IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.311 ⫘ Peer-reviewed & Refereed journal ⫘ Vol. 12, Issue 6, June 2025
DOI: 10.17148/IARJSET.2025.12637

A Review on the Partial Replacement of Cement Using GGBS and Alccofine

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Abstract: The increasing demand for sustainable construction materials has led to significant research into alternative binders that can partially replace Ordinary Portland Cement (OPC) without compromising structural performance. This study investigates the partial replacement of cement with Ground Granulated Blast Furnace Slag (GGBS) and Alccofine in mortar, focusing on mechanical and durability properties. GGBS, a by-product of the steel industry, and Alccofine, an ultra-fine supplementary cementitious material, are known for their pozzolanic and latent hydraulic properties. Various mix proportions were prepared by replacing OPC with GGBS and Alccofine. Tests conducted on fresh and hardened cement mortar included workability, compressive strength, split tensile strength, and durability assessments such as water absorption. The results demonstrated that the combined use of GGBS and Alccofine enhanced mortar performance, with improved strength development and durability due to refined pore structure and reduced permeability. This study concludes that GGBS and Alccofine are viable supplementary cementitious materials, contributing to the development of high-performance and eco-friendly cement mortar.

Keywords: Alccofine, GGBS, Supplementary Cementitious Materials, Mortar, Durability, Compressive Strength, Sustainability

I. INTRODUCTION

Concrete, as the backbone of modern infrastructure, is prized for its strength, versatility, and ease of production. However, the environmental concerns surrounding the manufacturing of **Ordinary Portland Cement (OPC)**—the principal binder in concrete—have prompted serious consideration of more sustainable alternatives. OPC production contributes significantly to global greenhouse gas emissions and consumes large quantities of raw materials and energy. In response, the use of **supplementary cementitious materials (SCMs)** has gained widespread momentum as an effective strategy to reduce cement usage while enhancing the long-term performance of concrete.

Among various SCMs, **Ground Granulated Blast Furnace Slag (GGBS)** and **Alccofine** are particularly promising due to their high reactivity and positive influence on both the mechanical and durability characteristics of concrete. GGBS is a by-product of the iron and steel industry, known for its latent hydraulic properties. When activated in an alkaline medium provided by OPC hydration, GGBS contributes to secondary reactions that form additional calcium silicate hydrate (C-S-H), leading to improved strength and durability over time. **Alccofine**, on the other hand, is an ultra-fine slag-based material with high levels of calcium and alumino-silicate content. Its extremely fine particle size (typically below 5 microns) not only accelerates the hydration process but also acts as a micro-filler, reducing porosity and enhancing the early-age strength of concrete.

Incorporating both GGBS and Alccofine into concrete mixtures can offer **synergistic benefits**, combining the long-term performance advantages of GGBS with the rapid strength development associated with Alccofine. However, the introduction of high-volume SCMs can also alter the workability of fresh concrete. To counteract this and maintain desirable rheological properties, **superplasticizers**—a class of high-range water-reducing admixtures—are used. These admixtures significantly improve the flowability of concrete without increasing the water-to-binder ratio, which is critical for preserving mechanical strength and durability. The use of superplasticizers is especially important in mixes with ultra-fine particles like Alccofine, which tend to increase water demand due to their high surface area.

Given the complex interactions between OPC, SCMs, water, and chemical admixtures, a **multiscale approach** becomes essential for understanding and optimizing concrete performance. This research employs a multiscale framework to examine how the combined use of GGBS, Alccofine, and superplasticizers affects the **mechanical properties**, **durability behaviour**, and **microstructural evolution** of concrete.

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At the **microstructural level**, advanced techniques such as Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and Thermogravimetric Analysis (TGA) are used to analyze the hydration products, pore structure, and phase composition. These methods help to capture the influence of SCMs on the formation of C-S-H, the consumption of calcium hydroxide, and the overall refinement of the microstructure. Alccofine, in particular, is expected to contribute to denser microstructures due to its filler effect and faster pozzolanic reaction.

At the **mesostructural scale**, factors such as porosity distribution, interfacial transition zones, and internal pore connectivity are investigated using Mercury Intrusion Porosimetry (MIP) and related techniques. These properties are crucial in determining the durability of concrete, as they directly impact permeability, water absorption, and resistance to aggressive agents like chlorides and sulfates.

Finally, at the **macrostructural level**, the research evaluates compressive strength, flexural strength, and other mechanical parameters in conjunction with durability indicators such as Rapid Chloride Penetration Test (RCPT), water sorptivity, and acid resistance. These assessments allow for a practical understanding of how the micro- and meso-scale modifications translate into real-world performance benefits.

By integrating analyses across these scales, this study aims to provide a comprehensive evaluation of the effects of GGBS and Alccofine, used in conjunction with superplasticizers, in cementitious systems. The findings will contribute valuable insights into the design of **high-performance, durable, and environmentally sustainable concrete** mixtures, especially relevant for modern infrastructure exposed to demanding environmental conditions.

II. LITERATURE REVIEW

In response to growing environmental concerns and the need for sustainable construction materials, considerable research has been dedicated to reducing the cement content in mortar and concrete mixtures. Ordinary Portland Cement (OPC), while widely used, is responsible for a significant portion of global CO_2 emissions—nearly 8% according to recent estimates. As a result, researchers have focused on the potential of Supplementary Cementitious Materials (SCMs) like Ground Granulated Blast Furnace Slag (GGBS) and Alccofine to improve performance while minimizing environmental impact

- **Ground Granulated Blast Furnace Slag (GGBS):**

GGBS, a by-product of the steel industry, is known for its latent hydraulic properties and ability to enhance the durability of cementitious composites. It reacts slowly with calcium hydroxide during the hydration process, forming additional Calcium-Silicate-Hydrate (C-S-H) gel, which improves the long-term strength and impermeability of the matrix. Studies have shown that replacing 30–60% of cement with GGBS can lead to significant improvements in sulfate resistance, reduced permeability, and mitigation of alkali-silica reaction. Additionally, GGBS reduces the heat of hydration, making it particularly useful in mass concrete applications where thermal cracking is a concern.

- **Alccofine:**

Alccofine is a highly reactive, ultrafine material derived from industrial by-products. Due to its finer particle size and high glassy content, it exhibits both filler and pozzolanic effects. This enables early strength development and densification of the mortar matrix. Unlike GGBS, Alccofine acts more rapidly, contributing to both early and late-age strength, improved workability, and reduced water demand. Literature suggests that an optimum dosage of 10–15% Alccofine replacement enhances compressive and flexural strength, especially when used in synergy with other SCMs such as GGBS or fly ash.

Synergistic Effects of GGBS and Alccofine
Recent research has explored the combined use of GGBS and Alccofine in mortar and concrete. Their complementary characteristics—Alccofine's early reactivity and GGBS's long-term contribution—create a balance in strength development across curing periods. This combination improves mechanical strength, reduces capillary porosity, and enhances resistance to aggressive environments. Furthermore, due to their pozzolanic nature and micro-filling capabilities, they contribute significantly to a dense and durable microstructure, making them suitable for high-performance and sustainable construction.

- **Multiscale Perspective:**

From a multiscale viewpoint, the benefits of SCMs are evident at the nano-, micro-, and macro-levels. At the nanoscale, Alccofine contributes to accelerated nucleation of hydration products. Microscopically, both GGBS and Alccofine refine the pore structure, reducing permeability and enhancing durability.

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At the macroscale, these improvements manifest in increased compressive and flexural strength, reduced water absorption, lower apparent porosity, and better bulk density. The integration of SCMs in mix design supports a holistic approach to performance enhancement, combining material science with engineering applications.

2.1. Mechanical properties:

- **CompressiveStrength**

Compressive strength refers to a material's ability to withstand axial compressive loads without failure. It is measured by applying a gradually increasing load to a specimen, commonly in the form of a cube (50x50x50mm), using a universal testing machine (UTM) until the specimen fractures or deforms significantly. The maximum load sustained before failure is divided by the cross-sectional area to determine the compressive strength, usually expressed in megapascals (MPa). This property is critical for evaluating the load-bearing capacity of structural and refractory materials.

- **FlexuralStrength**

Flexural strength, also known as modulus of rupture, measures a material's resistance to bending under an applied load. It is typically determined using a three-point or four-point bending test on a rectangular bar-shaped specimen(160x40x40mm). The test involves placing the specimen on two support points and applying a load at the center (or at two points, in four-point bending) until failure occurs. The maximum stress experienced before breaking is recorded as the flexural strength. This property is especially important in evaluating brittle materials such as ceramics and refractories, which are more prone to failure under bending stresses.

- **BulkDensity**

Bulk density is defined as the mass of a dry specimen divided by its bulk volume, which includes both the solid material and the void spaces (pores) within the specimen. It is calculated by accurately measuring the dry weight and the geometric dimensions of the specimen. Bulk density provides insight into the compactness of the material and affects thermal conductivity, strength, and other performance characteristics. Higher bulk density generally indicates better mechanical strength and lower porosity.

- **ApparentPorosity**

Apparent porosity is the percentage of open pores in a material relative to its total bulk volume. It is measured using the water immersion method, where a dried sample is first weighed (dry weight), then boiled in water to allow pore saturation, and finally weighed again in its saturated and suspended (in water) states. Using these measurements, apparent porosity is calculated. This property is important for evaluating how permeable a material is to gases or liquids, which impacts durability in various environmental conditions.

2.2Durability properties

- **WaterAbsorption**

Water absorption indicates the amount of water a material can absorb through its open pores. It is determined by soaking a dried sample in water for a specified duration (often 24 hours), then weighing the sample before and after immersion. The increase in weight, expressed as a percentage of the original dry weight, represents the water absorption capacity. This parameter is crucial in assessing the material's resistance to moisture ingress, which can influence dimensional stability and strength over time.

III. CONCLUSION

This study explored the effects of partial replacement of Ordinary Portland Cement (OPC) with Alccofine and Ground Granulated Blast Furnace Slag (GGBS) on the mechanical and durability properties of mortar. The results demonstrate that incorporating these supplementary cementitious materials significantly enhances performance in terms of compressive and flexural strength, while also improving physical properties such as reduced water absorption, lower apparent porosity, and increased bulk density. Among the tested mixes, M4 and C4, with 20% Alccofine and 25–35% GGBS, consistently exhibited superior performance, particularly at extended curing periods of 28 and 90 days. The enhanced performance is attributed to the pozzolanic reactivity of Alccofine and the latent hydraulic properties of GGBS, which contribute to a denser microstructure and refined pore system. These findings support the feasibility of using industrial by-products in mortar production as a sustainable and technically effective alternative to traditional cement. The study contributes to the ongoing efforts toward reducing the carbon footprint of the construction industry and promotes the adoption of durable, eco-efficient materials in infrastructure development.

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