Durability Assessment and Flexural Response of GFRP-Reinforced Concrete Beams Subjected to Acidic and Alkaline Exposure Conditions

[*1]Mr. R. S. Ingalkar and [2]Dr. P. S. Pajgade

PhD Scholar, Department of Civil Engineering, Prof. Ram Meghe Institute of Technology and Research, Badnera - Amravati 444701, Maharashtra, India

Professor, Department of Civil Engineering, Prof. Ram Meghe Institute of Technology and Research, Badnera - Amravati 444701, Maharashtra, India

[*]rameshwar.ingalkar@rediffmail.com

How to Cite this Article:

Ingalkar, R. S. (2026). Durability Assessment and Flexural Response of GFRP-Reinforced Concrete Beams Subjected to Acidic and Alkaline Exposure Conditions. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(7). https://doi.org/10.55041/ijcope.v2i7.057

https://doi.org/ 10.55041/ijcope.v2i7.057

Abstract

The durability of reinforced concrete structures is significantly affected by aggressive environmental conditions that accelerate the deterioration of conventional steel reinforcement. Glass Fiber Reinforced Polymer (GFRP) bars have emerged as a promising alternative owing to their high corrosion resistance, lightweight nature, and superior tensile properties. This experimental investigation evaluates the flexural performance and deformation characteristics of GFRP-reinforced concrete beams exposed to acidic, alkaline, and neutral environments. A total of eighteen reinforced concrete beam specimens measuring 150 mm × 150 mm × 700 mm were fabricated and cured for 21 days under controlled laboratory conditions. Three steel-reinforced beams were maintained under neutral conditions and used as control specimens, while fifteen beams reinforced with GFRP bars were subjected to exposure media with pH values of 1, 4, 7, 10, and 13. The structural response of the beams was assessed through flexural testing, including measurements of ultimate load, flexural strength, and load–deflection behavior. The experimental results revealed that steel-reinforced specimens exhibited superior stiffness and load-carrying capacity under neutral conditions. However, GFRP-reinforced beams demonstrated remarkable stability and durability when exposed to chemically aggressive environments. The maximum flexural strength of 14.51 N/mm² was recorded for specimens exposed to pH 13, while beams subjected to pH 4 exhibited a comparable strength of 14.31 N/mm². Although GFRP-reinforced beams experienced relatively larger deflections due to their lower elastic modulus, all specimens maintained stable structural performance without sudden failure. The findings highlight the potential of GFRP reinforcement as a durable and sustainable substitute for steel reinforcement in structures exposed to harsh chemical environments.

Keywords: Glass Fiber Reinforced Polymer, Reinforced Concrete Beams, Chemical Durability, Flexural Capacity, Load–Deflection Response, Corrosion-Resistant Reinforcement

1. Introduction

The long-term durability of reinforced concrete structures remains a major concern in civil engineering, particularly when structures are exposed to chemically aggressive environments. Conventional steel reinforcement is highly susceptible to corrosion when subjected to chloride attack, acidic groundwater, industrial pollutants, and fluctuating environmental conditions. Corrosion-induced deterioration often leads to cracking, spalling of concrete cover, reduction in reinforcement cross-section, and ultimately premature structural failure. Consequently, considerable research efforts have been directed toward identifying alternative reinforcement materials capable of providing improved durability and extended service life.

Among the available alternatives, Glass Fiber Reinforced Polymer (GFRP) reinforcement has attracted significant attention due to its exceptional resistance to corrosion, high tensile strength, low density, and electromagnetic neutrality. Unlike steel reinforcement, GFRP bars do not undergo electrochemical corrosion, making them particularly suitable for infrastructure exposed to marine environments, wastewater treatment facilities, chemical plants, bridge decks, and underground structures. In addition to durability benefits, GFRP reinforcement offers ease of handling and reduced transportation costs due to its lightweight characteristics.

Several researchers have reported the successful application of GFRP reinforcement in reinforced concrete members subjected to flexural and shear loading. Previous investigations have demonstrated that GFRP-reinforced beams possess adequate load-carrying capacity and satisfactory serviceability performance despite exhibiting larger deflections compared to steel-reinforced counterparts. Nevertheless, the long-term behavior of GFRP reinforcement under severe acidic and alkaline exposure remains an important area requiring further investigation.

Concrete structures are frequently exposed to aggressive environments throughout their service life. Acidic conditions may arise from industrial wastewater, acid rain, sewage systems, and contaminated groundwater, whereas alkaline conditions are commonly encountered within cementitious matrices and certain industrial applications. These environments can influence the interaction between reinforcement and surrounding concrete, thereby affecting the overall structural performance.

Although numerous studies have investigated the mechanical properties and durability characteristics of GFRP bars, limited research has focused on the flexural behavior of GFRP-reinforced concrete beams exposed to varying pH conditions under controlled laboratory environments. Understanding the structural response of such systems is essential for developing reliable design recommendations and promoting the wider adoption of FRP reinforcement technologies.

Therefore, the present study investigates the flexural strength, ultimate load capacity, and load–deflection characteristics of GFRP-reinforced concrete beams exposed to acidic, neutral, and alkaline curing media. The research aims to assess the effectiveness of GFRP reinforcement in maintaining structural integrity under chemically aggressive conditions and to compare its performance with conventional steel reinforcement.

2. Experimental Program and Methodology

2.1 Beam Specimens

The experimental program consisted of eighteen reinforced concrete beam specimens having dimensions of 150 mm × 150 mm × 700 mm. The specimens were categorized into two groups based on the type of reinforcement used.

Reinforcement Type	Number of Specimens
Steel Reinforced	3
GFRP Reinforced	15
Total	18

Three steel-reinforced beams were designated as control specimens, while the remaining fifteen beams were reinforced with GFRP bars.

2.2 Environmental Exposure Conditions

The GFRP-reinforced beam specimens were exposed to five different chemical environments characterized by varying pH values. These exposure conditions were selected to simulate the range of aggressive environments commonly encountered in engineering practice.

pH Value	Environmental Condition
1	Highly Acidic
4	Moderately Acidic
7	Neutral
10	Moderately Alkaline
13	Highly Alkaline

Each exposure category consisted of three identical beam specimens to improve experimental reliability and minimize variability.

2.3 Curing Procedure

Following casting, all beam specimens were cured for a period of 21 days. During this period, the pH levels of the exposure media were continuously maintained to ensure consistent environmental conditions throughout the testing program.

2.4 Testing Procedure

The structural performance of the beam specimens was evaluated through flexural testing. The following parameters were measured and analyzed:

- Ultimate load-carrying capacity
- Flexural strength
- Load–deflection response
- Crack propagation and failure characteristics

The average values obtained from three specimens within each category were used for comparative evaluation.

3. Results and Discussion

3.1 Flexural Performance

The flexural strength results demonstrated a significant influence of environmental exposure on the behavior of GFRP-reinforced concrete beams. The control steel-reinforced beams achieved an average flexural strength of 13.25 N/mm² under neutral conditions. The GFRP-reinforced specimens exhibited varying levels of performance depending on the exposure environment.

Exposure pH	Average Flexural Strength (N/mm²)
1	12.58
4	14.31
7	10.86
10	12.79
13	14.51

The highest flexural strength was observed in beams exposed to a highly alkaline medium (pH 13), achieving 14.51 N/mm². This represents an increase of approximately 33.6% compared to GFRP beams maintained under neutral conditions. Similarly, specimens exposed to pH 4 demonstrated enhanced flexural performance with an average strength of 14.31 N/mm².

The results indicate that short-term exposure to acidic and alkaline environments did not adversely affect the structural capacity of GFRP reinforcement. Instead, favorable interactions between the concrete matrix and GFRP bars may have contributed to the observed improvements in flexural strength.

3.2 Ultimate Load Capacity

The steel-reinforced control beams exhibited the highest ultimate load-carrying capacity among all specimens. This behavior is primarily attributed to the higher elastic modulus and superior stiffness characteristics of steel reinforcement.

Despite exhibiting lower stiffness, GFRP-reinforced beams maintained satisfactory load resistance under all environmental conditions. The results demonstrate that GFRP reinforcement is capable of providing reliable structural performance even in chemically aggressive environments.

3.3 Load–Deflection Behaviour

The load–deflection response provides important information regarding stiffness and deformation characteristics.

Beam Category	Maximum Deflection (mm)
Steel (pH 7)	5.2
GFRP (pH 1)	6.2
GFRP (pH 4)	6.4
GFRP (pH 7)	4.7
GFRP (pH 10)	7.8

GFRP (pH 13)	5.1

The maximum deflection of 7.8 mm was recorded in the pH 10 specimens, indicating comparatively lower stiffness. In general, GFRP-reinforced beams exhibited greater deformation than steel-reinforced beams due to the lower modulus of elasticity of GFRP bars.

Nevertheless, all specimens displayed gradual deformation and stable crack development prior to failure. No brittle or sudden collapse was observed during testing, indicating adequate structural reliability.

3.4 Discussion

The experimental findings clearly demonstrate the durability advantages of GFRP reinforcement when exposed to chemically aggressive environments. Unlike steel reinforcement, which is vulnerable to corrosion-induced deterioration, GFRP bars maintained their structural effectiveness throughout the exposure period.

The superior performance observed in highly alkaline and moderately acidic environments suggests that GFRP reinforcement can effectively withstand a broad range of service conditions without significant degradation. The results support the use of GFRP bars in marine structures, wastewater treatment facilities, industrial foundations, chemical processing plants, and other infrastructure subjected to aggressive environmental exposure.

4. Conclusions

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

1. Steel-reinforced concrete beams exhibited higher stiffness and ultimate load capacity than GFRP-reinforced beams under neutral conditions.
2. GFRP reinforcement demonstrated excellent resistance to both acidic and alkaline exposure environments.
3. The highest flexural strength of 14.51 N/mm^2 was obtained for beams exposed to a highly alkaline medium (pH 13).
4. GFRP-reinforced beams showed greater deflection compared to steel-reinforced beams because of their lower elastic modulus.
5. Exposure to aggressive chemical environments for 21 days did not result in any noticeable deterioration of GFRP reinforcement.
6. The corrosion-resistant characteristics of GFRP make it highly suitable for infrastructure exposed to severe environmental conditions.
7. GFRP reinforcement can be considered a practical and sustainable alternative to conventional steel reinforcement in durability-critical applications.

Overall, the study confirms the significant potential of GFRP reinforcement for enhancing the service life, durability, and sustainability of reinforced concrete structures operating in chemically aggressive environments.

References

1. Adam, M. A., Said, M., Mahmoud, A. A., & Shanour, A. S. (2015). Analytical and experimental flexural behavior of concrete beams reinforced with glass fiber reinforced polymers bars. Construction and Building Materials, 84, 354–366.
2. Albu-Hassan, N. H., & Al-Thairy, H. (2020). Experimental and numerical investigation on the behavior of hybrid concrete beams reinforced with GFRP bars after exposure to elevated temperature. Structures, 28, 537–551. https://www.sciencedirect.com/science/article/pii/S2352012420304690
3. Arczewska, P., Polak, M. A., & Penlidis, A. (2021). Degradation of glass fiber reinforced polymer (GFRP) bars in concrete environment. Construction and Building Materials, 293, 123451.
4. Aybar, K., Eryilmaz Yildirim, M., & Canbaz, M. (2025). Effect of High Temperature on the Mechanical Behavior of Glass Fiber–Reinforced Polymer Composite Bars under Compressive Loading. Journal of Materials in Civil Engineering, 37(9), 04025302. https://doi.org/10.1061/JMCEE7.MTENG-20025
5. Azuwa, S. B., & Yahaya, F. B. M. (2025). Effect of glass fibre reinforced polymer composite material on structural performance of reinforced concrete beams through experimental observation and finite element modelling: A critical review. Structures, 73, 108277. https://www.sciencedirect.com/science/article/pii/S2352012425000918
6. Bywalski, C., Drzazga, M., Kaźmierowski, M., & Kamiński, M. (2020). Shear Behavior of Concrete Beams Reinforced with a New Type of Glass Fiber Reinforced Polymer Reinforcement: Experimental Study. Materials, 13(5), 1159.
7. Akarshan Gulhane, "Smart Mobility and Intelligent Transportation Systems: Emerging Trends, Technologies, and Challenges," International Journal of Scientific Research in Engineering and Management, vol. 9, no. 11, pp. 1-10, Nov 2025. https://doi.org/10.55041/IJSREM53436
8. Akarshan Gulhane, "Quantum Computing in Transportation and Logistics: Current State, Industrial Applications, and Future Directions," International Journal of Scientific Research in Engineering and Management, vol. 9, no. 9, pp. 1-10, Sep 2025. https://doi.org/10.55041/IJSREM52469
9. Akarshan Gulhane, "Recent Advances in Electric Vehicle Battery Technologies: Materials, Management Systems, and Sustainability Perspectives," International Journal of Scientific Research in Engineering and Management, vol. 9, no. 7, pp. 1-20, Jul 2025. https://doi.org/10.55041/IJSREM51198
10. Manish Meshram, Real-Time Maintenance Risk Prediction and Propagation Analysis Using Artificial Intelligence and Reliability-Centered Maintenance Principles , 2024, International Journal of Engineering Sciences and Advanced Technology, 24(12), Page 318-329, ISSN No: 2250-3676.
11. Manish Meshram, Artificial Intelligence-Driven Dynamic Risk Modeling for Reliability-Centered Maintenance: Integrating Multi-Modal Condition Monitoring and Autonomous Decision Support , 2025, International Journal of Engineering Sciences and Advanced Technology, 25(12), Page 566-595, ISSN No: 2250-3676.
12. Akarshan Gulhane, , SUPPLY CHAIN RESILIENCE IN THE ERA OF DIGITAL TRANSFORMATION: A SYSTEMATIC LITERATURE REVIEW AND RESEARCH AGENDA. (2025). International Journal of Engineering Research and Science & Technology, 21(4), 1058-1068. https://doi.org/10.62643/ijerst.2025.v21.n4.3595
13. Akarshan Gulhane, , SOLAR-ASSISTED ELECTRIC MOBILITY: DESIGN FRAMEWORK AND PERFORMANCE ASSESSMENT OF SUSTAINABLE HYBRID VEHICLE ARCHITECTURES. (2025). International Journal of Engineering Research and Science & Technology, 21(3), 362-368. https://doi.org/10.62643/ijerst.2025.v21.n3.3594.
14. S. M. Harle, "Durability and Long-Term Performance of Fiber Reinforced Polymer (FRP) Composites: A Review," Structures, Elsevier, vol. 64, p. 105881, 2024.

15. S. M. Harle, "Advancements and Challenges in the Application of Artificial Intelligence in Civil Engineering: A Comprehensive Review," Asian Journal of Civil Engineering, vol. 25, no. 1, pp. 1061–1078, Jan. 2024.