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# Strength of Concrete-Filled Carbon Fiber-Reinforced Polymer Columns

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## ABSTRACT

*Carbon fiber, owing to its greater strength-to-weight ratio, has found its application in civil engineering and architecture as well. Carbon fiber reinforcement can be used for concrete columns instead of the traditional steel bar reinforcement. Carbon fiber provides not only additional strength but also encases the concrete, acting as a protective cover. It increases the reliability of the reinforced concrete columns at a lower service cost. This is especially useful in coastal areas or hilly areas, where the structure is prone to environmental damage or is difficult to be constructed by conventional methods. The effectiveness of these columns is a function of a number of factors which include the nature of fiber reinforcement, width of fiber wall, slenderness ratio and type of concrete used, among others. In the present research, the compressive strength of circular composite columns is determined as a function of three parameters, namely the diameter of column, thickness of carbon fiber wall and strength of concrete. To develop relations between these three parameters, fifteen fiber-reinforced columns are fabricated using the standard procedures, filled with concrete of various grades, and tested for compressive strength. The results of the compressive test further act as input to a design of experiments software, Design Expert 12.0, which provides regression equations for compressive strength as a function of the aforementioned input parameters.*

**KEYWORDS:** *Composites, carbon fiber, concrete column, compressive strength, design of experiments*.

## I. INTRODUCTION

A composite column is an amalgamation of several structural constituents used collectively to display the structural characteristics as desired. In this study, concrete is paired with carbon fiber to form such a column. One major benefit of reinforcing parts with fiber composites is their property of altering the strength and stiffness to bear different loads as per requirement. In case of structural compressive loading of these members, the inner filler material (concrete) comes under volumetric stress and the outer fiber polymer tube comes under both axial compressive stress and circumferential (or hoop) stress due to the inner filler material pushing outwards.

Carbon fiber is chosen over glass fiber owing to its greater strength-to-weight ratio and superior load-carrying capacity. The same as been experimentally shown by Aire, Gettu and Casas in their compressive behaviour study of confined concrete columns [I]. It is also known that fibers aligned in the circumferential direction impart axial and shear strength to the filler material, while those aligned longitudinally provide flexural reinforcement, through the research of Purba and Mufti [II]. One of the earliest researches by Amir Mirmiran [III] revealed that the strength of the column diminishes when there is an escalation in slenderness ratio. Moreover, confinement of circular columns is better than that of square or rectangular columns since the flat sides remain essentially non-confined and the encasement is effective along the cross-sectional diagonals only [IV]. The effects of cross-sectional shape, length and type of interfacial bond between concrete and shell, on confinement effectiveness were examined by Mirmiran, Shahawy and Samaan [V]. Other parameters including concrete strength, aspect ratio of cross-section and number of confining layers were explored by Chaallal, Shahawy and Hassan through a series tests on 90 specimens [VI]. The tests conducted by Xiao and Wu [VII] convey that concrete strength and confinement modulus, expressed as ratio of transverse confinement stress to transverse strain, have the maximum impact on the stress-strain behaviour of confined concrete. Elliptical concrete columns under eccentric loading have also been experimented by Parvin and Schroeder [VIII]. Chen, Yan and He proposed a formula for axial bearing capacity of concrete-filled glass fiber reinforced columns after testing 27 specimens across three parameters, namely concrete strength, hollow ratio and diameter-to-thickness ratio [IX].

The factors that are analysed in the present study are concrete strength, diameter of column and thickness of carbon fiber wall, which are studied at three levels each. Regression analysis is implemented via the central composite design to find the influence of various parameters and their interaction effects, and develop compressive strength as a function of the three input parameters. This is achieved by the use of Design

Expert, a statistical software that is exclusively dedicated to performing design of experiments (DOE). As an input requirement for the central composite design matrix, fifteen specimens, each of length 300 mm, are prepared and tested for compressive strength on a universal testing machine. Based on the input factors and test results, the Design Expert software employs regression analysis to formulate the required equations.

## II. METHODOLOGY

### A. Materials Used

Unidirectional carbon fiber polymer T-700 is utilized as reinforcement in a matrix of Araldite LY 1564 (resin) and Aradur 22962 (hardener). The elastic properties of these materials are provided in Table 1 and 2 respectively. The concrete used is a mixture of sand and aggregates joined together in an aqua-cement paste. Concrete of grades M20, M30 and M40, having compressive strengths of 20, 30 and 40 MPa respectively, are prepared conforming to IS 10262.

**Table 1: Elastic properties of carbon fiber T-700**

| S.NO. | PROPERTY | VALUE |
|---|---|---|
| 1. | Young's modulus: | |
| | In fiber direction | 230 GPa |
| | In transverse direction | 6.43 GPa |
| 2. | Major Poisson's ratio | 0.28 |
| 3. | Minor Poisson's ratio | 0.34 |
| 4. | Shear Modulus | 6.0 GPa |

**Table 2: Properties of epoxy-hardener formulation**

| S.NO. | PROPERTY | VALUE |
|---|---|---|
| 1. | Tensile Strength | 80 MPa |
| 2. | Tensile Modulus | 3000 MPa |
| 3. | Poisson's ratio | 0.34 |
| 4. | Shear Modulus | 6.0 GPa |

### B. Experimental Iterations

The specifications of the fifteen specimens, based on the central composite design matrix and the three levels of the parameters, are shown in Table 3.

**Table 3: Specifications of columns to be fabricated**

| S.No. | Internal Diameter (mm) | Thickness (mm) | Concrete Strength (MPa) |
|---|---|---|---|
| 1. | 45 | 2 | 20 |
| 2. | 45 | 2 | 40 |
| 3. | 45 | 3 | 30 |
| 4. | 45 | 4 | 20 |
| 5. | 45 | 4 | 40 |
| 6. | 60 | 2 | 30 |
| 7. | 60 | 3 | 20 |
| 8. | 60 | 3 | 30 |
| 9. | 60 | 3 | 40 |
| 10. | 60 | 4 | 30 |
| 11. | 75 | 2 | 20 |
| 12. | 75 | 2 | 40 |
| 13. | 75 | 3 | 30 |
| 14. | 75 | 4 | 20 |
| 15. | 75 | 4 | 40 |

### C. Fabrication

Firstly, stainless steel mandrels of the required diameter are selected. These are further polished to a high degree of smoothness for better finish of the interior of carbon fiber tubes. A release film is tightly wound around the mandrel for easy release of the cured tubes. For hand lay-up, the carbon fiber piece is cut according to the number of layers required and diameter of tube. The epoxy-hardener mixture is prepared by mixing them in the ratio of 1:3 respectively. The carbon fiber is weighed and an equal weight of the epoxy-hardener mixture is then applied to the carbon fiber using roller brushes. The wet carbon fiber is then wound on the mandrel firmly. The mandrel is further rolled on a smooth clean surface to further tighten the fiber and spread the resin evenly. A single layer of perforated release film is then wounded over the carbon fiber surface with minimal overlapping. The purpose of this film is to ensure smooth finish and release the excess resin to the breather through perforations. Over the release film, a layer of breather cloth is added whose purpose is to absorb the excess epoxy in the fiber. The preparation is then vacuum packed using a pressure pump and left for a curing period of 48 hours. The vacuum pump should be evenly spread across the tube circumference for even pressure it.

**Figure 1. Hollow carbon fiber columns**

The next step is the filling of concrete. Concretes of grade M20, M30 and M40 are prepared according to their specific cement, sand and aggregate ratios as per IS 10262. These are filled in the tubes according to the specifications as mentioned in Table 3. After the filling process, the concrete hardens over a period of one to two days, through which it is continuously cured with water.

**Figure 2. Filling of concrete**

### *D. Compressive Testing*

The fifteen specimens, each of length 300 mm are tested on a Universal Testing Machine (UTM) calibrated to assess the maximum static axial compressive load at the point of complete failure. However, before testing, the ends of the columns are made flat by sanding and grinding processes. Two collars of mild steel are also incorporated at the two ends of the tube for stability during the compressive load testing, as seen in Figure 3.

**Figure 3. Compressive Test**

The results of the experiment are tabulated in Table 4. The maximum axial load (shown in kN) is divided by the cross-sectional area of the column to obtain the compressive strength (in MPa).

**Table 4: Results of compressive test: Maximum Axial Load and Compressive Strength**

| S.No. | Internal diameter (mm) | External diameter (mm) | Thickness of wall (mm) | Concrete strength (MPa) | Maximum axial load (kN) | Area of cross-section ($m^2$) | Compressive strength (MPa) |
|---|---|---|---|---|---|---|---|
| 1 | 45 | 49 | 2 | 20 | 223 | 0.0075 | 29.579 |
| 2 | 45 | 49 | 2 | 40 | 246 | 0.0075 | 32.630 |
| 3 | 45 | 51 | 3 | 30 | 287 | 0.0082 | 35.141 |
| 4 | 45 | 53 | 4 | 20 | 317 | 0.0088 | 35.940 |
| 5 | 45 | 53 | 4 | 40 | 325 | 0.0088 | 36.847 |
| 6 | 60 | 64 | 2 | 30 | 515 | 0.0129 | 40.042 |
| 7 | 60 | 66 | 3 | 20 | 582 | 0.0137 | 42.551 |
| 8 | 60 | 66 | 3 | 30 | 608 | 0.0137 | 44.451 |
| 9 | 60 | 66 | 3 | 40 | 636 | 0.0137 | 46.499 |
| 10 | 60 | 68 | 4 | 30 | 695 | 0.0145 | 47.867 |
| 11 | 75 | 79 | 2 | 20 | 1038 | 0.0196 | 52.968 |
| 12 | 75 | 79 | 2 | 40 | 1092 | 0.0196 | 55.724 |
| 13 | 75 | 81 | 3 | 30 | 1196 | 0.0206 | 58.054 |
| 14 | 75 | 83 | 4 | 20 | 1351 | 0.0216 | 62.455 |
| 15 | 75 | 83 | 4 | 40 | 1426 | 0.0216 | 65.923 |

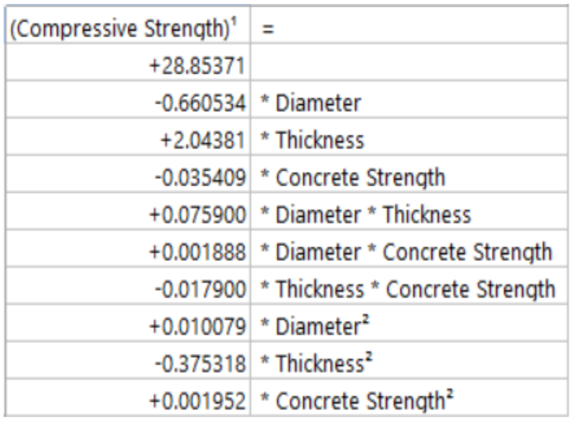
### *E. Regression Analysis*

The Design Expert software is used for this analysis and a central composite design is performed. A full factorial design is employed owing to which the design matrix has fifteen data points. The compressive strengths of the fifteen columns, each with different specifications, are used as inputs for the software. A quadratic model is used for the regression analysis and thus the formulation of regression equations.

The analysis of variance (ANOVA) for the quadratic model shows that F-value for the model is 425.92 implying that the model is significant. Moreover, the p-value is less than 0.05 indicating that the individual model terms are significant. The quadratic model is further validated by the fit statistics. The $R^2$ value is found to be 0.9974 which signifies that the compressive strength can be almost completely explained by the given input factors. The adjusted and predicted values of $R^2$ are also greater than 0.9 with the difference between them less than 0.1, thereby validating the goodness of fit of the regression model. The regression analysis results in the final equation for compressive strength as a function of the diameter of column, thickness of fiber wall (reinforcement) and concrete strength.

## III. RESULTS AND DISCUSSION

The results from the compressive test are tabulated in Table 4. The regression equation obtained using the Design Expert software is given in Figure 4. This equation has three linear terms, three quadratic terms, three liner-interaction terms and one constant term.



| $(\text{Compressive Strength})^1$ | = |
|---|---|
| +28.85371 | |
| -0.660534 | * Diameter |
| +2.04381 | * Thickness |
| -0.035409 | * Concrete Strength |
| +0.075900 | * Diameter * Thickness |
| +0.001888 | * Diameter * Concrete Strength |
| -0.017900 | * Thickness * Concrete Strength |
| +0.010079 | * $\text{Diameter}^2$ |
| -0.375318 | * $\text{Thickness}^2$ |
| +0.001952 | * $\text{Concrete Strength}^2$ |

**Figure 4. Compressive strength formula**

The individual factor effects are also shown in Figures 5, 6 and 7. It is seen that the compressive strength increases with the increase in all three factors but the slope of the increase is the maximum in case of diameter of column and minimum in case of the concrete strength. This shows that the influence of fiber wrapping around the concrete is much more than that of the strength of concrete itself.

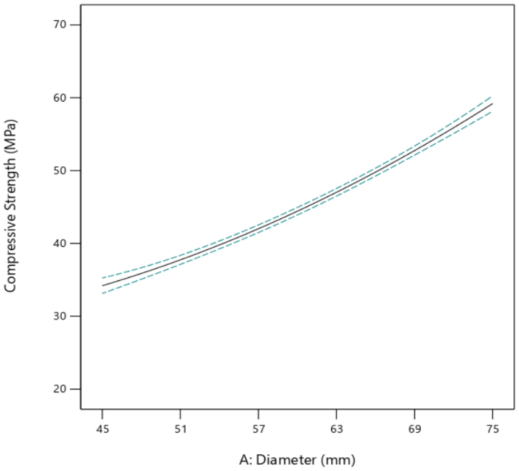


**Figure 5. Compressive Strength vs. Diameter**

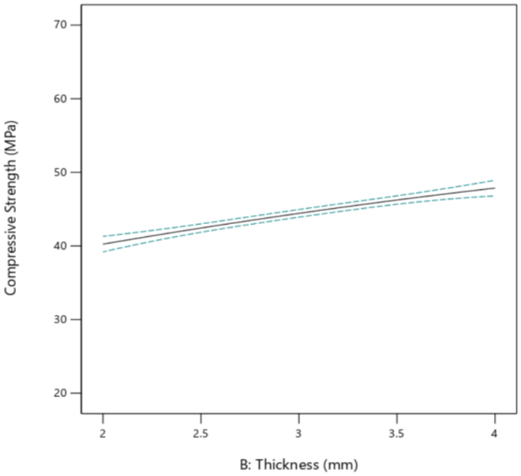


**Figure 6. Compressive Strength vs. Thickness**

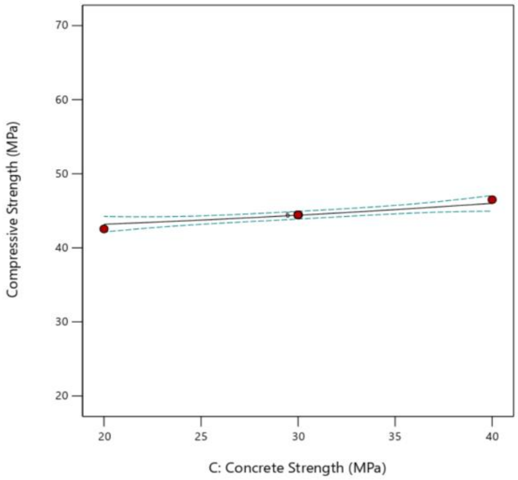


**Figure 7. Compressive Strength vs. Concrete Strength**

The empirical formula generated can be used to further estimate the compressive strength of columns used for construction activities. Since the three factors used in the study are the most prominent in terms of their effect on compressive strength, as shown by the closeness of the value of $R^2$ to 1, the regression formula could generate near accurate results for other specifications of the column. Moreover, since the effect of fiber wrapping on the compressive strength is more than that of concrete strength, the extent of wrapping of carbon fiber, or any other fiber polymer, should be given more focus for the construction of similar members. The orientation of these fibers around the concrete in a more efficient manner could further increase the strength of these columns.

## IV. CONCLUSIONS

In this work, fifteen fiber-reinforced, concrete-filled specimens are experimented upon and compressive strength is determined as a function of concrete strength, diameter of column and thickness of carbon fiber wall. The experiment can be concluded as follows

(i) There is maximum dependence of compressive strength on diameter of column and minimum dependence on concrete grade. The same can be observed both from the graphical representation (Figures 5, 6 and 7) and the regression equation terms (Figure 4).

(ii) The effect of fiber polymer wrapping over the concrete is substantialwhen compared to the strength of concrete, as can be seen by the increase in compressive strength when the diameter and wall thickness are increased.

(iii) The three input parameters are significant as shown by the analysis of variance (ANOVA) for quadratic model, and the $R^2$ values.

The future exploration in this area includes testing the composite column under other types of loading conditions like eccentric loading, seismic loading and shear loading. Moreover, under such loading conditions, optimal parameters such as tube thickness and winding angle can be found for maximum strength. The modes of failure could also be studied for a better understanding of the behaviour of fiber-reinforced, concrete-filled columns under different kinds of loads. These comprise of the Hill Tsai failure criterion or the Tsai Wu failure criterion. Furthermore, a variety of short, slender and long columns could be examined for structural applications.

## REFERENCES

[1] Aire, C., Gettu, R., & Casas, J. R. (2001). “*Study of the compressive behaviour of concrete confined by fiber reinforced composites*”. *carbon*, *1*.

[2] Purba, B. K., & Mufti, A. A. (1999). “*Investigation of the behaviour of circular concrete columns reinforced with carbon fiber reinforced polymer (CFRP) jackets*”. *Canadian Journal of Civil Engineering*, *26*(5), 590-596.

[3] KM, Ahsana Fathima, and Shibi Varghese. "Behavioral Study of Steel Fiber and Polypropylene Fiber Reinforced Concrete." *International journal of research in engineering and technology* 2.10 (2014): 17-24.

[4] Mirmiran, A., Shahawy, M., & Beitleman, T. (2001). Slenderness limit for hybrid FRP-concrete columns. *Journal of Composites for Construction*, *5*(1), 26-34.

[5] Yan, Z., & Pantelides, C. P. (2011). Concrete column shape modification with FRP shells and expansive cement concrete. *Construction and Building Materials*, *25*(1), 396-405.

[6] Aziz, OMAR Q., and BAHMAN O. Taha. "Mechanical properties of high strength concrete (HSC) with and without chopped carbon fiber (CCF)." *International journal of civil engineering (IJCE)*, *2 (1)*, *1* 12 (2013).

[7] Mirmiran, A., Shahawy, M., Samaan, M., Echary, H. E., Mastrapa, J. C., & Pico, O. (1998). Effect of column parameters on FRP-confined concrete. *Journal of Composites for construction*, *2*(4), 175-185.

[8] Al-Waily, Muhannad, et al. "Influences of Glass and Carbon Powder Reinforcement on the Vibration Response and Characterization of an Isotropic Hyper Composite Materials Plate Structure." *International Journal of Mechanical&Mechatronics Engineering IJMMEIJENS* 17.06 (2017).

[9] Chaallal, O., Shahawy, M., & Hassan, M. (2003). Performance of axially loaded short rectangular columns strengthened with carbon fiber-reinforced polymer wrapping. *Journal of Composites for Construction*, *7*(3), 200-208.

[10] Xiao, Y., & Wu, H. (2000). Compressive behaviour of concrete confined by carbon fiber composite jackets. *Journal of materials in civil engineering*, *12*(2), 139-146.

[11] Tomar, Archit, and Dheer Singh. "Modelling and Analysis of a Chassis Frame by Using Carbon Fiber and E-Glass Epoxy as Composite Material: A Comparative Study." *International Research Journal of Engineering and Technology* 3.04 (2016): 2395-0072.

[12] Parvin, A., & Schroeder, J. M. (2008). Investigation of eccentrically loaded CFRP-confined elliptical concrete columns. *Journal of Composites for Construction*, *12*(1), 93-101.

[13] JEEWG, MUHSIN J., ABDAL-KAREEM F. HASSAN, and JAWAD K. ZEBOON. "Experimental and numerical investigation of the dynamic characteristic of laminated composite plate hybrid with steel." *Int. J. of General Eng. and Techn.(IJGET)* 3 (2014): 1.

[14] He, K., Chen, Y., & Yan, Y. (2020). Axial mechanical properties of concrete-filled GFRP tubular hollow composite columns. *Composite Structures*, 112174.

[15] MAHALAKSHMI, B. NAGA, and V. VARA PRASAD. "Study of mechanical behavior of carbofiber reinforced epoxy composites." *International Journal of mechanical and production engineering research and development* (2013).