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# SUSTAINABLE CONCRETE WITH SALINE WATER AND GROUND GRANULATED BLAST FURNACE SLAG (GGBS)

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**ABSTRACT**

To conserve fresh water and make concrete production more sustainable, a study was carried out by using seawater and brine as the source of water and Ground Granulated Blast-furnace Slag (GGBS) as partial replacement of cement. Concrete samples having five different percentages of cement and GGBS contents were separately prepared with normal tap water, brine, and seawater. The seawater was obtained from Kovalam in Kerala. Compression and Rapid Chloride Permeability Test (RCPT) tests were conducted and their performance was analyzed and compared. The results obtained show that brine and seawater have higher compressive strength when compared to the potable water sample. The reduction in carbon footprint by the use of GGBS as part replacement of cement was also found in the study.

**Keywords** - Sustainable concrete, Ground Granulated Blast-furnace Slag, Sea water, Brine, Rapid Chloride Permeability test

## 1. INTRODUCTION

The construction industry is a significant contributor to the global economy, with the demand for construction materials steadily increasing as the world population grows. However, producing these materials significantly impacts the environment, particularly in terms of greenhouse gas emissions and the depletion of natural resources. One of the primary materials used in construction is cement, a crucial concrete component. Unfortunately, the production of cement is energy-intensive and generates significant amounts of carbon dioxide. Moreover, the use of freshwater in concrete mixing further exacerbates the strain on already scarce freshwater resources. As the world's population continues to grow, the demand for freshwater is increasing, leading to water scarcity in many regions. To address these issues, the construction industry is exploring innovative solutions to reduce environmental impact. One of these solutions is the use of Ground Granulated Blast Furnace Slag (GGBS) to partially replace cement in concrete. GGBS is a byproduct of the iron and steel-making process and is an effective substitute for cement in concrete.[6] Seawater and brine have been identified as potential substitutes for freshwater, as they are readily available and can help to conserve freshwater resources. By replacing freshwater with seawater or brine in different proportions, the construction industry can help reduce the strain on freshwater resources while maintaining concrete's desired consistency and strength.

## 2. BACKGROUND OF THE STUDY

India has many coastal areas where seawater is abundant, but its high saline concentration makes it unsuitable for use in the construction industry. [4] The construction industry in India relies heavily on freshwater, which is depleting rapidly due to overuse and other factors. The utilization of seawater in the construction industry can significantly reduce the burden on freshwater resources, but the high saline content needs to be addressed. [8] Compared to cement, Ground Granulated Blast Furnace Slag has a lower carbon footprint, as it requires less energy to produce and emits fewer greenhouse gases during the manufacturing process. [1]

## 3. OBJECTIVES OF THE STUDY

Objectives of the present study are:

- To replace potable water with different solutions(reject brine, seawater) in manufacture of concrete and evaluate its performance
- To determine feasibility of concrete by replacing cement with GGBS to make it more sustainable.

## 4. MATERIALS USED

Following materials were used for present study:

1. Portland Pozzolana Cement (PPC)

PPC is a type of blended cement. It consists of 15-35% pozzolanic material, 4% gypsum, and clinker.

2. Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a fine powder obtained as a by product from iron industry. This powder is extremely cementitious and contains high levels of calcium silicate hydrates (CSH) that enhance its strength and durability. GGBS will usually replace between 30% and 70% of cement in the concrete, although that figure can go up to as high as 85%. It usually replaces cement.

3. Fine Aggregates (sand < 425µ)

Manufactured sand (M-Sand) is a substitute for river sand for concrete construction. Manufactured sand is produced from hard granite stone by crushing. The size of manufactured sand (M-Sand) is less than 4.75mm.

4. Coarse Aggregates (20 mm)

These are obtained by crushing rocks, having angular shapes, and are retained on a 20 mm sieve while 60-70% of the aggregates pass through the 20mm sieve.

5. Water samples

Potable water from tap, synthetic brine and sea water were the three samples used for the study.

*Sea water*

The sea water is collected from Kovalam Beach, Trivandrum

*Brine*

Brine is a high-concentration solution of salt (typically sodium chloride or calcium chloride) in water. In diverse contexts, brine may refer to the salt solutions ranging from about 3.5% (a typical concentration of seawater, on the lower end of that of solutions used for brining foods) up to about 26% (a typical saturated solution, depending on temperature). In this study, 4% (40 g/l) concentration of salt in water was used.

6. Superplasticizer

Superplasticizers (SPs), also known as high-range water reducers, are additives used in making high-strength concrete. Plasticizers are chemical compounds that enable the production of concrete with approximately 15% less water content. Superplasticizers allow a reduction in water content by 30% or more.

## 5. METHODOLOGY

The water samples and cementitious materials were tested to obtain their characteristic properties. Different concrete mixes were prepared with varying proportions and appropriate replacements. The fresh concrete mixes were tested for workability, followed by casting and curing. The compressive test was carried out for both 14 and 28 days. The results obtained were analyzed and compared. The optimum mixes obtained were used to conduct the Rapid Chloride Permeability Test (RCPT) test and results were obtained. An Environmental and Economic analysis was also done and conclusions were drawn.

### 5.1 Test on materials

The Mix Design for the M30 mix was done in accordance with IS10262.

The properties of cement and GGBS were determined according to IS 1489(Part 1):1991 and IS 12089:1987. The testing of cement and GGBS showed a Specific gravity of 2.2 and 2.7, Fineness greater than 300m$^2$/kg and 350m$^2$/kg respectively.

The properties of fine aggregate (sand < 425µ) and coarse aggregate (20mm) were determined. It resulted in Specific gravity of 2.58 conforming to Zone II as per 1S 383-2016 for fine aggregate and Specific gravity 2.82 conforming to 1S 383-2016 for coarse aggregate.

The characteristics of the different samples (potable water, brine, sea water) were analyzed in accordance with IS456 2000 standards. The testing of potable water, brine and sea water resulted in a pH of 6.73, 8.31, 7.87, Total dissolved solids of 99 mg/l, 767 mg/l, 699 mg/l, Hardness 72 mg/l, 560 mg/l, 536 mg/l, Alkalinity 64 mg/l, 36 mg/l, 70 mg/l respectively. The chloride content is 187 mg/l in potable water whereas it is greater than 6000 mg/l for brine and sea water.

5.2 Concrete mix preparation

15 different mixes were prepared by varying the proportions of cement and GGBS as well as replacement of water with brine and sea water. A part of cement was replaced using different percentages of GGBS (0, 10, 20, 30 and 40). 5 mixes were prepared using water, 5 mixes using brine and 5 mixes were prepared using seawater.

5.3 Test on fresh concrete

Test on fresh concrete was done with reference to IS 1199 – 1959. After each concrete mix was prepared, slump cone test was conducted to determine its workability.

5.4 Test on hardened concrete

After curing period, Compressive strength test were done on the samples in accordance with IS 516 - 1959.The proportion of cement and GGBS that gave the maximum strength while using the different types of water were taken as the optimum mixes.

5.5 Rapid Chloride Permeability Test (RCPT)

The Rapid Chloride Permeability Test is a non-destructive test used to measure the permeability of concrete to chloride ions.From the results of the compressive test, the optimum mixes for each type of water sample were found.These optimum mixes were used to conduct the rapid chloride permeability test in accordance with ASTM C 1202.

5.6 Environmental and Economic Impact Analysis

The environmental impact of producing a sustainable concrete with GGBS and brine was calculated based on the amount of $CO_2$ reduction potential, both as a result of reduction in cement and desalinated water use.

## 6. RESULTS AND DISCUSSIONS

6.1 Workability

The slump value obtained for all the mixes where less than 25mm, which shows that the mixes are of low workability.

6.2 Compressive strength test

The different concrete samples were tested for compressive strength after curing period of 14 days and 28 days, and the values were obtained.

Table 1: Compressive strength at 14 days

| MIX | PPC (%) | GGBS (%) | WATER $Nmm^{-2}$ | BRINE $Nmm^{-2}$ | SEAWATER $Nmm^{-2}$ |
|---|---|---|---|---|---|
| 1 | 100 | 0 | 33.11 | 33.8 | 34 |
| 2 | 90 | 10 | 33.7 | 33.5 | 34.2 |
| 3 | 80 | 20 | 31.78 | 34.2 | 32.2 |
| 4 | 70 | 30 | 29.5 | 33 | 34.8 |
| 5 | 60 | 40 | 29 | 29.3 | 32 |

Table 1 gives the compressive strength obtained at 14 days. The optimum value for water is obtained when 10% of cement is replaced with GGBS. For Brine, the optimum value is obtained when 20% of cement is replaced by GGBS and for sea water, when 30% of cement is replaced by GGBS.

Table 2: Compressive strength at 28 days

| MIX | PPC (%) | GGBS (%) | WATER ($Nmm^{-2}$) | BRINE ($Nmm^{-2}$) | SEAWATER ($Nmm^{-2}$) |
|---|---|---|---|---|---|
| 1 | 100 | 0 | 37.33 | 37.9 | 38.11 |
| 2 | 90 | 10 | 39 | 39.11 | 36.89 |
| 3 | 80 | 20 | 36.44 | 34.3 | 38.67 |
| 4 | 70 | 30 | 34.82 | 34 | 32 |
| 5 | 60 | 40 | 31.1 | 29.5 | 26.67 |

Table 2 gives the compressive strength obtained at 28 days. The optimum value for water and brine is obtained when 10% of cement is replaced with GGBS. For sea water, the optimum mix is obtained when 30% of cement is replaced by GGBS.

6.3 Rapid Chloride Permeability test (RCPT)

The incorporation of GGBS produces a less porous concrete that reduces the flow of coulomb ions through the concrete specimens. The impact of GGBS on the permeability of concrete was even more enhanced when brine was used instead of tap water to prepare the concrete specimens. [8] The concrete samples prepared from the optimal mixes were tested and the results were in the range of 1000 to 2000 coulombs, which signifies low permeability, with seawater having the lowest permeability when compared to brine and potable water. It needs further investigation and the work is in progress.

6.4 Environmental and Economic Impacts of proposed concrete mix

*6.4.1Environmental Impacts of GGBS*

The use of ground granulated blast furnace slag (GGBS) in concrete production has several environmental benefits, including reduced carbon footprint, energy consumption, waste generation, and improved durability. [7] GGBS is a sustainable alternative to traditional cement and can significantly reduce the environmental impact of the building industry. By replacing cement with GGBS, around 40 kg of CO2 emissions can be prevented. In this study, substituting cement with GGBS reduced the amount of cement used in the production of concrete. The results showed that substituting 30% of PC by GGBS is expected to reduce carbon dioxide emissions by 106 kg CO2 equivalent per one cubic meter.

*6.4.2 Environmental Impacts of Brine*

Brine being a highly concentrated solution of salt and water, can have negative impacts on the natural environment and human health when released without proper management or treatment. It can contaminate water sources, degrade soil, damage ecosystems, pose a risk to human health, and contribute to greenhouse gas emissions. [2] Thus, proper management and treatment are necessary to minimize its environmental impact. [3]

*6.4.3 Economical Impacts*

An economic analysis was done by calculating the amount of money saved by replacing cement with GGBS. Considering the optimal mixes, while there is 10% (for water), 10% (for brine), and 20% (for sea water) of Portland Cement being replaced by GGBS, a total of Rs. 4 is reduced in the production of the sample cubes.

## 7. CONCLUSIONS

The replacement of traditional cement with GGBS in concrete lowers the carbon footprint equivalent since GGBS production releases far less carbon dioxide than PC. There is a potential for a 40 kg reduction of $CO_2$ equivalent for three cubes (150x150x150 mm). Moreover, it is observed that GGBS-based concretes achieved an increase in compressive strength of around 2.92 % (synthesized brine) and 6.11% (seawater). This increase is likely to be due to the filler effect and higher production of Calcium Silicate Hydrate (CSH) gel that is responsible for compressive strength. By using synthesized brine and seawater instead of potable water in concrete, valuable natural water can be conserved and thus produce more sustainable and environmental friendly concrete.

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