Influence of addition of ground granulated blast furnace slag on various concrete properties - A Review

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Abstract - *Concrete is one of the most versatile construction materials used around the world. However, the production of concrete leads to the emission of massive amounts of carbon dioxide into the atmosphere, thus affecting the environment. One of the best alternatives to create environment-friendly construction materials is to replace cement with an industrial by-product, i.e., Ground Granulated Blast Furnace Slag (GGBS). GGBS is produced during the manufacturing of iron. This study aims to examine the usage of GGBS in concrete as a partial replacement material for cement. The literature shows that GGBS improves the properties of concrete at later ages, subject to replacement level.*

Key Words*: *Concrete, Cement, Constriction, GGBS.

1. INTRODUCTION

Concrete is the most widely used and practical material in the building sector and has helped advance civilizations over the past century. Concrete is used in vast quantities, which means that producing, transporting, and using raw materials consumes a lot of energy **[1]**. Cement is one of the main components of concrete. However, a considerable amount of greenhouse gases, primarily carbon dioxide (CO_2), are released into the atmosphere while manufacturing cement. According to reports, the production of one tonne of OPC results in the production of about one tonne of CO_2 **[2]**. Therefore, it is advised to look for an alternate substance to cement in concrete to lessen the adverse effects of utilizing the most widely used construction material.

The use of supplementary cementitious materials (SCMs) is one alternative to minimize the negative environmental impact. Some industrial byproducts such as fly ash, silica fume, and ground granulated blast furnace slag, can be used as SCMs to replace cement in concrete mixes. The present research work aims to study the influence of ground granulated blast furnace slag on concrete properties.

2. Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS) is the by-product of producing iron in a blast furnace, which heats iron ore, limestone, and coke to 1500°C **[3]**. The chemical composition of slag varies greatly depending on the composition of the raw materials used in iron manufacturing. The approximate chemical composition of GGBS reported by some authors is as shown in **Table-1 [4-6]**.

Table-1: Chemical Composition of GGBS

Oxides	Percent Content
Lime (CaO)	30 - 42
Silica (SiO_2)	35 - 40
Alumina (Al_2O_3)	10 - 14
Iron Oxide (Fe_2O_3)	8 - 10
Magnesia (MgO)	0.3 - 2.5

Generally, GGBS is a fine, glassy substance. It has a higher degree of fineness but a lower specific gravity than cement. **Table-2** lists some of its physical qualities **[4-6]**. GGBS's color can range from beige to dark to off-white depending on the moisture content, chemistry, and granulation effectiveness **[7]**.

Table-2: Physical properties of GGBS

Properties	Approximate Range
Specific Gravity	2.85 - 2.90
Fineness (m^2/kg)	370 - 470
Bulk Density (kg/m^3)	1200

2.1 Advantages of using GGBS in concrete

- Improvement in workability, pumpability and compaction characteristics for concrete placement.
- Increase in strength and durability.
- Reduction in permeability.
- High resistance to chloride penetration.
- High resistance to sulfate attack.
- Very low heat of hydration.

- More chemically stable.
- Production of GGBS involves virtually zero CO_2 emissions.

3. LITERATURE REVIEW

Oner and Akyuz [5] conducted laboratory experiments to find the optimal level of ground granulated blast furnace slag (GGBS) and its effect on concrete's compressive strength. Test concretes were made by adding GGBS to control concretes with doses of 250, 300, 350, and 400 kg/m^3 in amounts that were about equal to 0, 15, 30, 50, 70, 90, and 110% of the cement content of control concretes. The test findings demonstrated that as the amount of GGBS increased, the compressive strength of concrete mixtures containing GGBS increased. Adding GGBS did not increase the compressive strength after an optimum point, at around 55% of the total binder concentration. It could be explained by the fact that the paste contains unreacted GGBS that serves as a filler material.

Shi et al. [6] experimentally tested high performance concrete (HPC) with fly ash (FA) or ground granulated blast furnace slag (GGBS) for compressive strength and carbonation. The findings of the tests demonstrated that water-binder (w/b) ratios had a substantial impact on the impacts of FA with replacement up to 60% on the properties under investigation. Contrary to FA, however, w/b ratios have minimal effect on the influences of GGBS on HPC; similar changing trends could be seen for both of the chosen w/b ratios. Additionally, HPC with GGBS performs significantly better than FA at the same w/b ratio.

Gholampour and Ozbakkaloglu [8] experimentally investigated the properties of concrete comprising ternary binders with large volume fl ash (FA) and GGBS partially replacing cement up to 90%. A total of 15 batches of concrete were created using cement, FA, and binary and ternary binders. The density, workability, compressive strength, elastic modulus, flexural strength, splitting tensile strength, and water absorption of various mixes were determined through experimental experiments. The findings show that as the FA concentration is raised from 50% to 90%, the compressive strength of concrete containing FA decreased significantly. After 28 days, the concretes containing GGBS at up to 90% cement replacement had compressive strengths that were comparable to those of standard concrete. Additionally, the findings demonstrate that GGBS mixes had a somewhat greater 28-day elastic modulus than the standard concrete mixes. It was found that an increase in the FA and GGBS content caused the water absorption of concrete to increase and moderately decrease, respectively significantly. All ternary mixtures that substitute cement to a maximum of 90% do so with less water absorption than traditional concrete mixes. These incredibly encouraging results implied that the technology employed in this work might offer a desirable route for the high-volume application of FA and GGBS in concrete while also having the potential to lessen significantly its environmental effect.

Karri et al. [10] examined the properties of M20 and M40 grade concrete with a cement replacement of 30%, 40%, or 50% with ground granulated blast furnace slag (GGBS). The compressive strength, split tensile strength, and flexural strength tests on the concrete specimens were performed. The concrete attained maximum compressive strength for both M20 and M40 grade of concrete at 40% replacement of cement by GGBS. The split tensile strength and flexural strength values were also maximum at 40% replacement level of cement by GGBS.

Arivalagan [11] evaluated the strength and strength efficiency factors of hardened concrete for M35 grade concrete at various ages by partially substituting cement with varying percentages of ground granulated blast furnace slag (GGBS). The findings of the study suggested that while GGBS initially had lower strength than regular Portland cement due to its smaller grain size, it gradually became stronger over time. It was found that GGBS based concretes showed an increase in strength for a 20% cement replacement at 28 days. Strengthening was brought on by the GGBS filling action. With the addition of GGBS up to 40% replacement level for M35 grade concrete, the workability of the concrete was reported to be normal. The experimental findings demonstrated that GGBS could be utilized as a cement substitute, lowering cement consumption and construction costs.

Awasare and Nagendra [12] investigated the strength properties of M20 grade concrete with GGBS substitution at levels of 30%, 40%, and 50% and compared it to standard concrete. The experimental results showed that the maximum compressive strength achieved was 29.78 MPa at 30% GGBS replacement, and those achieved for 20%, 40%, and 50% of concrete were respectively 27.11 MPa, 26.37 MPa, and 22.22 MPa as compared to 25.61MPa of strength of plain cement concrete for 28 days.

Mangamma et al. [13] investigated the partial replacement of ground granulated blast furnace slag (GGBS) in production of concrete. By substituting GGBS for 10%, 20%, 30%, 40%, and 50% of the binding material for M20 and M30, the compressive strength of the concrete mix was tested. It was concluded that the partial replacement of GGBS increased the strengths at 10%,20%, and 30% while decreased the strength at 40% and 50% replacement levels.

Yeau and Kim [14] conducted experimental studies to replace 0%, 25%, 40%, and 55% of the cement with GGBS up to 90 days of curing. By 28 days, the performance of the concrete containing 25%, 40%, and 55% of GGBS was comparable to that of the control concrete, but by 56 days, they had exceeded it. When 40% of the GGBS was replaced after 90 days, the compressive strength was at its highest. Prior to seven days, all GGBS combinations, up to a 55% cement substitution, had lower compressive strengths than the control mixture. . These results show that the higher GGBS concentration at an early age prevented the development of compressive strength due to latent hydraulicity responses by GGBS.

Bilim et al. [15] employed GGBS in concrete mixtures at percentages of 20%, 40%, 60%, and 80%, with three different water-to-cement (w/c) ratios of 0.30, 0.40, and 0.50, up to one year's worth of curing times. Due to the high GGBS replacement percentage, the strength influence of GGBS on concrete at 7 days of age was negligible. However, the compressive strength of GGBS concrete was greater than ordinary Portland cement concrete for 28 days, three months, and up to 1 year for 20% and 40% substitution with a w/c ratio of 0.3. For three months and one year of cure age, the optimal replacement was reported to be 60%. The initial drop was due to the pozzolan's substantially slower rate of hydration. On the other hand, GGBS undergoes hydration processes with calcium hydroxide, $Ca(OH)_2$, in the presence of water over time.

4. Conclusions

Cement is the primary component of concrete, one of the most frequently used construction materials. Concrete is in greater demand as a construction material. However, the usage and production of cement pollute the environment. Due to this, interest in using industrial by-products such as GGBS to reduce the usage of Portland cement grows. The use of GGBS improves the workability and compaction characteristics of concrete. The strength characteristics i.e., compressive, split tensile, and flexural strength, get enhanced but at later ages of curing. The concrete containing GGBS shows better resistance to chloride and sulfate attack. Overall, it can be concluded from the present research that GGBS can be effectively used to improve the various properties of concrete.

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