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Effect of Partial Replacement of Ground Granulated Blast Furnace Slag for Cement in Conventional Concrete Exposed to Marine Environment: A Review

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Abstract: At present, the usage of concrete is increasing day by day. In future days cement may find its scarcity due to over usage. After water, cement is the second most consumed product in the world. This scarcity may affect the construction industry. The rapid production of cement may create several environmental issues also, for which solution is to be found out. In the production process of cement, CO_2 emission takes place. One ton of CO_2 gets emitted for one ton of OPC manufacture. And cement production requires the availability of lime which will be soon in the list of limited resource available. Hence it is necessary to find a replacement to cement in concrete as a substitute to it.. Ground Granulated Blast Furnace Slag (GGBS) is been continuously used as a replacement material for cement. But a very little knowledge about GGBS concrete behaviour in marine environment is available. Nowadays due to a revolutionary improvement in marine structure and due to which the present study holds importance.

I. INTRODUCTION

In order to find the alternative material, different alternatives should be checked for their properties in concrete production and the behaviour of concrete when these materials are used in it. One of the alternatives which can be used is Ground Granulated Blast Furnace Slag (GGBS). GGBS is a by-product in the steel manufacturing industry and it can be used as an alternative material to OPC due to its inherent binding properties. In this paper a detailed review of literature is carried out in order to study the feasibility of GGBS with the cement in concrete. This is a review paper where the aspects of strength and durability of GGBS concrete is studied in marine environment.

II. PHYSICAL AND CHEMICAL COMPOSITIONS OF PORTLAND CEMENT AND GROUND GRANULATED BLAST FURNACE SLAG (GGBS).

By reviewing a number of papers on composition of GGBS and Portland cement the property comparison of GGBS and Portland cement is achieved and it's as per the table

Table Icomparison Of Properties Of Ggbs And Opc

Components	GGBS	Cement
CaO	39	62
SiO_2	32	22
Al_2O_3	12	8
Fe_2O_3	1	3
Insoluble residue	0.4	0.6
Relative density	2.7	3.25
Bulk density, kg/m ^{3}	1100	1300
Colour	Off-white	Grey

By comparing the composition of both the materials, calcium oxide content is more in cement when compared to GGBS and other components like Aluminium oxide and Fe_2O_3 is more in GGBS when compared to Cement. Bulk density and relative density of GGBS is less when compared to cement. By going through the properties and composition the partial replacement can be seen feasible.

III. BACKGROUND OF GROUND GRANULATED BLAST FURNACE SLAG USAGE IN CONCRETE AS A REPLACEMENT TO CEMENT

GGBS was discovered in Germany by Emil Langen in the year 1862. Concrete containing GGBS was used in almost all the countries due to its acceptable property and many countries suggested its usage in its construction specifications. In the year 1880 GGBS was first used with Portland cement and it was extensively used in England and in the UK and it was also included in the British Standard in around 1920.

IV. MANUFACTURING OF GGBS AND ITS MICRO-STRUCTURE

GGBS has silicates and alumina silicates along with all the by-products of iron manufacture through blast furnace. Granulation and pelletization are the two methods with which GGBS can be extracted from blast furnace process. In granulation technique, molten slag is forced over a weir into high pressure water jets which rapidly cools the slag as granules of 5 mm (0.197 in.) diameter; however, in pelletization technique, molten slag is poured into cold water rotating drum. The materials produced from these two techniques can be used as raw material for glass structured GGBS.

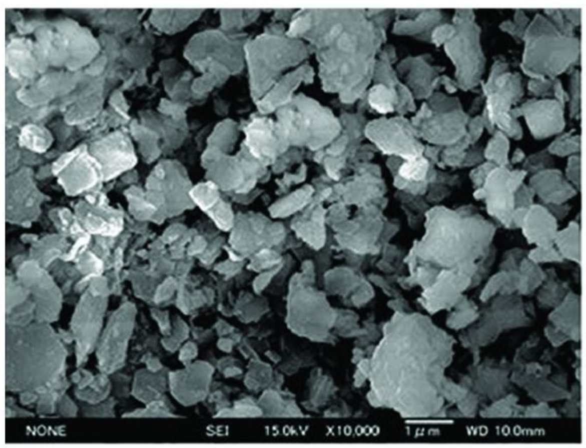

Figure 1: Microstructure of Ground Granulated Blast furnace slag(Courtesy: Image published in Effects of Different Mineral Admixtures on the Properties of Fresh Concrete Feb 2014)

As its can be observed in the microstructure image in Figure Number 1 , the particle size is very uneven and it may require more amount of grinding when compared to other materials of same type.

V. CHEMICAL REACTION OF GGBS WITH PORTLAND CEMENT (OPC)

GGBS to react with lime during hydration requires an activator. Since the structure of GGBS is Glassy, its reaction in hydration is very slow when activator used is water. Hence usually Sulphates or alkalis are used as activators which disturb the glassy nature of GGBS and allows the reaction to take place in a right way. GGBS needs a pH level of 12. In concrete, due to hydration of cement, $Ca(OH)_2$ is produced and acts as an activator.

VI. PROPERTIES OF FRESH CONCRETE WHEN CEMENT IS REPLACED BY GGBS PARTIALLY

A. Water Demand or Workability

Water requirement is less when GGBS is added to concrete. As per the earlier work study, generally 25% to 75% of cement is replaced by GGBS. *GGBS* requires about 3% lesser water content in comparison to OPC for the equal slump requirement. This is due to smooth surface texture and delay in hydration.

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B. Heat of Hydration

The heat of hydration reduces as the content of GGBS increases in concrete. This will be helpful in large concreting where the temperature rise will be low and hence thermal cracking will be reduced.

C. Setting Time

Since GGBS reacts slowly with water, the setting time of GGBS concrete will be more. It will be more in high replacement levels above 50%. The high reactivity increases hydration rate of the C_3S fraction of the cement in the first instance and thus decreases the setting time.

D. Bleeding

As per the study bleeding is less as far as GGBS concrete is concerned when compared to the conventional concrete. The reduction in bleeding is due to greater surface area of particles of GGBS and lower water content with GGBS for a given workability.

VII. STRENGTH AND DURABILITY PROPERTIES OF HARDENED CONCRETE WHEN CEMENT IS REPLACED BY GGBS PARTIALLY

A. Compressive Strength

As per the study of most of the papers compressive strength of the cement concrete increases with the increase of GGBS content in concrete up to a certain limit above which it decreases. In order to find that optimum value cube compression test is carried out for different percentage replacement of cement by GGBS for 7days to 90days. After testing a number of samples in a number of papers the optimum percentage of replacement of GGBS in cement is 40% to 50% in order to achieve high compressive strength when the results of all the tests are compared.

B. Split Tensile Strength

As per the study the split tensile strength of the cement concrete increases with the increase of GGBS content in concrete up to a certain limit above which it fluctuates. In order to find that optimum value split tensile strength test is carried out for different percentage replacement of cement by GGBS for 28days only. After testing a number of samples in a number of papers the optimum percentage of replacement of GGBS in cement is 40% to 50%.

C. Acid Attack

In order to find the effect of Acid on the concrete sample with GGBS, the concrete cubes which are 28days water cured are immersed in 5% Sulphuric Acid solution and they are tested for compression for 28, 56,90 days of acid curing. The compression test results of these cubes are then studied and accordingly the inference is made. As per the observation, as GGBS content increases in concrete, the behaviour of concrete to acid attack improves and better resistance to acid attack is seen as per the review of papers related to acid attack.

D. Water Permeability

Water permeability is one of the major durability properties. As per the review papers To conduct water permeability test, the test specimens are set up in the water permeability apparatus and with a high pressure of $7kg/cm^2$, water is pushed on to the surface of the concrete is specimen for more than 24 hours. Then the specimens are removed and they are cut in to two pieces to know the depth of penetration of water inside the specimen. Once the depth of penetration is known, the co-efficient of permeability can be found out. Using the value of co-efficient of permeability, the water permeability for different specimens with different GGBS replacement can be known and tabulated. For water permeability, the rectangular mould of 20cm X 20cm X 15cm is used. As per the review of papers, water permeability decreases constantly as the amount of GGBS increases in the concrete and also as the number of days which the specimen is water cured increases.

E. Chloride Attack

By reviewing a number of papers, a number of tests are available to find the action of Chloride on the concrete specimen is found. Rapid Chloride Ion Penetration Test is based on ASTM C1202. This test indicates the chloride ion penetration in terms of Coulombs. For this particular test the cylinders of 20cm height and 10cm diameter are casted and kept in water curing. These cylinders are then cut in to 50 mm thick slices for the purpose of experiment. The experiment setup has two cell chambers, one with 3% Nacl solution and another one with 0.3N NaOH solution. The 50mm thick specimen is covered with insulating tape and is kept

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in between the two cells and electricity is passed through it. When the electricity is passed, the chloride ion passes from one cell to another through the concrete specimen and the amount of chloride ion passed between the specimens is noted down in coulombs. This test is conducted for 6 hours or 360 minutes. One more test is Chloride immersion test. To conduct chloride immersion test, the concrete cubes which are 28days water cured are immersed in 5% sodium chloride solution and they are tested for compression for 28, 56,90 days of Nacl curing. The compression test results are tabulated and also the surface damage if any is studied. After the compression test, the specimen is broken in to two pieces and Silver Nitrate solution is sprinkled in to the inside section of the concrete specimen and the whitish precipitate occurs wherever the chloride penetration persists. The depth of the chloride penetration can be found out by the colour change and can be tabulated. By reviewing all the paper, using both the above test, resistance to chloride attack increases as the GGBS content in concrete increases.

VIII. BEHAVIOUR OF GGBS CONCRETE IN MARINE ENVIRONMENT

As per the review of a number of papers related to GGBS concrete in marine environment, GGBS concrete has shown a great improvement in Chloride ion penetration, Compressive strength and Tensile strength. GGBS concrete with 40% replacement of cement has shown a great improvement in strength and durability aspects in marine exposure. According to one of the papers, artificial marine environment can be simulated in a temperature controlled curing tank of dimensions 2m X 1.5m X 0.5m. A solution of 3% $NaCl$ + $CaCl_2$ with 0.5% $MgSO_4$ is to be prepared in the curing tank, the solution is to be circulated throughout the curing tank using a standard electric pump. By testing the samples in this artificial marine environment for durability and strength aspects, it was found that GGBS concrete is highly stable in marine environment.

IX. CONCLUSIONS

The rate of strength development in GGBS concrete is slow at early stages. This may be due to delayed pozzolanic activity, however at later stages the strength development increases. GGBS concrete develops strength at low rate and hence heat of hydration will be less. Thus concrete does not develop any thermal crack. Initial setting time of GGBS concrete will be more since GGBS reacts slowly with water in the initial stages. GGBS makes the concrete denser and hence there will be less bleeding in the initial stages of concrete. In hardened state the concrete shows better compressive strength and split tensile strength along with a great improvement in durability properties like Acid attack, Water permeability, Chloride attack. Hence overall GGBS replacement is highly beneficial with respect to both strength and durability aspects of conventional concrete in normal environment as well as in marine exposure.

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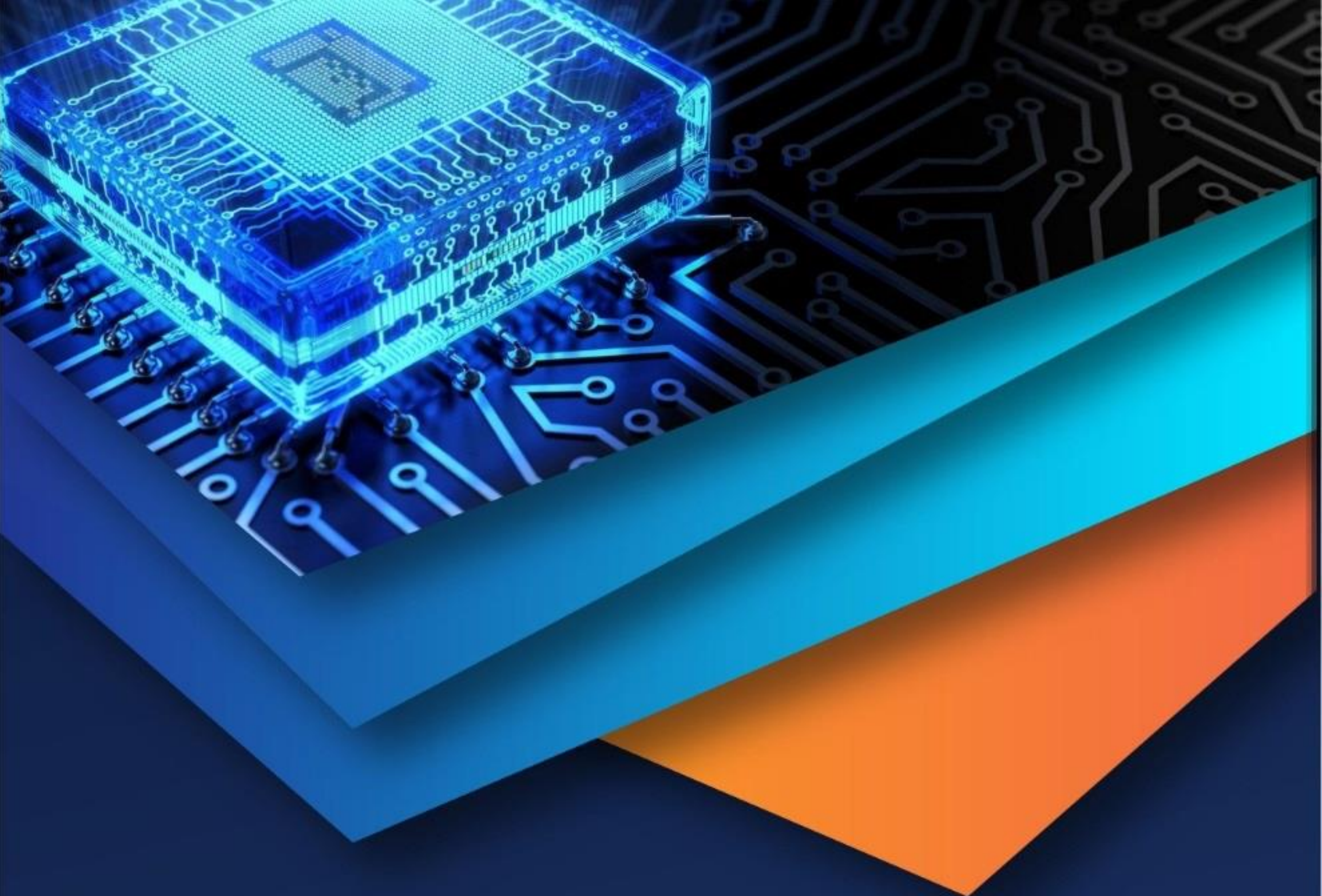

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