Experimental study on FRP bonded concrete reinforcement system exposed to sulphate environment.

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Abstract - *In this study, we are experimenting with investigating the flexural strength of concrete beams bonded with Glass Fiber Reinforced Polymer (GFRP) sheets and subjected to sulphate environments. The concrete beams are cast and bonded with GFRP sheets before being immersed in a sulphate solution for a prolonged duration. The research included conducting flexural strength tests to evaluate how sulphate exposure affects the GFRP-concrete interface. The findings were compared with those from conventional concrete beams that are not reinforced with FRP and treated in both normal and sulphate environments. This analysis intends to assess how effectively FRP reinforcement can alleviate the negative impacts of sulphate exposure on concrete structures. The results offer important information regarding the durability and structural strength of FRP- FRP-reinforced concrete systems in harsh environments, supplying essential data for the design and upkeep of infrastructure exposed to conditions rich in sulphates.*

Key Words:

Fiber-reinforced polymer (FRP) Epoxy resin
Concrete Durability
Sulphate environment

1. INTRODUCTION

Reinforced concrete (RC) structures are widely used in the construction sector because of their natural strength, longevity, and affordability. Nonetheless, when subjected to harsh environments, such as those containing sulphates, RC structures can face premature deterioration. The reaction between sulphates and the concrete matrix can initiate chemical processes that weaken the material's structure, leading to a notable decrease in service life and structural efficiency. To address this issue, Fiber-Reinforced Polymer (FRP) composites have surfaced as an effective option for strengthening and rehabilitating deteriorating RC structures. FRP-bonded concrete reinforcement systems have shown significant promise in improving the structural performance of these constructions, especially in lessening the impact of environmental damage. Despite their efficiency, the long-term performance of FRP-bonded concrete reinforcement systems, particularly in environments rich in sulphate, continues to be a major concern. The main aim of this experimental research is to thoroughly examine the impact of sulphate exposure on the bonding behavior and durability of FRP-bonded concrete reinforcement systems. In particular, the research will emphasize evaluating the effects of factors such as sulphate concentration, duration of exposure, and the inherent material properties of FRP on the bond strength between FRP and concrete, along with the deterioration of the FRP-concrete interface over time. This research seeks to deliver important insights into the long-term effectiveness of FRP reinforcement systems in environments exposed to sulphates through thorough experimentation and analysis. The outcomes of this investigation will play a crucial role in creating more efficient, long-lasting, and sustainable FRP-bonded concrete reinforcement systems. In the end, these improvements will increase the durability and lifespan of infrastructure facing harsh environmental conditions, promoting greater sustainability and minimizing the necessity for expensive repairs or replacements.

1.1 Need for FRP

Concrete structures in sulphate-bearing conditions are exposed to degradation concerns, such as cracking and reduction in strength. Conventional steel reinforcement rusts,

providing added decline. In this research, Glass Fiber Reinforced Polymer (GFRP) is investigated as a substitute reinforcing material because of its corrosion resistance, light weight, high tensile strength, and low thermal/electrical conductivity. GFRP possesses several advantages:

- High corrosion resistance, increased lifespan
- Less heavy than steel, simplified handling/installation
- High tensile strength, cracking/tensile force-resistant
- Low maintenance, long service life
- Flexibility in application, including insulation

1.2 Objectives

The prime aims of the study are as follows:

- Assess the Sulphate exposure on FRP Concrete.
- To perform the test of strength and durability.
- Identify the influence of Sulphate concentration and exposure time on FRP concrete.
- Compare normal concrete with FRP concrete

2. EXPERIMENTAL PROGRAM

2.1 Raw materials

Bidirectional Glass Fiber Reinforced Polymer (GFRP) sheets are used in this research. The sheets are capable of playing two roles: reinforcing as well as strengthening structures. Here, specifically, the role is to improve structural resistance. The GFRP sheets used in this research are of 875 GSM grammage. The Ramdev Sales Corporation in Palghar, Thane, Maharashtra, India, is the source of the GFRP sheets. The epoxy resin used with the GFRP sheets is Nitobond EP, which is a concrete bonding agent. The epoxy resin is composed of two parts: Part A (Base) and Part B (Hardener), and they are combined in a ratio of 1:1.6 for bonding. Importantly, the firm supplying the epoxy resin has ISO 9001 and 14001 certifications. Ordinary concrete is mixed with a grade of M30, following a mix design proportion of 1:1.86:2.16 for cement, fine aggregate, and coarse aggregate, respectively.

The nominal value of the slump for the concrete mix is 5mm. The concrete's 28-day flexural strength and 28-day compressive strength are important parameters in evaluating its performance.

2.2 SPECIMEN FABRICATION

2.2.1 Specimens

A thorough experiment was carried out to study the impact of sulphate solution on concrete beams and the effectiveness of Glass Fiber Reinforced Polymer (GFRP) wrapping in reducing these impacts. To accomplish this, 81 beams were produced and classified into three separate groups. The first group had 27 beams, which were cast and treated under normal water at ambient temperature. This was the control group, to enable researchers to establish the flexural strength of the beams under normal conditions. The second group also consisted of 27 beams, but they were cast and treated in a sulphate solution.

This group was meant to test the effect of sulphate exposure on the flexural strength of the beams. The third and last group consisted of 27 beams, which were cast, wrapped with GFRP, and treated in a sulphate solution. This group was meant to test the effectiveness of GFRP wrapping in improving the durability and flexural strength of the beams when subjected to a sulphate solution.

2.2.2 Epoxy adhesive

There was a single epoxy adhesive was used for bonding, which was the NITOBOND EP epoxy resin concrete bonding agent. The epoxy adhesive was combined in a proportion of 1:1.6, as indicated by the manufacturer. For effective bonding, the combined epoxy adhesive was left to dry for 24-48 hours. This helped create a firm and long-lasting bond between the surfaces.

2.2.3 Concrete

Concrete beams of size 500mm x 100mm x 100mm were cast according to IS 516:1959 with M30 grade concrete and a mix ratio of 1:1.86:2.16 (cement: fine aggregate: coarse aggregate). The beams were cast, cured at room temperature for 24 hours, demoulded, and kept under standard curing conditions for 7 days. Then, the beams were exposed to a sulphate solution for 7, 21, and 28 days, and 27 specimens were cast for every group to study the influence of sulphate exposure on the concrete beams.

2.2.4 Sulphate solution

An artificial sulphate solution of 0.1 normality was prepared with sodium sulphate anhydrous (Na2SO4) purchased from Nice Chemicals Pvt. Ltd., Edappally, Kochi, Kerala.

For preparing the solution, 7.1 grams of sodium sulphate anhydrous was dissolved in distilled water to obtain the required normality of 0.1. The artificial sulphate solution was utilized to mimic the corrosive atmosphere and determine the strength of the concrete beams. To prepare

0.1 N sodium sulphate (Na_2SO_4) solution:

1. Equivalent weight = Molar mass / n-factor = 142 / 2 = 71 grams.

2. The amount required for 0.1 N solution = 0.1 equivalents/L =

7.1 grams/L

3. Take 7.1 grams of Na_2SO_4, dissolve it in distilled water, and

dilute it to 1 liter.

This provides a 0.1 N sodium sulphate solution.

3. MECHANICAL TESTS

3.1 Flexural strength test of GFRP composite

Fig -1: Flexural strength test of the normal concrete beam.

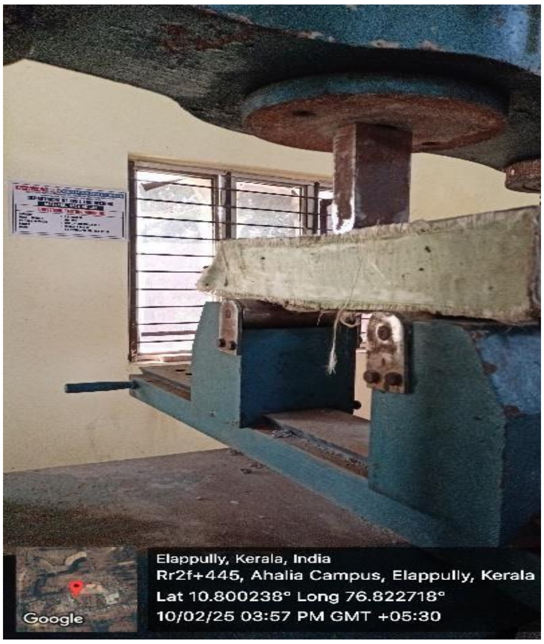


Fig -2: Flexural strength test of GFRP bonded concrete beam.

Flexural strength tests were performed on Glass Fiber fiber-reinforced polymer (GFRP) composite beams to determine their tensile strength. The tests were conducted using a Universal Testing Machine (UTM), which is a versatile machine used to test the mechanical properties of various materials. The UTM was set to apply a load at a rate specified by the Indian Standard (IS) code. This ensured that the test was conducted in a standardized manner.

The load was applied to the middle portion of the beam, which was supported at both ends. The distance between the supports, also known as the span, was 300mm. This setup allowed the beam to bend and deform under the applied load. The tensile strength of the beam was calculated using the following Formula:

$\text{Tensile Strength} = (3/2) \times (P \times L) / (b \times d^2)$ Where:

P = Load in Newtons (the maximum load applied to the beam)

L = Span in mm (the distance between the supports, which was 300mm)

b = Breadth in mm (the width of the beam)

d = Depth in mm (the height or thickness of the beam)

This formula takes into account the load applied, the span, and the dimensions of the beam to calculate its tensile strength. The tensile strength is a measure of the beam's ability to withstand tensile forces or forces that stretch or pull it apart.

3.2 Compressive strength test of GFRP Composite

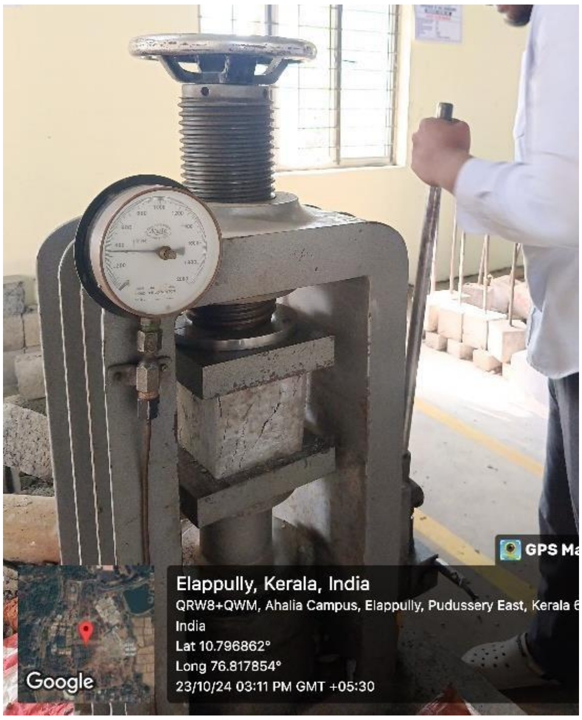


Fig. -1: Compressive strength test of the normal cube on CTM

Fig. -2: Compressive strength test of GFRP cube on CTM

Concrete specimens were compressed to determine their compressive strength. Compression tests were done with the help of a Compression Testing Machine which is in line with Indian Standard codes. Specimens included 150x150x150 mm concrete cubes cured in water, concrete cubes cured in a sulphate solution, and concrete cubes bonded to Glass Fiber Reinforced Polymer and cured in a sulphate solution. Compressive strength was calculated by the formula Compressive strength = Load / Area.

Where;

The maximum load to which the sample is subjected is measured in Newtons (N) and is termed the load.

Area refers to the cross-sectional area of the specimen in square millimeters (mm^2)

The compressive strength is given in units of N/mm^2, and it signifies the amount of force required to compress the specimen by unit area. By comparing the compressive strength of the different specimens differing effects of sulphate exposure and GFRP bonding on the concrete's compressive strength can be given. Such information is important in determining the durability and structural integrity of concrete structures that are exposed to rough conditions.

4.0 RESULT AND DISCUSSION

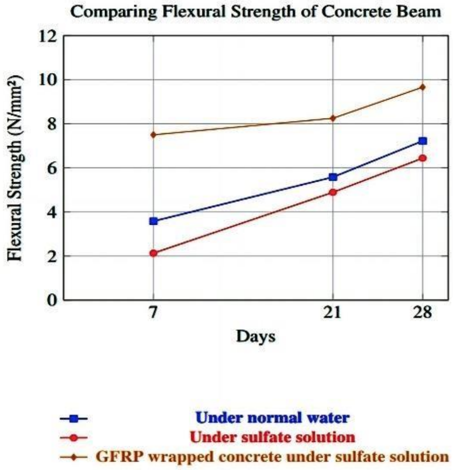
4.1 Durability of FRP composites

4.1.1 Flexural strength of GFRP composites

The illustration represents the strength of Reinforced Polymers (FRPs) after being exposed to a sulphate solution for several days. The results are then compared to those of the control specimens. A distinctive observation from the figure is that the GFRP-wrapped concrete beams show the same il strength as the normal concrete beams, which shows that the GFRP wraps in some way improve the il strength of the FRP beams. Additionally, from the graph, it can be observed that the tensile strength of GFRP-bonded concrete beams is significantly higher than that of normal concrete after exposure to a sulphate solution. More specifically, the tensile strength of GFRP-bonded concrete beams increases notably after 7, 21, and 28 days of exposure. The increase in tensile strength is because GFRP bonds with concrete, which makes the beam more resistant to tensile forces. Therefore, the increase in strength is a clear indication that bound GFRP is beneficial for concrete beams, especially in areas where they will be exposed to a sulphate solution.

Table -1: Comparison of flexural strength of concrete beams.

Days	Flexural strength of concrete beam under normal water (N/mm^2)	Flexural strength of concrete beam under sulphate solution(N/mm^2)	Flexural strength of GFRP-wrapped concrete beam under sulphate solution(N/mm^2)
7	3.58	2.13	7.5
21	5.58	4.89	8.25
28	7.22	6.44	9.66



Graph-1: Comparison of flexural strength of concrete beams.

4.1.2 Compressive strength of GFRP-bonded concrete cubes.

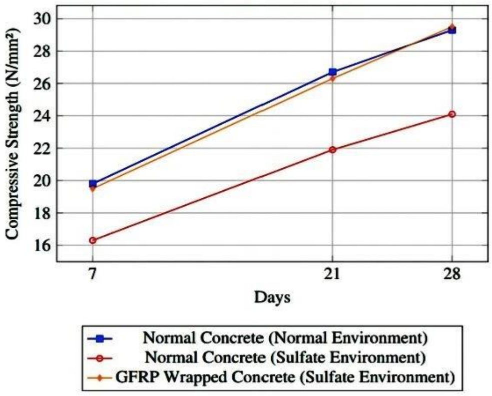
The table displays the compression strength results of Reinforced Polymer (FRP) specimens after they were immersed in a sulphate solution for different periods. It is compared with compressive strength results of unexposed control samples. In particular, the table shows that the compressive strength results of glass fiber-reinforced polymer (GFRP) -wrapped concrete cubes are equal to the compressive strength results of standard concrete cubes, which demonstrates the efficiency of GFRP wrapping.

Furthermore, the graph illustrates the compressive strength of sulfur-exposed plain concrete cubes compared to GFRP-bonded concrete cubes. There is a significant improvement in the compressive strength of GFRP-bonded concrete cubes compared to plain concrete cubes. Particularly, significant strength increases in GFRP-bonded cubes are observed after 7, 21 and 28 days.

The strength increase observed is due to the bond of GFRP-concrete, which increases the resistance of the cube to compressive stresses. This increase in strength emphasizes the benefits of using GFRP bonding in concrete cubes, especially in sulphate-rich environments.

Table -2: Comparison of compressive strength of concrete beams.

Days	Compressive strength of concrete beam under normal water (N/mm^2)	Compressive strength of concrete beam under sulphate solution(N/mm^2)	Compressive strength of GFRP-wrapped concrete beam under sulphate solution(N/mm^2)
7	19.8	16.3	19.5
21	26.7	21.9	26.3
28	29.3	24.1	29.5



Graph-2: Comparison of compressive strength of concrete beams.

5. CONCLUSIONS

In this context, the experimental study on concrete reinforcement systems with the use of FRP as bonded materials explained the effects of sulphate ions on concrete and the feasibility of GFRP wrapping to enhance durability and strength retention. The experiments showed that normal concrete exposed to a sulphate environment loses about 58% compressive strength and 69% flexural strength because of sulphate deterioration. The sulphates, which react with cement hydration products, form expansive compounds such as ettringite and gypsum, micro-cracking, dimensional instability, and structural decay of concrete, resulting in the loss of 10-15% compressive strength and up to 40% loss of flexural strength in early ages, and progressive reduction with time when compared to normal concrete kept in a non-aggressive environment.

FRP-bonded concrete, however, shows remarkable resistance to sulphate attack, retaining strength levels almost as those of normal concrete in a normal curing environment. The GFRP wrapping acts as a barrier to prevent sulphate penetration, thus limiting internal deterioration. Confinement of FRP also improves the load-carrying capacity of concrete, hence better flexural performance. On the other hand, the compressive strength of FRP-wrapped concrete is nearly unaffected by sulphate exposure, while its flexural strength shows significant improvement when compared with normal concrete, even in a non-aggressive environment.

FRP bonding may be an efficient means of improving the life economy of concrete structures against aggressiveness from sulphate. Because of reduced sulphate-induced damage, coupled with improved compressive and flexural strengths, FRP systems are an efficient and feasible means of enhancing the service life of concrete structures in aggressive conditions. This research yields a significant portion of knowledge concerning long-term behavior in FRP-bonded concrete, which could act as a precursor for adopting more robust, sustainable, and cost-effective construction practices against sulphate-affected regions.

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