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STRENGTHENING OF CONCRETE CYLINDERS WITH CFRP SHEET

G. MOUNIKA [1], T. NEEHARIKA [2]

[1]Assistant Professor, Dept. of civil engineering, Visvodaya Engineering College, Kavali, Spsr Nellore District.

[2] M.Tech Scholar, Structural Engineering, Dept. of civil engineering, Visvodaya Engineering College, Kavali, Spsr Nellore District.

ABSTRACT:- Strengthening of Concrete structures with externally wrapping CFRP sheets and plates has become very popular over the past decade. Wrapping is generally applied to concrete specimens, with the aim of enhancing their load carrying and to increase concrete strength and ductility. When concrete cylinder is loaded to axial compressive stress, it expands laterally. The Carbon fiber reinforced polymer (CFRP) has significantly enhanced the strength and ductility of concrete by forming perfect adhesive bond between concrete and the wrapping material.

In this work, studied the behavior of the concrete wrapped with bidirectional GFRP sheet under uniaxial compression. Specimens considered for the work was cylinders having circular in shape of diameter 150mm and height 300mm. Experiments were conducted on concrete cylinders with and without CFRP wrapping. Three specimens were tested with conventional concrete and 1 layer, 2 layers and 3 layers of 100mm center wrapping. The specimens were tested for compressive strength and split-tensile strength. Along that stress-strain curve is presented to predict the axial compressive behavior of CFRP wrapped and unwrapped concrete cylinders by noting deformations at different loads. Comparisons between the analytical results obtained using the proposed model and experimental results are also presented.

Key words: CFRP Sheet, Epoxy Resin, Wrapping, Compression and Split-Tensile strength, stress-strain curve

1. INTRODUCTION

Fiber reinforced concrete has several advantages over traditional materials used to build, such as light weight, rigidity, and high corrosion resistance. It creates the impact of minimal architecture because of low fiber thickness and ease of repair. However, it is expensive and has a linear stress-strain relationship leading to brittle fracture behavior. Currently, the main application in structural engineering is packing.

Steel reinforcements in the concrete have advantages and disadvantages such as corrosion, heavy weight and handling difficulties. In contrast, the glass fiber reinforced polymer and carbon (FRP) reinforcement sheets have more advantages, including a high strength to weight ratio, light weight, corrosion resistance, low conductivity, an electrical resistance high, and the mechanical properties of electromagnetic transparency at low temperatures. These are different from conventional reinforcing concrete, where in the steel bars are placed separately, and the concrete is cast around it, in the case of a polymer sheet reinforced concrete strengthened with fibers. Traditional rebar or reinforcing may or may not be there in the concrete structure, according to the particular application. This fiber polymer sheet the strengthening of concrete structures offer potential life increasingly, economic and environmental benefits. FRP sheets have different mechanical properties of steel bars, including brittle elastic stress-strain.

Fiberglass reinforced polymers are composed of extremely fine glass fibers. It turned out to be the solution, a major development in the technology of reinforced concrete. It has gross mechanical properties compared to the carbon fibers. However, it is stronger and more rigid or carbon fiber; it is much cheaper cost and materially less fragile. Therefore, these glass fibers are used as reinforcing agent for various polymeric products to build a very strong and adequately light material polymer composite reinforced with carbon fibers known as carbon fiber reinforced polymers (CFRP).

1.1. Objectives

- To experimentally investigate the Compression and Split-tensile strength of concrete cylinder samples wrapped with multiple layers of CFRP sheet configurations.
- To compare the strengths of conventional concrete with wrapped concrete cylinder
- To develop stress-strain curve for conventional and wrapped concrete cylinders.

2. BACKGROUND

- **Norris and Saadatmanesh et al. (1994)** cast thirteen concrete beams for flexural tests to compare three different fiber/epoxy systems and several orientations of fiber. The beams (5"x8"x96") contained close to the minimal amount of steel reinforcement (two 3/8" diameter bars) and were over-designed against shear. Some beams were pre-cracked before the application of the CFRP to see if pre-cracking caused any substantial differences in behavior. Norris concluded that off-axis CFRP laminates need to be studied at length. Use of different orientations could increase the strength and stiffness of concrete beams without causing catastrophic, brittle failures associated with unidirectional laminates.
- **Shahawy et al. (1995)** assessed the effectiveness of external reinforcement in terms of the cracking moment, maximum moment, deflection, and crack patterns. Four beams (8"x12"x108") were tested using minimum steel reinforcement (two ½" diameter bars) and varying the layers of unidirectional CFRP. This shows an enhanced concrete refinement due to the CFRP sheets.
- **Rania AI-Ham et al. (2006)** investigated on flexural behavior of corroded steel reinforced concrete beams under repeated loading. This investigation was carried out on thirty beams of sizes 152x254x2000mm repaired with carbon fiber reinforced polymer (CFRP) sheets. The authors reported that repairing with CFRP sheets increased the fatigue capacity of the beams with corroded steel reinforcement beyond that of the control unrepaired beams with un-corroded steel reinforcement.
- **Thong M. Pham et al. (2016)** investigated on the structural behavior and failure modes of fiber-reinforced-polymer (FRP) confined concrete wrapped with different FRP arrangements. In this study the wrapping arrangements in order to investigate the confinement efficacy between fully, partially and a proposed non-uniform wrapping arrangement for FRP-confined concrete. Finally, this study investigated and provided some recommendation on the application of different wrapping arrangements.

3. MATERIALS AND THEIR PROPERTIES

3.1. Concrete

Ordinary Portland cement 53 Grade was used in this experiment. Casting of all cylinder specimens are conducted by using M20 grade concrete mix. The mix proportion for concrete is shown in Table 1.

Table-1: Mix proportion of M_{20} Grade concrete

Ingredients	Quantity
Cement	372 Kg/m^3
Water	186 Kg/m^3
Coarse aggregate	1197.61 Kg/m^3
Fine aggregate	585.34 Kg/m^3

3.2. CFRP Sheet and Epoxy resin

Carbon fibers have a very high tensile strength and elastic modulus. The elastic modulus of "high modulus" carbon fiber is similar to steel. CFR using high and ultra-high modulus carbon fibers are popular in the aerospace industry because its strength to weight ratio is among the highest of all FRPs. High strength, normal modulus fibers are used with CFRPs in the infrastructure industry.

Materials used for strengthening of concrete are CFRP (Carbon fiber reinforced concrete), Epoxy resin, Hardener as shown in figure 1. CFRP sheet was taken from Go green products, Chennai. The properties of epoxy resin are given by the suppliers is shown in table 1.

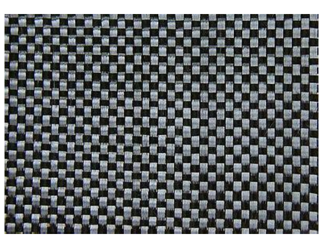
(a)  (b) 

Fig-1: (a) CFRP Sheet (Bidirectional), (b) Epoxy Resin

Properties of CFRP Sheet:

Carbon fiber is frequently supplied in the form of a continuous tow wound onto a reel. The tow is a bundle of thousands of continuous individual carbon filaments held together and protected by an organic coating, or size, such as polyethylene oxide (PEO) or polyvinyl alcohol (PVA). Each carbon filament in the tow is a continuous cylinder with a diameter of 5–10 micrometers and consists almost exclusively of carbon. The earliest generation (e.g. T300, HTA and AS4) had diameters of 16– 22 micrometers. Later fibers (e.g. IM6 or IM600) have diameters that are approximately 5 micrometers. The atomic structure of carbon fiber is similar to that of graphite, consisting of sheets of carbon atoms arranged in a regular hexagonal pattern (grapheme sheets), the difference being in the way these sheets interlock.

Properties of Epoxy resin:

Table-2: Properties of Epoxy

Property	Specification	Unit	Araldite LY 556	Aradur HY 951
Viscosity at 25℃	ISO 12058	mPa.s	10,000-12,000	10-20
Density at 25℃	ISO 1675	gm/cc	1.15-1.20	0.97-0.99
Flash point	ISO 2729	℃	>200	>180

Processing of Epoxy and Hardener:

Araldite LY 556 is medium viscosity, a liquid epoxy resin unmodified based on bisphenol-A. Aradur HY 951 is a low viscosity, an unmodified polyamine, aliphatic. Araldite with Aradur provides a low viscosity, room temperature curing solvent-free lamination system. By varying the content of Aradur hardener From 10 to 12 parts, the reactivity of the system can be adapted to the processing conditions and curing. The processing ratio is given in table 3.

Table-3: Mixing Ratio of Epoxy and Hardener

Mixing Ratio	Parts by Weight
Araldite LY 556	100
Aradur HY 951	10-12

4. EXPERIMENTAL PROGRAM

In this investigation, the material used Carbon FRP sheet is attempted to strengthen or wrap the concrete. Carbon fiber reinforced polymer sheet is shown high strength than conventional concrete.

4.1. Casting of concrete cylinder specimens

The ingredients were mixed by hand. Molds cast iron 150 mm diameter 300 mm height of cylinder samples were used. Once the concrete has been poured into molds, they were compacted thoroughly by placing on table vibrator. Moldings were performed 24 hours after casting and the samples were stored for curing in the curing tank.

4.2. CFRP Wrapping

Concrete surface required to be cleaned with a wire brush to remove any loose dust particles. Both parts of the epoxy system used, consisting of a resin and a hardener, were thoroughly mixed by hand for at least 5 minutes before use. CFRP sheets were then applied directly onto the surface of the samples providing a bidirectional lateral confinement in the circumferential direction. In this study the cylinders are wrapped center of 150mm height. The number of sheets per cylinder ranges from 1 to 3 as shown in figure 2.

Fig-2: CFRP Sheet wrapped on concrete

4.3. Test Procedure

3.3.1 Compression test

When the test cylinders are cured and dried surface then it is placed vertically on the bottom plate of the compression testing machine (CTM) as shown in figure 3. The cylinder specimens are compressed and deformations at various loads were recorded. The compressive strength is calculated using the following expression.

$$\text{Compressive strength: (ultimate load / contact area of cylinder)} = \frac{P}{\frac{\pi d^2}{4}}$$

3.3.2 Split-Tensile test

The static compressive test or split-tensile test setup is given in figure 3. The test specimens were placed horizontally between the steel bearing plates. The split tensile strength and deformations at different loads were noted during split-tensile test. The Split-Tensile strength is calculated using the following expression.

$$\text{Split-tensile strength: } \frac{2P}{\pi dl} \quad \text{Where, D = 150cm; L = 300cm;}$$

(a) (b) (c)

Fig-3: (a) Compression strength test (b) Split-Tensile Test (c) Tested sample specimen

5. TEST RESULTS AND DISCUSSIONS

5.1. Compression test results

Compressive strength test indicates that the resistance of the aggregate samples with wrapping and unwrapping. Three cylinders were tested at a time. The results are presented in the table 4.

Table-4: Compression strength of specimens with and without CFRP wrapping

S.No.	Number of CFRP layers	Average compressive strength (Mpa)
1	0	26.5
2	1	29.2
3	2	30.5
4	3	31.8

The Compressive strength of every Specimen is shown in Chart 1. Maximum load was carried by specimen strengthened with three layers of CFRP center wrapping is 249.9KN.Compressive strength is about 31.8 N/mm2. There is considerable increase in strength of concrete with 1 layer, 2 layers, and 3 layers of CFRP wrapping increased by10.2%, 15.1% and 20%in comparison with conventional concrete strength.

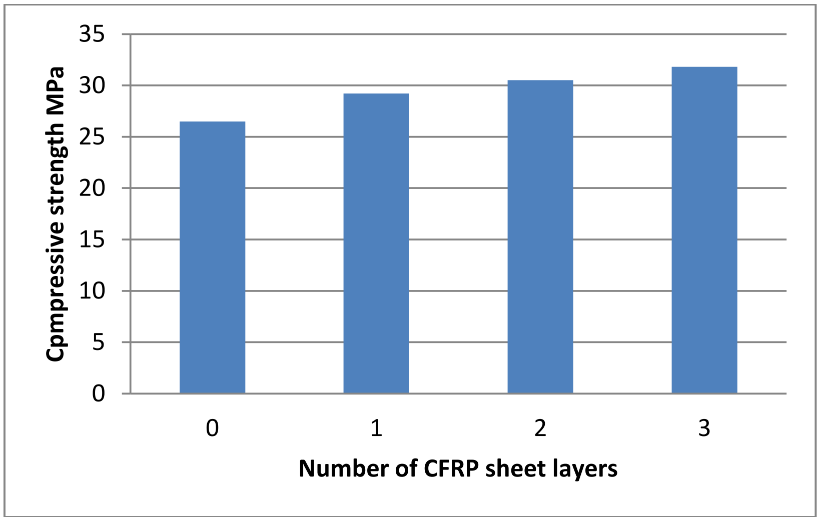


Chart-1: Compressive strength of Concrete specimens

5.2. Split-Tensile test results

The indirect tensile strength indicates a downtrend of tensile strength when the aggregate percentage is increased. Tensile forces develop the cracks between concrete .Following Table 5 shows the average split-tensile strength of concrete noted during the test.

Table-5: Split-tensile strength of specimens with and without CFRP wrapping

S.No.	Number of CFRP layers	Average compressive strength (Mpa)
1	0	4.6
2	1	5.3
3	2	6.4
4	3	7.2

The Split-tensile strength of every Specimen is shown in Chart 2. From the above chart the Maximum load was carried by specimen strengthened with three layers of CFRP center wrapping is 226 KN. The tensile strength is about 7.2 N/mm^2. There is considerable increase in strength of concrete with 1 layer, 2 layers, and 3 layers of CFRP wrapping increased by15.2%, 39.13% and 56.5%in comparison with conventional concrete strength.

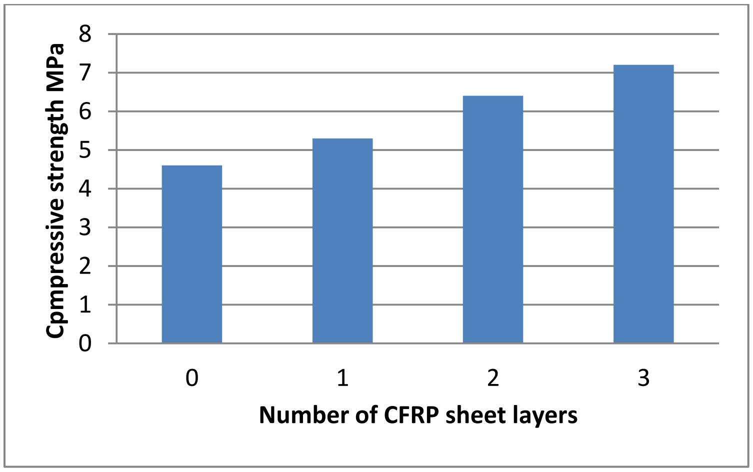
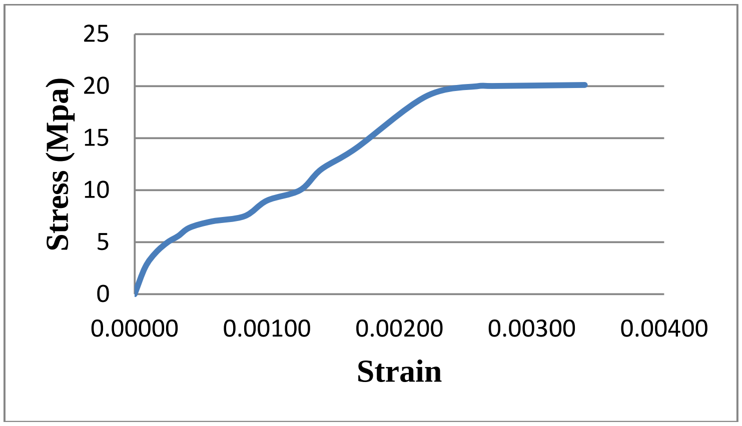


Chart-2: Split-Tensile strength of specimens

5.3. Stress-Strain

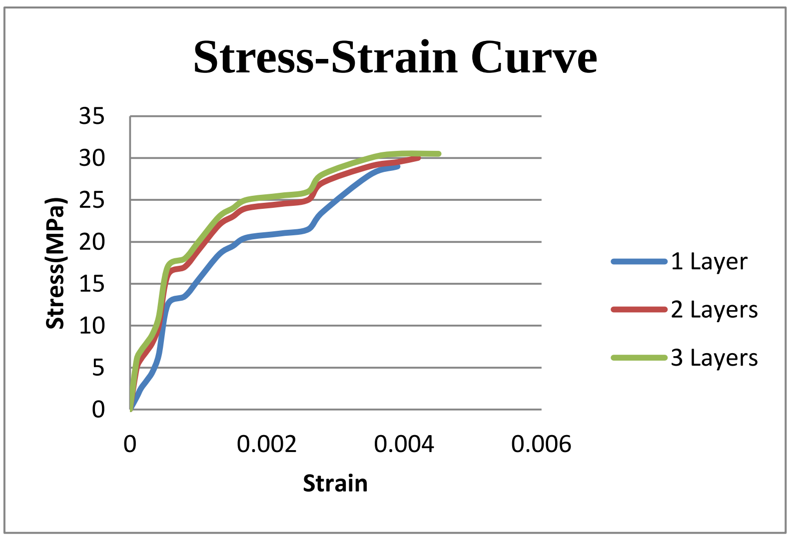
4.3.1. Stress-strain for conventional concrete



Graph-1: Stress-strain curve for conventional concrete

The stress-strain curves for the plain specimens are presented in Graph 1. This figure shows that the unwrapped concrete average strength is 26.5Mpa and corresponding strain of 0.0034 was calculated.

5.3.1. Stress-strain for concrete wrapped with CFRP sheet



Graph-2: Stress-strain curve for concrete with CFRP wrapping

The axial stress-strain curves for the plain specimens are presented in Graph 2. This figure shows that the CFRP wrapped concrete strength varies between 29.2 and 31.8Mpa for 1, 2 and 3 layers and the corresponding strain of the wrapped concrete varies between 0.03 and 0.042.

6. CONCLUSION

This work is based on the testing results on the behavior of concrete cylinders with and without CFRP sheets wrapping, the below conclusions are drawn:

- The maximum compressive strength is obtained for 3 layers compared to 1, 2, 0 layers of Wrapping with CFRP. This is about 31.8 Mpa. The cylinder specimens wrapped with 1 layer, 2 layers and 3 layers of CFRP shows10.2%, 15.1% and 20% increase in the Compression respectively compared to the specimen without wrapping
- The maximum Split-tensile strength is obtained for 3 layers compared to 1, 2, 0 layers of Wrapping with CFRP. This is about 7.2 Mpa. The cylinder specimens wrapped with 1 layer, 2 layers and 3 layers of CFRP shows15.2%, 39.13% and 56.5%increase in the Compression respectively compared to the specimen without wrapping.
- The CFRP wrapped concrete strength varies between 29.2 and 31.8 Mpa for 1, 2 and 3 layers and the corresponding strain of the wrapped concrete varies between 0.039 and 0.048. Thus the wrapping of CFRP sheets improves the compression tensile strengths and also improves the ductility property.

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