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An Experimental study on Strength and Durability aspects of Ground Granulated Blast Furnace Slag Concrete in Marine Environment

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Abstract
Concrete exposed to marine environment may deteriorate as a result of combined effects of chemical action of seawater constituents on cement hydration products, alkali-aggregate expansion, crystallization pressure of salts within concrete if one face of the structure is subject to wetting and others to drying conditions, frost action in cold climates, corrosion of embedded steel in reinforced or prestressed members, and physical erosion due to wave action and floating objects. Attack on concrete due to any one of these causes tends to increase the permeability; not only would this make the material progressively more susceptible to further action by the same destructive agent but also to other types of attack. Hence in this particular study, cement in conventional concrete is replaced by ground granulated blast furnace slag partially and its behaviour is studied in Marine Environment. Ground Granulated Blast Furnace Slag has been constantly in use as cementitious replacement for sustainable infrastructure. But little is known about interaction of GGBS based concrete with marine environment. These days due to the rapid development in offshore engineering marine environment and its simulation has come under limelight. The present study is aimed in studying permeability, corrosion of rebar, chloride ion attack, acid attack in the normal environment with partial replacement of Cement by GGBS and comparing it with the normal concrete. Here it's aimed to conduct a study on M40 grade concrete so that further study in Artificial Marine Environment can be done.

Keywords: Durability of Concrete, GGBS

Introduction

In today's construction industry, the use of concrete is increasing rapidly day by day. Concrete is a heterogeneous mixture of different ingredients like cement, sand, aggregates and water. Cement is one of the major constituents of concrete and due to the continuous consumption of cement; there might be a scarcity for cement in future days. 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. 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.

Methodology

The present study is to check when cement is replaced with GGBS in the concrete formation, the resulting must be of considerable strength and it should be durable. In the current study, cement in the concrete production is replaced up to 70% by GGBS and the compressive strength, Split Tensile strength and the reduction in the emission of carbon dioxide and the effect on economy due to the reduction in cement content. In the present study, the compressive strength is calculated for the cubes with 7, 28 days of water curing ranging from 0% to 70% replacement of cement by GGBS and Split Tensile Strength for the cylinders with 28 days of water curing ranging from 0% to 70% replacement of cement by GGBS.

Objectives

- The objective of the present work is to develop concrete with good strength, so that durability will be reached
- Use of ground granulated blast furnace slag as a replacement to cement
- To estimate the reduction in Carbon footprint
- To investigate different basic properties of concrete such as compressive strength, splitting tensile strength etc and comparing the to investigate the properties of concrete in fresh and hardened for the concrete made of GGBS at different percentages
- Determination of durability properties

- Is to use industrial waste in the medium strength concrete by reducing the cement content and to achieve high durability conditions

Ingredients and Their Properties

Cement

Cement is a binder, a substance that sets and hardens and can bind other materials together. The word "cement" can be traced back to the Roman term opus caementicium, used to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder.

Table 1 Physical properties of Cement

Sl No.	Properties	Values	Requirements as per IS 4031:1988 (Part 1 to 5)
1	Specific Gravity	3.15	Not Specified
2	Normal Consistency	33%	Not Specified
3	Initial Setting Time	75 min	Shall not be less than 30 minutes
4	Final Setting Time	589 min	Shall not be greater than 600 minutes
5	Specific Surface	334.30 cm^2/g	Not Specified

Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a material which is recyclable and created when the molten slag from melted iron ore is quenched rapidly and then ground into a powder.

Table 2 Physical Properties of GGBS

Sl No.	Properties	Values
1	Specific Gravity	2.90
2	Bulk Density	1245
3	Colour	Whitish
4	Fineness by 45µ sieve	6.90%

Fine Aggregates and Coarse Aggregates

Fine aggregates are the material passing through IS sieve that is less than 4.75 mm gauge, beyond which they are called as coarse aggregates. Here we have used river sand as fine aggregates and coarse aggregates of 20 mm down-size and 12 mm down-size for the study.

Table 3 Physical properties of Fine Aggregates

Sl No.	Properties	Values	Requirements as per IS 383: 1970 ; RA 2007
1	Specific Gravity	2.53	Not Specifies
2	Fineness Modulus	2.1	Should be less than 10% by its weight

Table 4 Physical Properties of 20 mm down-size Aggregates

Aggregate Impact Value	16.74%	Max. 45%
Specific Gravity	2.6	2.6-2.8
Elongation Index	18.60%	Shall not be more than 30%
Flakiness Index	23.00%	Shall not be more than 30%

Table 5 Physical Properties of 12.5 mm Down-size Aggregates

Aggregates Impact Value	18.44%	Max. 45%
Specific Gravity	2.67	2.6-2.8
Elongation Index	10.74%	Shall not be greater than 30%
Flakiness Index	18.10 %	Shall not be greater than 30%

Water

Almost any natural water that is drinkable and has no odour can be used to prepare concrete. Water containing less than 2000 ppm of total dissolved solids can be satisfactorily used to make concrete. pH level up to 9 is allowed. For this study, the potable water according to IS 456:2000 has been used.

Hyper-Plasticizer

It is the high range water reducing and retarding super plasticizer for concrete. This type of super plasticizing admixtures is used to produce flow able or pump able concrete. For the current study, the optimum dosage of super plasticizer is calculated through Marsh Cone Test and from the test results, it is found to be 1.2% by weight of cementitious material.

Table 6 Properties of Hyper-Plasticizer (Admixture)

Parameters	Specifications
Appearance	Dark Brown Liquid
Base Material	Sulphonated Naphthalene Formaldehyde
Specific Gravity	1.24±0.02@30ºC
pH	Min. 6
Solid Content (%)	44±5
Chloride Content (%)	Max. 0.2

Testing of Specimens

Compressive strength and Split Tensile strength of cubes and cylinders respectively is determined at 7 days, 28 days using compression testing machine (CTM) of capacity 2000 KN.

Compressive Strength Test on Concrete Cubes

A Cube Compressive Strength test is carried out on standard specimens of size 150X150X150 for 7 days, 28 days of water curing for both normal concrete and GGBS concrete using compression testing machine and the failure load is noted down.

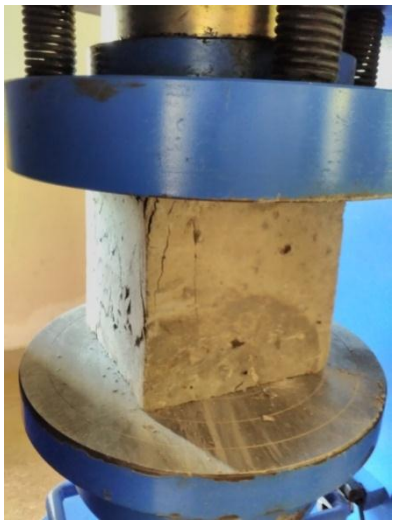

Figure 1 Compression Testing

Split Tensile Strength Test on Concrete Cylinders

The tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure.

The test consists of applying a compressive line load along the opposite generators of concrete cylinders for 28 days of water curing for normal and GGBS concrete placed with its axis horizontal between the compressive platens. Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. The magnitude of this tensile stress Osp (acting in a direction perpendicular to the line of action of applied loading) is given by the formula (IS: 5816-1970):

Osp = 0.637 P/dl

Where P is the failure load in kN, d is the diameter in mm and l is the length in mm.

Figure 2 Split Tensile Testing

Rapid Chloride Ion Penetration Test (RCPT)

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 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.

Acid Attack Test

To conduct the acid attack test, 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 are tabulated and also the surface damage if any is studied.

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.

Water Permeability Test

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.

Test Results

Compressive strength of M40 concrete over different percentage GGBS as replacement for cement for 7, 28.56,90 days using cement as OPC

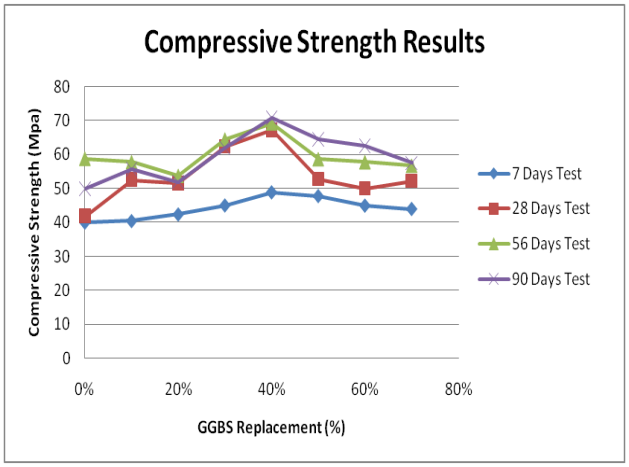

Figure 3 Compressive strength for M40 grade concrete

Split Tensile Strength of M40 concrete over different percentage GGBS as replacement for cement using cement as OPC

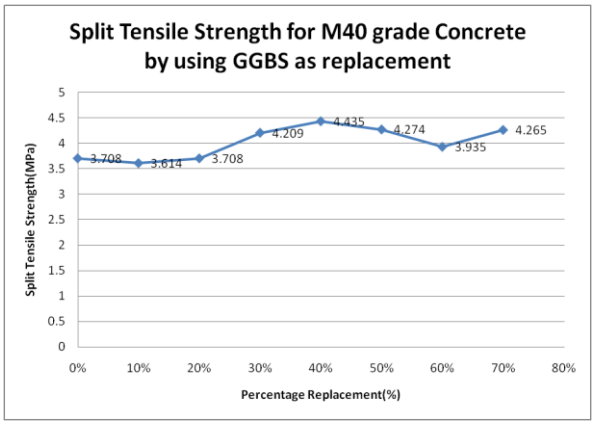

Figure 4 Splitting Tensile Strength for M40 Grade Concrete

Acid Attack Test of M40 concrete over different percentage GGBS as replacement for cement using cement as OPC for 28 and 56 days of Acid Immersion

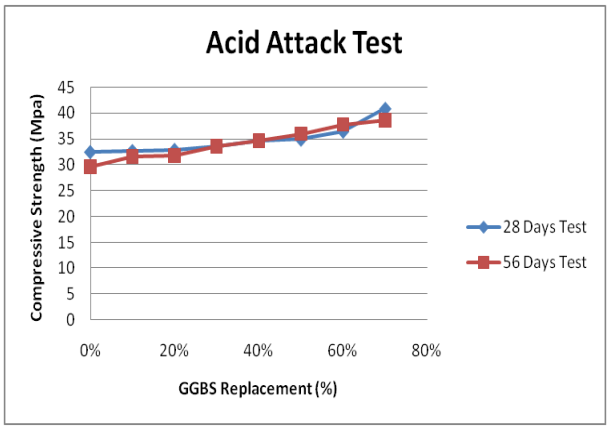

Figure 5 Acid Attack Test for M40 grade concrete

Water Permeability Test of M40 concrete over different percentage GGBS as replacement for cement using cement as OPC for 7, 28 and 56 days.

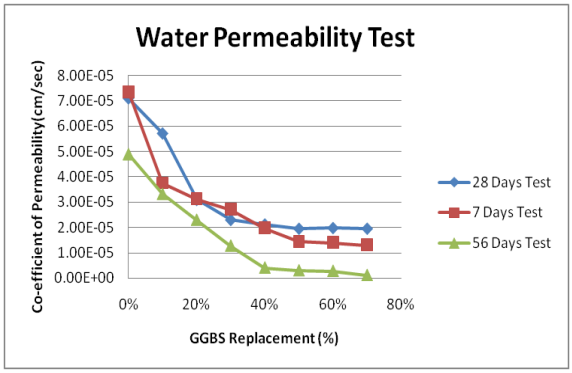

Figure 6 Water Permeability Test for M40 grade concrete

Chloride Immersion Test of M40 concrete over different percentage GGBS as replacement for cement using cement as OPC for 28 and 56 days of Sodium Chloride Immersion.

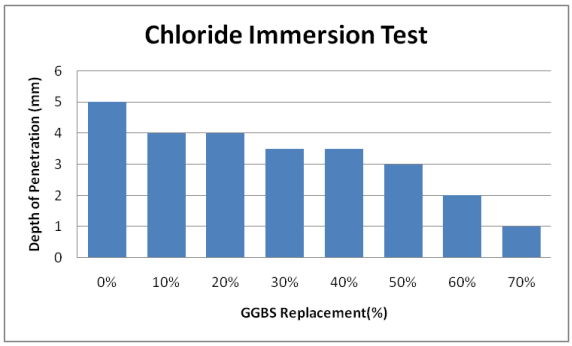

Figure 7 28 Days Chloride Immersion test of M40 concrete

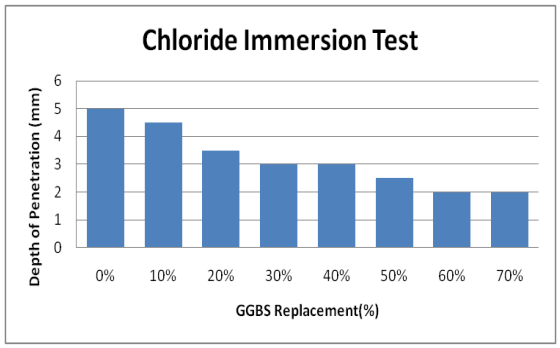

Figure 8 56 Days Chloride Immersion test of M40 concrete

Rapid Chloride Ion Penetration test over different percentage GGBS as replacement for cement for 28 days using cement as OPC

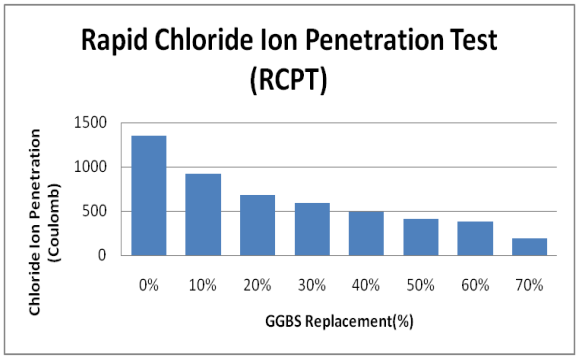

Figure 9 28 Days RCPT of M40 concrete

Discussion

Compressive Strength Results

7 Days Compressive Strength

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the compressive strength got maximum, which is 48.88MPa for 40% replacement of cement by GGBS.

28 Days Compressive Strength

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the compressive strength got maximum, which is 67.257 MPa for 40% replacement of cement by GGBS.

56 Days Compressive Strength

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the compressive strength got maximum, which is 69.189Mpa for 40% replacement of cement by GGBS.

90 Days Compressive Strength

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the compressive strength got maximum, which is 70.851Mpa for 40% replacement of cement by GGBS.

Split Tensile Strength Results

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- For 40% replacement of cement by GGBS, the maximum Split Tensile Strength of 4.435MPa was seen.

Acid Attack Test Results

28 Days Acid Immersion Compressive Strength

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2% and 5% Sulphuric Acid
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the compressive strength got maximum, which is 40.899Mpa for 70% replacement of cement by GGBS when immersed in 5% Sulphuric Acid Solution.

56 Days Acid Immersion Compressive Strength

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2% and 5% Sulphuric Acid
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the compressive strength got maximum, which is 38.667Mpa for 70% replacement of cement by

GGBS when immersed in 5% Sulphuric Acid solution.

Rapid Chloride Ion Penetration Test

28 Days Water curing RCPT results

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the chloride ions passage in coulombs got decreased from 1348.84 coulombs for conventional concrete to 194.8 coulombs for 70% GGBS replaced concrete for 28 days of water curing.

Water Permeability Test Results

7 Days Water Permeability test

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the Co-efficient of penetration decreased from 7.35E-05 for 0% replacement to 1.29E-05 for 70% replacement.

28 Days Water Permeability test

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the Co-efficient of penetration decreased from 7.08E-05 for 0% replacement to 1.963E-05 for 70% replacement.

56 Days Water Permeability test

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the Co-efficient of penetration decreased from 4.901E-05 for 0% replacement to 1.11E-05 for 70% replacement.

Chloride Immersion Test

28 Days chloride immersion test

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the chloride penetration was found to be 5.00mm for conventional concrete and 1.00mm for 70% GGBS replaced concrete.

56 Days chloride immersion test

- For cement content 330.15kg/m^3, water-cement ratio = 0.36 and Hyper-Plasticizer= 1.2%
- The cement was replaced by GGBS in various percentages starting from 10% to 70%. It was seen that the chloride penetration was found to be 5.00mm for conventional concrete and 2.00mm for 70% GGBS replaced concrete.

Final Optimization

From the above observation, it is noted that the compressive strength and split tensile strength is maximum for 40% of GGBS replacement for cement. From all the durability tests, it is clearly noted that as the GGBS content got increased as replacement to cement, the durability aspects like Water Permeability, Acid Attack, and Chloride Attack also got reduced. Since we need Strength along with durability, 40% to 50% will be the optimum replacement of GGBS to cement.

Calculation of Carbon Credits

- India's cement production for the year 2013-14 was 366million tonnes. The cement industry of India is expected to ass 30-40 million tons per annum capacity in 2015. The industry has current capacity of 366 MTPA and operates with 70-80% utilization.
- From the current study 40% of cement can be saved, this accounts 146.4 million tons.
- By saving 146.4 million tons, same amount of CO_2 emission can also be reduced in India by cement industries.

Calculation of Number of vehicles required to transport the Saved Cement and also the probable CO_2 emission from these vehicles.

- As per standard data, a 10 wheeled truck (3 axles) carries 19 tons of cement.
- Hence, 146.4 million tons require $7X10^6$ trucks.
- From data obtained by Environmental Protection Agency (USA), 1 litre combustion of Diesel by trucks emits 2.66kg of CO_2.
- Let us consider a truck travels 100km for transporting cement with a fuel efficiency of 2km/litre.
- Hence, $7X10^6$ trucks consume $350X10^6$ litres of Diesel and emit $931X10^3$ tons of CO_2.

Calculations

- On an average in the international market, a ton of CO_2 fetches around 40$ to 50$.
- Let us consider it as 50$/ton of CO_2.
- 146.4 million tons of CO_2 is saved from the cement industry emission.
- $146.4X10^6X50=7.32X10^9$ $, which is Rs.46636 Crores.
- For 931 kilo tons of CO_2 saved from vehicle emission, it will be $931X10^3X50=46.55X10^6$ $.
- It is approximately Rs. 297 Crores.
- Grand Total= 46636 Crores+297 Crores, which is **Rs. 46933 Crores.**

- Indian population is 140 Crores at present and savings per head is approximately **Rs.335 per capita/year.**

Conclusion

- 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.
- GGBS concrete mix of M40 grade was done prepared with various cement replacement percentages from 0% to 70% for which both compressive strength and tensile strength was checked.
- GGBS concrete mix of M40 grade was done prepared with various cement replacement percentages from 0% to 70% for which durability tests like water permeability, acid attack and chloride attack were checked.
- From the current study, it is noted that 40% cement replacement by GGBS gave maximum compressive strength of 48.88 MPa for 7 day water curing and 67.25 MPa for 28 days of water curing, 69.189Mpa for 56 days of water curing and 70.881Mpa for 90 Days of water curing for M40 grade of concrete.
- From the current study, it is also seen that for 40% replacement of cement by GGBS, the maximum Split Tensile Strength of 4.435MPa was achieved.
- From the current study, all the durability aspects went on showing positive aspect when the GGBS replacement for cement got increased in the concrete.
- Current study includes carbon credit calculation and as per the study 40% of cement content can be saved and which is 146.4 million tons as per Indian scenario and also 146.6 million tons of carbon dioxide emission can be prevented. When this amount of carbon dioxide is converted in to Rupees, it will fetch Rs. 46636 Crores and 931 kilo tons of carbon dioxide can also be saved by no vehicular transportation. The grand total becomes Rs. 46933 Crores.
- Indian population is 140 Crores at present and savings per head is approximately Rs.335 per capita/year.

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