



Investigating The Impact Of Environmental Factors On The Strength Of Concrete Columns Reinforced With Carbon Fiber Polymers

¹Praveen, ²Er. Raj Bala, ³Er. Hardeep Singh

¹ M. TECH Scholar, ²³ Assistant Professor

¹²³Department of Civil Engineering, JCDCMCOE, Sirsa, India

Abstract

CFRP is the most promising material in civil engineering, it offers not only exceptional tensile strength but also an ultra-light-weight along with remarkable resistance to corrosion and environmental degradation. This paper attempts to study the performance of CFRP in improving the mechanical behavior and durability of concrete columns when exposed to severe conditions like moisture intrusion and thermal variations. To simulate real attack, reinforced and unreinforced test specimens have been exposed to controlled environmental conditions like chlorine salt immersion and salt-freezing cycles. The critical parameters were tensile strength, strain, modulus of elasticity, flexural strength, and deflection obtained through experimental testing. Results established that CFRP-reinforced specimens (RFND) performed much better than unreinforced ones (URFND) under all test conditions. The non-deteriorated tensile strength of CFRP sheets was found to be 3511.21MPa whereas for that subjected to prolonged salt immersion it was found to be only 3442.15MPa. Flexural strength increased significantly, the maximum value for reinforced concrete was 16.024MPa (RFND) as against 4.703MPa (URFND) for unreinforced concrete cast under similar conditions.

Keywords: CFRP, Mechanical, Environmental factor, Concrete, Moisture and temperature

1. Introduction

Civil engineers are mainly known for their excellent capability in assessing the structural limitations of a building and developed new technologies that permit greater height, strength, and efficiency in construction. The development of novel materials, such as composites, is driven by the need to construct taller or smaller buildings while simultaneously decreasing their weight and increasing their lengths [1]. The main components of fiber-reinforced polymer are a polymer matrix and reinforcing fibers [2]. Basalt Fiber-Reinforced Polymers (BFRP), Glass Fiber-Reinforced Polymers (GFRP), Aramid Fiber-Reinforced Polymers (AFRP), and Carbon Fiber-Reinforced Polymers (CFRP) are among the list of several FRPs that have been manufactured (Figure 1) [3-5].

Composites made of CFRP are nowadays more common in many fields of engineering, especially in civil engineering. CFRP composites are ideal for use in civil engineering because of their low weight, good durability, and exceptional mechanical properties. Over the last few decades, CFRP composites have become more popular for usage in building and bridge construction [6]. CFRP composites are very strong and durable because they consist of woven carbon fibers impregnated with resin. The resin matrix protects the material from environmental threats like moisture and UV radiation, whereas the carbon fibers provide outstanding tensile strength, stiffness, and fatigue resistance. Composites are great for structural applications because they are lightweight and have a high strength-to-weight ratio [7, 8].



Figure 1: Four types of FRP bars [9].

The advantage of CFRP composites is better strength to weight ratio than the metals. In relation to other common construction material such as steel and concrete, the CFRP composites possess a significantly improved strength/weight ration. As such, constructions that are made of CFRP composites are lighter as well as more effective than steel- or concrete-based constructions yet offer the same strength and sturdiness. This is particularly so in situations where weight is a deciding factor and the case of bridges and other tall structures. There is another advantage of using CFRP composites – their durability [10]. The pros and cons of CFRP are summarized in Figure 2. Factors like, the lifetime of the concrete material, life expectancy of epoxy resin, CFRP life cycles and the interface life cycle of CFRP concrete both works to determine how long CFRP reinforced concrete constructs last.

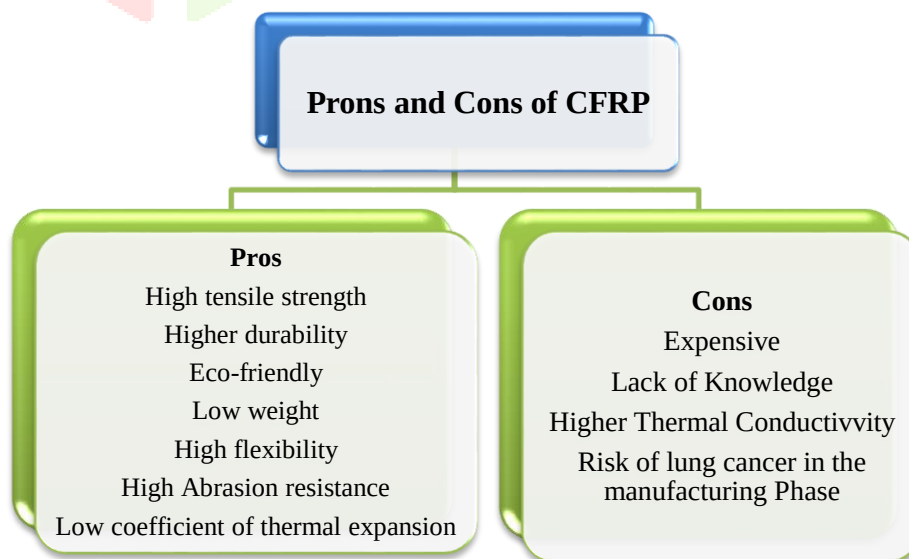


Figure 2: Pros and Cons of CFRP [11].

Study on the durability and impact of the curing of concrete columns using CFRPs on strength, moisture and temperature constancy is one of the research topics that are of value to civil engineering. CFRPs are globally well known for high strength to weight ratio, good resistance to corrosion, and increased mechanical properties of concrete structures. Specifically, the behaviour of CFRP-strengthened columns with time is of interest in the study and thus the investigation of the effects of environmental conditions including the presence of moisture and changes in temperature. The effect of moisture on the bond strength between CFRP and concrete can decrease over time and temperature effects can cause thermal stresses and incompatible material and structure. Based on these interactions, the study is also expected to establish the preferred conditions and design approaches to achieve the longest possible CFRP life and improved structural rigidity of reinforced concrete columns in various environmental settings. The following are among the possible research objectives for studies:

- i. To evaluate the structural properties and performance of CFRP-reinforced under different service environments.
- ii. To determine effects on tensile strength, flexural strength, deflection behavior and duration effects of moisture, temperature and effects of salt deterioration.
- iii. To analyze the outcome, compare CFRP reinforced concrete with URFND & RFND to assess the ability of CFRP in improving concrete and structures durability.

The study investigates the impact of environmental factors on the strength of concrete columns reinforced with CFRP. After that, the remaining parts of the paper are organized as follows: In section 2, a literature review of the study is presented. The explanation of the issue is presented in Section 3. The formulation of the suggested model and CFRP is discussed in Section 4. The results and analysis of the study are then presented in Section 5. This research subject is brought to a conclusion in section 6.

2. Literature Review

In this literature review, the authors consider such aspects of CFRP reinforced concrete works, as the effects of environmental conditions such as moisture and temperature on the material's strength and durability. Compressive strength (CS), Flexural Strength (FS), and Splitting Tensile Strength (SPS) are the major performance parameters that are used for the result analysis in previous studies.

In Study [12], introduced a novel CFRP pile mechanism, wherein the flexural performance of CFRP pre-stressed spinning high-strength concrete piles is evaluated. Experimental tests on three full-scale piles and numerical analysis of eight additional piles with varying parameters reveal a 90% predictive accuracy of the proposed model. This study recommends that CFRP enhance the durability of pile foundations by great accuracy. CFRP-confined partially encased recycled coarse aggregate (RCA) concrete columns [13]. The performance of these columns is assessed in terms of slenderness ratios, RCA replacement ratios, and the number of CFRP layers. The study finds that the RCA replacement ratio has a minimal impact on the bearing capacity, typically not exceeding 6%, and the error between experimental and theoretical results is within 10%.

The influence of temperature on CFRP's performance is further explored, which examines the effect of high temperatures (up to 350°C) on the compression strength of FRP tubes [14]. The study concludes that the strength of C/GFRP tubes reduces significantly around 350°C, with distinct differences between hoop and cross-ply fiber configurations. Study [15] also investigates the effect of elevated temperatures on CFRP-strengthened Reinforced Concrete (RC) beams. Results indicate no significant reduction in stiffness or ultimate load for specimens tested up to 60°C. However, at temperatures of 70°C and 85°C, the failure mechanism shifts from FRP rupture to concrete breaking, illustrating the vulnerability of CFRP at high temperatures.

Different types of FRP (GFRP, CFRP, and HFRP) perform under elevated temperatures and durability [16,17]. The durability of CFRP in reinforcing wooden structures is significantly enhanced under dry-wet cycling in saltwater and freeze-thaw conditions, showing up to a 40% improvement in CS and a 25% increase in toughness with additional CFRP layers [16]. Further, the bond strength of FRP tubes filled with Seawater Sea Sand Concrete (SWSSC) is discussed where it is seen that GFRP tubes perform better than CFRP tubes and the variation of different types of FRP tubes in severe conditions up to 250°C [17].

Further durability studies are presented in Study [18], which investigates the water-based durability of carbon-glass hybrid fiber reinforced polymer (HFRP) bars. The study finds that HFRP bars exhibit higher water diffusivity and experience a greater loss in inter-laminar shear strength compared to GFRP bars after prolonged exposure to water at 60°C. Similarly, study [19] explores the effect of short CFRM composites on water absorption and strength. The study shows that up to 3% fiber content improves CS and reduces water absorption, although the absorption rate increases beyond this point. The mechanical performance of two types of pervious concrete (PC) reinforced with basalt fibers (BFRPC) and carbon fibers (CFRPC) is analyzed in [20]. The study shows that the optimal mix containing 12.5 mm coarse aggregates, and 0.2% carbon fiber enhances CS by 11.59%, SPT by 32.70% and FS by 35.32%, outperforming the traditional mix.

Therefore, the study shows that reinforcement of concrete elements with CFRP leads to the increased bearing capacity of concrete structures, its increased resistance to environmental factors. However, the behavior of CFRP is highly dependent on temperature and humidity thus affecting its durability. These results have pointed out the need for future studies which could be directed towards enhancement of CFRP usage for strengthening concrete, especially under extreme conditions such as high temperatures and or effect of water.

3. Problem Formulation

Concrete is one of the most used construction materials in the industry due to its favorable mechanical properties. Nonetheless, the exposure of the material to environmental parameters like moisture and temperature greatly influences its longevity and mechanical performance. Long-term exposure of the material to these conditions results in cracking and decreased load-carrying capacity and general deterioration of critical members such as columns. Generally, broad traditional programs of reinforcement learning are unable to sufficiently address these issues, especially when operating in abrasive conditions. In order to offset these effects, the use of CFRP has gained increasing acceptance. CFRPs can effectively offer excellent tensile strength, resistance to corrosion and reduced densities for use in strengthening concrete structures. It is crucial to know how a number of factors, moisture penetration, fluctuation in temperature, cyclic exposure influence the durability and load-bearing capacity of these few reinforced columns.

This research seeks to assess the effectiveness of CFRP in reducing the impact of the environmental conditions on concrete columns. This research aims at filling that gap by comparing their behavior under various imposed moisture and temperature conditions with a view of obtaining a better understanding of how CFRP can be used to increase the durability and the service life of concrete structures in harsh conditions.

4. Material and Methods

Figure 3 illustrates a structured research method that would be employed in assessing the durability and strength of concrete columns augmented with CFRP under different combinations of moisture and temperature regimes. The first step is concerned with the formulation of the research problem emphasizing on the effects of environmental impacts such as moisture and temperature on concrete structures' performance and durability. A critical analysis of prior research is used to develop research objectives aligned with the goal of assessing the benefits of CFRP in increasing the sustainability's of columns. The following step is the proper choice of

cement, water, sand, and gravel, as well as the CFRP materials such as single-oriented carbon fibre fabrics and epoxy resin bonding agents in the perfect ratio.

It also employs controlled conditions of environmental exposure including no deterioration (ND), chlorine salt immersion (SI) and salt coupling freezing (SF for several cycles). Mechanical testing represents the most significant part of the experimental stage, which includes tensile and flexural tests for overall assessment of CFRP reinforced concrete columns' bearing characteristics. In last the results obtained from these tests are comprehensively used in identifying the contribution of CFRT in the reduction of further environmental degradation besides strengthening the durability of the column.

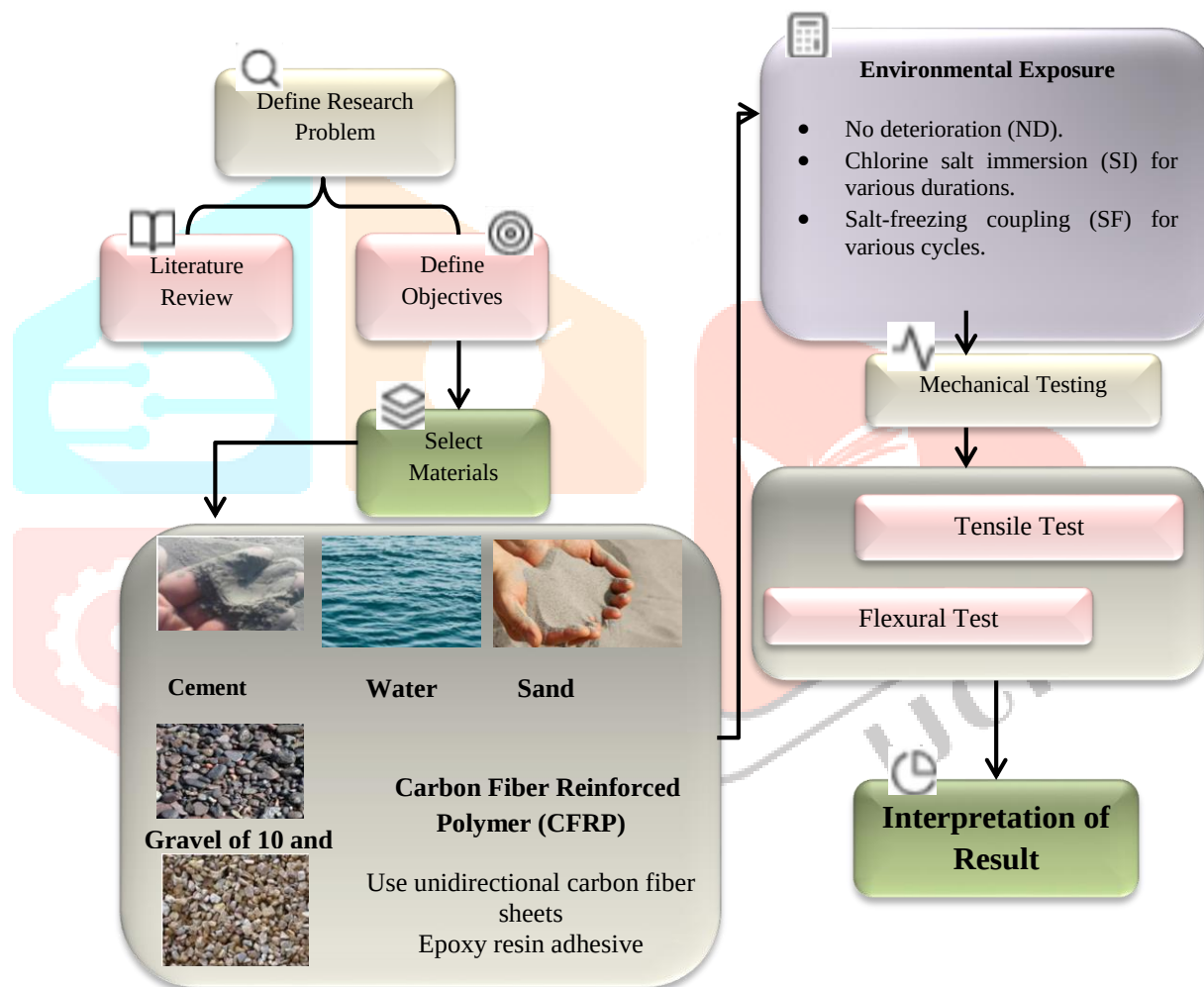


Figure 3: Flowchart of Proposed Work

4.1 Carbon Fiber Cloth and Epoxy Resin Adhesive

The test makes use of a 0.167 mm thick unidirectional carbon fiber sheet, as seen in Figure 4 a. Carbon fiber is a common reinforcing material in concrete engineering; it is made by mixing polyacrylonitrile (PAN) with lignin and then spinning the mixture in a wet process. Figure 4 b shows the two halves of the CFRP bonding adhesive, labeled A and B, which consist of an Epoxy Resin (ER) and a curing agent. After 7 days, ER had

cured to a 95% degree. In Table 1, it can see the material's characteristics. In Shanghai, China, it can find Shanghai Jingdong Construction Technology Co., Ltd., which makes ER and carbon fiber fabric.

Table 1: Tensile properties of ER and CFRP

Materials	Tensile Strength/MPa	Elastic Modulus/GPa	Elongation at Break/%
CFRP composite	3522	271	1.83
Epoxy resin adhesive	56.4	3.2	3.32

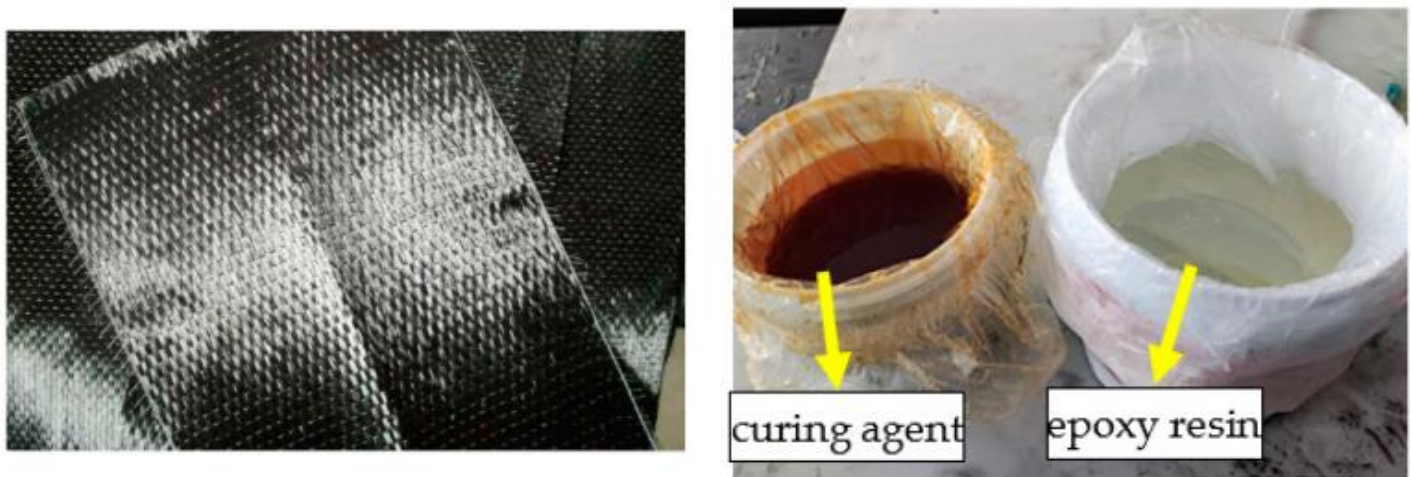


Figure 4: This product combines two common materials: a) CFRP sheet and b) ER

Curing for seven days at 25°C room temperature requires a 2:1 mixture of curing agent and ER. The strain gauge layout point, and epoxy specimen size are both shown in Figure 5. To make a CFRP sheet, the carbon fiber is cut into pieces that are 250 mm long and 200 mm wide, as shown in Figure 6. ER is applied to both sides of the pieces.

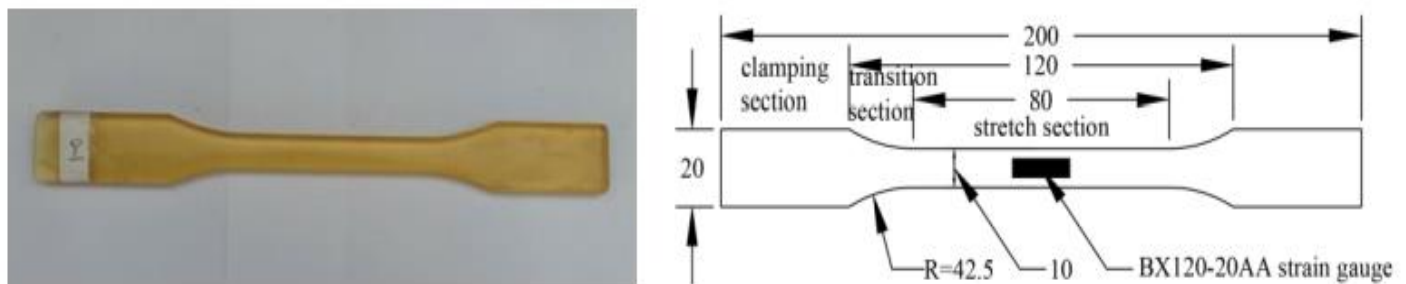


Figure 5: Adhesive sheet made of ER a) Sheet and b) Strain gauge dimensions and position

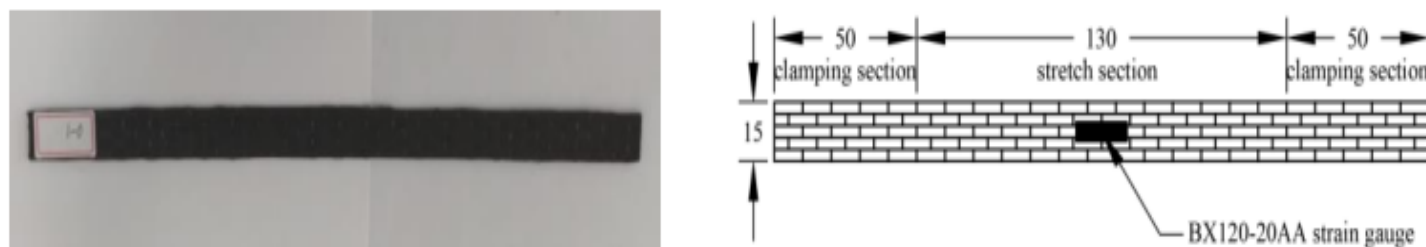


Figure 6: CFRP sheet a) Sheet and b) dimensions and placement of strain gauge [21].

4.2 Concrete

The proportion of concrete which is made of water, cement, sand and gravel can be seen in Figure 7. The design strength of the material in this test is 40MPa. The concrete mix design is presented in Table 2; the cement utilized is normal RCA Grade Portland cement. In the fine aggregate, the medium sand is identified to have a modulus coefficient of 3.1. The total coarse aggregates, gravels of 6mm to 10mm contributed 40% and 12mm to 20mm contributed 80%.

Table 2: Mix proportion of Concrete

Material	Water	Cement	Sand	Crushed Stone
Content (kg/m ³)	214	393	657	1250



Figure 7: Concrete composition materials

They are 200 mm width, 200 mm height, and 500 mm length for our unreinforced and CFRP prism illustrations. As seen in Figure 3.6, a rectangle shaped 200 mm × 400 mm CFRP strip is bonded to the tensile side of the CFRP specimen, and a 30 mm high notch is constructed on the tension side of the mid-span to ensure bending failure. Figure 8 shows the 4-point loading method with a strain gauge placed on the surface of CFRP to measure the changes in the mechanical load during the process.



Figure 8: Flexural specimens of reinforced and unreinforced concrete

4.3 Exposure Environment

The epoxy resin, CFRP sheets and concrete specimens are organized and labeled in a manner to differentiate between various exposure conditions and times. In tables 3 and 4 are definitions of numerical information; thus, CFRP stands for Carbon Fiber Reinforced Plastics and its serial number is CFRP, while EP indicates epoxy resin. In the same way, the reinforced concrete Specimen is labeled as RF while the unreinforced concrete specimen is labeled as URF. In regard to the environmental impact, there is the ND, SI and the SF environment.

Table 1: Number of ER and CFRP sheet

Exposure Environment	Epoxy Resin Adhesive Sheet	CFRP Sheet
No deterioration	EPND	CFRPND
Chlorine salt immersion for 100 h	EPSI-100	CFRPSI-100
Chlorine salt immersion for 200 h	EPSI-200	CFRPSI-200
Chlorine salt immersion for 300 h	EPSI-300	CFRPSI-300
Chlorine salt immersion for 400 h	EPSI-400	CFRPSI-400
Chlorine salt immersion for 500 h	EPSI-500	CFRPSI-500
Salt-freezing coupling 5 times	EPSF-5	CFRPSF-5
Salt-freezing coupling 25 times	EPSF-25	CFRPSF-25
Salt-freezing coupling 50 times	EPSF-50	CFRPSF-50
Salt-freezing coupling 75 times	EPSF-75	CFRPSF-75
Salt-freezing coupling 100 times	EPSF-100	CFRPSF-100

Table 2: Number of concrete specimens

Exposure Environment	Unreinforced Specimen	Reinforced Specimen
No deterioration	URFND	RFND
Chlorine salt immersion for 100 h	URFSI-100	RFSI-100
Chlorine salt immersion for 200 h	URFSI -200	RFSI -200
Chlorine salt immersion for 300 h	URFSI-300	RFSI-300
Chlorine salt immersion for 400 h	URFSI -400	RFSI -400
Chlorine salt immersion for 500 h	URFSI -500	RFSI-500
Salt-freezing coupling 5 times	URFSF-5	RFSF-5
Salt-freezing coupling 25 times	URFSF -25	RFSF -25
Salt-freezing coupling 50 times	URFSF -50	RFSF-50
Salt-freezing coupling 75 times	URFSF -75	RFSF -75
Salt-freezing coupling 100 times	URFSF -100	RFSF-100

4.4 Mechanical Test

To investigate the degradation of mechanical performance in a corrosive setting, epoxy resin and CFRP sheets are subjected to tensile testing. In Figure 9, they can see that the tensile testing technique uses a mechanical control and data collection system to apply a loading rate of 2 mm/min.

**Figure 9:** Stress testing of epoxy resin and CFRP

The procedure of 4-point flexural tension test on concrete specimens in different exposure situations is shown in Figure 10, where the loading rate was fixed at 0.06 MPa/s. For monitoring the strain increment in the direction of the CFRP sheet, 5 strain gauges are attached to the CFRP surface and numbered from left to right

as A, B, C, D and E. A displacement meter is placed at mid span of the bottom of the flexural specimen to measure its deflection.

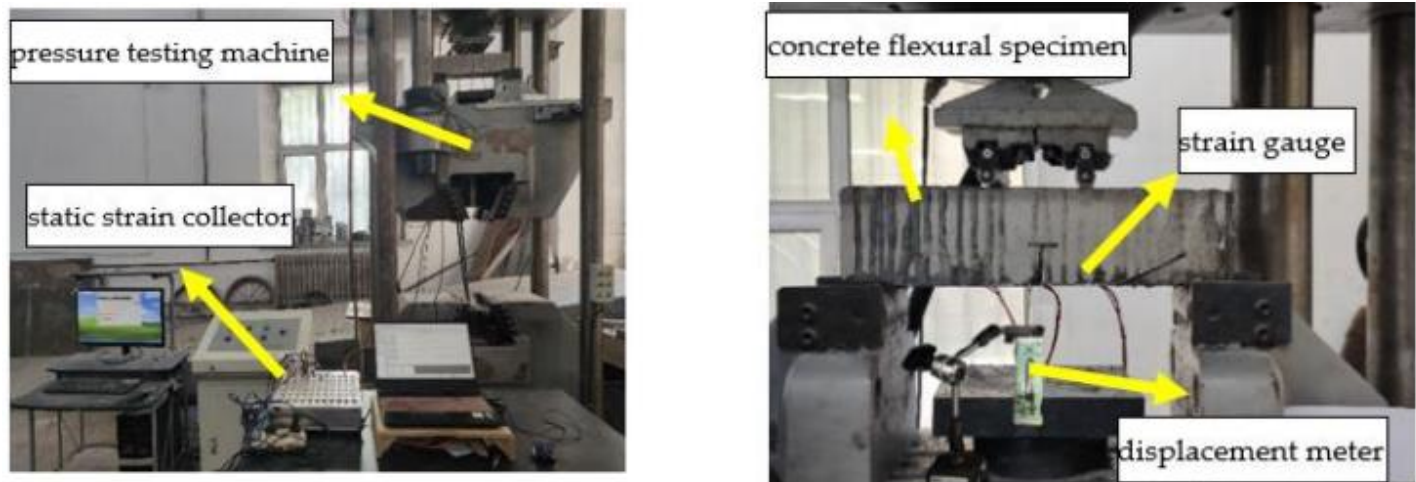


Figure 10: Mechanical bending test on both the overload and detail data gathering settings

5. Test Result and Discussion

The test findings derived from the experimental studies are provided as follows:

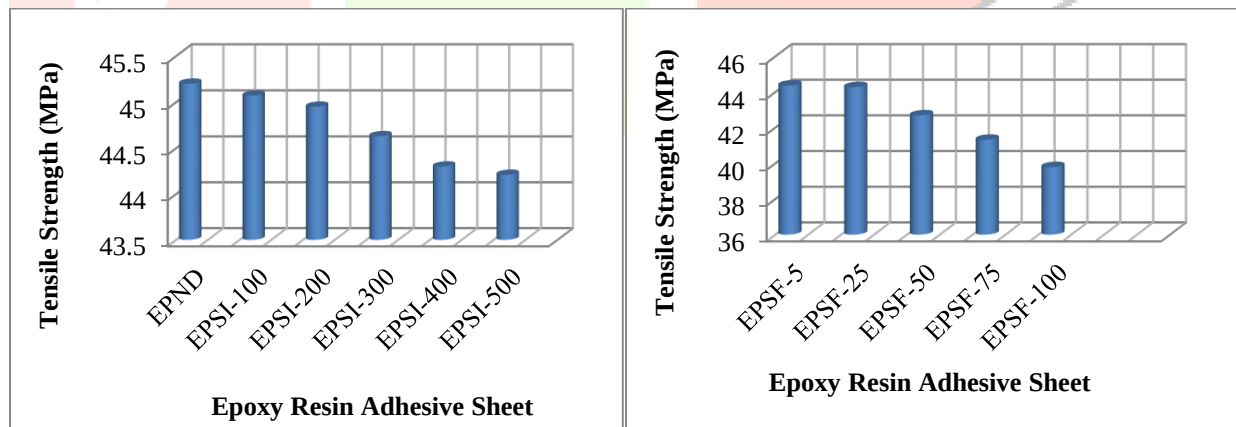
5.1 Tensile Performance

The Tensile Strength (TS) data for Epoxy Resin (ER) adhesive sheets and CFRP sheets reveal interesting trends and relationships shown in Table 5. The TS of the epoxy resin adhesive sheets ranges from 45.20MPa (EPND) to 39.78MPa (EPSF-100), while the CFRP sheets exhibit significantly higher TS, varying from 3587.25MPa (CFRPSF-5) to 3442.15MPa (CFRPSI-500). The highest TS among epoxy resin adhesives, 45.20MPa, are observed for EPND. It could be because its chemistry provides better adhesion performance as well as mechanical strength. On the other hand, the minimum values of TS (39.78MPa) are exhibited by the EPSF-100. This loss can be accounted to pragmatically parameters like higher filler content or simply due to aging the tensile capacity of the material can be affected.

Based on the results obtained for CFRP sheets, CFRPSF-5 achieved the highest TS of 3587.25MPa. This enhanced performance could be attributed to the optimized resin fiber interface or the increased fiber volume content that led to better load bearing and strength. However, CFRPSI-500 has the lowest TS of 3442.15MPa; this might be due to changes in the fiber direction or poor interface adhesion between the fibers and the resin matrix. A noticeable pattern is observed when comparing the TS of adhesives and CFRP sheets: as the adhesive TS slightly decreases (e.g., from EPSI-100 to EPSI-500), the CFRP tensile strength also exhibits a downward trend. This implies that CFRP performance can be influenced by the adhesive properties so that CFRP acts differently because of the range in bonding efficacy. Figure 11 and 12 show the TS curve of epoxy resin and CFRP sheet.

Table 5: TS of ER and CFRP sheet

ER Adhesive Sheet	TS/MPa	CFRP Sheet	TS/MPa
EPND	45.20	CFRPND	3511.21
EPSI-100	45.07	CFRPSI-100	3501.24
EPSI-200	44.95	CFRPSI-200	3482.31
EPSI-300	44.63	CFRPSI-300	3475.52
EPSI-400	44.30	CFRPSI-400	3451.64
EPSI-500	44.21	CFRPSI-500	3442.15
EPSF-5	44.36	CFRPSF-5	3587.25
EPSF-25	44.27	CFRPSF-25	3572.84
EPSF-50	42.68	CFRPSF-50	3564.26
EPSF-75	41.31	CFRPSF-75	3553.61
EPSF-100	39.78	CFRPSF-100	3486.12

**Figure 11:** TS curve of ER

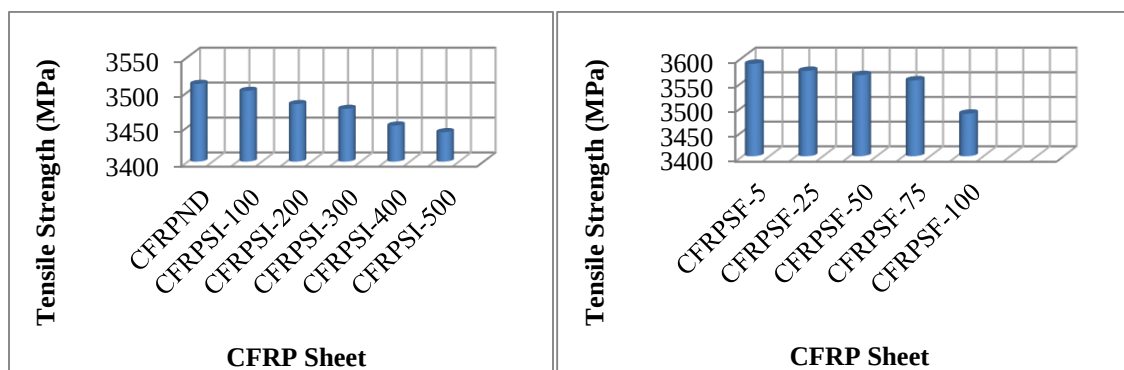


Figure 11: TS curve of CFRP sheet

Table 6 compares tensile strain values of ER adhesive sheets and CFRP sheets under different conditions. The tensile strain of ER adhesive sheets increases progressively from 16,483 $\mu\epsilon$ (EPND) to 19,453 $\mu\epsilon$ (EPSI-500). This increase reflects the improved adhesive properties and higher flexibility of the epoxy resin sheets with advanced formulations or treatments, enabling greater deformation under tensile loads. Similarly, CFRP sheets exhibit a consistent rise in tensile strain, from 14,512 $\mu\epsilon$ (CFRPND) to 15,048 $\mu\epsilon$ (CFRPSF-100). The increment suggests enhanced compatibility with the adhesive sheets, leading to better strain transfer and higher tensile capacity. Remarkably, the formulations such as EPSI-500 and EPSF-100 give the highest strain due to well selected resin contents which are perhaps to improve on the mechanical interlocking and fiber/resin bonding. Smaller values like EPND and CFRPND indicate ordinary formulations where very much basic enhancement has not been done and thus the restricted tensile strain. The overall trend indicates improvements in material properties with tailored formulations. Figure 13 and 14 show the tensile strain curve of ER and CFRP sheet.

Table 6: Tensile Strain of ER and CFRP sheet

Epoxy Resin Adhesive Sheet	Tensile Strain/ $\mu\epsilon$	CFRP Sheet	Tensile Strain/ $\mu\epsilon$
EPND	16,483	CFRPND	14,512
EPSI-100	16,873	CFRPSI-100	14,573
EPSI-200	17,532	CFRPSI-200	14,646
EPSI-300	17,862	CFRPSI-300	14,781
EPSI-400	18,746	CFRPSI-400	14,842
EPSI-500	19,453	CFRPSI-500	14,958
EPSF-5	16,764	CFRPSF-5	14,640
EPSF-25	17,857	CFRPSF-25	14,737
EPSF-50	18,416	CFRPSF-50	14,812
EPSF-75	18,714	CFRPSF-75	14,936
EPSF-100	19,012	CFRPSF-100	15,048

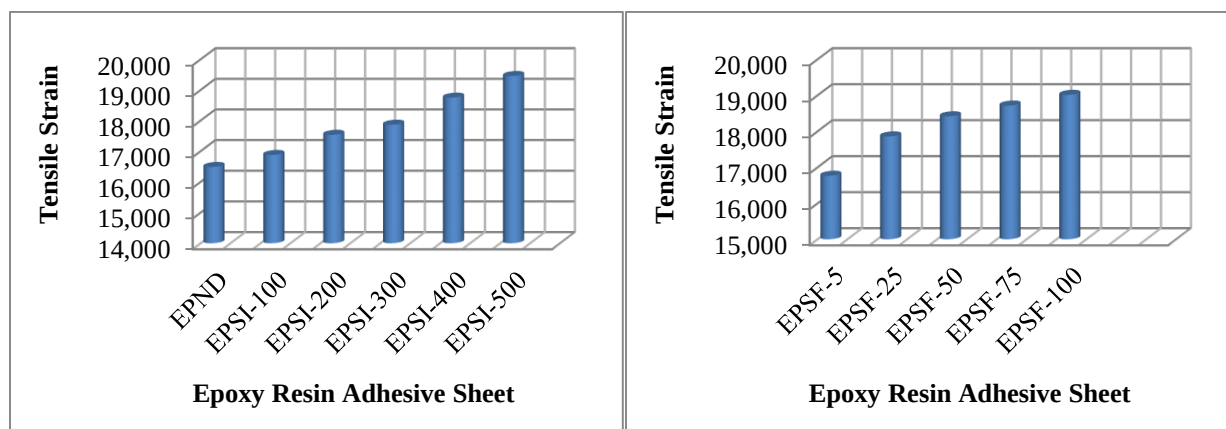


Figure 12: Tensile Strain curve of ER

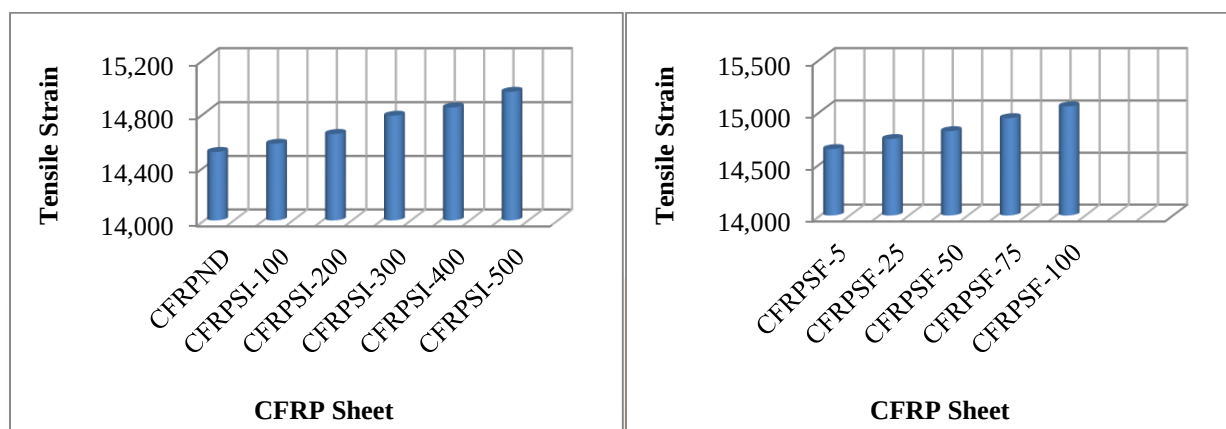


Figure 13: Tensile Strain curve of CFRP sheet

Table 7 compares the tensile modulus of elasticity (TMOE) for various ER adhesive sheets and corresponding CFRP sheets. EPND exhibits the highest modulus among adhesives (2655MPa) due to its enhanced rigidity, closely matched by CFRPND (257,534MPa). EPSI adhesives show a decreasing trend in modulus with increasing grade, reflecting possible modifications reducing rigidity. Similarly, CFRP moduli decline slightly, likely due to changes in resin properties affecting fiber bonding. Figure 15 and 16 show the TMOE curve of ER and CFRP sheet.

Table 7: TMOE of ER and CFRP sheet

Epoxy Resin Adhesive Sheet	Tensile Modulus of Elasticity/MPa	CFRP Sheet	Tensile Modulus of Elasticity/MPa
EPND	2655	CFRPND	257,534
EPSI-100	2581	CFRPSI-100	256,852
EPSI-200	2553	CFRPSI-200	255,461
EPSI-300	2426	CFRPSI-300	254,275
EPSI-400	2394	CFRPSI-400	252,689
EPSI-500	2347	CFRPSI-500	250,682

EPSF-5	2557	CFRPSF-5	255,738
EPSF-25	2372	CFRPSF-25	253,036
EPSF-50	2174	CFRPSF-50	250,847
EPSF-75	1985	CFRPSF-75	248,261
EPSF-100	1916	CFRPSF-100	246,693

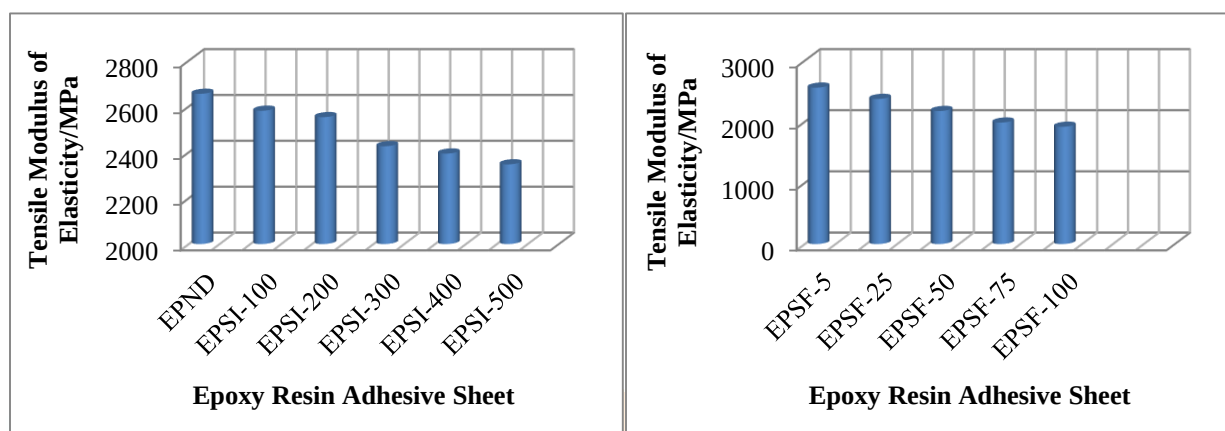


Figure 14: TMOE curve of ER

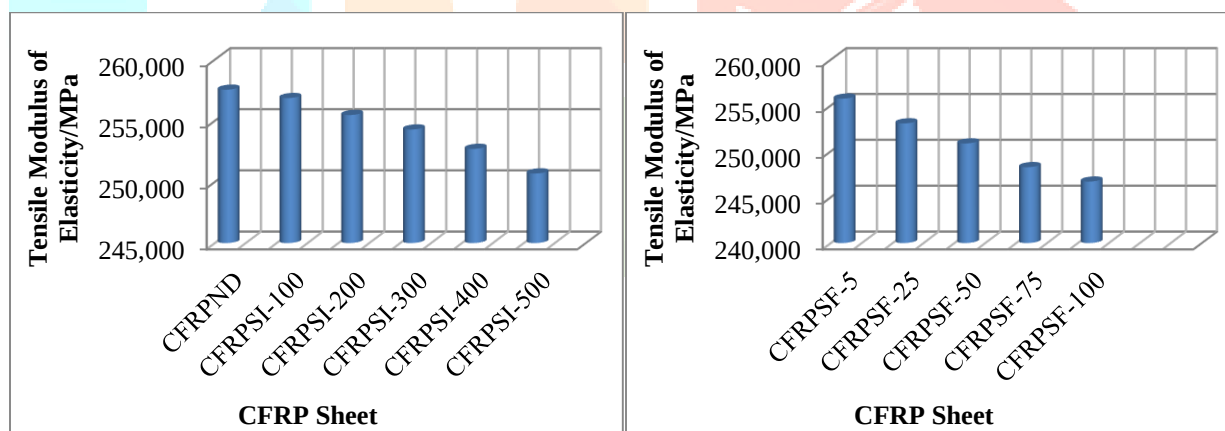


Figure 15: TMOE curve of CFRP sheet

5.2 Concrete Flexural Test

Both URFND and RFND specimens are examined for the whole cement mortar matrix surface in the absence of environmental. The Flexural Strength (FS) of URFND shows a gradual decline as modifications are introduced, such as increased surface imperfections (e.g., URFSI series) or fiber content (e.g., URFSF series) (Table 8). The highest strength, 4.703MPa, is observed in the URFND due to the absence of defects. The presence of imperfections or fibers decreases the FS, which is attributed to a poor bond strength and stress concentration on the crack surfaces. Conversely, RFND exhibit significantly higher FS due to steel reinforcement, peaking at 16.024MPa. Strength decreases such as imperfections or higher fiber content are introduced, possibly due to reinforcement inefficiencies in these conditions. Figure 17 and 18 show the FS of unreinforced and reinforced concrete.

Table 8: FS of Concrete Flexural Specimen (CFS)

URF Specimen	FS/MPa	RF Specimen	FS/MPa
URFND	4.703	RFND	16.024
URFSI-100	4.319	RFSI-100	15.643
URFSI-200	3.728	RFSI-200	14.926
URFSI-300	3.562	RFSI-300	14.359
URFSI-400	3.359	RFSI-400	13.703
URFSI-500	3.012	RFSI-500	13.251
URFSF-5	4.312	RFSF-5	14.940
URFSF-25	3.963	RFSF-25	14.283
URFSF-50	2.426	RFSF-50	13.878
URFSF-75	1.836	RFSF-75	11.632
URFSF-100	1.407	RFSF-100	10.306

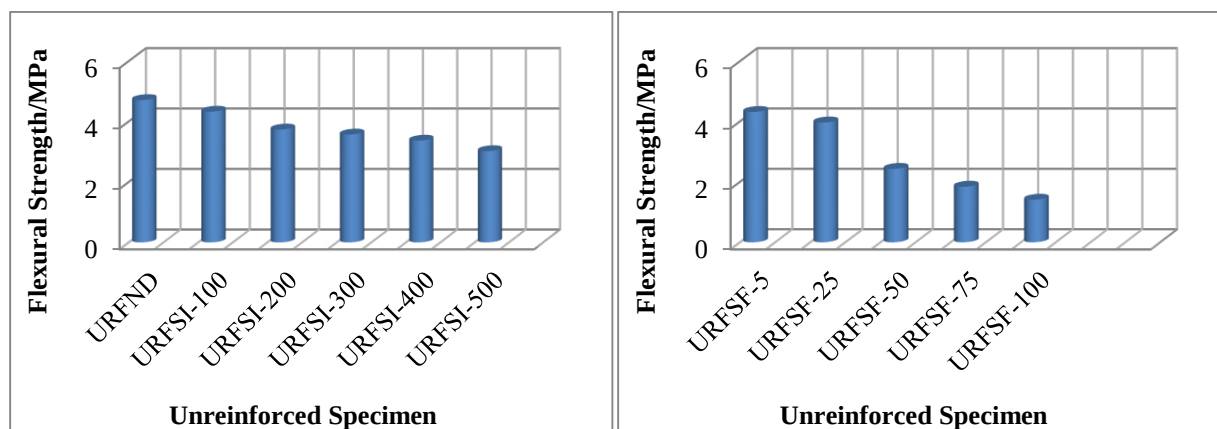


Figure 16: FS of unreinforced concrete

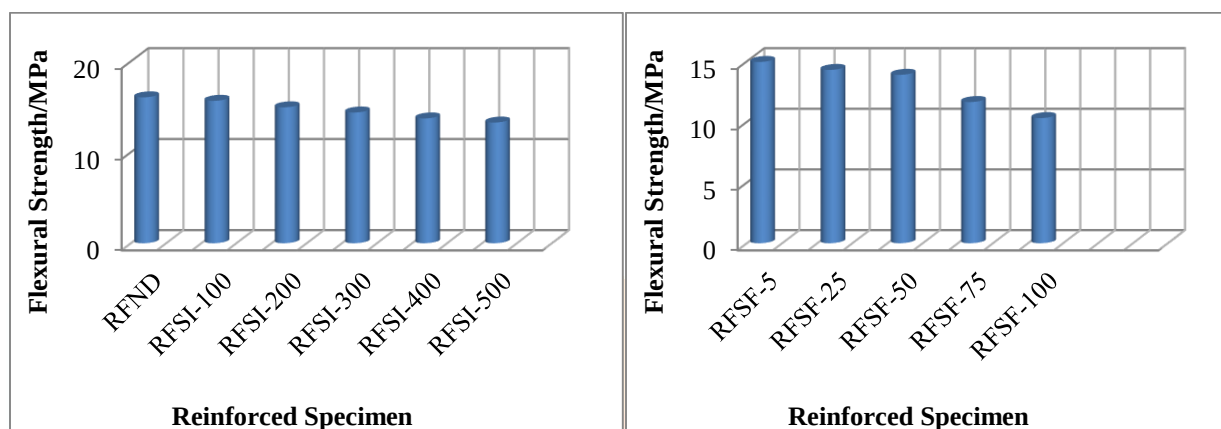
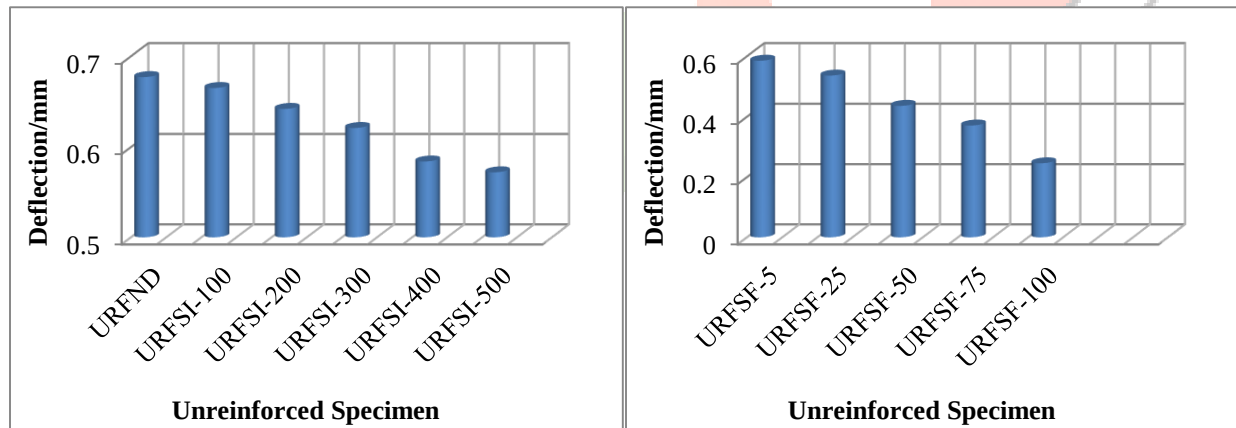


Figure 17: FS of reinforced concrete

Table 9 presents the deflection data for unreinforced and reinforced CFS under various conditions. For the unreinforced specimens, labeled URFND, the deflection starts at 0.677 mm and decreases as the specimen's reinforcement increases, with the lowest deflection of 0.246 mm observed for the URFSF-100. This suggests that increased reinforcement reduces the deflection of the unreinforced specimens. On the other hand, for the reinforced specimens (denoted RFND through RFSF-100), the deflections are notably higher, starting from 2.582 mm for the RFND and decreasing gradually as the reinforcement increases. The deflection of the reinforced specimens at 2.134 mm for the RFSF-100 is the smallest among the reinforced group, though still significantly higher than the unreinforced specimens. Figure 19 and 20 show the load-deflection curve of unreinforced and reinforced CFS.

Table 9: Deflection of CFS

URF Specimen	Deflection/mm	RF Specimen	Deflection/mm
URFND	0.677	RFND	2.582
URFSI-100	0.665	RFSI-100	2.573
URFSI-200	0.642	RFSI-200	2.552
URFSI-300	0.621	RFSI-300	2.548
URFSI-400	0.584	RFSI-400	2.532
URFSI-500	0.572	RFSI-500	2.504
URFSF-5	0.585	RFSF-5	2.495
URFSF-25	0.536	RFSF-25	2.373
URFSF-50	0.436	RFSF-50	2.281
URFSF-75	0.371	RFSF-75	2.253
URFSF-100	0.246	RFSF-100	2.134

**Figure 18:** Load-deflection curve of unreinforced CFS

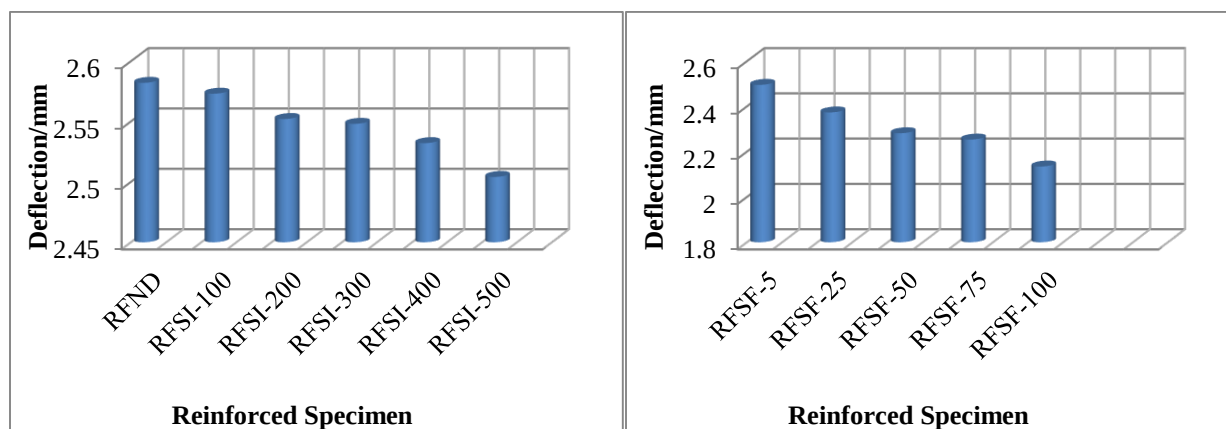


Figure 20: Load-deflection curve of reinforced CFS

6. Conclusion

In the study, CFRP is applied to concrete columns for enhancement of structures durability and their performance under environment conditions. These conditions were intended for assessment of effects of changes in moisture and temperatures on the mechanical behavior and durability of concrete reinforced with CFRP. The systematic investigation of some of the parameters including tensile strength, strain, modulus of elasticity, and flexural strength went a long way in detailing the possibility of using CFRP in increasing the durability of concrete structures.

- CFRP sheets demonstrated significantly higher tensile strength compared to epoxy resin adhesive sheets. While epoxy resin sheets showed a reduction from 45.20 MPa (non-deteriorated) to 39.78MPa after salt-freezing cycles, CFRP sheets exhibited a smaller decrease from 3511.21MPa to 3442.15MPa after salt immersion.
- Flexural strength tests revealed superior performance of reinforced specimens over unreinforced ones. Non-deteriorated reinforced concrete achieved 16.024 MPa compared to 4.703MPa for unreinforced, while under salt-freezing cycles, reinforced concrete maintained 10.306MPa versus 1.407MPa for unreinforced.
- Deflection tests indicated that CFRP reinforcement improved structural resilience, with RFND higher deflection values (2.582 mm to 2.134 mm) compared to URFND deflection value (0.677 mm to 0.246 mm) under prolonged exposure.
- Tensile strain increased with environmental exposure to both materials. Epoxy resin sheets rose from 16,483 $\mu\epsilon$ to 19,453 $\mu\epsilon$, while CFRP sheets showed a smaller increase from 14,512 $\mu\epsilon$ to 15,048 $\mu\epsilon$, highlighting their superior deformation capacity under tensile loads.

Reference

1. Olofin, I., and Ronggui Liu. "The application of carbon fibre reinforced polymer (CFRP) cables in civil engineering structures." *Int. J. Civ. Eng* 2, no. 7 (2015): 1-5.
2. Sharifianjazi, Fariborz, Parham Zeydi, Milad Bazli, Amirhossein Esmaeilkhani, Roozbeh Rahmani, Leila Bazli, and Samad Khaksar. "Fibre-reinforced polymer reinforced concrete members under elevated temperatures: a review on structural performance." *Polymers* 14, no. 3 (2022): 472.
3. Oskouei, Asghar Vatani, Armin Jafari, Milad Bazli, and Rasool Ghahri. "Effect of different retrofitting techniques on in-plane behavior of masonry wallettes." *Construction and Building Materials* 169 (2018): 578-590.
4. Bazli, Milad, Xiao-Ling Zhao, RK Singh Raman, Yu Bai, and Saad Al-Saadi. "Bond performance between FRP tubes and seawater sea sand concrete after exposure to seawater condition." *Construction and Building Materials* 265 (2020): 120342.
5. Jafari, Armin, Hamed Ashrafi, Milad Bazli, and Togay Ozbakkaloglu. "Effect of thermal cycles on mechanical response of pultruded glass fiber reinforced polymer profiles of different geometries." *Composite Structures* 223 (2019): 110959.
6. Kiersnowska, Agnieszka, Wojciech Fabianowski, and Eugeniusz Koda. "The influence of the accelerated aging conditions on the properties of polyolefin geogrids used for landfill slope reinforcement." *Polymers* 12, no. 9 (2020): 1874.
7. Chalot, A., L. Michel, and E. Ferrier. "Experimental study of external bonded CFRP-concrete interface under low cycle fatigue loading." *Composites Part B: Engineering* 177 (2019): 107255.
8. Lee, Taemin, Saebyeok Jeong, Ukyong Woo, Hajin Choi, and Donghyuk Jung. "Experimental evaluation of shape memory alloy retrofitting effect for circular concrete column using ultrasonic pulse velocity." *International Journal of Concrete Structures and Materials* 17, no. 1 (2023): 13.
9. Gudonis, Eugenijus, Edgaras Timinskas, Viktor Gribniak, Gintaris Kaklauskas, Aleksandr K. Arnautov, and Vytautas Tamulėnas. "FRP reinforcement for concrete structures: state-of-the-art review of application and design." *Engineering Structures and Technologies* 5, no. 4 (2013): 147-158.
10. Cruz, Ricardo, Luís Correia, Susana Cabral-Fonseca, and José Sena-Cruz. "Durability of bond of EBR CFRP laminates to concrete under real-time field exposure and laboratory accelerated ageing." *Construction and Building Materials* 377 (2023): 131047.
11. <https://www.slideshare.net/fathyibrahim/carbon-fiber-reinforced-concrete-carbocrete>.
12. Tan, Cheng, Xu Jiang, Xuhong Qiang, and Mingxin Fan. "Flexural performance of carbon fiber-reinforced polymer prestressed spun high-strength concrete pile." *Applied Sciences* 14, no. 16 (2024): 7170.
13. Wang, Yunchen, Jiongfeng Liang, Caisen Wang, and Wei Li. "Axial compression behavior of carbon fiber reinforced polymer confined partially encased recycled concrete columns." *Plos one* 19, no. 6 (2024): e0304797.
14. Abolfazli, Milad, Milad Bazli, Ali Rajabipour, Michael Heitzmann, Hamid Pourasiabi, Hao Wang, and Mehrdad Arashpour. "Residual compressive strength of filament wound hybrid glass/carbon fibre reinforced polymer tubes after exposure to elevated temperature." *Composite Structures* 316 (2023): 117050.

15. Jahani, Younes, Marta Baena, Javier Gómez, Cristina Barris, and Lluís Torres. "Experimental study of the effect of high service temperature on the flexural performance of near-surface mounted (NSM) carbon fiber-reinforced polymer (CFRP)-strengthened concrete beams." *Polymers* 13, no. 6 (2021): 920.
16. Lee, Ming-Gin, Yishuo Huang, Yu-Cheng Kan, Yung-Chih Wang, Yu-Sung Chen, and Shih-Chi Kao. "Experimental study on durability of CFRP-strengthened wood members." *Journal of Materials Research and Technology* 24 (2023): 3704-3716.
17. Abolfazli, Milad, Rodolfo Ivan John Reyes, Dion Choong, Milad Bazli, Ali Rajabipour, Hamid Pourasiabi, and Mehrdad Arashpour. "Bond behaviour between CFRP, GFRP, and hybrid C-GFRP tubes and seawater sea sand concrete after exposure to elevated temperatures." *Construction and Building Materials* 392 (2023): 131884.
18. Yu, Yixun, Yunfeng Pan, Ronggui Zhou, and Xinbo Miao. "Effects of water and alkaline solution on durability of carbon-glass hybrid fiber reinforced polymer bars." *Polymers* 13, no. 21 (2021): 3844.
19. Safiuddin, Md, George Abdel-Sayed, and Nataliya Hearn. "Absorption and strength properties of short carbon fiber reinforced mortar composite." *Buildings* 11, no. 7 (2021): 300.
20. Bright Singh, S., and Murugan Madasamy. "Investigation of aggregate size effects on properties of basalt and carbon fibre-reinforced pervious concrete." *Road Materials and Pavement Design* 23, no. 6 (2022): 1305-1328.
21. Li, Wei, Dayang Wang, Wenyuan Xu, and Yongcheng Ji. "Investigation on damage evolution mechanism of various FRP strengthened concrete subjected to chemical-freeze-thaw coupling erosion." *Plos one* 19, no. 5 (2024): e0303645.

