

# Utilizing Ground Granulated Blast Furnace Slag (GGBS) as a Partial Substitute for Cement in Concrete

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## Abstract

Concrete is a critical material in civil engineering, valued for its strength and durability. However, the increasing demand for concrete, driven by rapid urbanization, has raised environmental concerns. Cement, a primary component of concrete, is a significant source of carbon dioxide emissions during its production, contributing to climate change and environmental degradation. This study investigates a sustainable alternative to traditional cement by partially replacing it with Ground Granulated Blast Furnace Slag (GGBS), an industrial by-product with similar cementitious properties. Utilizing GGBS not only helps in reducing the environmental footprint of concrete production but also offers a cost-effective solution to construction practices. As a by-product of iron manufacturing, GGBS provides an eco-friendly means of recycling industrial waste into construction materials. The research examines the impact of replacing cement with GGBS at levels of 10%, 20%, 30%, and 40% by weight on the compressive strength of M25 grade concrete. Concrete specimens were tested at curing periods of 7, 14, 21, and 28 days to evaluate their strength characteristics. The results indicate that replacing cement with 10% GGBS achieves compressive strength comparable to traditional concrete. However, as the percentage of GGBS increases beyond 20%, there is a noticeable decline in strength, particularly at 30% and 40% replacement levels. This study demonstrates that GGBS can be effectively used as a partial cement replacement at an optimal level of 10%, offering environmental benefits without compromising concrete performance. Adopting GGBS in construction practices can contribute to reducing carbon emissions and promoting sustainable development within the construction industry. This research highlights the potential of integrating industrial by-products into concrete mixtures to achieve a balance between environmental sustainability and structural efficiency.

**Keywords:** Ground granulated blast furnace slag (GGBS), cement replacement, concrete sustainability, cost reduction

## INTRODUCTION

Concrete, a composite material, consists of cement, aggregates, and water. As the global demand for cement increases, concerns about its environmental impact grow due to the significant carbon dioxide emissions associated with cement production. In developing nations, rapid infrastructure development further exacerbates the demand for cement, which leads to environmental degradation [1–5].

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To address these challenges, the concrete industry is actively searching for alternatives that reduce both costs and the environmental impact. One such alternative is Ground Granulated Blast Furnace Slag (GGBS), a waste product from the steel industry. GGBS has cementitious properties like Portland cement and offers environmental benefits by reducing the need for cement production.

This study aims to explore the feasibility of using GGBS as a partial replacement for cement in concrete. The experiment replaces cement with GGBS at varying percentages (10%, 20%, 30%, and 40%) and evaluates the compressive strength at different curing intervals (7, 14, 21, and 28 days). The results of this investigation will provide insights into how GGBS can enhance concrete sustainability while maintaining performance [6–9].

## LITERATURE REVIEW

Several studies have focused on incorporating supplementary cementitious materials like GGBS in concrete. Research shows that replacing cement with GGBS can improve the durability of concrete, reduce its permeability, and decrease its environmental impact. GGBS can enhance the concrete's resistance to chemical attacks, making it more suitable for aggressive environments [10–13].

While GGBS has many benefits, it can also affect the early strength of concrete, especially when the replacement exceeds 40%. Studies indicate that a 20% replacement of cement with GGBS results in a minor reduction (4–6%) in compressive and flexural strength over 90 days. However, replacing more than 20% leads to a significant decrease in strength (more than 15%).

Despite these potential drawbacks, replacing cement with GGBS provides a cost-effective solution, with some studies reporting up to a 14% reduction in concrete costs when 20% of cement is substituted with GGBS. Additionally, this practice helps manage the environmental impact of steel industry waste [14–16].

## METHODOLOGY

The aim of this study is to examine how the partial replacement of cement with Ground Granulated Blast Furnace Slag (GGBS) affects the strength of concrete. The replacement percentages were set at 10%, 20%, 30%, and 40%, and the concrete mixtures were tested for compressive strength at curing ages of 7, 14, 21, and 28 days [17, 18].

For each replacement level, cubes were cast and tested in triplicate, and the average compressive strength was calculated. The water-to-cement ratio was kept constant at 0.40 across all mixes. The study aims to determine whether GGBS can be an effective substitute for cement while maintaining or improving the performance of concrete. To assess the effect of these replacements on concrete strength, a total of 36 concrete cubes will be prepared and tested. The tests will be conducted at four different curing ages: 7 days, 14 days, 21 days, and 28 days. These specific durations allow for evaluating the compressive strength development of the concrete over time [19].

To systematically achieve the project's goals, the following methodology will be followed:

### 1. Material Collection and Preparation

- The materials required for the study include cement, GGBS, fine aggregates, coarse aggregates, and water. All materials will be collected from reliable sources and checked for their properties to ensure they meet standard specifications.
- GGBS will be procured, and its physical and chemical properties will be analyzed to ensure its compatibility with concrete [20–22].

### 2. Mix Proportioning

- The mix design will be conducted according to standard guidelines, such as IS 10262 or equivalent codes, ensuring proper workability and strength of concrete.
- Four concrete mixes will be prepared, with cement being replaced by GGBS at levels of 10%, 20%, 30%, and 40%. A control mix (0% GGBS replacement) will also be prepared for comparison.

### 3. Casting of Cubes

- A total of 36 cubes will be cast using standardized cube molds (150 mm × 150 mm × 150 mm). The concrete will be properly mixed, placed into molds in three layers, and compacted using a

tamping rod or mechanical vibrator to remove air voids.

- Each set of cubes will be marked for identification and classification based on the GGBS percentage and the curing duration.

#### 4. Curing of Specimens

- After demolding, the cubes will be placed in a curing tank filled with clean water. Curing will be carried out for 7, 14, 21, and 28 days to evaluate the progressive development of compressive strength.

#### 5. Testing

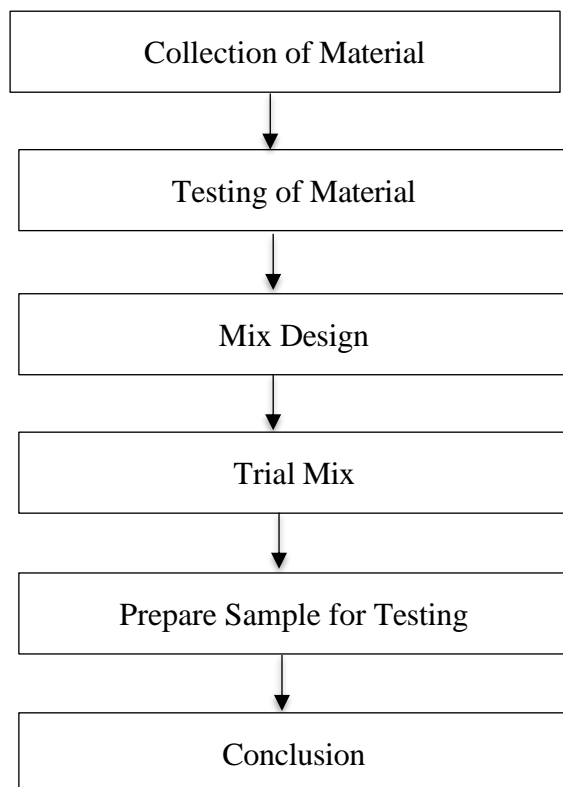
- The compressive strength of the concrete cubes will be evaluated at 7, 14, 21, and 28 days using a Compression Testing Machine (CTM).
- The results will be recorded, and the average compressive strength for each mix will be calculated.

#### 6. Analysis and Comparison

- The results of the compressive strength tests will be analyzed to study the effect of partial replacement of cement with GGBS.
- A comparative analysis will be performed between the control mix (0% GGBS) and the mixes with varying percentages of GGBS to determine the optimal replacement level that enhances strength.

The above steps are summarized in the Figure 1:

*(Insert flowchart here depicting the methodology steps mentioned above)*



**Figure 1.** Methodology details flow.

#### ADVANTAGES

Replacing a portion of cement with GGBS provides notable benefits, including improved strength, durability, cost savings, and environmental sustainability. The following points highlight the key benefits:

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### Improved Long-term Strength

The compressive strength of concrete with GGBS improves gradually over time. Studies and data indicate that after 90 days, concrete containing GGBS exhibits a continuous increase in strength. This is due to the pozzolanic properties of GGBS, which allow it to react with calcium hydroxide in the concrete to form additional calcium silicate hydrate (C-S-H), thereby increasing strength.

### Gradual Strength Development

While ordinary Portland cement (OPC) achieves its initial strength quickly, GGBS contributes to a slower but steady gain in strength. This makes GGBS-concrete particularly suitable for large-scale projects where long-term durability and strength are critical.

### Cost-Effective Alternative

- GGBS is a byproduct of the steel industry, making it more affordable than OPC. By partially replacing cement with GGBS, the overall cost of concrete production is reduced, leading to significant savings in construction projects.
- This cost reduction makes GGBS-concrete an economically viable solution, especially in large-scale infrastructure projects.

### Reduction in Carbon Footprint

- The production of cement significantly contributes to greenhouse gas emissions because of the substantial energy usage and CO<sub>2</sub> emissions that occur during the calcination process. GGBS, being an industrial byproduct, significantly reduces the environmental impact when used as a cement replacement.
- By incorporating GGBS into concrete, the carbon footprint of construction activities is reduced, making it a more sustainable and eco-friendly choice.

### Improved Durability

- Concrete with GGBS exhibits better durability properties compared to conventional concrete. It offers enhanced resistance to chemical attacks, chloride penetration, and sulfate attacks, thereby increasing the service life of structures.
- The lower heat of hydration in GGBS-based concrete helps to reduce the likelihood of thermal cracking, which is particularly advantageous in large-scale concrete projects.

### Enhanced Workability

- The fine particle size of GGBS improves the workability of concrete, allowing for easier placement, compaction, and finishing.
- This property reduces the water demand in concrete, which further contributes to higher durability and strength.

### Resource Utilization and Waste Management

By utilizing GGBS, a byproduct of the steel industry, the disposal burden of industrial waste is minimized. This promotes sustainable resource utilization and supports circular economy principles.

### Applications in Modern Construction

The use of GGBS in concrete makes it an ideal material for modern construction projects, including roads, bridges, high-rise buildings, and marine structures where strength, durability, and cost-efficiency are crucial factors.

## CONCLUSIONS

The results were analyzed to draw conclusions about the workability, strength, durability, and overall characteristics of concrete when partially replacing cement with GGBS in M25 Grade concrete. The findings are summarized as follows:

- Replacing cement with GGBS leads to higher compressive strength compared to conventional mixes. The natural hydraulic properties of GGBS contribute to its active role in the concrete mix.
- Concrete containing GGBS experiences slower strength gain when compared to conventional concrete.
- This slower strength development makes GGBS-concrete unsuitable for projects where time is critical, as it may cause delays in construction.
- At replacement levels of 10%, 20%, 30%, and 40%, the compressive strength at 7, 14, 21, and 28 days was higher than that of conventional concrete, up to 20% replacement.
- However, the strength began to decline at 30% and 40% replacement levels of cement with GGBS. As the percentage of GGBS increases, the strength of the concrete decreases.
- Based on these findings, it is recommended that the optimum replacement percentage of cement with GGBS is 10%.

The compressive strength of the concrete increased after using GGBS. The grade attains a higher strength in the M25 grade concrete.

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