Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 41 Issue: 11-2022
DOI 10.17605/OSF.IO/87KWE

PERFORMANCE OF CARBON FIBER REINFORCED POLYMER (CFRP) STRENGTHENED CONCRETE BEAMS IN FLEXURE

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Abstract:

The use of composite materials such as carbon fibre reinforced polymers in strengthening and repairing of structural elements, particularly those made of concrete, is widely spreading. However, for successful and cost-effective applications, researchers must improve their knowledge with respect to the actual behavior of strengthened structures. Therefore, carbon fiber reinforced polymers, because they are more cost effective, less time consuming than traditional retrofitting methods, can be considered as an alternative solution to repair and strengthen concrete members. The present study is conducted to examine the efficiency of CFRP in strengthened concrete beams in flexure. The investigation carried out has examined the flexural strength of both M20 and M40 concrete grades. The aim of this study was to regain the flexural strength of the damaged concert beam by wrapping with CFRP and to investigate if CFRP can be utilized for retrofitting and strengthening cracked beams. This experimental study revealed that the Concrete beams strengthened with CFRP are significantly improved in the resistance to loadings.

Keywords: Carbon Fibre Reinforced Polymers, Strengthening, Retrofitting.

1. INTRODUCTION:

Intensive researches have been carried out on strengthening structural members. Structural strengthening has become a necessity in today’s age. A structural member's deterioration is influenced by a number of factors. Structural strengthening is not only required for old structures but also for newly constructed structures. Apart from structural deterioration due to aging, errors made during design and construction phase, and increased load. Many factors such as low material quality, shortage of skilled labors, design fault, improper supervision during construction activity which all contribute to the deficient behavior of structures are the reasons that even the newly constructed structures require structural strengthening. FRP are of many types depending upon the type of fiver used viz. Carbon, Aramid and Glass. In the present study emphasis is given on utilization of Carbon Fiber Reinforced polymer because of its superior qualities like high tensile strength, low weight, good resistance to corrosion, creep and fatigue, and low linear expansion coefficient and relaxation rate over the other materials. [1-4]

A structural system fails when its load-bearing capability is lost, resulting in a loss of structural integrity. For any type of loading, a partial failure in a well-designed system shouldn't result in the immediate or even gradual collapse of the entire structure. The use of Fiber Reinforced Polymer (FRP) in the construction sector for the maintenance, rehabilitation, and upgrading of structural components has been the subject of several studies throughout the years. These research concentrated on various FRP-related topics, including application systems, geographic regions, and distinct FRP kinds (Glass Fiber, Carbon Fiber and Aramid Fiber). The following lists a few older investigations and their conclusions. [5-9]

In a study utilising FRP fabric, **N. Attari et al. [10]** looked at the effectiveness of external strengthening systems for reinforced concrete beams (Glass–Carbon). Different strengthening configurations are taken into consideration in order to solve this issue (use of separate unidirectional glass and carbon fibres with some U-anchorages or of bidirectional glass–carbon fibre hybrid fabric). To perform a failure analysis, a 4-point bending device is used to instrument and test a total of 7 flexural strengthened RC beams under various loading scenarios. For the various strengthening solutions taken into consideration, the results for strength, stiffness, ductility, and failure modes are examined. Additionally, a mathematical model is created to forecast the flexural failure of reinforced concrete components. The outcomes show that the model adequately predicts the behaviour of reinforced concrete beams under applied loads. The current tests also show that twin layer glass-carbon FRP fabric is a cost-effective configuration for strengthening reinforced concrete structures.

The investigation by **N. Nikoloutsopoulos et al. [11]** sought to strengthen beams using fibre reinforced polymers (FRP) as efficiently as possible while minimising drilling operations to the current load bearing part and taking cost analysis into consideration. With single and double carbon fibre ropes installed onto the notch at angles of 45° and 90°, theoretical and experimental examination on various methods of beam strengthening took conducted. Additionally, a research of rope anchoring and fabric strips made of carbon fibre was conducted. Construction was done on reinforced concrete beams of 15x15x70 cm, made of concrete categorised as C30/37 and reinforced with 3φ10 B500c steel bars.

An analytical analysis on the increasing failure of FRP wraps in such strengthened beams was reported by **G.M. Chen et al. [12]** in their research study. The debonding and subsequent rupture processes are deduced in this study, and the FRP contribution to the beam's shear capacity is assessed. By contrasting the analytical solution's predictions with those of a finite element model, the analytical solution is shown to be correct. An additional benefit of the analytical solution is the ability to quantitatively quantify the development of the FRP shear contribution with the occurrence of the shear crack. This capability makes it possible to conduct further research on the shear interaction of the various components (concrete, steel, and FRP shear reinforcements) in RC beams that have been reinforced with FRP.

The objective of the study by **Giuseppe Spadea et al. [13]** was to present a summary of the state of the art with regard to the structural behaviour of concrete beams externally reinforced with Fiber Reinforced Polymers (FRP) systems. A critical analysis of the findings from a multiphase, extensive ongoing experimental investigation conducted at the University of Calabria serves as an illustration of the pertinent features that primarily characterise the overall performance of strengthened beams, such as

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strength increase, ductility, and the ability to dissipate the internal strain energy. The latter demonstrated how a comprehensive strategy may be used to achieve a stable and controlled progressive failure of reinforced concrete (RC) beams enhanced with FRP materials. The idea of a "performance factor," created by the interaction of "deformability" and "strength" aspects, serves as the foundation of a holistic design.

1.1.Research relevancy

There has been a lot of progress on the behaviour of reinforced concrete beams externally strengthened with hybrid FRP and with GFRP, according to a review of the literature on the topic. In contrast, there are not many researches that address the issue of the behaviour of CFRP strengthened beams. The behaviour of concrete beams that have been reinforced with CFRP is discussed with this goal in mind. The flexural strength of beams with and without CFRP wrapping was determined by a thorough experimental programme, which is presented in this study. This study also aims to evaluate the CFRP strengthening method's effectiveness in terms of structural reinforcement. In order to assess the deformability of the strengthened specimens, the strengthening assessment discussed here concentrates on the flexure behaviour. In seismic zones, this structural characteristic is in fact very significant.

2. Experimental programme

A total of 36 concrete beams were casted and tested for flexure. Out of the 36 concrete beams 18 beams belonged to M20 grade out which were 9 were tested on the 7^{th} day and the remaining 9 on the 28^{th} day. Similarly, remaining 18 beams belonged to M40 grade out which were 9 were tested on the 7^{th} day and the remaining 9 on the 28^{th} day. All the beams were rectangular in cross section and the size of beam was 100x100x500 mm. The concrete used to cast all beams was mixed, and cured in the laboratory.

This experimental program was carried out to investigate the behavior of concrete beams flexurally strengthened using Carbon Fiber Reinforced Polymer (CFRP) wrapping technique. Six trials (3trials for 7^{th} day testing and 3 trials for 28^{th} day testing) each were conducted for two grades of concrete i.e M20 and M40 and each trial consisted of 3 beam specimens. The flexural strength of the concrete beam of M20 and M40 was calculated on 7^{th} day and 28^{th} day. The standard beams specimens were casted for M20 and M40 grade and flexural test was conducted using two point loading on these specimens. These tested specimens were repaired using CFRP wrapping and again tested for flexure on 7^{th} day and 28^{th} day. The CFRP used for retrofitting the damaged specimens was of 200 GSM. U-shape wrapping was done on these concrete beams specimens.

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Figure 1: Flexural Test on Standard Specimen

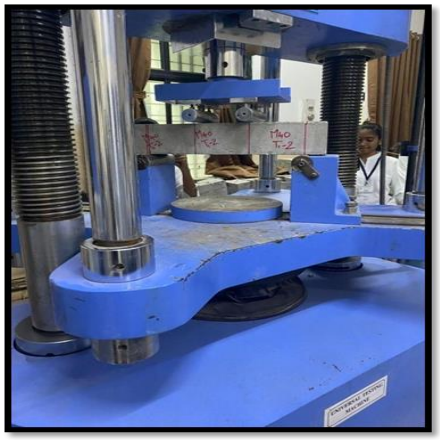
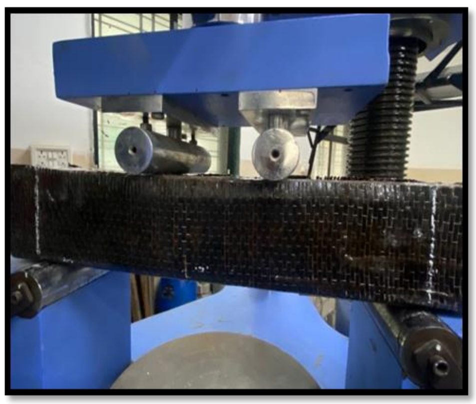


Figure 2: Flexural Test on CFRP Wrapped Specimen



2.1 CFRP Wrapping System

The specimens which were cracked by applying loads in flexure test are repaired with wrapping CFRP. These repaired specimens are again tested for Flexural strength and the results are compared with the results of the initial testing.

The following procedure is adopted for wrapping CFRP to the specimens:

a) Surface preparation:

The concrete surface to be wrapped with CFRP is grinded and leveled for any uneven surface. Concrete surface is thoroughly cleaned and made free from loose particles, oil, paints, or any other foreign agents which may affect the bonding.

Figure 3: Surface Perparation of Beam Specimen

b) Application of Primer:

The primer is applied manually using a brush or roller to the surface to be wrapped. The application of the primer increases the bonding capacity of the concrete surface. It is seen that all the corners and edges are impregnated properly and no dry patch are found. The primer is allowed to set for 30-40 minutes.

Figure 4: Application of Primer

c) Application of Sealant:

After the primer is completely dried, the sealant is applied by trowel spatula. The sealant acts as a leveling compound and is used to fill surface cracks, voids and to provide a smooth surface to which CFRP can be bonded effectively. This also prevents the CFRP from taking undulated profile.

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Figure 5: Application of Sealant

d) Application of Saturant:

The prepared concrete surface of the specimens is coated with Saturant. Saturant acts as an adhesion and helps in holding the carbon fiber sheet in position and bonding the carbon fiber sheet to the concrete surface. Proper application of the saturant is done evenly on the concrete surface and utmost care is taken to cover the corners and edges.

Figure 6: Application of Saturant

e) Wrapping with CFRP:

Carbon Fiber sheet is cut to the required length and width as per the requirement. After first coat of saturant has becomes tacky the CFRP wrap shall be gently pressed into the saturant. The carbon fiber sheet shall then be rolled and pressed against the prepared surface with a medium nap roller and remove any entrapped air between the fiber sheet and the surface. After fixing and setting the fiber sheet apply second coat of saturant.

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Figure 7: CFRP Wrapping

3. Test results

Table 1: Flexural Strength of M20 grade concrete (N/mm^2)

Grade of Concrete	Trial No	7 Days	28 Days
M20	I	5.13	6.81
	II	5.17	6.89
	III	5.51	6.65
	Average	**5.27**	**6.79**

Table 2: Flexural Strength of CFRP Wrapped M20 grade concrete (N/mm^2)

Grade of Concrete	Trial No	7 Days	28 Days
M20 (CFRP Wrapped)	I	6.35	8.43
	II	6.51	8.60
	III	6.85	8.25
	Average	**6.57**	**8.43**

Table3: Flexural Strength of M40 grade concrete (N/mm^2)

Grade of Concrete	Trial No	7 Days	28 Days
M40	I	7.12	8.59
	II	7.21	8.57
	III	6.99	8.97
	Average	**7.11**	**8.71**

Table3: Flexural Strength of CFRP Wrapped M40 grade concrete (N/mm^2)

Grade of Concrete	Trial No	7 Days	28 Days
M40 (CFRP Wrapped)	I	8.84	10.75
	II	9.00	10.60
	III	8.69	11.31
	Average	**8.84**	**10.88**

4. Conclusion:

In this study, application of CFRP wrapping to strengthen concrete beams is investigated from experimental analysis. The experimental findings can be summarized as follows:

- It is observed from the above results that the cracked concrete specimens after wrapping with CFRP have gained more strength than the actual strength of the specimen for both M20 and M40 grade of concrete.
- **Flexural strength** of the cracked specimens of M20and M40 grade concrete have increased 20% to 25% after wrapping it with CFRP material as compared to standard specimen.

Acknowledgements:

The first author acknowledged the support of KRISHNA CONCHEM PRODUCTS PVT LTD**,** Mumbai and Shri TulsiBuildcon for their constant support during the research work.

Author contributions: The first author proposed the formulation in this paper and wrote the manuscript and draw figures. The second author edited the manuscript.

Funding: For the preparation of this manuscript and conducting this research, no fund was received.

Declarations: Conflict of interest on behalf of all the authors of this paper, the corresponding author declares and guarantees that there is no conflict of interest.

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