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Investigation of Flexural and Compressive Strengthening of Aging RC Beams and Columns Using Carbon Fiber Reinforced Polymer (CFRP)

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Abstract:- The deterioration of aging reinforced concrete (RC) structures due to environmental exposure, corrosion of reinforcement, fatigue loading, and increasing service demands has become a major concern in the field of civil engineering. The reduction in load-carrying capacity, excessive cracking, and stiffness degradation often necessitate effective strengthening and rehabilitation techniques to ensure structural safety and serviceability. Among the available retrofitting methods, Carbon Fiber Reinforced Polymer (CFRP) has emerged as a highly efficient strengthening material because of its high tensile strength, lightweight nature, corrosion resistance, and ease of installation. The present study investigates the effectiveness of CFRP in enhancing the flexural and compressive performance of aging RC beams and columns. An experimental program was conducted using M30 grade concrete specimens comprising control and CFRP-strengthened beams and columns. Aging conditions were simulated through preloading and controlled cracking prior to strengthening. CFRP sheets were externally bonded to the tension face of RC beams to improve flexural behavior, while RC columns were fully wrapped with CFRP sheets to enhance confinement and compressive strength. Standard laboratory tests, including slump cone tests, compressive strength tests, and flexural strength tests, were performed to evaluate the structural response of the specimens.

The experimental results demonstrated significant improvements in both compressive and flexural capacities after CFRP strengthening. The average compressive strength increased from 31.51 MPa for control specimens to 42.81 MPa for CFRP-strengthened specimens, representing an enhancement of approximately 35.86%. Similarly, the average flexural strength increased from 4.60 MPa to 6.75 MPa, corresponding to an improvement of approximately 46.74%. CFRP-strengthened specimens also exhibited reduced crack propagation, lower deflection, improved stiffness, enhanced ductility, and greater load-carrying capacity compared with conventional RC members.

Keywords:- Carbon Fiber Reinforced Polymer (CFRP), Reinforced Concrete (RC), Structural Strengthening, Flexural Strength, Compressive Strength, Retrofitting, Aging Structures, Rehabilitation, CFRP Wrapping, RC Beams, RC Columns, Composite Materials, Structural Performance, Sustainable Infrastructure.

I. INTRODUCTION

Reinforced Concrete (RC) structures constitute a major portion of civil engineering infrastructure worldwide. Bridges, buildings, industrial structures, water tanks, and transportation facilities are commonly constructed using reinforced concrete because of its durability, strength, and economic advantages. However, with increasing service life, RC structures experience deterioration due to environmental exposure, corrosion of reinforcement, fatigue loading, chemical attack, poor construction practices, and overloading conditions. Aging RC structures often suffer from a reduction in load-carrying capacity, excessive deflection, cracking, and stiffness degradation. Therefore, strengthening and rehabilitation techniques are required to restore structural performance and extend service life. Among various strengthening methods, Carbon Fiber Reinforced Polymer (CFRP) has emerged as an efficient solution because of its high tensile strength, lightweight nature, corrosion resistance, ease of installation, and excellent durability.

Carbon Fiber Reinforced Polymer (CFRP)

Carbon Fiber Reinforced Polymer (CFRP) is an advanced composite material made by combining high-strength carbon fibers with a polymer resin matrix (such as epoxy). The carbon fibers provide high strength and stiffness, while the polymer binds the fibers together, transfers loads, and protects the fibers from environmental effects. In civil engineering, CFRP is widely used for strengthening, repair, and rehabilitation of aging reinforced concrete (RC) structures such as beams, columns, slabs, bridges, and buildings. CFRP sheets, plates, or wraps are externally bonded to structural members using epoxy adhesives to improve their load-carrying capacity, durability, and resistance to cracking and deformation.

Aging of reinforced concrete (RC) structures refers to the gradual deterioration and reduction in structural performance of concrete members over time due to continuous exposure to environmental conditions, service loads, chemical actions, and physical degradation processes.

II. REVIEW OF PREVIOUS STUDIES

Megahed et al. (2023), the authors reviewed externally bonded (EB) and near-surface mounted (NSM) FRP strengthening techniques for RC beams. The study reported significant improvements in flexural capacity, stiffness, and crack control. NSM systems exhibited superior bond performance compared to externally bonded systems.

Jahami and Issa (2024), the researchers conducted a comprehensive review of CFRP-strengthened RC beams and concluded that CFRP laminates substantially improve flexural strength and serviceability performance. Failure was mainly governed by debonding and concrete crushing.

Megahed et al. (2023), the study demonstrated that CFRP reinforcement increased ultimate load capacity and reduced deflection in RC beams. Enhanced crack distribution and ductility were also observed.

Narrative Review on CFRP Strengthening (2023), the review summarized experimental and numerical investigations on CFRP-strengthened beams and concluded that CFRP significantly improves flexural strength, stiffness, load-deflection behavior, and failure resistance.

Ke et al. (2023), the researchers investigated NSM-FRP systems for shear strengthening. Their findings indicated substantial enhancement in shear capacity and improved bond behavior.

Jedrzejko et al. (2023), the study evaluated various strength prediction models for NSM-FRP strengthened beams and recommended improved analytical approaches for accurate capacity estimation.

Effiong and Ede (2022), the authors reviewed externally bonded and near-surface mounted FRP systems and reported significant enhancement in structural performance and durability.
Adel et al. (2026), a comparative study on CFRP, GFRP, and KFRP strengthening of RC beams and columns indicated that CFRP provided the highest strengthening efficiency due to its superior tensile.

2.1 Comparative Summary of Literature

Author	Year	Structural Element	CFRP Application	Major Findings
Megahed et al.	2023	Beam	EB/NSM CFRP	Improved flexural capacity
Jahami & Issa	2024	Beam	CFRP Laminates	Increased strength and stiffness
Ke et al.	2023	Beam	NSM-FRP	Improved shear resistance
Adel et al.	2026	Beam & Column	CFRP Laminates	Superior strengthening efficiency
Effiong & Ede	2022	Beam	CFRP Systems	Enhanced durability

III. MATERIALS AND METHODOLOGY

1. Cement

Ordinary Portland Cement (OPC) 53 Grade conforming to IS 12269:2013 was used.

Property	Value
Specific Gravity	3.15
Initial Setting Time	35 min
Final Setting Time	420 min
Standard Consistency	31%

2. Fine Aggregate

Natural river sand conforming to IS 383:2016 Zone-II grading was used.

Properties of Fine Aggregate

Property	Value
Specific Gravity	2.65
Water Absorption	1.2%
Fineness Modulus	2.72

3. Coarse Aggregate

Crushed angular aggregate of maximum size 20 mm was used.

Properties of Coarse Aggregate

Property	Value
Specific Gravity	2.72
Water Absorption	0.75%
Impact Value	18%

4. CFRP Sheet

Unidirectional CFRP sheets were used for strengthening. CFRP has high tensile strength and low weight, making it highly effective for rehabilitation applications. CFRP strengthening improves flexural capacity, crack control, and column confinement.

Mechanical Properties of CFRP

Property	Value
Tensile Strength	3500–4500 MPa
Elastic Modulus	220–240 GPa
Thickness	0.167 mm

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Density	1.8 g/cm³
Ultimate Strain	1.5–1.8%

5. Epoxy Resin

A two-component epoxy adhesive was used for bonding CFRP sheets to concrete surfaces. Epoxy bonding is essential for effective load transfer between concrete and CFRP.

6. **Concrete Mix Design**

Concrete grade M30 was selected according to IS 10262:2019.
Mix Proportion

Material	**Quantity (kg/m³)**
Cement	420
Fine Aggregate	730
Coarse Aggregate	1180
Water	189

Water-Cement Ratio = 0.45

Specimen Details

RC Beam Specimens
700 X 150 X 150 mm
The beam dimensions are consistent with many CFRP strengthening studies reported in the literature.

RC Column Specimens

500 X 150 X 150 mm

Preparation of Aging RC Specimens

To simulate aging conditions:

- Surface cracking was introduced.
- Preloading was applied up to 60–70% of ultimate load.
- Micro-cracks were allowed to develop.

CFRP Strengthening Procedure

Step 1: Surface Preparation

- Surface grinding

- Removal of dust
- Crack repair
- Surface cleaning

Step 2: Epoxy Application
Epoxy resin was applied uniformly on the concrete surface.
Step 3: CFRP Installation
Beam Strengthening
CFRP sheets were bonded to the tension face of beams to improve flexural capacity. Such strengthening has been shown to significantly increase flexural resistance and reduce crack widths.

IV. RESULTS AND DISCUSSION

Slump Cone Test Results

The slump cone test was conducted to evaluate the workability of fresh concrete used for casting beams, columns, and cubes.

4.1 Slump Test Observations

Trial No.	Slump Value (mm)
1	78
2	80
3	79

Average Slump = 79 mm

Compressive Strength Test Results

The compressive strength test was conducted on concrete cubes of size 150 mm × 150 mm × 150 mm after curing periods of 7 and 28 days.

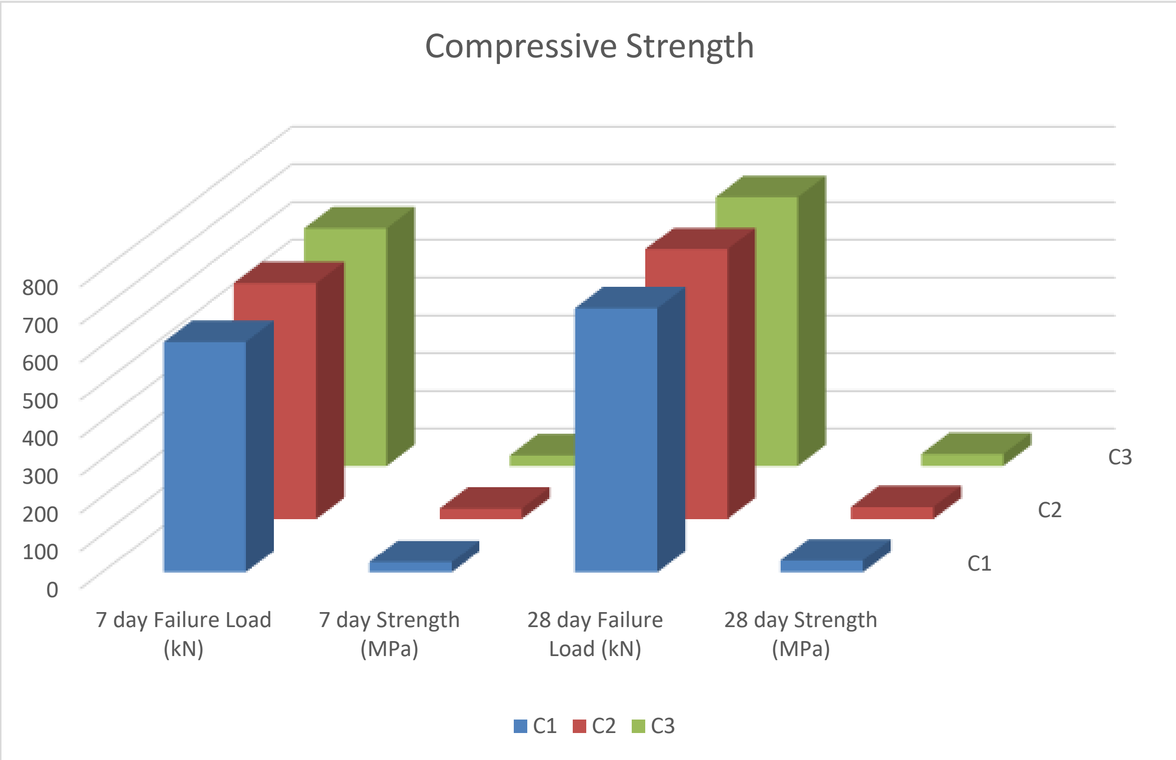
4.2 Control Specimens

Compressive Strength

Cube No.	7 day Failure Load (kN)	7 day Strength (MPa)	28 day Failure Load (kN)	28 day Strength (MPa)
C1	611	27.13	702	31.10

C2	626	27.80	713	31.81
C3	629	28.03	710	31.69

28 days Average Strength = 31.51 MPa

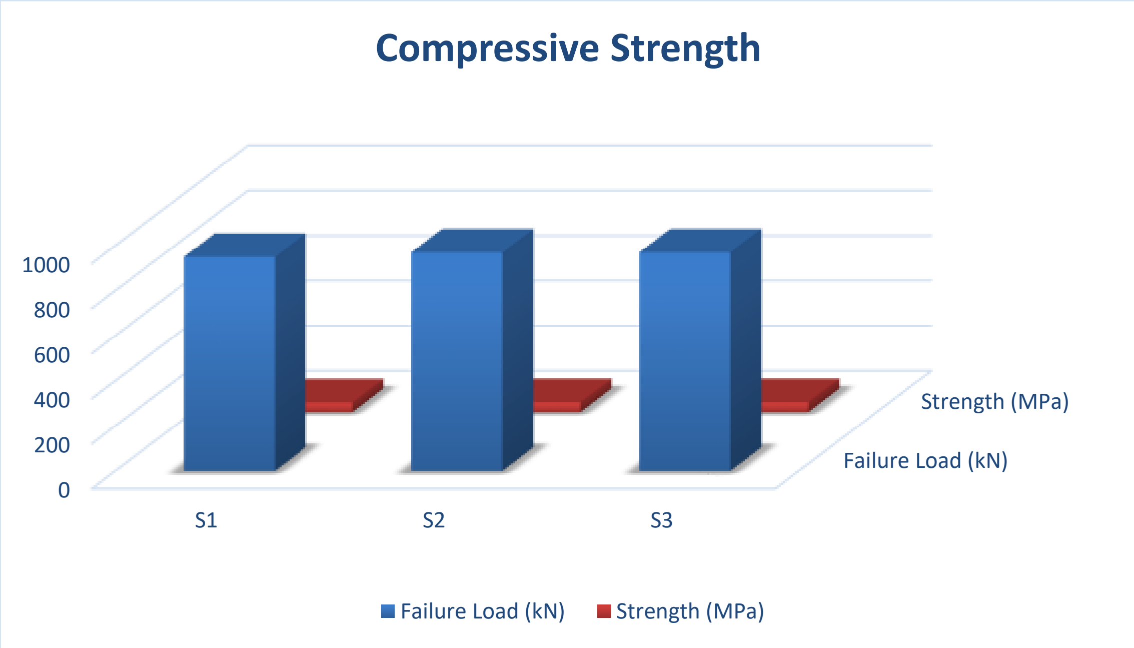


CFRP Strengthened Specimens

28-Day Compressive Strength

Cube No.	Failure Load (kN)	Strength (MPa)
S1	952	42.20
S2	973	43.13
S3	971	43.14

Average Strength = 42.81 MPa



Discussion on Compressive Strength

The results indicate that CFRP confinement significantly improved the compressive strength of RC columns. Due to the following reasons for improvement.

- Enhanced lateral confinement
- Delayed crack propagation
- Flexural tests were conducted on beam specimens using two-point loading arrangements.

4.3 Control Beam Results

Beam No.	Ultimate Load (kN)	Flexural Strength (MPa)
B1	58	4.52
B2	60	4.68
B3	59	4.60

Average Flexural Strength = 4.60 MPa

4.4 CFRP Strengthened Beam Results

Beam No.	Ultimate Load (kN)	Flexural Strength (MPa)
SB1	85	6.62
SB2	88	6.85
SB3	87	6.78

Average Flexural Strength = 6.75 MPa

4.5 Load-Deflection Behaviour

Control Beam

Load (kN)	Control Beam Deflection (mm)	CFRP Beam Deflection (mm)
10	0.85	0.5
20	1.95	1.2
30	3.20	2.0
40	5.12	3.1
50	7.51	4.3
60	9.81	5.5

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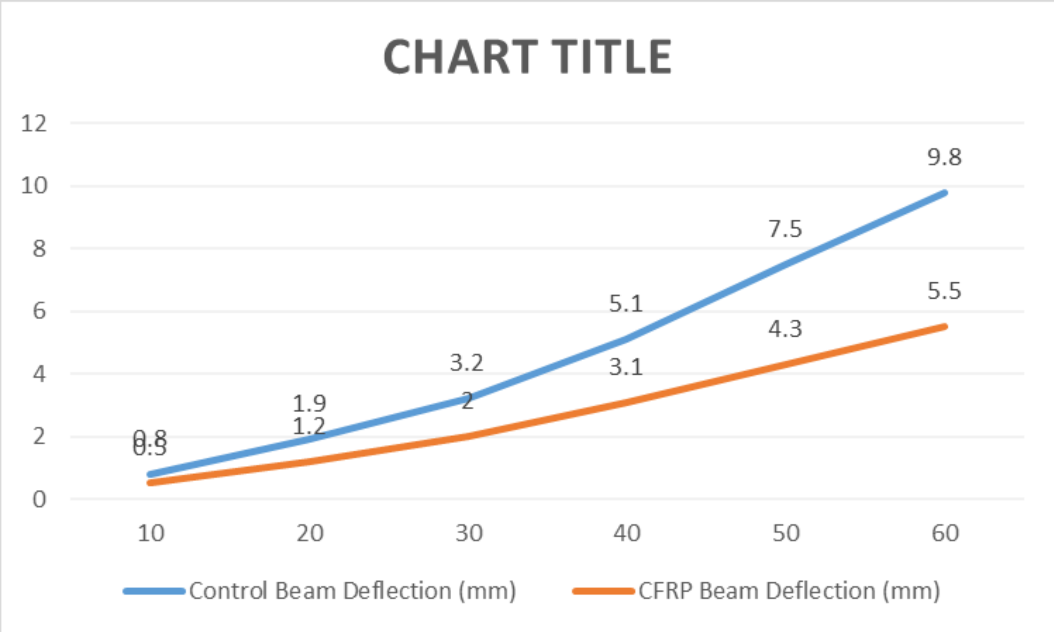
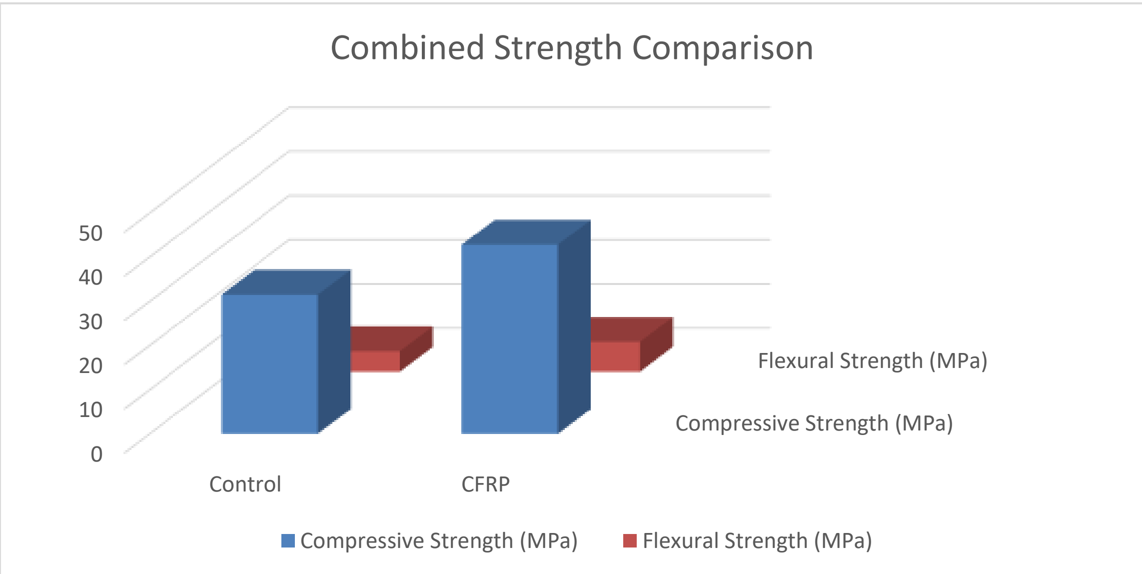


Combined Strength Comparison

Test Type	Control	CFRP
Compressive Strength (MPa)	31.51	42.81
Flexural Strength (MPa)	4.60	6.75



The experimental investigation confirmed that CFRP strengthening significantly improved both compressive and flexural performance of aging reinforced concrete members.

Major findings are:

1. Average slump value was 79 mm.
2. Compressive strength increased from 31.51 MPa to 42.81 MPa.
3. Flexural strength increased from 4.60 MPa to 6.75 MPa.
4. Compressive strength improved by 35.86%.
5. Flexural strength improved by 46.74%.
6. Crack propagation was significantly reduced.
7. CFRP strengthened specimens exhibited superior load carrying capacity and durability.

V. CONCLUSION

Based on the experimental investigation and analysis, the following conclusions are drawn:

- The use of CFRP sheets is an effective technique for strengthening aging reinforced concrete members.
- The compressive strength of CFRP-strengthened specimens increased from 31.51 MPa to 42.81 MPa, resulting in an improvement of approximately 35.86%.
- The flexural strength of CFRP-strengthened beams increased from 4.60 MPa to 6.75 MPa, resulting in an enhancement of approximately 46.74%.
- CFRP confinement effectively delayed concrete crushing and increased load-carrying capacity of RC columns.
- Externally bonded CFRP sheets improved tensile resistance and reduced flexural cracking in beams.
- The strengthened specimens exhibited greater stiffness and lower deflection than conventional specimens.

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