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Experimental Investigation with Ground Granulated Blast Furnace Slag as a Cementitious Material

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ABSTRACT: This study investigates the effects of partial replacement of Ground Granulated Blast Furnace Slag (GGBFS) with cement in Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) mixes for M20 and M25 grade concrete. GGBFS, a by-product of the iron-making industry with pozzolanic properties, is known to enhance concrete durability and strength. Mix proportions adhered to Indian standards, with varying GGBFS replacement levels (0%, 15%, 20%, and 25%) explored for optimal performance in both OPC and PPC mixes. Fresh and hardened concrete properties, such as workability, compressive strength, and durability, were comprehensively evaluated to assess the viability and effectiveness of GGBFS as a cement replacement.

KEYWORDS: Ground Granulated Blast Furnace Slag (GGBFS), Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), workability, compressive strength, durability, Indian standards.

I. INTRODUCTION

Concrete is one of the most widely used construction materials globally, valued for its versatility, durability, and affordability. The key ingredient in concrete is cement, which binds the other components together to form a solid, cohesive material. However, the production of cement is associated with significant environmental impacts, including the emission of greenhouse gases such as carbon dioxide (CO2) and the consumption of natural resources. In recent years, there has been a growing emphasis on sustainable construction practices, driving research into alternative materials that can reduce the environmental footprint of concrete production.

One such alternative is Ground Granulated Blast Furnace Slag (GGBFS), a by-product of the iron-making industry. GGBFS is obtained by quenching molten iron slag (a by-product of iron production) with water to form a glassy, granular material. GGBFS is known for its pozzolanic properties, which enable it to react with calcium hydroxide (a by-product of cement hydration) to form additional cementitious compounds. This pozzolanic reaction not only improves the durability and strength of concrete but also reduces the overall amount of cement required in concrete mixes. The use of GGBFS as a partial replacement for cement in concrete mixes has been studied extensively worldwide. Research has shown that GGBFS can improve the workability, compressive strength, and durability of concrete, while also reducing the heat of hydration and the risk of thermal cracking. Additionally, the use of GGBFS in concrete production can reduce the carbon footprint of concrete, as GGBFS production requires less energy and emits fewer greenhouse gases compared to cement production.

In India, the construction industry is a major consumer of cement, and the environmental impact of cement production is a growing concern. The Indian government has set ambitious targets to reduce the carbon intensity of the economy, which includes the construction sector. As such, there is a need to explore sustainable alternatives to

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traditional cement in concrete production. This study aims to contribute to this effort by investigating the effects of partial replacement of GGBFS with cement in both Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) mixes for M20 and M25 grade concrete.

Fig. 1 CO2 Emission

Objective of the Study

1. To determine the optimal dosage range of GGBFS for partial replacement of cement in M20 and M25 grade concrete mixes, based on concrete mix studies.
2. To assess the performance of concrete mixes containing GGBFS and compare them with controlled concrete mixes without GGBFS.
3. To evaluate the influence of partial replacement of cement with GGBFS on the economy of construction.
4. To design and proportion concrete mixes for M20 and M25 grade concrete according to the guidelines provided in IS: 10262:2009.
5. To determine the compressive strength of concrete mixes with varying percentages (0%, 15%, 20%, and 25%) of GGBFS replacement and compare them with the controlled concrete mix.

II. LITERATURE REVIEW

A. Dubey et al. (2012) Investigated the Ordinary Portland cement (OPC) is one of the main ingredients used for the production of concrete. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is inevitable either to search for another material or partially replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Concrete property can be maintained with advanced mineral admixtures such as blast furnace slag powder as partial replacement of cement 5% to 30%. Compressive strength of blast furnace slag concrete with different dosage of slag was studied as a partial replacement of cement. From the experimental investigations, it has been observed that, the optimum replacement of Ground Granulated Blast Furnace Slag Powder to cement without changing much the compressive strength is 15%.

Sonali K. Gadpalliwar et. al (2014) The workability of concrete had been found to be decrease with increase of quarry sand in concrete. The workability of concrete had been found to be decrease with increase of RHA but the GGBS increases the workability of concrete. Compressive strength increases with increase of percent of quarry sand up to certain limit. Concrete acquires maximum increase in compressive strength at 60% quarry sand replaced by natural sand for M40 grade of concrete.

Sreejith Haridas et. al (2017) Studied that the GGBS increases the workability of concrete, as compared to control mix. The optimum replacement percentage of cement with GGBS is found to be 40%. Compressive strength of mix with optimum percentage of GGBS shows 3.53% higher strength than control mix in 28 days. Use of M60 mix in which cement is replaced with 40% GGBS can reduce the consumption, thus reducing production of cement and emission of carbon dioxide to atmosphere.

Vedprakash et. al (2018) The study investigated the use of silica fume (SF) as a partial replacement for Plain Portland Cement (PPC) in concrete. Various mixes with 0%, 5%, 10%, 15%, and 20% SF replacements were tested for compressive strength at 7 and 28 days. The results showed that up to 10% SF replacement, the concrete met or exceeded target strengths. However, higher SF replacements led to reduced strengths, likely due to impurities in the SF. Overall, the study suggests that SF can be effectively used as a supplementary material in concrete mixes, but careful consideration of the replacement percentage is crucial to maintain desired strength properties.

Shelke et. al (2020) The study investigates the partial replacement of cement with GGBS and fine aggregate with crusher dust in concrete. It finds that the workability of concrete improves with increasing GGBS but decreases with increasing crusher dust. The compressive and flexural strengths increase with up to 30% GGBS and decrease thereafter, with 10% crusher dust being optimal for strength. Drying shrinkage increases with both additives. Overall, using GGBS and crusher dust reduces production costs, aids in industrial by-product disposal, and improves environmental sustainability. The study concludes that GGBS and crusher dust can be effectively used in concrete, with 30% GGBS and 10% crusher dust being the optimal proportions for best performance, but further research is needed on long-term durability under different conditions.

Vaibhav et. al (2022) The study investigates the use of granulated blast furnace slag (GBFS) as a fine aggregate in concrete and determines that the optimum content for replacement of natural river sand is 30%. At this level, concrete shows increased compressive, tensile, and flexural strengths compared to the control specimen. However, beyond 30% replacement, the strength begins to decrease. The paper concludes that GBFS can be effectively used as a partial replacement for natural river sand in concrete, offering environmental and economic benefits while maintaining strength and durability. Further research is recommended to study the long-term performance of concrete with GBFS under various environmental conditions.

Sunil Bhagwan et. al (2018) The paper presents an experimental study on the use of ground granulated blast furnace slag (GGBS) as a partial replacement of cement in concrete. It finds that the optimum percentage of GGBS for maximum strength and durability is 40% for both ordinary Portland cement (OPC) and Portland pozzolana cement (PPC). While GGBS concrete shows slower strength gain than plain cement concrete (PCC) at early ages, it demonstrates higher strength at later ages (after 28 days). Additionally, GGBS concrete exhibits better resistance to acid attack compared to PCC, with lower weight and strength loss.

Ajinkya Balpande et. al (2023) The paper presents an experimental study on using ground granulated blast furnace slag (GGBS) and demolished aggregate (DA) in concrete. It concludes that replacing a portion of cement with GGBS reduces natural resource consumption and greenhouse gas emissions, while enhancing concrete durability and strength. Similarly, replacing natural aggregate with DA decreases construction and demolition waste, preserving the environment without compromising concrete workability or strength. The optimal replacement ratio of GGBS and DA is found to be 30%, which yields the highest compressive strength and lowest water absorption among the tested mixes..

T.Kajaharan et. al 2019 The study demonstrates that replacing cement with ground granulated blast furnace slag (GGBS) in concrete can improve durability without significantly compromising early strength. An optimum replacement level of 20% GGBS balances strength and durability, with concrete expected to gain strength over time due to ongoing hydration. GGBS is deemed beneficial for enhancing concrete performance, reducing environmental impact, and can be a viable alternative in harsh environments. Further research is suggested to explore its effects on other concrete properties like shrinkage, cracking, and fire resistance, highlighting its potential for green and durable concrete solutions.

Tran Minh et. al (2022) The study found that adding ground granulated blast furnace slag (GGBS) to recycled aggregate concrete (RAC) improves workability and reduces crack formation after exposure to elevated temperatures. GGBS-RAC showed lower mass loss and higher residual mechanical strength compared to normal concrete and RAC without GGBS at all tested temperatures. SEM analysis revealed a denser and more stable microstructure in GGBS-RAC, indicating enhanced hydration and pozzolanic reaction. The study concludes that GGBS can enhance the performance and sustainability of RAC in fire-prone environments, offering potential benefits for civil engineering construction materials.

Literature Gap

A gap exists in research regarding alternative secondary cementitious materials in concrete production, particularly in self-compacting concrete (SCC) mixes. While studies have explored concrete's mechanical properties, such as compressive and split tensile strength, with crushed sand as fine aggregate, there's limited investigation into various secondary cementitious materials. Further research is needed to assess these materials' feasibility in SCC mixes and their impact on concrete performance, aiding in optimizing mix designs for sustainability and construction applications.

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III. METHODOLOGY

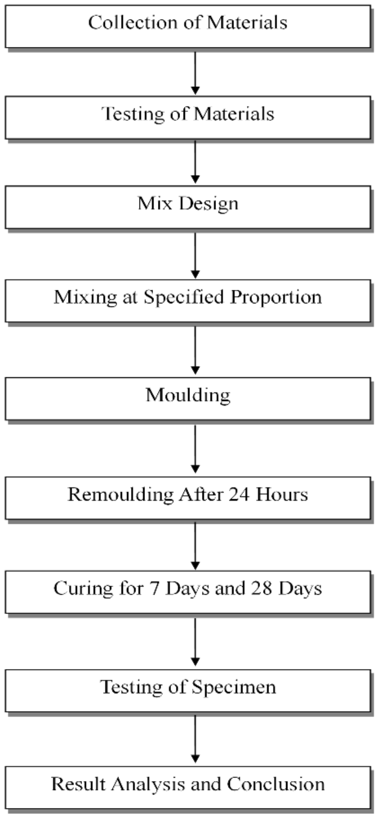

Fig.1 Schematic Flow of methodology

Step 1- Collection of Materials:

This initial step involves gathering all the necessary materials to create the concrete mix and specimens for testing. These would typically include:
Ground Granulated Blast Furnace Slag
Fine Aggregate
Cement
Coarse Aggregate
Water

Step 2 - Mix Design:

In this phase, the researcher determines the specific quantities of each ingredient to be used in the concrete mix. This will influence the final properties of the concrete, including its strength. The researcher will likely experiment with different mix ratios to find the optimal combination for incorporating waste plastic bottles while achieving the desired strength.

Step 3- Mixing at Specified Proportion:

Once the mix design is finalized, the concrete ingredients are combined according to the predetermined proportions. This might involve using a mechanical mixer to ensure a homogenous mixture.

Step 4 -Molding:

The prepared concrete mix is then poured into molds. These molds will determine the shape of the concrete specimens that will be subsequently tested for strength.

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Step 5 - Remolding After 24 Hours:

After 24 hours, the concrete specimens are removed from the initial molds.

Step 7 -Curing for 7 Days and 28 Days:

Curing is a vital process that allows the concrete to gain strength. During curing, the molded concrete specimens are placed in a controlled environment with specific temperature and humidity conditions. The flowchart specifies curing periods of 7 days and 28 days.

Step 8 - Testing of Specimens:

After the curing period, the concrete specimens undergo testing to determine their mechanical properties, such as compressive strength and flexural strength. This data is used to assess the effectiveness of the mix design in incorporating waste plastic bottles for strength optimization.

Step 9 - Result Analysis & Conclusion:

Finally, we analyzes the data collected from the tests performed on the concrete specimens. This analysis helps determine the optimal mix design for using waste plastic bottles to achieve the desired strength in fiber-reinforced concrete.

IV. EXPERIMENTAL WORK

A. MATERIAL USED

1. Ground Granulated Blast Furnace Slag (GGBFS)

Ground Granulated Blast Furnace Slag (GGBFS) is a byproduct of steel manufacturing, produced by quenching molten iron slag with water or steam. It's finely ground and exhibits cementitious properties when activated with alkalis or lime in concrete. GGBFS is commonly used to replace a portion of Portland cement in concrete mixes, enhancing workability, durability, and strength while reducing environmental impact. In experiments, GGBFS is studied for its effects on concrete properties like compressive strength and durability, determining optimal replacement percentages for desired outcomes. Its functions include increasing cementitious content, reducing heat of hydration, improving workability, reducing permeability, offering environmental benefits, enhancing sulfate resistance, and boosting long-term strength.

Fig.2 Ground Granulated Blast Furnace Slag

In our project, Ground Granulated Blast Furnace Slag (GGBFS) is being used as a partial replacement for cement in concrete mixes. This means that a portion of the cement in the concrete mix is being replaced with GGBFS. The percentage of replacement can vary depending on the desired properties of the concrete.

2. Cement

Cement plays a pivotal role in construction, acting as the primary binding agent in concrete and mortar production. To ensure its reliability and performance, various tests are conducted according to established standards such as IS 4031 in India. These tests assess key properties like particle size (fineness), setting times, consistency, and color, providing insights into cement's suitability for different applications.
Ground Granulated Blast Furnace Slag (GGBFS) is emerging as a promising cementitious material, often used in conjunction with Ordinary Portland Cement (OPC) or Portland Pozzolana Cement (PPC). These materials, conforming to specific grade standards like IS-269 and IS 1489, are utilized for casting concrete samples in experimental investigations.
OPC 43 Grade of Cement (confirming IS-269) and PPC 43 Grade of Cement (confirming IS 1489- Part2) is used for casting of Normal Concrete samples and GGBFS Concrete samples

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Fig.3 Cement

3. Coarse Aggregate

Coarse Aggregates are inert materials mixed with a binding agent to make concrete. In pervious concrete, they determine porosity, strength, and permeability. Common types include crushed stone, gravel, expanded shale/clay, and porous ceramic aggregates. Qualities of aggregates include chemical inertness, hardness, toughness, strength, purity, and workability. Tests include specific gravity, water absorption, moisture content, sieve analysis, impact value, and abrasion value.
20 mm to 40mm aggregate was used in this project for both Normal and GGBFS Concrete. Coarse aggregate sieve analysis was determined according to ASTM C 136.

Fig.4 Coarse Aggregate

5. Fine Aggregate

Fine Aggregate is a granular material made of rock and mineral particles, typically silica or calcium carbonate. It's finer than gravel and coarser than silt, forming a significant part of soils with over 85% sand-sized particles. Testing methods for fine aggregate (sand) include sieve analysis to determine particle size distribution, specific gravity measurement using a pycnometer, water absorption assessment by soaking samples, and moisture content determination through drying and weighing.

Fig.6 Fine Aggregate

6. Water

Water plays a crucial role in concrete manufacturing by chemically reacting with cement and facilitating the workability of the mixture. Its quality impacts concrete strength, with excessive mixing water often leading to poor-quality concrete. Water used in experiments adheres to IS : 456-2000 standards, ensuring cleanliness and freedom from harmful substances like oils, acids, alkalis, salts, sugars, and organic materials. Potable water is typically suitable for concrete mixing, with a pH value not less than 6 recommended.

Fig.7 Water

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B. MIX DESIGN

Mix design is defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. Generally we are using M20 and M25 grade of concrete for better result Mix design of M20 and M25 grade concrete as per Indian standard codebook: Normally we used w/c ratio falls under 0.4 to 0.6 as per IS Code 10262 for nominal mix M25 (1:1:2) and M20 (1:1.5:3) The Mix design is done as per ***IS 10262:2009***

Mixing of GGBFS

We had prepared M20 and M25 grade concrete by the partial replacement of Cement with Ground Granulated Blast Furnace Slag The prepared grade concrete of M20 and M25 mix had replaced cement with GGBFS by 15%, 20% and 25% to check the compressive strength of the concrete.

Mix design is a process of selecting suitable ingredients for concrete and determining their proportions which would produce economical concrete. The proportioning of the ingredients of concrete is an important segment of concrete technology as it ensures quality and economy. For obtaining the concrete of desired performance characteristics, the component materials should be selected likewise. Then by considering these components, appropriate mix design is prepared.

Water-cement ratio 0.47 was used in this research. The details of mixes are shown below

Casting of Specimen

Specimens for compressive strength and split tensile strength were cast using mix proportions from a specified table. Materials like cement, Ground Granulated Blast Furnace Slag, fine aggregates, and coarse aggregates were dry mixed for uniformity. 50% of the total water was added initially and mixed for 3-4 minutes, followed by addition of 40% of water. Remaining 10% of water was sprinkled and mixed thoroughly. Oiled molds were filled with the mix and placed on a vibrating table for proper mixing. Specimens were then cured in open air for 24 hours after casting.

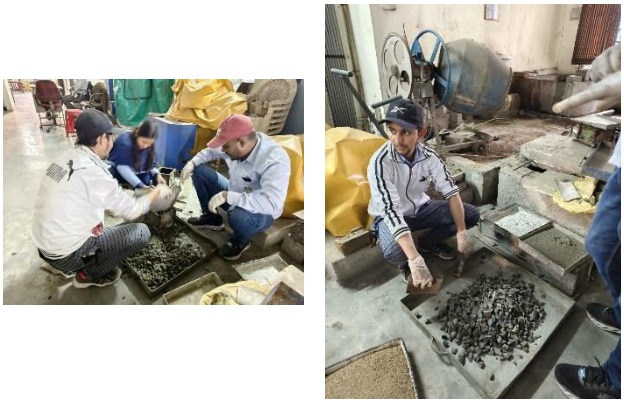

Fig. 8 Casting of Specimen

Curing

In investigating the use of Ground Granulated Blast Furnace Slag (GGBFS) in concrete, curing is crucial for achieving required strength and durability. Moisture retention is key for proper hydration, with methods like wet burlap or curing compounds used. Temperature control ensures optimal strength development. Curing duration may vary, and quality control involves monitoring conditions and concrete samples. Testing post-curing assesses properties like compressive strength to evaluate GGBFS effectiveness as a cementitious material. Overall, curing is tailored to optimize concrete performance and assess GGBFS benefits.

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Fig. 9 Curing of Concrete

Testing of Specimen

After casting, specimens undergo curing for a predetermined time. When testing compressive strength of GGBFS concrete cubes, specimens are demolded after 24 hours and placed in a curing tank. Upon testing, specimens are removed from the tank and allowed to surface dry for 10-15 minutes. Testing is conducted using a Compression Testing Machine (CTM) at a load rate of 5 kN/sec as per IS: 516-1959 standards. The maximum load sustained just before failure is recorded to evaluate compressive strength.

Fig. 10 Testing of Cubes

V. RESULTS

1. OPC Concrete Cube Results (7 Days)

Cubes	M20	M25
Normal	17.83	21.61
15 % Replacement	18.52	22.36
20 % Replacement	17.7	21.33
25% Replacement	16.78	20.62

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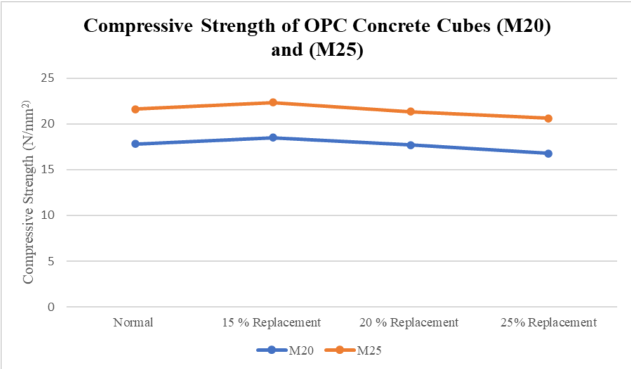
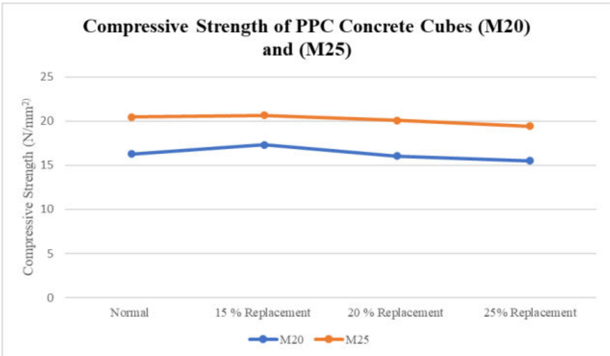


2. PPC Concrete Cube Result (7 Days)

Cubes	M20	M25
Normal	16.29	20.48
15 % Replacement	17.33	20.66
20 % Replacement	16.04	20.07
25% Replacement	15.5	19.42



VI. CONCLUSION

The experimental exploration of Ground Granulated Blast Furnace Slag (GGBFS) as a supplementary material in concrete has yielded insightful outcomes. Within the studied range, replacing cement with GGBFS up to 15% has shown a marginal increase in compressive strength, attributed to the pozzolanic reaction fostering densification of the concrete matrix. However, beyond this threshold, at 20% and 25% replacement levels, the improvement in strength diminishes, signaling an optimal balance between benefits and dilution effects. Additionally, GGBFS contributes significantly to the durability of concrete by mitigating permeability and enhancing resistance against chemical aggressions such as sulfate and alkali-silica reactions, thereby potentially prolonging the lifespan of concrete structures, especially in adverse environmental conditions. Furthermore, embracing GGBFS as a substitute for conventional cement aligns with sustainable construction practices, as it reduces the environmental footprint by curtailing the energy-intensive and carbon dioxide-emitting processes associated with traditional cement production. This integration of GGBFS underscores a promising avenue for enhancing both the performance and sustainability of concrete infrastructure.

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26. IS 456: Code of Practice for Plain and Reinforced Concrete
27. IS 516: Methods of Tests for Strength of Concrete
28. IS 456: Code of Practice for Plain and Reinforced Concrete

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