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Impact of Marine Water on Mechanistic Characteristics of Slag Cement in Concrete

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ABSTRACT: The present experimental investigation focuses on consequences of marine environment on tensile strength & crush strength of concrete using GGBFS. The concrete grade chosen in the present research is M50 with least w/c ratio which makes the concrete impermeable hence emanating the voids in the concrete to urge microscopic by preventing expansion by freeze-thaw effect. From East Coastal beach, Chennai, India the marine water was collected and used for curing test specimens to facilitate marine conditions. From ECR beach, the marine water was collected and stored. Additionally, in this research work slag cement (GGBFS) is added partially by replacing cement at 40% in the concrete specimen. The scientific aim of this research is to clearly show the end outcomes on comparison of the control and the tested specimen under contrasting environmental conditions (Standard and Oceanic Environment) additionally with distinct ages of concrete (Seven, Fourteen and Twenty-eight days). It demonstrated the trend of strength cutback because of direct contact with the marine solution in control specimen. Considering, the utilization slag cement in concrete i.e. Tested specimen, even though depletion in durability is noticed in fourteen days, but for the concrete cured for twenty eight days the value has incremented to 53.7 N/mm^2 from 51.7 N/mm^2 under marine & standard environmental condition, discretely.

KEYWORDS: GGBFS, durability, standard environment, marine environment.

I. INTRODUCTION

In construction sector, concrete has become the pre-eminent and universally used material having several strength and weakness on its own when it comes to contact with standard water and sea water, respectively. Marine concrete structures tend to use greater volume of concrete in comparison with the structure in lithospheric surface, rather by self-healing matrix, it is possible to scale back the required cover for the structural concrete members for safeguarding the steel reinforcement. At certain situation when they are subjected to different conditions especially under marine environment, suitable protective measures must be taken into consideration. Exposure of concrete under marine condition may lead to freezing-thawing effect, wetting and reinforcement corrosion.

Concrete which is made up of three basic constituents such as water, cement, and aggregates (rock, sand, or gravel). The usage of cement causes varied environmental pollutions and thus resulting in the declination of raw materials. In recent years, researchers have studied the usage of GGBS and have shown to minimize the CO_2 emission during the manufacturing process of cement by acting as an environment-friendly material by reducing the greenhouse gas emission. The application of slag cement in concrete as an alternative for Ordinary Portland cement provides a greener and a healthier environment. However, its partial replacement with cement is approachable, usage of GGBS provides an enriching result in terms of durability thus leading to a sustainable development. The rich chemical properties in slag cement makes it insignificantly affected by the sulphate and the chloride attacks. Therefore, it minimizes the risk of reinforcement corrosion.

The study conducted by Sunil Bhagwan Yamgar and Takkalaki [1] investigated the durability of GGBFS cement in concrete under different weather conditions. They examined the changes in strength development of the concrete when they were cured in summertime and wintertime conditions. They concluded that the robustness of OPC cement in concrete to be higher than the early age GGBS concrete. Hence, they came into a conclusion that the concrete with (100%) GGBS could withstand extreme loads by possessing w/c as 0.35. Both M20 and M40 grade concrete achieved an improved compressive strength when there was a replacement of OPC (40%) by GGBFS.

Khaja Khutubuddin S et al. [2] proposed the ideal proportion of GGBFS in concrete. Their study engrossed on the variation of percentile level of replacement of cement by GGBFS under contrasting volume of mixing water. Hence, they summarized in their research that durability characteristics of tested specimen was enhanced when concrete was made with greater amount of slag.

The research focused on replacement of OPC by slag cement (GGBFS) in concrete. It has significantly shown that quantity of GGBFS, w/c and period of curing affect the strength attributes of concrete significantly. They concluded that increment of water binder ratio improvises the compressive strength because of uniform hydration. This rate of increment in compressive stress ranges from 10% - 20% within 120 days [3].

Brooks J.J et al. [4] evaluated the purpose of microsilica, GGBFS and flue ash on crush strength, flexural strength, nature of porosity, plasticity, and other mechanical properties. They proved that workability of concrete increases by adding slag cement as a limited substitution for cement. Their research revealed that within 28 and 90 days of curing period, the concrete using GGBS attained utmost strength.

Osborne et al. [5] experimentally inspected the durability attributes of GGBFS in concrete. The study was to find the quantity of slag cement in concrete which was primarily based on experiments carried out at the site building as well as in laboratory. They concluded that under normal or slight exposure condition concrete structures with 50% GGBS are appropriate.

Santosh Kumar Karri et al. [6] investigating the strength characteristics of two distinct grades of concrete with limited substitution of OPC accompanied by slag cement in concrete (GGBFS). Their research concluded that concrete with GGBS provides greater compressive strength. They experimentally proved that concrete using slag cement at 40 % replacement provides a greater compressive strength for the above respective grade designations of concrete. Also, their research revealed that with increase of slag cement in concrete provides greater flexural strength

The objectives mentioned below are formulated to implement the experimental investigation for research purposes:

- To study and analyse the mechanical properties of limited replacement of OPC by slag cement (GGBFS) in concrete and Control specimen when liable to standard and saline solution environment.
- To compare and investigate the disparity of M_{50} grade of two contrasting concrete specimens corresponding to the age of curing (seven, fourteen and twenty-eight days**)** exhibited to standard and marine environment.

Hence, this paper aim to investigate and analyse the effectiveness of potable water and marine water on mechanistic characteristics of concrete (compressive stress and tensile strength) when there is replacement of OPC partially (40%) by GGBFS and compare their properties with control specimen.

II. Methodology

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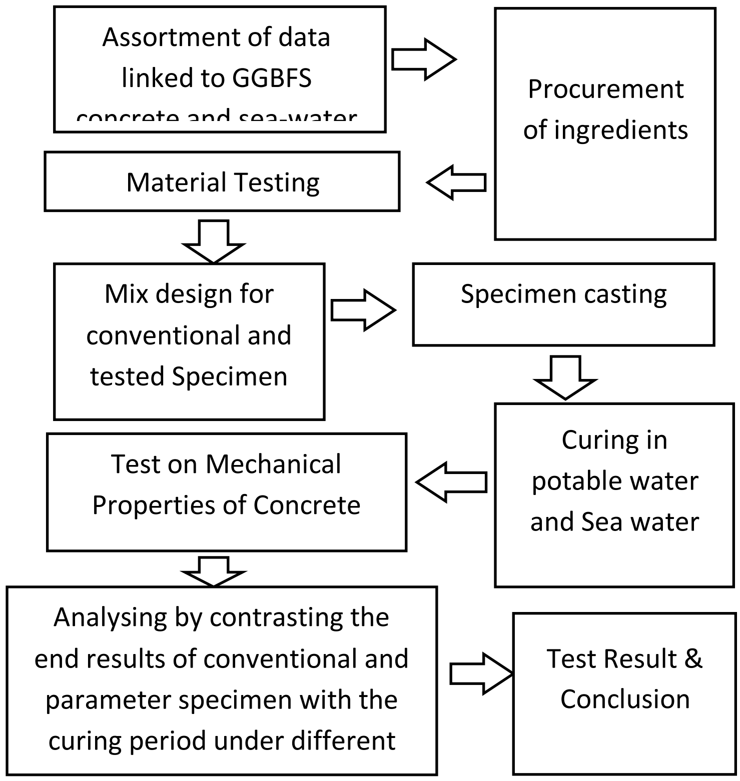

Figure 1. Methodological Chart

III. List of Material Used

The material used in this research work are OPC53, GGBFS, sand, gravel, potable water, sea water and admixture.

3.1. Cement

In this research (Ultratech) Ordinary Portland cement 53 is employed. By referring IS code specifications and guidelines, properties of cement are tested

Table 1. OPC_{53} Characteristics

Characteristics of Ordinary Portland cement 53	
Test Particulars	**Results**
Sieve analysis-Fineness	2.2%
Relative density	3.15
Time Consistency	4 minutes
Setting Time	
Initial. time	63 mins
Final. time	242 mins

3.2. Blast Furnace slag cement (GGBFS)

During the mass production of pig iron, a valuable compound named slag cement or GGBS (GGBFS) is obtained in blast furnace. The compound is a mixture of various minerals such as silica, alumina, and the oxides in OPC but in varying proportion. Experiments conducted by researchers showed that the usage of GGBFS has increased the strength properties of concrete drastically when its used along with OPC and other pozzolanic materials. From the below Table 2 the physical properties of GGBFS cement is provided.

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Table 2. GGBFS

Characteristics of GGBFS	
Test Particulars	**Results**
Surface Area (SSA)	460-620 (m^2/Kg)
Relative Density	2.85
Volumetric Density	1055 -1325 Kg/m^3
Appearance	White powdered form

3.3. Sand

M-sand is used in the present study is produced from crushing of hard granite stone. Due to booming demand of sand and tremendous environmental deficiency of river sand, Manufactured sand has become an alternative for river sand. Various test conducted on fine aggregate and their result is provided in Table 3.

Table 3. Fine Aggregates

Characteristics of Sand	
Particulars	**Outcomes**
Quality of sand	Manufactured sand
Relative density	2.70
F.M value	2.5
Size of Particle and shape	4.85 mm exceeding and lower, Round

3.4. Gravel

One of the vital ingredients used in the concrete mix is Coarse aggregate. It is obtained from the demolished concrete structures that are embedded in the mix which are in smaller portion by breaking the larger stones. The size of Coarse aggregate usually spans within 9.5 mm and 38 mm in diameter. Characteristics of gravel are outlined in Table 4.

Table 4. Characteristics of Gravel

Characteristics of Gravel	
Test Particulars	**Outcome**
Dimension of aggregate	Min:10 mm
	Max: 20 mm
Relative density	2.75
Absorption of water	6%

3.5. Standard Water

For mixing of concrete specimens only potable water was used which has no chemical substances and suspended particles. Moderately, this potable water is utilized for purpose of curing some of the specimens and other specimens were cured in marine water. It must be noted that the water utilized in the mix and for curing must have direct effects in the strength of mortar and the cement.

3.6. Marine Water

Concrete structures undergo reinforcement corrosion when they are cured in sea water and may lead to reduction in strength up to a certain limit as reported by researchers who carried out experiments in marine concrete structures[7]-[9]. From the coastal beach in Chennai, sea water was collected and stored for curing. By analyzing this water, the following salt concentration was determined and given in percentage of weight of salt:NaCl-80%, $MgCl_2$ - 9.72%, $MgSO_4$ - 4.93%, $CaSO_4$-1.21%, K_2SO_4-1.3 %, KBr - 1.9%, $MgBr_2$ -0.94%.

3.7. Admixture

A high-performance super plasticizing admixture named CONPLAST SP430 is utilized in this experimental study. And its distinctive characteristics are stated in Table 5.

Table 5. characteristics of Conplast sp430

Features	
Color	Brownish Liquid
Relative density	1.230 @ 28°C
Air Entrained	1.2% Excess unoccupied void

IV. Experimental Investigation

Tensile strength of Concrete cylinder and compressive stress on concrete cubes was studied and analyzed under the effects of Oceanic environment, of two varying mixes(Conventional -M_{50} OPC_{53}& Tested- M_{50} with 40% replacement of OPC53 with GGBFS) for which they are casted with standard water and half of them immersed in potable water and sea water. The specimens are casted based on Indian Standard recommendation method of design mix by adding the admixture within the specimen. By inferring the manual IS 10262:2019 the design for the mix was computed.

With the help of the trowel, concrete was carefully placed beneath and along the sides of the mould. Gradually when concrete is getting filled in the mould every one third of their height, it must be given compaction 30 times repeatedly with the air of steel rod. After 24 hours the specimens were demolded and half of them were cured in fresh water and the other in the sea water. They were cured in both the standard and marine environment for 7, 14, 28 days, independently.

V. Design Mix Proportion

As per the Indian standard method IS 10262:2019 the design mix proportioning was enumerated. Two mix designs were calculated as follows:

- Conventional – M_{50} OPC_{53} (Control)
- Parameter – M_{50} with 40% replacement of OPC_{53} with GGBFS (slag cement)

The proportion for the mix design of 1 m^3 of (control specimen) conventional concrete is summarized in Table 6

Table 6. Mix Proportion for Conventional Concrete

Cement	**Fine Aggregate**	**Coarse Aggregate**	**Water**
424 Kg/m^3	672 Kg/m^3	1161 Kg/m^3	168 Kg/m^3
1	1.47	2.54	0.36

The proportion for the mix design of 1 m^3 of (tested specimen) parameter specimen with replacement of OPC partially by GGBS at 40% are presented in Table 7

Table 7. Partial Replacement with Slag Cement (40% GGBFS)

Cement	**GGBS**	**Fine Aggregate**	**Coarse Aggregate**	**Water**
274Kg/m^3	182Kg/m^3	666Kg/m^3	1151Kg/m^3	168Kg/m^3
1	0.66	2.43	4.2	0.618

5.1. Preparation of Specimen

Molds that are to be utilized are must be carefully applied with thin quantity of oil such as grease to make it lubricant between surfaces and within the interiors. It must be ensured there must be no getaway of water and oil during the filling. Fresh concrete was mixed manually. The main intention of this mix is to obtain a consistent mixture that shows uniformity in terms of appearance and firmness. The fresh concrete is poured in the molds and

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with the aid of tamping rod, specimen must be tamped cautiously to evade the rise of void arising in the specimen. Molds must confine the fresh concrete without outflow. Molds are than demolded after twenty-four hours. The specimens are than cured in their respective environmental conditions (seven, fourteen and twenty-eight days).

Figure 2. Manual Blending of Ingredients

Figure 3. Cubical Molds

Figure 4. Manual Mixing for Tested Specimen

VI. Result and Analysis

6.1. Compressive Strength

Generally, referred as capability of a material to withstand the optimal load of applied compressive force. Mathematically, it is given by load at which specimen fails divided by area of specimen.

Compressive Stress = $\frac{BreakingLoad}{CrossSectionalArea}$ in N/mm^2 (1)

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Figure 5. Compressive testing machine and Specimen

Table 8. Average Compressive Strength

S.no	Concrete Mix	Environmental Conditions	Average Compressive Strength (N/mm^2) Age of Concrete		
			07 Days	14 Days	28 Days
1	M_{50} OPC_{53}(Control)	Standard Environment	33.183	44.22	51.33
		Marine Environment	36.22	40.44	50.86
2	M_{50} OPC_{53} + 40% replacement of OPC with GGBFS (Parameter)	Standard Environment	35.33	44.58	51.7
		Marine Environment	38.21	43.33	53.7

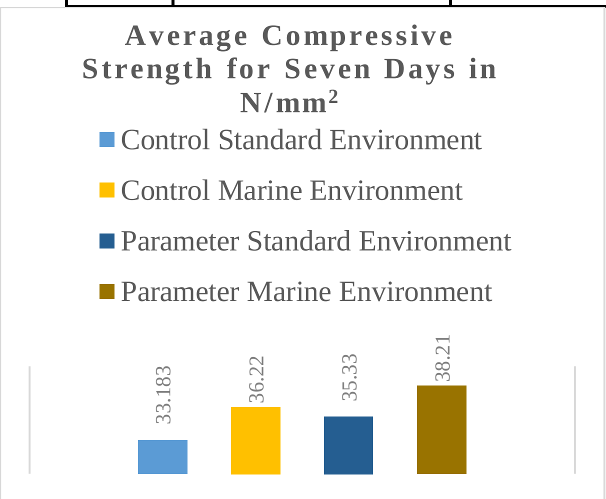

Figure 6. Seven days Compressive strength

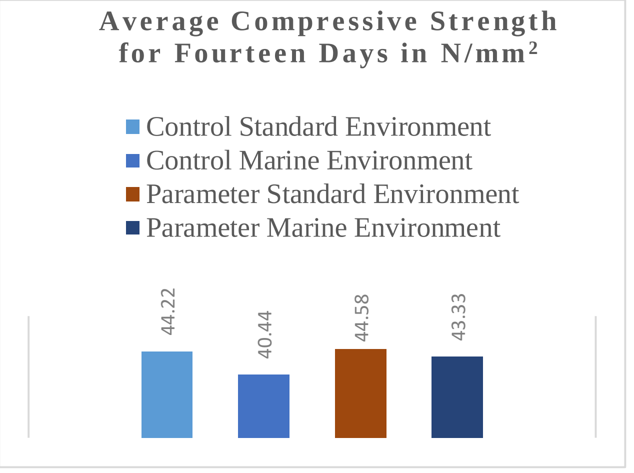

Figure 7. Fourteen days Compressive strength

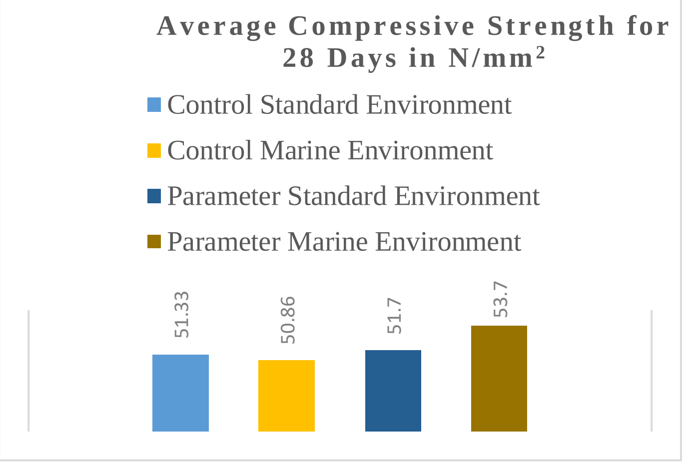

Figure 8. Twenty-eight days Compressive strength

6.2. Tensile Strength Test

Generally, it is referred as development of tensile stresses during the application of compressive forces due to which the specimen cracks. This test is characterized as a property of concrete that relates to its tensile strength. Furthermore, the concrete structures are extremely vulnerable in tension cause of its hardness. The expression given below is applied to deduce the tensile strength of tested specimen:

$\mathbf{F} = \frac{2P}{\pi LD}$ in N/mm^2(2)

P = Loading intensity at which the specimen fails

D = Dia of tested specimen (150 mm)

L = Span of the tested specimen (300 mm)

Figure 9. Specimen under tensile load failure

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Concrete Mix	**Environmental Conditions**	**Average Split Tensile Strength (N/mm^2)**		
		Age of Concrete		
		07 Days	**14 Days**	**28 Days**
M_{50} OPC $_{53}$ (Control)	Standard Environment	3.88	4.35	5.73
	Marine Environment	3.18	4.21	5.54
M_{50} OPC $_{53}$ + 40% replacement of OPC with GGBFS (Parameter)	Standard Environment	4.03	4.45	5.82
	Marine Environment	3.81	4.28	5.87

Table 9. Average Tensile Strength

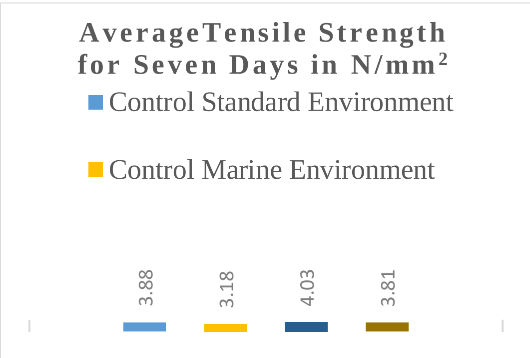

Figure 10. Seven days Split tensile Strength

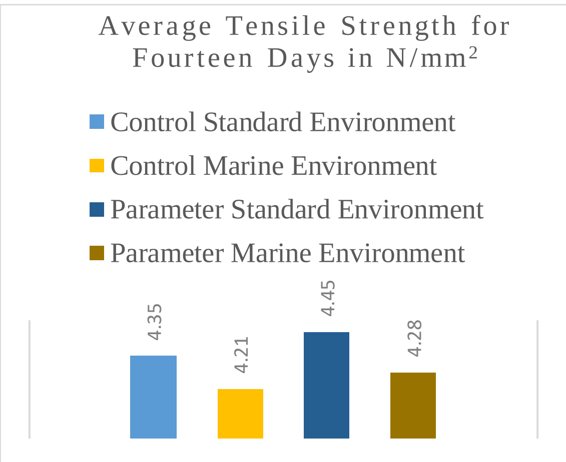

Figure 11. Fourteen days Split tensile Strength

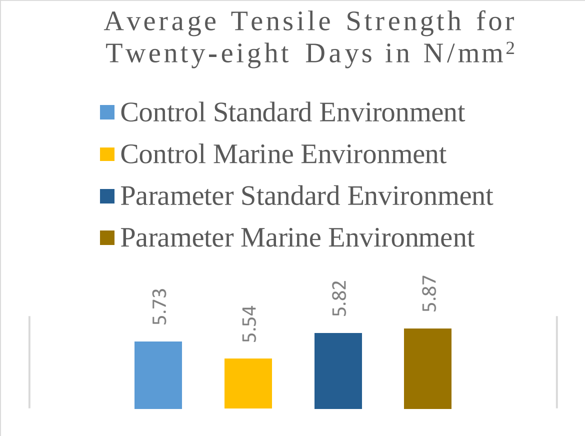

Figure 12. Twenty-eight days Split tensile strength

VII. Conclusion

This present study provided a series of experimental solutions in compressive and tensile strength of concrete (grade of concrete M-50) when it was exposed with marine water. Several researchers have conducted the study on strength characteristics of GGBS concrete [10]-[12]. The study identified the modification in the strength characteristics when concrete is exposed to marine condition. From the experimental investigation, the following points are summarized as below:

7.1.1 Compressive Strength

The succeeding points are noted and recorded below by summarizing from Table 8:

- Both the control specimen and the Tested specimen (GGBS) compressive strength has increased gradually for (7, 14, 28 days) curing under the conditions of standard water and saline water (Marine) Environment.
- By comparing crushing strength characteristics, it is inferred that the strength of the control specimen has reduced from 51.33 N/mm^2 under Standard environment to 50.86 N/mm^2 under Marine environment (28 days curing). Also, the same progression is noticed in 14 days curing of control and the parameter specimen under standard and sea-water environment.
- It exhibited the same influence of strength depletion in conventional concrete on account of action of saline solution.
- Although, in GGBFS concrete (Parameter), though strength depletion is noticed in fourteen days, but for twenty-eight days curing the tally has surged to 53.7 N/mm^2 from 51.7 N/mm^2 in accordance with marine and standard environment, discretely.

7.2.2 Split Tensile Strength

The succeeding points are noted and recorded below by summarizing from Table 9:

- Both the conventional and the parameter specimen (GGBS) tensile strength has increased gradually for (7 ,14, 28 days) curing under the conditions of standard water and saline water (Marine) Environment.
- By comparing the tensile strength characteristics, it is inferred that value of tensile strength of control specimen has reduced from 5.73 N/mm^2 under standard environment to 5.54 N/mm^2 under marine environment (28 days curing) Also, the same progression is noticed in 14 days curing of specimen under standard and marine environment.
- Although, in GGBFS in concrete (parameter), though Tensile strength deduction is noticed in fourteen days, but for twenty-eight days curing the value has surged to 5.87 N/mm^2 from 5.82 N/mm^2 under saline and standard environment, discretely.

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1. Scope of the Study

Additionally, the current investigation conveyed the enhanced strength prospects of GGBFS concrete which makes certain the suitability of GGBFS especially for the marine exposed structures. It is also encouraged to analyze

i. The microstructural positioning of GGBFS concrete for establishing a better strength characteristic.

Modification of design mix proportion to evaluate the most highly suitable % substitution of cement by GGBFS.

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