) mm prisms.	Wrapping the columns with fiber thickness of 0.176 mm.	Near-surface mounted (NSM) laminate strips has been used to increase the load-carrying capacity of concrete structures.	The ultimate strength of the confined concrete is closely related to the failure strength of the FRP wraps.
3.	M. Reza Esfahani et al., 2005.	3circular column of (850×203)mm and 3 square column of (180×850)mm	All specimens were wrapped using two layers of CFRP. The thickness of each layer of FRP was 1mm.	Axial load and displacement of columns Were recorded during tests using a displacement control test set up.	Closely spaced transverse reinforcement increase the compressive strength. The confining effect of FRP wraps starts to increase the compressive strength of the columns.
4.	Giuseppe CAMPIONE et al., 2011.	RC column of size (925×205)mm with 57.3Mpa grade concrete and (608×152)mm with 33.2Mpa grade concrete.	Wrapped with carbon fiber reinforced wraps having thickness 1.6mm.	The moment capacity of strengthened columns can be computed by using the method discretization of the cross-section.	Pressure induced by the external wraps increased the concrete strength, limit’s spellingof concrete cover, reduces the critical length, minimized the local second order effects.

2.2 Stress-Strain Curve

The analytical load-axial shortening response of the compressed columns was obtained on the basis of the stress-strain curves of the confined concrete and compressed steel bars. Axial and lateral strains were measured using extensometers.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	M.N.S. Hadi et al., 2010.	12circular columns (295×40)mm and 6 square columns of (295×295×295)mm.	2 layers of CFRP strips externally wrapped on columns with a width of 75 mm, and at10^0 Horizontal.	Columns wrapped with CFRP experience higher maximum stresses capacity and larger axial strains.	Columns experience decreases in their stress carrying capacity when it reaches its maximum stress capacity. The columns axial strains still expand until they reach their ultimate strain capacity.
2.	K Yoshimura et al., 2002.	Rectangular columns with (210×240) mm and circular column with (240×350)mm.	0.222mm thickness fiber strip is used.	Displacements and strains in reinforcing bars and jacketing materials were measured by using the displacement transducers and strain gages.	The compressive stress-strain relations of all the concrete were modeled by considering the confining effects given by the strengthening methods and materials, and cross-sectional shapes of each column.

2.3 Load-Displacement Curve

Depending upon the dimensions of the element it is possible to achieve load deflection characteristic curve which are nearly linear or strongly curved the formation of the curve depends upon the ratio of h/t it is called load-deflection curve.

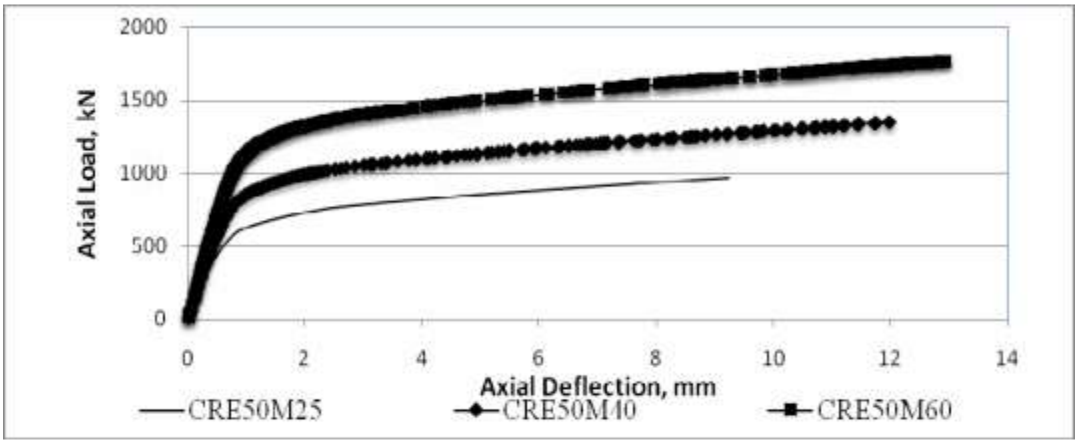

Fig.1 Effect of grade of concrete on load deflection curve

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	Muhammad NS HADI et al., 2010.	16 square columns of (200×200×800) mm with corner radius 34mm.	Fibers with thickness of 100mm and 75mm are used as 1 and 3 layer in circumferential and 1 layer vertical.	25mm and 50mm eccentric loading provided.	The load displacement curves of the columns, increases with the increasing the load until approaching the maximum load.
2.	M. Reza Esfahani et al., 2005.	3circular column of (850×203)mm and 3 square column of (180×850)mm.	All specimens were wrapped using two layers of CFRP. The thickness of each layer of FRP was 1mm.	Axial load and displacement of columns were recorded during tests using a displacement control test set up.	The stiffness of the columns has decreased because of the cracking and the expansion of the confined concrete. The load-displacement relationships of the confined columns are still linear but with smaller slopes.

2.4 Size and Shear Displacement

In some specific position like construction on slope application of the short RC column is unavoidable. To get high ultimate strength column with small diameter (150mm) is mostly preferred.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	Muhammad NS HADI et al., 2010.	16 square columns of (200×200×800)mm with corner radius 34mm.	Fibers with thickness of 100mm and 75mm are used as 1 and 3 layer in circumferential and 1 layer vertical.	25mm and 50mm eccentric loading provided.	Short columns were designed to avoid the formation of secondary moments due to the slenderness effect.
2.	G.P.Lignola et al., 2008.	Square column with 1500mm width.	Fibers are wrapped unidirection.	The model, coupled with the algorithm, it is able to guess the fundamental behavior of the hollow square members confined with FRP both in terms of strength and ductility,the evolution of stresses and strains inthe concrete and in the	Shear displacement occurs because of the plastic hinge model can only give limited predictions in terms of deformability.

				confinement jacket. and the assessment of the member deformability in terms of both curvature and displacement ductility.	

2.5 Shape

Shape of cross-sections of columns can directly affect the confinement effectiveness of externally bonded FRP jackets. Benefit of strength is higher for circular than for square or rectangular sections. Poor confinement may be due to low FRP jacket stiffness (type of FRP and numbers of layers) or due to sharp edges in cross sections. Mitigation of this shape effect is achieved by rounding the corners of the square or rectangular sections.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	K. olivová et al., 2008.	4 series of columns with dimensions Of (250x250x1500) mm, 3 numbers of (100x100x400) mm prisms.	Wrapping the columns with fiber thickness of 0.176 mm.	Near-surface mounted (NSM) laminate strips has been used to increase the load-carrying capacity of concrete structures.	The shape of the cross sections and sharp edges in the cross sections of columns directly affect the confinement effectiveness of externally bonded concrete. The efficiency of FRP confinement is higher for circular than square sections.
2.	N. Chikh et al., 2011.	(320×160)mm and (1000×197)mm circular column and (140×140×280) mm square column with 50Mpa grade concrete.	Specimens were wrapped under a monotonic uni-axial compression load up to failure unidirectional wrap with 1and 3 layers.	The load was applied at a rate of 0.24 MPa/s and recorded with an automatic data acquisition system. Axial and lateral strains were measured using extensometers.	Failure initiated near a corner, because of the high stress concentration at that locations. The efficiency of the CFRP confinement is higher for circular than for square sections, as the composite wrap was greatly affected by its premature damage at the sharp column corner.
3.	M.N.S. Hadi et al., 2010.	12circular columns (295×40)mm and 6 square columns of (295×295×295) mm.	2 layers of CFRP strips externally wrapped on columns with a width of 75 mm, and at 10^0Horizontal.	Columns wrapped with CFRP experienced higher maximum stresses capacity and larger axial strains compared to columns that are not wrapped with CFRP.	Circular columns have much better performance in stress carrying capacity compared to square columns. Square columns wrapped with CFRP tend to have more capability to receive repeated large loadings and stresses,and experience a significant vertical decrease in stress

					carrying capacity.
4.	Mahmoud Mohamed El-Taher et al., 2012.	9 rectangular R.C. columns with different rectangularity of cross-sections were constructedund eraxial static centric load.	Thickness of 0.131mm carbon fibers were wrapped uni-directionally with spacing such as 120,96,75mm.	The axial nominal stress and the axial nominal strain are evaluated during the testing of each column up to failure .	The strength, the ductility, the stiffness efficiency and the absorbed energy efficiency are higher for confined of both one layer and two layers than that for unconfined columns. for rectangular section reinforced concrete columns as the rectangularity (t/b) increases, the axial nominal stress, the axial nominal strain, the modulus of elasticity and the modulus of toughness are increased by the confined one layer and two layers are decreased.
5.	E EEtman et al., 2002.	2 square column of 150mm length and 2 circular column of 150mm diameter.	The column was then wrapped with the CFRP sheet; the end of the sheet overlapped100 mm.	The vertical longitudinal strain, for the square specimens, was measured using 4, 30 mm gauge Length. Lateral strains were measured on the concrete face at mid height using 2 electrical strain gauges glued on two opposite sides.	The circular columns showed extra capacity than the square columns by a ratio between 35% and 21%. The use of FRP fabric for the jacketing of reinforced concrete circular or square columns increased the ductility and increased the ultimate strain of the section.

2.6 Ductility

The confinement provided by the CFRP improves the ductility of the column. Ductility of the confined concrete increases with the increased lateral pressure. Number of layer increases ductility also increases. Increase in ductility depends upon the decrease in compressive strength.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	PezhmanTaghia et al., 2013.	Circular columns with dia=150, 250,300,450 and 600mm, and height 450mm and 750mm.	0.165mm thick fibers are wrapped in uni-direction.	Structural behaviour of the RC short column achieved by using nonlinear finite element analysis.	If number of layer increases ductility also increases. Increase in ductility depends upon the decrease in compressive strength. Low strength concrete column exhibits higher

					ductility then high strength concrete.
2.	A. Napoli et al., 2010.	9 specimens of (300×700)mm and length 2500mm.	External Confinement by wrapping members with unidirectional CFRP layers and four longitudinal steel angles placed at the member corners and glued to the concrete substrate by means of an epoxy adhesive.	Tests were conducted in displacement control by subjecting columns to a constant axial force and cyclically reversed horizontal force.	The high side ratio in the FRP confinement leads to a non-negligible ductility enhancement of the columns.

2.7 Loading

In all real framing systems, columns are not only axially loaded, they can be subjected to various loads and combination of loads. Currently, the study of RC columns confined with composite materials subjected to eccentric compression is relatively new and limited. FRP confinement systems are less effective under eccentric loading compared to concentric one. The efficiency of the RC columns confined with CFRP membranes is reduced if the load eccentricity increased. The failure of the eccentrically loaded elements occurred at the compressed side. Failure of the FRP confined RC elements depends on the failure of the FRP composite membrane.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	Muhammad N. Hadi et al., 2014.	Square column of size (200×00)mm and corners are rounded for 32mm radius.	Fibers are wrapped at ±45^o orientation in hoop direction.	The specimens are tested for 3 eccentricities: 0 (concentric), 25, and 50 mm up to failure.	When the eccentricity is large, the load carrying capacity is significantly reduced because both axial action and bending action are induced. The increase in the applied load results in lateral deflection increases and the total eccentricity of the applied load is thereby increased. This in turn increases the internal moment of the column and causes compressive strength capacity reduction. When columns were tested under eccentric loading, the contribution of vertical and 45angle layers was evident in resisting the bending moment.
2.	G. P.	Square column	Two layers of	The strength	strength and ductility

	Lignola et al., 2007.	of size (36×36)cm with 2cm rounded corner.	CFRP used in unidirection.	improvement Was relevant to the specimens loaded with smaller eccentricity, the ductility improvement was relevant to the bigger eccentricity. The ductility measurements have been estimated using curvature ductility indexes.	increases of members, under large eccentricities.

2.8 Load Carrying Capacity

A recent strengthening technique based on near-surface mounted (NSM) laminate strips of carbon fiber reinforced polymer (CFRP) has been used to increase the load-carrying capacity of concrete structures by introducing laminate strips into pre-cut grooves on the concrete cover of the elements to be strengthened.

S. no	**Name Of The Author and Year**	**Specimen Detail (L×D or a×a×L)**	**Wrapping detail**	**Methods adopted**	**Remarks**
1.	Mieczyslaw Kaminski et al., 2006.	RC column with (80×150)mm are used.	5mm thickness fibers are used as strips and wraps.	External adhesive bonding of longitudinal CFRP strips, external adhesive bonding of longitudinal CFRP strips and transverse CFRP band wraps, external adhesive bonding of longitudinal CFRP strips and transverse wrapping, external adhesive bonding of transverse CFRP wraps are the strengthening technics used.	The application of CFRP strips to strengthen compressed elements increases their boundary load-carrying capacity that decrease the longitudinal strains in relation with control elements at an equal increase of longitudinal force. The use of additional external CFRP band wraps prevents debonding of a strip till the moment of the wrap breaking and the element damage.
2.	N. Chikh et al., 2011.	(320×160)mm and (1000×197)mm circular column and (140×140×280) mm square column with 50Mpa grade concrete.	Specimens were loaded under a monotonic uni-axial compression load up to failure unidirectional wrap with 1and 3 layers.	The load was applied at a rate of 0.24 MPa/s and recorded with an automatic data acquisition system. Axial and lateral strains were measured using extensometers.	The confinement provided by the CFRP improved the load-carrying capacity of the column. The effect of increasing the strengthened columln's slenderness ratio (≅2÷7) results on overall in small effect on its load carrying capacities.

2.9 Slenderness Ratio

No distinct post behaviour is observed as the slenderness ratio increases. The effect of increasing the strengthened column's slenderness ratio (≅2÷7) results on overall in small effect on its load carrying and deformation capacities.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	E EEtman et al., 2002.	2 square column of 150mm length and 2 circular column of 150mm diameter.	The column was then wrapped with the CFRP sheet; the end of the sheet overlapped 100 mm.	The vertical longitudinal strain, for the square specimens, was measured using 4, 30 mm gauge Length. Lateral strains were measured on the concrete face at mid height using 2 electrical strain gauges glued on two opposite sides.	The increase in slenderness ratio, reduces the ultimate strength and strain of the unwrapped columns. For the jacketed columns, the effect of slenderness ratio would be verified after the specimens reach a stress level equal to or over the concrete compressive strength, as the increase in slenderness ratio reduces the stiffness of the section.
2.	RUXANDRA OLTEAN et al., 2011.	6 square columns of 250mm dimension.	1 and 2 layers of CFRP strips.	The experimental study was performed under static loading as the specimens being subjected to a monotonous and uniform load up to the peak load.	The efficiency of the RC columns confined with CFRP membranes is reduced if the slenderness are increased.

3.0 Wrapping Configuration

Wrapping the beam in the hoop direction with CFRP did not improve significantly the performance of the beam under flexural loading. The presence of CFRP straps that were applied longitudinally in Beam produced a large improvement in the load carrying capacity of the column. Increasing the number of the CFRP layers resulted in increasing the load and the performance of the columns. Zero degree fiber orientation has been observed to be the most effective for models under pure axial load and 90 degrees fiber orientation was the most effective for eccentric loading.

S.no	Name Of The Author and Year	Specimen Detail (L×D or a×a×L)	Wrapping detail	Methods adopted	Remarks
1.	PezhmanTaghia et al., 2013.	Circular columns with dia=150, 250,300,450 and 600mm, and height 450mm and 750mm.	0.165mm thick fibers are wrapped in uni-direction.	Structural behaviour of the RC short column achieved by using nonlinear finite element analysis.	It was found that FRP confinement in lateral direction increases the hollow RC columns compressive strength and axial strain in concentric loading.

2.	RiadBenzaid et al., 2013.	Circular specimen of size (160×320)mmand square specimen of size (140×140)mm.	1mm thickness fibers wrapped at 45° orientation.	Specimens were loaded under a monotonic uni-axial compression load up to failure. The compressive load was applied at a rate corresponding to 0,24MPa/s and was recorded with an automatic data acquisition system.	For normal concrete the increase in strength for 1 layer is 141% and 46% for 3 layers of CFRP jackets, for medium-strength concrete were 33% and 17% for 1 layer, 72% and 30% for 3 layers of CFRP jackets., for high-strength concrete specimens with circular and square cross-sections, average 20% and 17% for 1 layer, 50% and 24% for CFRP jackets of 3 layers, respectively.
3.	Muhammad N. Hadi et al., 2014.	Square column of size (200×00)mm and corners are rounded for 32mm radius.	Fibers are wrapped at ±45° orientation in hoop direction.	The specimens are tested for 3 eccentricities 0 (concentric), 25, and 50 mm up to failure.	The combination of 45°CFRP layers and one hoop layer was expected to have the largest ductility. The combination of ±45° CFRP layers and one hoop layer did not show any increase in deflections of the columns under both concentric and eccentric testing. The enhancement in ductility was more evident than the enhancement in strength for all types of wrapping, in particular for columns wrapped with only hoop-oriented layers.

4.0 Conclusion

Carbon fibre has high tensile strength and modulus of elasticity and a brittle stress-strain characteristic. Wet layup method is most widely used for wrapping. Shape of the specimen place an important role in construction. Additional research is needed to determine the feasibility of carbon-fibre concrete on an economic basis. A more attention should be taken for finding the fire-resistance properties of carbon-fibre composites need to be evaluated.

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