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Carbon Fiber: The Future of Building Materials

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Abstract: The need for rehabilitation, repair and strengthening of concrete structure has increased worldwide with a growing number of systems employing concrete jacketing, various retrofitting techniques, externally applied fiber-reinforced polymer (FRP) composites, etc**.** For structural applications, an overview of the different FRP composites are provided by various polymer composites and in civil structures FRP composites are used to restore or strengthen the building block. This paper is focused on investigation of the ability of woven carbon fiber reinforced fabric packaging to improve the strength of various building components. To this end, few concrete cubes were poured and were wrapped in carbon to verify the increase in strength. The strengths of cubes with carbon fiber wrapping and without carbon fiber wrapping were compared and the results were observed to have increased in strength for the carbon fiber wrapped cubes. A non-destructive Rebound Hammer test was performed on this column and later it was wrapped in a carbon fiber cloth to increase its strength. In addition, the expense of the two methods i.e. concrete jacketing and carbon fiber wrap was compared and carbon fiber wrap was found to be economical than the other method. In both cases, the resistance was found to be greater than the initial resistance. Therefore, carbon fiber has proven to be effective in both.

Keywords: Carbon Fibre, Carbon Fibre Reinforced Fabric, Strengthening of members

I. INTRODUCTION

A large number of the reinforced concrete infrastructure found in developed countries including bridges, municipal buildings, transportation systems, and parking facilities are suffering from distress due to overuse or inadequate maintenance. Demolishing and building a new structure is very costly and time consuming. Structural strengthening is more economical solution and hence frequently required to extend the functional service lives of deficient RC structures. Reinforced concrete and injection molding steel casing systems are the most popular methods developed in the past for upgrading RC shafts. Although both methods are effective in increasing structural capacity, they are labor-intensive and sometimes difficult to implement on site. In addition, the RC casing system will greatly increase the shaft cross section. The steel casing system is often heavy and performs poorly in resisting adverse environmental conditions. Hence, an innovative, durable, easy-to-install and cost-effective stiffening system is required to replace old technologies.
Carbon fiber fabric has emerged as a promising alternative reinforcing material for upgrading poor RC infrastructure. This fabric can easily be wrapped around the cross section of the column with a heavy duty adhesive to provide a boundary. Carbon fiber and other composite materials have high performance; they are very light in weight but can withstand enormous loads, because carbon fiber has unique properties that make it an ideal building material. Composites represent a very interesting opportunity for rapid manufacturing and customization; it would take just a few weeks to build a small carbon fiber shell, compared to months with conventional materials. Composite structures can be erected fairly quickly and do not require a lot of skilled labor and workflows from general contractors and subcontractors, for example for the supply of materials. Therefore, we can go faster, the delivery chain is shorter, the amount of material is reduced and it is less expensive.
As the carbon fiber are flexible and light weight, can be moved easily. Modules can be picked up, picked up elsewhere and chained to produce larger assemblies if required. This makes composite structures far more flexible than conventional buildings.

A. Carbon Fiber

Carbon fibers are fibers that are about 5-10 microns in diameter and are made up mostly of carbon atoms. Carbon fibers have several advantages, including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in the aerospace, civil engineering, military and motorsport industries, as well as in other competitive sports.
To produce carbon fibers, the carbon atoms are bonded to each other in crystals aligned somewhat parallel to the long axis of the fiber as the crystal alignment gives the fibers a high strength to size ratio (making them strong for their size). Several thousand carbon fibers are grouped together to form clouds that can be used alone or woven into a fabric.

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B. Problem Statement

The problem with steel cladding and retrofitting is that it is a time-consuming and costly process, while the use of externally bonded FRP composites for repair can be a cost-effective alternative to restore or improve column performance. However, CFRP confinement procedures and models were previously developed for circular columns and could not be used in the case of rectangular columns. Our research aims to improve the limited research on rectangular columns adapted by FRP coating and also to provide an overview of the behavior of rectangular columns confined with a FRP coating.

C. Objectives

- Investigation of the life cycle of carbon fibers for lightweight constructions.
- To study the behavior of various types of carbon fiber sheets, carbon fiber reinforced polymers, carbon fiber strands, etc. that can be used for various Civil Engineering works and problems.
- Study the reinforcement of axially and eccentrically loaded reinforced concrete columns with carbon fiber reinforced polymer wrapping systems.

II. METHODOLOGY

A. Research Methodology

In this research, study has been carried out for identifying different properties of carbon fiber and how it is made, the defects that could be generated during the manufacture of carbon fiber which may cause a failure of its characteristics and lead to carbon fiber being weak. Carbon fiber and other composite the materials are highly efficient; they have a very small weight but can withstand huge loads, because carbon fiber has such unique properties, making it an ideal building Equipment.

B. Approach to the Material

It is found that the applications of carbon fibers are very important in the automotive industry, aerospace industry but very little development has been so far in the construction sector, hence study has been carried out on the columns and beams with carbon fiber reinforced fabric, to increase their resistance and load capacity. For this, a case study has been taken at Vani, Nashik, Maharashtra where columns failed due to lack of care after construction and needed to be re strengthened.
So instead of a regular upgrade with steel jackets or with renovation of concrete, it is suggested that the solution for carbon wrapping of faulty columns in the building.
Non-destructive testing was carried out on the columns using a rebound hammer and recorded the failure of the Columns. The site in charge was quite generous to allow us to wrap a carbon fiber column Reinforced fabric. After testing the columns with the rebound hammer, I found that most of the columns failed and had compressive strength less than 20 N/mm2. There were a few columns whose compressive strength appeared less than 10 N / mm2 and needed urgent upgrading. Following is the tabular data of the rebound hammer test that we conducted on the columns.

III. TEST REPORT FOR NDT

A. Rebound Hammer Test

Table 1 - Rebound Hammer Test.

Rebound Hammer Test	
Date of Testing Site Address	12/9/2019
	Vani, Nashik, Maharashtra.
Structure	R.C.C. Framed Structure
Instrument Details	Schmidt's Rebound Hammer
Code of Reference	IS13311 Part (1): 1992, BS1881 :
	Part 203 : 1986

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Table 2 - Rebound Hammer Test Results on Failed Columns for Ground Floor.

Sr. No.	Member	Rebound Number							Avg. Char. Comp. Strength. (MPA)
	Ground Floor	1	2	3	4	5	6	Avg.	
1	Column C1	22	19	26	24	26	21	23	14
2	Column C2	24	24	20	26	26	-	24	16
3	Column C3	20	18	18	21	23	22	20.33	10.5
4	Column C4	19	19	24	20	16	18	19.33	fail
5	Column C5	26	22	24	24	24	-	24	16
6	Column C6	24	24	22	25	20	-	21.8	12
7	Column C7	37	33	34	34	36	36	31.5	28
8	Column C8	27	25	26	26	28	28	26.67	19.5
9	**Column C9**	**18**	**14**	**18**	**19**	**15**	**14**	**16.33**	**Fail (Less than 10)**
10	Column C10	20	20	28	22	24	28	23.67	15.5
11	Column C11	29	35	28	30	30	28	29	24
12	Column C12	22	21	25	25	26	26	24.2	16
13	Column C13	27	31	28	31	28	26	28.5	25
14	Column C14	28	29	30	18	24	28	26.2	19
15	Column C15	28	27	26	24	31	28	27.33	20.5
16	Column C16	26	26	25	24	23	29	25.5	18
17	Column C17	26	24	28	27	24	26	25.83	18.5
18	Column C18	26	26	27	26	28	-	26.6	19.5
19	Column C19	28	26	24	24	25	-	25.4	18
20	Column C20	26	23	24	28	24	26	25.2	17.5
21	Column C21	33	34	36	40	32	-	35	34
22	Column C22	32	34	30	32	32	28	31.33	27.5
23	Column C23	24	24	22	22	26	24	23.67	15.5
24	Column C24	32	30	32	28	26	32	28.33	22
25	Column C25	20	18	16	17	16	12	16.5	Fail
26	Column C26	23	18	24	26	25	23	23.2	14.5
27	Column C27	22	20	18	24	22	21	21.2	11.5
28	Column C28	27	26	24	28	24	30	26.5	19
29	Column C29	23	26	23	20	19	27	23	14

30	Column C30	25	22	20	18	25	22	22	13
31	Column C31	21	22	18	22	24	19	21	11

Table 3 - Rebound Hammer Test Results on Failed Columns for First Floor.

Sr. No.	Member	Rebound Number							Avg. Char. Comp. Strength. (MPA)
	Ground Floor	1	2	3	4	5	6	Avg.	
1	Column C1	22	20	23	24	20	21	21.67	11.5
2	Column C2	28	24	23	25	23	20	23.83	15.5
3	Column C3	22	20	20	20	20	26	21.33	11
4	Column C4	22	26	26	24	24	-	24.4	16.5
5	Column C5	24	23	20	21	22	23	22.2	13.5
6	Column C6	26	25	24	23	24	21	23.83	15.5
7	Column C7	31	30	30	28	30	-	29.8	24.5
8	Column C8	28	26	27	26	24	-	26.2	19
9	Column C9	29	25	24	22	26	28	25.67	18
10	Column C10	30	28	29	30	30	32	29.83	24.5
11	Column C11	24	26	26	26	25	24	25.2	17.5
12	Column C12	28	24	23	26	27	23	25.2	17.5
13	Column C13	23	20	22	19	22	17	20.5	11
14	Column C14	22	23	24	25	25	24	23.83	15.5
15	Column C15	24	26	25	26	25	26	25.33	17.5
16	Column C16	34	28	28	25	30	28	28.83	23
17	Column C17	30	29	28	29	-	-	29	*24*
18	Column C18	26	25	24	28	26	25	25.67	18
19	Column C19	32	33	32	30	28	27	30.33	25.5
20	Column C20	26	22	24	20	20	22	22.33	13
21	Column C21	20	24	27	23	20	25	23.2	14.5
22	Column C22	19	18	22	17	20	19	19.2	*Fail*
23	Column C23	24	21	17	22	22	22	21.33	11
24	Column C24	20	20	20	20	20	22	20.33	10.5
25	Column C25	16	20	19	21	-	-	19	*Fail*
26	Column C26	22	22	24	20	26	23	22.83	13.5

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27	Column C27	23	22	22	26	23	22	23	14
28	Column C28	21	20	19	23	20	22	20.67	10.5
29	Column C30	23	26	30	26	24	24	25.5	18
30	Column C31	24	30	28	28	26	-	27.2	20.5
31	Column C32	20	18	22	22	20	18	20	10
32	Column C33	18	16	18	14	18	14	16.33	*Fail*
33	Column C34	14	13	14	13	16	13	13.83	*Fail*
34	Column C35	17	16	17	17	17	15	16.5	*Fail*
35	Column C36	22	22	24	22	24	25	23.2	14.5
36	Column C37	26	25	24	20	18	19	22	13
37	Column C38	24	23	24	22	23	21	22.83	13.5
38	Beam B47	28	28	32	28	30	-	30.83	26
39	Beam B56	39	30	38	32	34	40	35.5	35
40	Beam B66	22	26	26	30	28	32	27.33	21
41	Slab S5	41	39	44	38	42	37	40.2	35
42	Slab S10	44	48	44	45	43	40	44	42
43	Slab S12	42	38	38	38	46	34	39.33	33

B. *Expected Outcomes*

- Carbon fiber, being the most used material in engineering fields such as automotive and aerospace engineering, or in the sports sector, etc. would have increased applications in the civil engineering industry good.
- Modernization of steel and modernization of reinforced concrete could obtain an economically stable alternative.
- So far only steel structures have been seen, our research could be a starting point towards the beginning of an era with r / f carbon fiber or carbon fiber structures.
- An alternative to steel may soon be available with less much greater space occupancy and resistance.

IV. RESEARCH ELABORATIONS

A. *Experimental Program*

The test specimens were six square concrete cubes of M20 grade of size 15cm x 15cm x 15cm. proper curing of 7 days for three cubes and 28 days for another three cubes was done. Compression tests were performed on these cubes using a standard compression testing machine until the first crack appeared. The cubes were then wrapped with the unidirectional 300 GSM 12k carbon fiber fabric. After packaging, the increase in cube size was negligible. For packaging purposes, araldite solution was used. Araldite and hardener were mixed in the equal proportion and applied to the surface of the cubes with the spatula. Immediately after applying the solution to four sides of the cube, carbon fiber fabric has been applied and another layer of the araldite solution was applied to the Fabric. The cubes were then allowed to dry out and strengthen for two days and again the same compression test performed on the cubes. The test matrix is given in table no. 4 and 5. The parameters included in the test were samples, compressive strength.

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Table 4 - Strength before carbon wrap.

7th Day Readings		28th Days Readings	
Specimen	Compressive Strength (KN/m2)	Specimen	Compressive Strength (KN/m2)
Cube 1	19.36	Cube 1	27.09
Cube 2	19.10	Cube 2	37.78
Cube 3	23.86	Cube 3	48.02
Cube 4	21.70	Cube 4	36.06
Cube 5	22.74	Cube 5	32.14
Cube 6	25.30	Cube 6	38.71
Cube 7	21.29	Cube 7	35.23
Cube 8	18.28	Cube 8	31.59
Cube 9	18.34	Cube 9	28.90

Table 5 - Strength after carbon wrap.

7th Day Readings		28th Days Readings	
Specimen	Compressive Strength (KN/m2)	Specimen	Compressive Strength (KN/m2)
Cube 1	19.64	Cube 1	27.09
Cube 2	17.18	Cube 2	29.31
Cube 3	15.18	Cube 3	25.12
Cube 4	18.69	Cube 4	28.54
Cube 5	19.27	Cube 5	28.59
Cube 6	22.27	Cube 6	29.94
Cube 7	19.56	Cube 7	28.46
Cube 8	17.70	Cube 8	31.60
Cube 9	17.83	Cube 9	29.76

B. Column of the Building

A building was found in Vani, a village near Nashik city. It is government building built about four years ago which components failed due to inadequate maintenance. Non-destructive test was carried out on all columns, beams and slab. A column that failed completely was selected for carbon fiber packaging. The selected column was wrapped in carbon fiber fabric and was allowed to dry and gain strength for 2 days. After 2 days, the non-destructive test was performed again and the readings were recorded as follows-

Table 6 - Strength before carbon wrap.

Col. No.	Rebound Number				Average Rebound No.	Result
	1	2	3	4		
C9	18	14	18	19	17.25	Less than 10 MPA (Fail)

Table 7 - Strength after carbon wrap.

Col. No.	Rebound Number				Average Rebound No.	Result
	1	2	3	4		
C9	28	26	34	30	29.5	25.45

C. Carbon Fiber Reinforced (CFRF) Wrapping System

For full packaging scheme, one layer of continuous CFRF laminate was wrapped around the section of the column in the test region with fibers oriented longitudinally along the column loading axis. To avoid premature failure at the ends of the test area, the tape width was increased to 125 mm at each end. The CFRF laminates had an overlap of 50 mm in the transverse direction.

The CFRP packaging included surface preparation and CFRF application. The concrete surface has been prepared to remove any dust and loose particles from the concrete surface. The epoxy resin was applied directly to the surface using trowels. The CFRF fabrics, pre-cut dimensions, were then placed on the resin coating and smooth with gloved hands. The correct pressure was applied until resin is pressed between the fabric deliriums. A final coat of resin sealant was then applied to the exposed surface.

Carbon fiber reinforced fabric takes almost forty-eight hours to gain full strength. After a period of twenty-four hours after applying the tissue to the column, site was supervised and reapplied a sealant on the wrapped column wherever necessary. Then after a period of forty-eight hours, NDT test with a Schmidt rebound hammer were conducted on the same wrapped column. A total of six readings on each of the four surfaces at different locations on the column has been taken. The readings showed an increase in resistance value in columns after carbon packaging.

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V.RESULTS

The construction industry is still sustainable and constantly expanding without any pause. The need for shelters, buildings, roads, airports, etc. is endless. In the same way the renovation, innovation and creation of new techniques, new the infrastructure is also continuous. There is a constant need to correction, reconstruction, improvement of all kinds of structures.
To meet this need, another new, innovative and simple set up was implemented to correct and rectify failing structures for those to be renovated.
During tests, it is observed that the loading pattern and the direction of the woven fiber plays an important role in the strength results of the carbon fiber reinforced fabric. The fabric gives more resistance if it is applied with its longitudinal fibers with respect to the loading axis of the element.
When testing the cubes, it was observed that if the cubes were loaded in the direction perpendicular to the fibers, carbon fiber reinforced fabric did not give force, as in the case of the following cubes.

Table 8: Readings of Cube that were tested in direction perpendicular to that of the fibers; before and after carbon wrap

Description	Cubes	Compressive Strength without Carbon Fiber Fabric Wrapping.(KN/m2)	Compressive Strength with Carbon Fiber Fabric Wrapping.(KN/m2)
	Cube 1	20.06	19.64
7 Days	Cube 2	19.1	17.18
	Cube 7	21.29	19.56
	Cube 9	18.34	17.83
	Cube 1	27.09	19.36
28 Days	Cube 8	31.6	31.59
	Cube 9	29.76	28.9

Compared with other methods, such as reinforced concrete Coat and refurbished, wrapped in carbon fiber fabric proven to be better in almost all aspects. As stated in the early days, there were several types of carbon fiber reinforced fabrics Advantages compared with traditional transformation methods, such as:

- The thickness of repaired parts will not increase.
- The initial cost required is relatively low.
- No skilled labor is required.
- Time required for carbon fiber reinforced fabric less packaging.
- Material handling is easier.

According to the experiments and tests conducted, as mentioned above, it can be inferred that carbon fiber the material effectively improves the strength of the sample.

VI.CONCLUSION

Carbon fiber reinforced fabric has the following characteristics better than traditional reinforced cement Concrete sheath:

Table 9: Comparison between Carbon Fiber Reinforced Fabric and Reinforced Cement Concrete Jacketing

	Carbon Fiber Reinforced Fabric	Reinforced Cement Concrete Jacketing
Initial Cost.	Initial cost or Packaging cost Required column Used carbon fiber fabric, which is 300 GSM, One-way braid Carbon fiber fabric a bit less. The following is Applicable in real time The unit we quoted column, Total surface area Column: 3.333m2	Initial cost Reinforcement requirements BS Sheath quote Contractor On the website is more.

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	Carbon fiber rate Fabric: Rs. 1200 per square meter Fabric cost required: Rs 4000/-	The price details are as follows.
	The cost of resin and curing agent: 700 rupees/kg.	Total cost required A substance Column: Rupee. 2800 /- Scaffolding rate: Rs.
	Labor required: 2 @ 400/day: Rs. 800/day.	450 /-
	Total cost required	Labor required:
	One column: Rupee. 4900 /-	2 @ 400 / day: Rs. 800. Bar bending: Rs. 600/day.
		Cement growers: 500 rupees per day.
		Total cost required Column Reinforced cement Concrete: Rs. 5150 /-
Thickness.	Negligible increase in thickness is seen in this method as only two layers of resin and hardener are applied as well the thickness of the Carbon Fiber Reinforced Fabric is also less. Approximately 2-3 mm increase in thickness is observed.	Reinforced Cement Concrete Jacketing consists of jacketing the column with further steel Reinforcement and concreting. This increases the column size many folds thus reducing the usable area in buildings.
Labor Required.	No Skilled Labor is required as it consists only of applying layer of resin and hardener using a spatula and applying the fabric over it and sticking it, to the surface of the failed column.	Skilled labor is required in this case for bar bending, erecting formwork, cement grouting, etc.
Time	Time required by this technique is less as compared. After applying the sealing layer of the epoxy hardener, approximately only 48 hours' time is required for the material and the member to gain strength.	Time required in this case is more. As drilling of holes, erecting of formwork, concreting, etc and then the curing of concrete to attain its strength requires more time and efforts.
Handling	Due to light weight of the Carbon Fiber Reinforced Fabric, it is easier to handle. Being a fabric, its application to the member is also effortless.	As mentioned earlier Skilled labor is required, this, in turn, makes the handling and completion difficult.

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