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Effect of Different Patterns and Cracking in FRP Wrapping on Compressive Strength of Confined Concrete

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Abstract

Fiber Reinforced Polymers (FRP) are being introduced into a wide variety of civil engineering applications. These materials have been found to be particularly attractive for applications involving the strengthening and rehabilitation of reinforced concrete structure. The FRP strips provide the necessary longitudinal and hoop reinforcement, as well as a permanent formwork for the concrete core. In return, the concrete core contributes to the overall stability and stiffness of the composite system. A parametric study has been carried out to evaluate effect of number of FRP wrap layers, wrap position and position of crack in wrap on compressive strength of concrete. E Glass fiber wrapping is deployed in the present investigation. Cylinders of 300 mm height and 150 mm diameter were cast with M20 and M40 grade concrete and tested in unconfined and confined conditions with different patterns of FRP wraps such as one layer full wrap, two layers full wrap, 100 mm centre wrap and two strips wrap. Also, edge crack and centre crack were introduced in FRP wrap to understand crack propagation and subsequent loss of strength in the concrete-FRP composite system. Analytical study carried out using ANSYS 10 software shows good agreement with experimental observations. The main objective of this investigation is to optimize FRP wrapping and to predict ultimate compressive strength of FRP wrapped concrete columns.

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Keywords: Confined Concrete, Fiber Reinforced Polymer (FRP), Finite Element Analysis (FEA).

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1. Introduction

Fiber Reinforced Polymers (FRP) composites were first developed during the 1940s, primarily for military and aerospace engineering applications. FRPs have been successfully used in many civil engineering applications as well including load bearing and infill panels, pressure pipes, tank liners, roofs, bridge repair and retrofit, mooring cables, structural strengthening, etc. FRP is a relatively new class of composite material manufactured from fibers and resins and 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 [7]. Strengthening and increased durability against steel corrosion can be achieved in a RC structure by wrapping them with fiber reinforced polymer (2-4).

Mehdi et al. [5] carried out axial compressive tests on plain concrete and GFRP confined concrete cylinders. A total of 14 GFRP confined and 6 unconfined control concrete cylinders with a diameter of 150 mm and a height of 300 mm were tested. The effect of unconfined concrete core strength was examined by using three target strengths of 10, 20 and 40 MPa. The low, normal and high strength concrete cylinders were wrapped with one layer of GFRP sheet with 0º fiber orientation with respect to the hoop direction [5]. Ciupala et al. [1] conducted studies on axial compression test of concrete cylinders confined with carbon, glass and aramid fiber reinforced epoxy composite jackets. They presented results of the behavior of concrete cylinders confined with one layer of carbon fiber reinforced polymer (CFRP), aramid fiber reinforced polymer (AFRP) and glass fibre reinforced polymer (GFRP) [1].

Watanabe et al. [8] investigated experimentally and analytically the confinement effect of FRP sheets on the strength and ductility of concrete cylinders subjected to a uniaxial compression. Plain concrete cylinder specimens with dimensions of ф 100 x 200 mm retrofitted with FRP sheets were tested under a uniaxial compression. Variables selected for the test and analysis includes the type and the number of FRP sheets. Carbon fiber reinforced plastic (CFRP), high stiffness carbon fiber reinforced plastic (HCFRP) and aramid fiber reinforced plastic (AFRP) were used and the number of FRP sheet layers varied from 1 to 4. The analytical procedure considered a nonlinear 3-Dimensional FEM. Comparison of test results with those obtained by the analytical study showed good agreement [8]. Rochette and Labossiere [6] used an incremental finite element technique to evaluate the response of fiber wrapped square concrete columns. The model favorably compared with the results of their own uniaxial compression tests [6].

Parametric study has not been done so far by incorporating predefined crack into the wrap at various locations. In very special cases, the structures come across such a situation when either by human mistake, handling defect or due to any accidental reason cracking occurs in wrapping which leads to poor performance of the fiber wrapping in confinement. Present investigation will enable the designer to estimate strength parameters of retrofitted members in such cases.

2. Experimental Investigation

The concrete mix proportions were 1: 2.2: 3.1 with w/c ratio of 0.42 and 1: 2.5: 3.3 with w/c ratio of 0.36 for M20 and M40 grade of concrete respectively. The cylinders were wrapped fully and partially with E-glass fiber reinforced polymers. Installation of glass fiber sheet on the test specimen is done with the help of the MBrace Composite Strengthening Resin System which consists of MBrace Primer and MBrace Saturant for effective adhesion of fiber sheet to the concrete surface. The experimental program comprised of testing of a total number of 34 cylindrical specimens having diameter of 150 mm and 300 mm height which included 17 numbers of specimens each for M20 and M40 grade of concrete. All the specimens were wrapped and subjected to axial compressive load after 28 days of normal water curing. Specimens were treated with different wrap positions and number of layers along with introduction of centre crack and edge crack as indicated in Fig. 1. Table 1 describes mechanical properties of E Glass fiber [9] used in the present investigation. Table 2 shows identification and detail of types of specimen with different wrap positions used in the present investigation. The location and size of the cracks are based on the criticality of influence on the effect of wraps.

Table 1. Mechanical Properties of E Glass Fiber

Sr. No	Description of Property	Value
1	Density	2.7 g/cm3
2	Tensile Strength	3400 MPa
3	Modulus of Elasticity	75 GPa
4	Strain	4.5

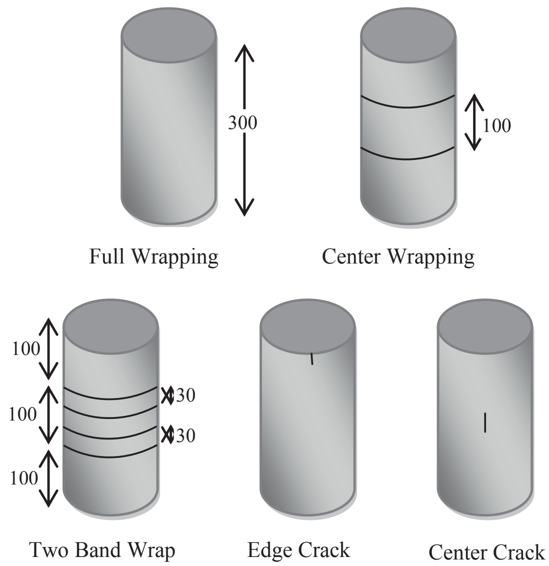


Fig. 1. Patterns of Fiber Wrapping and Introduction of Crack in Wrap

Table 2. Types of Specimen with different Wrap Position

Type of Specimen	Description of Wrap
A	One layer full wrap
B	100 mm wrap in middle
C	Two layers wrap
D	Edge Crack
E	Centre Crack

3. Discussion of test result

All the specimens were wrapped after 28 days of casting ensuring proper curing of the GFRP sheets and then loaded to axial compression. Before testing the specimens, edge crack having lengths of 15 mm and 20 mm and a centre crack having length of 30 mm were made in fiber wrap. All the cylindrical specimens were tested in Universal Testing Machine (UTM) for axial compression. As can be seen from Fig 2, the composite wraps have failed in tension due to bulging of the concrete. No debonding of wraps from concrete surface has been observed as expected under this type of loading.

The confined and the unconfined compressive strength of cylinder specimens for M20 and M40 grade concrete are as summarized in **Table 3** and **Table 4** respectively. The results of M20 and M40 grade of concrete by introducing the edge cracks and centre crack in fiber wrap are as summarized in the **Table 5** and **Table 6** respectively. Unconfined strength of concrete for M20 and M40 grade of concrete is found to be 24.48 MPa and 45 MPa respectively.

Improvement in compressive strength of confined concrete in type A and type B specimens over unconfined concrete of M20 grade is 57.80% and 85.00% respectively which reveals that single layer of wrap is much beneficial compared to two layers as far as economy is concern. Gain in two wrap layers over single layer is only 27.2% which is not benefiting much. Center and two bands wrapping are not recommended being least effective.

Table 3. Compressive Strength of M20 Concrete with different Wrap Positions and Types

Description of Strength	One Layer Wrap (A)	Two Layers Wrap (B)	Wrapping at Centre (C)	Two Bands Wrapping (D)
Confined Strength (MPa)	38.63	45.29	30.57	33.66
% Gain	57.80%	85.00%	24.87%	37.50%

Table 4. Compressive Strength of M40 Concrete with different Wrap Positions and Types

Description of Strength	One Layer Wrap (A)	Two Layers Wrap (B)	Wrapping at Centre (C)	Two Bands Wrapping (D)
Confined Strength (MPa)	55.62	77.42	52.08	54.15
% Gain	23.60%	72.04%	15.73 %	20.33%

Table 5. Compressive Strength of M20 Grade Concrete with Introduction of Crack

Description of Strength	15 mm edge crack	20 mm edge crack	30 mm centre crack
Confined Strength (MPa)	38.63	38.63	38.63
Confined Strength with Crack (MPa)	37.36	37.08	32.55
% Loss	3.28%	4.01%	15.73 %

Table 6. Compressive Strength of M40 Grade Concrete with Introduction of Crack

Description of Strength	15 mm edge crack	20 mm edge crack	30 mm centre crack
Confined Strength (MPa)	55.62	55.62	55.62
Confined Strength with Crack (MPa)	55.20	54.63	49.53
% Loss	0.76%	1.78%	10.95 %

(a) (b) (c) (d)

Fig. 2. Failure of Specimens having different Patterns of Fiber Wrapping and Cracking (a)Fully Confined (b)Fully Confined with edge crack (c)Partial Confined Double Band (d)Partial Confined Central Band

4. Finite Element Modeling of Concrete Confinement

In this present study, a finite element model of FRP confined concrete column was developed and validated by existing experimental results. The models were simulated using ANSYS 10 software. In general, the conclusions and methods would be very similar using other non linear FEA programs. A 3-D layered structural element SOLID 46 was used to model FRP composites. SOLID 46 was selected over shell elements due to the fact that the shell elements would share nodes with the concrete cylinder surface. Such a choice would make introduction of cracks difficult. The element allows up to 250 layers. Initial cracks have been introduced in the model by geometric modelling and subsequent expansion of the cracks has been model by reduced elasticity modulus of the wraps after failure. The element has three degrees of freedom at each node: translation in x, y, z directions. The element is defined by eight nodes, layer thickness, layer material direction angles and orthotropic material properties. For the modelling of concrete, a 3-D concrete solid element SOLID 65 was used. It can be used with or without reinforcing bars. The solid is capable of cracking in tension and crushing in compression. The element is defined by eight nodes having three degrees of freedom at each node: translations in x, y, z directions. The element allows application of different isotropic material properties for tensile and compressive stress domains. The material properties of the FRP composites are calculated using micro mechanics approach as given below.

$E_x = E_1$; $E_y = E_2$; $E_z = E_3$.

$\mu_{xy} = \mu_{12}$; $\mu_{yz} = \mu_{23}$; $\mu_{zx} = \mu_{31}$.
$G_{xy} = G_{12}$; $G_{yz} = G_{23}$; $G_{zx} = G_{31}$.
From the rule of mixtures;

$$E_1 = E_f V_f + E_m V_m$$

$$E_2 = \frac{E_m E_f}{E_m V_f + E_f V_m}$$

Where, E_f = Modulus of elasticity of the Fiber
E_m = Modulus of elasticity of the Matrix
V_f = Volume fraction of fiber and V_m = Volume fraction of matrix
Similarly the shear modulus can be calculated,

$$G_{12} = \frac{G_m G_f}{G_m V_f + G_f V_m}$$

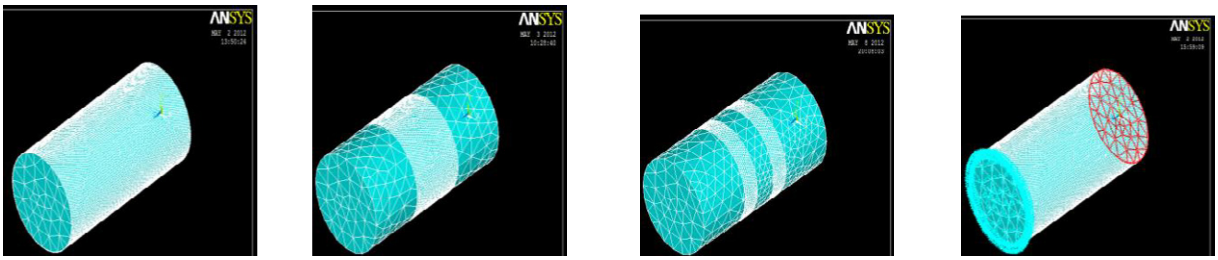
Where G_m = shear modulus of matrix, G_f = shear modulus of fiber
Following the same procedure the major Poisson's ratio is calculated,

$$\mu_{12} = V_f \mu_f + V_m \mu_m$$

Where μ_f = Poisson's ratio of fiber, μ_m = Poisson's ratio of matrix
The relation between the major Poisson's ratio and the minor Poisson's ratio can be given by the following equation;

$$\frac{\upsilon_{12}}{E_1} = \frac{\upsilon_{21}}{E_2}$$

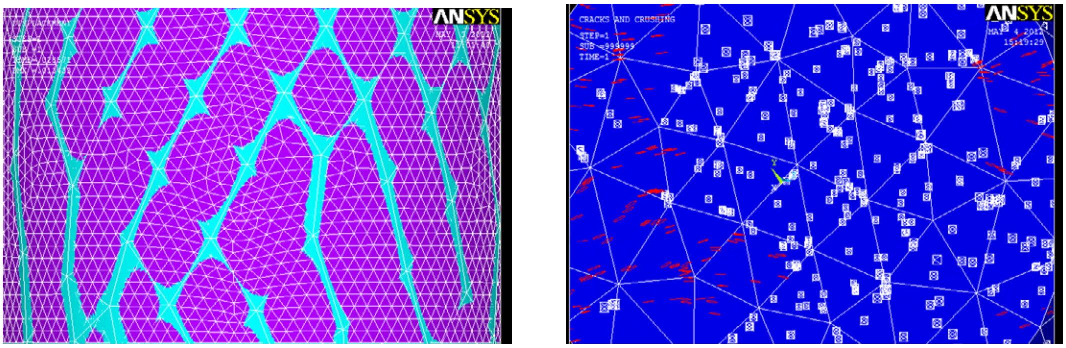
For FRP composite as defined by the element, the input data used are the number of layers, thickness of the layers and orientation of fiber direction for each layer. The composite is orthotropic in nature therefore; nine different properties have to be the input i.e. the elastic modulus in three different directions (Ex , Ey , Ez), the shear modulus in the three directions (Gxy ,Gyz ,Gzx) and the Poisson's ratio in the three directions (μ_{xy} , μ_{yz} , μ_{zx}). To obtain isotropic material properties for concrete, the elastic modulus (Ex) is estimated by $5000\sqrt{f_{ck}}$ (MPa) and the Poisson's ratio (μ_{xy}) of 0.15 are taken for input to the element along with the values of ultimate tensile strength and ultimate compressive strength .



(a) (b) (c) (d)

Fig. 3. FEM Modeling of various Specimens (a) Fully Confined Concrete (b) Centrally wrapped Concrete(c) Double Band Wrapped (d) Loading and Boundary Conditions

When a FRP wrapped concrete column is subjected to a compressive load, concrete will be the initial load bearing member of the structure. The compressive load initiates micro-cracks in the concrete as shown in **Fig. 4 (a)**. The concrete crushes when its ultimate compressive strength is reached. ANSYS is able to demonstrate the cracking and crushing of the concrete for an applied load. **Fig. 4 (b)** shows the concrete crushing and cracking; the octagons represent crushing and the circles represent the cracking in the concrete. The FRP starts confining the concrete column, when the concrete reaches its ultimate compressive strength. Thus, the FRP and the concrete core will carry the load collaboratively. The failure in the structure occurs when eventually the FRP fails.



(a) (b)

Fig. 4. Failure indicated by FEA Modeling (a) Initial Cracking in Fiber Wrapping (b) Cracking and Crushing of Concrete

The comparison between the experimental results and the results predicted by FEA without introduction of crack in the fiber is tabulated in **Table 7** which shows that the FEA results have good agreement with experimental results.

Table 7. Compressive Strength of M40 Grade Concrete with Introduction of Crack

No.		Description	Confined Strength (MPa) Exptl.	Confined Strength (Mpa) FEA	% Error
1	M20	One layer	38.63	36	6.8
2	M20	Two layer	45.29	46	-1.57
3	M20	Centre wrap	30.57	32	-4.67
4	M20	Two band wrap	33.66	34	-1.01
5	M40	One layer	55.62	58	-4.27
6	M40	Two layer	77.42	79	-2.04
7	M40	Centre wrap	52.08	54	-3.68
8	M40	Two band wrap	54.15	55	-1.56

5. Conclusion

- The confined concrete strength is essentially dependent on the maximum confining pressure that the FRP can apply. The FRP confinement increases the axial load carrying capacity of concrete structures. Better confinement was achieved when concrete cylinders were fully confined with GFRP than partially confined specimens.
- The confinement effectiveness increases with increase in the number of layers/wrap. Better confinement was achieved when number of the layers of GFRP was increased, resulting in enhanced load carrying capacity. This is due to larger area available to provide hoop action.
- The failure of the specimens took place in the middle half region of the specimens when full confinement was provided and it took place at top and bottom portion in case of partially confined specimens.
- Crack in FRP layer affects the compressive strength of concrete. Crack location and crack length affects differently to compressive strength of concrete. Loss in compressive strength is more in specimens with centre crack than specimens with edge crack.
- From the literature referred it is found that the confinement models developed for concrete columns confined with steel tend to over predict the strength enhancement when applied to the FRP confined concrete columns. This is mainly because of the behavioral difference between the two materials, that is steel and FRP.Steel being an elasto-plastic material, exerts a constant confining pressure after its yield. While FRP, being a linearly elastic material, confines the concrete with an ever increasing confining pressure until its rupture.
- Results obtained by 3-D FEA modeling shows good agreement with the experimental results.

References

[1] Ciupala et al., “Confinement of concrete cylinders with fibre reinforced composite jackets”, Report of the University of Sheffield, Sheffield, UK.
[2] Lee C., Bonacci J. F., Thomas M. D. A., Maalej M., Khajehpour S., Hearn N., Pantazopoulou S. and Sheikh S., 2000. “Accelerated corrosion and repair of reinforced concrete columns using carbon fiber reinforced polymer sheets”, Canadian Journal of Civil Engineering, Vol. 27, No. 5, pp. 941-948.
[3] Li G., Hedlund S., Pang S., Alaywan W., Eggers j. and Abadie C., 2003. “Repair of Damaged RC Columns Using Fast Curing Composite.” Composite Part B: Engineering, Vol. 34.
[4] Masoud S. and Soudki K. May 2002. “Post-repair performance of corroded reinforced concrete beams repaired with FRP sheets”, Proceedings of the 2nd International Conference on Durability of Fiber Reinforced Polymer Composites for Construction, Montreal, pp. 113-126.
[5] Mehdi B., Bahareh A., Masoud., Mohammad S.: “The experimental modeling of GFRP confined concrete cylinders subjected to axial loads”, Ph. D Thesis, Civil and Environmental Engg. Dept., Arizona State University, USA.
[6] Rochette, P., and Labossiere, P. 1996. "A plasticity approach for concrete columns confined with composite materials." Adv. Composite Mater. in Bridges and Struct., El-Badry, M. M.(Ed.), CSCE, 359-366.
[7] Shilpa K., Panda G. and Kumari Mamta, 2010. “Damage and degradation study of FRP composite”, Report of Department of Metallurgical and Materials Engineering, National Institute of Technology, Rourkela.
[8] Watanabe K. et al. 1997. "Confinement effect of FRP sheet on strength and ductility of concrete cylinders under uniaxial compression", Proceedings of the Third International Symposium, Vol. 1, Sapporo, Japan, pp. 233-238.
[9] Kaw A. 2005. “Introduction to Composite Materials”, 2e., CRC Press.