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Sustainable Concrete Production via Partial Replacement of Cement with Waste GFRP Powder

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Abstract: The sustainable management of Glass Fiber Reinforced Polymer (GFRP) waste is a critical environmental concern. This experimental study explores the feasibility of incorporating waste GFRP powder as a partial cement replacement in concrete to mitigate landfill accumulation. Concrete specimens were prepared with GFRP substitutions ranging from 5% to 30% by weight of cement, and their workability, compressive, and split tensile strengths were assessed. A 5% replacement exhibited improvements in workability and compressive strength, while higher substitutions resulted in a decrease in compressive strength. However, a 20% replacement yielded an optimum balance between these properties. The split tensile strength demonstrated an increase with increasing GFRP content, indicating that the fibrous nature of GFRP contributes to enhanced mechanical characteristics, including flexural strength. While GFRP waste holds potential as a sustainable concrete constituent, further research into long-term performance is warranted.

Keywords: Concrete, GFRP waste powder, Cement replacement, Compressive strength, Split tensile strength, Flexural strength, Sustainability.

I. Introduction

1.1 General

The construction industry is a major consumer of natural resources and a significant contributor to environmental issues, primarily due to the production of cement, which accounts for approximately 8% of global carbon dioxide emissions. Simultaneously, the disposal of industrial waste, such as Glass Fiber Reinforced Polymer (GFRP), has emerged as a growing environmental challenge. GFRP, widely used in industries like wind energy, automotive, and construction, is primarily composed of thermosetting resins and silica-rich glass fibers. Its non-biodegradable nature makes disposal difficult, often leading to waste accumulation in landfills. Innovative solutions that utilize GFRP waste in construction can potentially serve as a partial replacement for cement in concrete mixes.

1.2 Background

Glass manufacturing wastes are widely explored as raw material in construction products; however, many are still in the research stage. It is estimated that 209 million tons of glass are produced annually, from which if 10% of waste is considered, approximately 20 million tons of waste are produced. This waste will take up landfill space or be sent for incineration, which are conventional methods adopted by waste disposal industries. Thus, the need to understand and recycle the waste is necessary to reduce landfill space as well as reduce water and air pollution.

One of the glass products is Glass Fiber Reinforced Polymer (GFRP), a composite which is increasingly used in the construction

industry. Global production of GFRP has risen to 8 million tons per year, while waste has risen to 1.5 million tons, and only 13% of the waste is recycled. This composite is a competitive material with great potential for use in high-value applications due to its superior properties in terms of high stiffness, low density, low water absorption, high tensile strength, and corrosion resistance. However, their waste is less studied due to inconsistent supply and unknown long-term effects.

1.3 Objectives

The main objectives of this experimental research are:

1. To determine the optimal percentage of Glass Fiber Reinforced Polymer (GFRP) waste powder as a partial cement replacement in concrete by evaluating its effect on compressive strength.
2. To assess the impact of varying percentages of GFRP waste powder (5%, 10%, 15%, 20%, 25%, and 30%) on the workability of fresh concrete.
3. To evaluate the influence of GFRP waste powder on the hardened properties of concrete, specifically by measuring compressive strength at 7, 14, and 28 days.
4. To determine the effect of GFRP waste powder on the split tensile strength of hardened concrete.
5. To investigate the contribution of GFRP waste powder to the flexural strength of hardened concrete.
6. To compare the mechanical properties (compressive, split tensile, and flexural strengths) of concrete mixes containing varying percentages of GFRP waste powder

with a control mix (0% GFRP).

7. To establish a relationship between the percentage of GFRP waste powder replacement and the resulting changes in workability, compressive, split tensile, and flexural strengths.

1.4 Scope

1. Investigate: Study the effects of replacing cement with GFRP waste powder in concrete.
2. Optimization: Determine the ideal proportion of replacement for optimal mechanical performance.
3. Durability & Workability: Analyze the workability of concrete mixes incorporating GFRP powder, along with durability characteristics such as resistance to water penetration and environmental conditions.
4. Environmental Impact: Evaluate potential reductions in cement usage, carbon emissions, and GFRP waste disposal alongside analyzing cost-effectiveness.
5. Industrial Application: Promote the large-scale utilization of GFRP powder in sustainable construction practices, encouraging circular economy principles.
6. Limitations: While focusing on short-term performance, highlight the need for further research on long-term durability, large-scale structural behavior, and compatibility.

1.5 Benefits

1. Environmental Sustainability: Reduces the consumption of cement, a major source of carbon emissions in concrete production, thereby lowering the carbon footprint of construction projects.
2. Waste Management Solution: Reuses non-biodegradable GFRP industrial waste, providing an eco-friendly alternative for managing waste from wind energy, automotive, and construction sectors.
3. Cost Efficiency: Reduces reliance on expensive cement by substituting it with low-cost industrial waste, decreasing overall material costs.
4. Improved Durability: Reduces permeability and enhances resistance to water ingress and chemical attack, increasing concrete structural lifespan.
5. Resource Conservation: Decreases dependency on natural resources used in cement manufacturing, such as limestone and clay.

II. Literature Review

2.1 General

This section presents background information on critical research issues and highlights the significance of utilizing recycled composites in structural elements.

2.2 Literature Survey

2.2.1 Jun Wang et al. (April 2022) - 'Recycling Use of GFRP Powder As Replacement of Cement': Set GFRP waste replacement at 20–40 wt% to explore innovative approaches for

improving sustainability in construction materials.

2.2.2 Y. Tao et al. (July 2023) - 'Recycling of Glass Fiber Reinforced Polymer Composite Wastes in Concrete': Recycled GFRP composite waste as a partial replacement for cement, noting potential enhancements in tensile strength, durability, and reduction of CO2 emissions.

2.2.3 Youssof El Bitouri et al. (Feb 2024) - 'The Effects of Replacing Sand with GFRP Waste on Mechanical Properties': Examined partial replacement (0–15%) of sand/cement with GFRP waste in mortars. A 3% replacement-maintained strength, while 10% replacement retained 37% flexural and 54% compressive strength.

2.2.4 FNAA Aziz et al. (June 2023) - 'Properties of Concrete with GFRP Waste as Partial Replacement of Cement': Investigated GFRP waste ground to 0.15–2.36 mm at replacement levels of 5% to 25% by weight, observing improved workability and compressive characteristics. **Hong Chuji et al. (January 2022) - 'Characteristics And Microstructures Of The GFRP Waste Powder':** Analyzed GFRP waste powder as a precursor in geopolymers, measuring early strength gain and microstructural development.

2.2.5 G. Anand et al. (November 2019) - 'Review on Partial Replacement of Cement in Concrete by Using Waste Material': Reviewed partial replacement of concrete binding ingredients using various industrial waste materials to address rising raw material costs.

2.2.6 Y. Wei et al. (September 2022) - 'Cost Benefit and Life Cycle Analysis of GFRP Waste Treatment Methods': Evaluated cost implications, environmental impacts, and Life Cycle Analysis (LCA) across landfilling, incineration, mechanical recycling, and chemical recycling.

2.2.7 Tianhao et al. (October 2023) - 'Effect of GFRP Waste on Mechanical Properties of Concrete': Utilized sieved GFRP powder and clusters (< 1.18 mm) to evaluate sequential dry and wet mixing procedures for structural feasibility.

III. Materials and Methodology

3.1 Material Specifications

1. Cement: Binding material that sets and hardens to bind aggregate together.
2. Fine Aggregate: Granular particles passing through a 4.75 mm sieve.
3. Coarse Aggregate: Crushed angular aggregates of 20 mm nominal size with a specific gravity of 2.9.
4. Water: Potable water conforming to IS:456-2000 standard specifications.
5. GFRP Waste Powder: Finely ground glass fiber reinforced polymer waste used as partial cement substitute.

3.2 Fresh Concrete Testing

Workability was evaluated using the Slump Cone Test and Compaction Factor Test.

Table 1: Slump Cone Test Results

Trial	W/C Ratio	Slump Value (mm)
Trial 1	0.4	75
Trial 2	0.5	79
Average	-	77

The Compaction Factor test determines the degree of compaction for mixes with lower workability where slump tests are less sensitive:

Compaction Factor = Weight of Partially Compacted Concrete (W1) / Weight of Fully Compacted Concrete (W2)

Table 2: Compaction Factor Test Data

S.No.	Weight W1 (kg)	Weight W2 (kg)	Compaction Factor
1	11.4	13.5	0.85
2	11.0	13.1	0.83

3.3 Specimen Preparation

Moulds of 150 x 150 x 150 mm size were cleaned and lubricated. Concrete ingredients were thoroughly mixed by hand in dry state, followed by water addition. Concrete was deposited in layers approximately 5 cm deep and manually compacted with 25 strokes per layer. Specimens were demoulded after 24 hours and submerged in curing tanks for 7, 14, and 28 days.

IV. Results and Discussion

3.4 Compressive Strength Test

Compressive strength testing was performed using a Compression Testing Machine (CTM) on 150 mm cube specimens evaluated at 7, 14, and 28 days. The compressive strength is calculated as:

$$\text{Compressive Strength (N/mm}^2\text{)} = \text{Crushing Load (N)} / \text{Cross-Sectional Area (mm}^2\text{)}$$

Table 3: Compressive Strength Results (N/mm²)

S.No.	GFRP Replacement (%)	7 Days	14 Days	28 Days
1	0%	13.41	19.30	28.50
2	5%	12.37	18.60	27.90
3	10%	12.14	18.34	27.50
4	15%	13.78	19.13	28.88
5	20% (Optimum)	16.74	21.33	32.37
6	25%	13.48	18.96	29.50
7	30%	13.24	18.56	28.90

3.5 Split Tensile Strength Test

Split tensile strength increases steadily from 7 to 14 days, attaining

peak strength at 28 days. Typically, 7-day tensile strength accounts for 60-70% of the 28-day value.

Table 4: Split Tensile Strength Results (N/mm²)

S.No.	GFRP Replacement (%)	7 Days	14 Days	28 Days
1	0%	1.15	1.31	1.78
2	5%	1.18	1.32	1.81
3	10%	1.10	1.21	1.70
4	15%	1.17	1.23	1.75
5	20% (Optimum)	1.29	1.37	1.87
6	25%	1.14	1.21	1.70

3.6 Flexural Strength Test

Flexural strength measures the ultimate bending capacity before cracking or structural collapse, crucial for beam design.

Table 5: Flexural Strength Test Results (N/mm²)

S.No.	GFRP Replacement (%)	7 Days	14 Days	28 Days
1	0%	2.01	2.98	3.70
2	5%	2.12	1.56	2.83
3	10%	1.69	2.11	2.85
4	15%	1.96	2.82	3.40
5	20% (Optimum)	3.09	2.22	4.31
6	25%	1.78	2.52	3.68
7	30%	1.21	1.53	2.03

IV. Conclusion

This experimental study demonstrated the efficacy of GFRP waste powder as a partial cement replacement in concrete. The fibrous nature of GFRP contributed to enhanced mechanical performance, particularly split tensile and flexural strengths. The study conclusively established that a 20% replacement by weight of cement achieved optimum compressive strength (32.37 N/mm² at 28 days), alongside corresponding peaks in tensile (1.87 N/mm²) and flexural (4.31 N/mm²) strengths. Thus, GFRP waste powder presents a valuable eco-friendly resource for concrete manufacturing, though future research should evaluate long-term durability metrics.

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