Durability Aspects Study of GGBS and Crusher Sand Based High Performance Concrete

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Abstract— Concrete made from ordinary Portland cement continues to be used as one of the primary material because of its durability and strength characteristics in service life. But the contrary becomes the case when such concrete is exposed to aggressive environment created by the prevalence of chloride ions that are common in marine/coastal environment characterized by temperature extremes, that is peculiar to India. Same time, present global environmental requirements suggest the civil engineers for reducing the consumption of OPC. Use of mineral admixtures like Blast Furnace Slag, Fly Ash and Silica Fume etc. in concrete may be a suitable solution in such situation. Hot marine and coastal environment with large variations in temperature, constitute an aggressive environment that has been found to be deleterious to the strength and durability characteristics of concrete, thus causing premature deterioration of concrete structures. Research works to reverse this trend go on continuously. This paper presents one of such works which investigates the effect of partial replacement of cement with slag and replacement of normal river sand with crusher dust for concrete preparation. The specimens cured at elevated temperatures were studied for all the durability criteria at the optimized crusher sand percentage. It discusses the resistance of GGBFS blended concrete to Chloride attack, Sulfate attack, Carbonation, Aggregate-Silica reaction and Frost attack with factors influencing its performance. It was found out that partial replacement of cement with slag increases the resistance of concrete to chloride penetration. The durability of HPC specimens was evaluated on the basis of reduction in compressive strength when exposed in Sulfuric acid (pH=5) solution for 28 days. Specimens containing lesser alkali were found to have lower water absorption as compared to normal concrete.

Key words: High Performance Concrete, Ground Granulated Blast Furnace Slag, Crusher Sand, Compressive Strength

I. Introduction

Concrete is considered as an inevitable part of construction industry. It is the second largest material consumed by human beings, after water. However, the production of cement which is one of the main constituent of concrete, causes huge amount of CO_2 emissions which leads to global warming and green house effect. Further, several environmental hazards are introduced due to the development and advancement in our modern concrete industry, like environmental pollution, harmful solid and liquid waste dumping, emission of toxic gases, depletion of natural resources, etc. By-products like fly-ash from thermal power stations, blast furnace slag from steel industry, silica fume from metallurgical industries, etc., pose a severe threat to the environment if not disposed off efficiently. If cement can be replaced with the help of these by-products, it would be a major contribution to the durability aspects of concrete and lead to sustainable development of human society.

According to ACI, "High Performance Concrete (HPC) is defined as a concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices". High Performance Concrete is a concrete made with appropriate materials, combined according to a selected mix design; properly mixed, transported, placed, consolidated and cured so that the resulting concrete will give an excellent performance in the structure in which it is placed, in the environment to which it is exposed and with the loads to which it will be subjected for its design. HPC has resistance to fluid penetration, abrasion, weathering action, chemical attack, impact, heating and cooling, wetting and drying, freezing and thawing as well as satisfies the strength requirement. HPC also requires a high modulus of elasticity greater than 6,500,000psi (44816 MPa). For producing high performance concrete (HPC), it is well recognized that the use of supplementary cementitious materials (SCMs), such as silica fume (SF), ground granulated glass blast-furnace slag (GGBS) and fly ash (FA) are necessary.

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by slaking molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and pulverized into a fine powder. The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). Two foremost uses of GGBS are in the production of quality-improved slag cement, namely Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging typically from 30 to 70%; and in the production of ready-mixed or site-batched durable concrete.

Due to rapid growth and development in construction industry, the available sources of natural sand are getting exhausted. Crusher Sand retained on 600 μ is one such material which can be used to replace sand as fine aggregate. The crusher sand, amounting to 25% of the coarse aggregates produced in stone crushers which were considered to be waste material facing the solid waste disposal problem, is being experimented as an alternate to river sand in construction industry for concrete.

II. SIGNIFICANCE OF STUDY

A. *Objectives of Study:*

- To analyze the compressive strength of concrete at 3, 7, 14 and 28 days (3 samples per day) under the different proportions of crusher sand and GGBS.
- To analyze the durability properties by acid attack test, carbonation test, alkalinity test, wetting-drying test, freezing-thawing, rapid chloride penetration test and water absorption test.
- The tests were performed for the following combinations:
  1) Only OPC (Ordinary Portland cement)
  2) 40% GGBS and 0% Crusher sand
  3) 40% GGBS and 10% Crusher sand
  4) 40% GGBS and 20% Crusher sand
  5) 40% GGBS and 30% Crusher sand
- Workability of concrete is determined using slump test.

B. *Scope of work:*

The current work tries to investigate the effect of partial replacement of cement with slag and replacement of normal river sand with crusher sand for concrete preparation. The specimens cured at elevated temperatures were studied for all the durability criteria at the optimized crusher sand percentage. The resistance of GGBFS blended concrete to chloride attack, sulfate attack, carbonation, aggregate-silica reaction and frost attack with factors influencing its performance were also discussed. It was found that partial replacement of cement with slag increases the resistance of concrete to chloride penetration. The durability of HPC specimens was evaluated on the basis of reduction in compressive strength when exposed in Sulfuric acid (pH=5) solution for 28 days. Specimens containing lesser alkali were found to have lower water absorption as compared to normal concrete.

III. EXPERIMENTAL INVESTIGATION

A. *Materials used:*

- Ground granulated blast furnace slag
- Crusher sand
- Aggregates
- Chemical admixture (high-range water-reducing naphthalene based super plasticizer)
- Cement (53 grade)
- Water (pH value vary from 7.48 to 7.56)

B. *Trial Mix Proportions:*

Trial mix no.	Volume of concrete (m^3)	Cement (Kg)	GGBS (Kg)	Sand (Kg)	Crusher Dust (Kg)	Kapachi (Kg)	Grit (Kg)	Super-plasticizer (Kg)
1	1	442.1	0	756.2	0	655.9	437.3	6.64
2	1	221.05	221.05	756.2	0	655.9	437.3	5.53
3	1	309.47	132.63	756.2	0	655.9	437.3	6.64
4	1	265.26	176.84	756.2	0	655.9	437.3	6.64
5	1	221.05	221.05	756.2	0	655.9	437.3	6.64

Table 1: Trial mix proportions

C. *Mix Design for Experimental Work:*

Materials	Unit Kg/m^3
Cement	291.8
Slag	194.5
Admixture	6.64
Sand	756.2
Coarse Aggregate (20 mm) (10 mm)	655.9 437.3
Water	181.3

Table 2: Mix design for experimental work

D. *Physical properties of GGBS:*

Bulk density	1150 kg/m^3
Specific Gravity	2.9
Moisture Content	1.3 %

Table 3: Physical properties of GGBS

E. *Test value of Fine Aggregates:*

Gradation	Falls in Zone I
Moisture Content	1.8 %
Fine Modulus	3.27
Silt Content	0.30%

Table 4: Test value of fine aggregates

F. *Slump Values for Various Mix Design:*

Mix Design	Slump value (mm)
OPC	170
0% Crusher sand	150
10% Crusher sand	160
20% Crusher sand	170
30% Crusher sand	160

Table 5: Slump values for various mix design

IV. RESULTS AND DISCUSSION

A. *Test results of Trial Mix:*

Trial mix no.	Volume of concrete (m^3)	Cement (Kg)	GGBS (Kg)	Sand (Kg)	Crusher Sand (Kg)	Coarse Aggregate (20 mm) (Kg)	Grit (Kg)	Super-plasticizer (Kg)	Compressive Strength N/mm^2	
									7-Days	28-Days
1	1	442.1	0	756.2	0	655.9	437.3	6.64	26.73	39.1
2	1	221.05	221.05	756.2	0	655.9	437.3	5.53	20.76	-
3	1	309.47	132.63	756.2	0	655.9	437.3	6.64	30.56	-
4	1	265.26	176.84	756.2	0	655.9	437.3	6.64	29.98	39.2
5	1	221.05	221.05	756.2	0	655.9	437.3	6.64	24.23	-

Table 6: Test results of Trial Mix

- While replacing the cement with 30% slag, the cubes set within 24 hours, while cubes with 40% and 50% replacement took more than 24 hours. Hence the effect of GGBS at replacement levels of 40% and higher causes excessive retardation in setting time.
- HPC cubes were casted for different admixture proportions of 1%, 1.25 % and 1.5 % and the result showed that the compressive strength at 1.5 % admixture proportion was greater with respect to others. Thus, the workability and compression of concrete improved with the increase in the percentage of super-plasticizer.
- For the trial mix proportion number 3, 12 number cubes were casted and 6 cubes were cured in water up to the testing and rest were cured in water for 3 days and kept outside the water, then tested on 7th day. The compressive strength of the cubes cured till testing was greater than the cubes that were removed from curing much before testing. Thus,

the compressive strength of GGBS replaced concrete improves, when it is cured in suitable moist condition.

– As GGBS occupies more solid volume for the same mass it improves the workability of the concrete. Thus lower density of GGBS causes an increase in paste volume and improved the workability.

B. Compressive Strength Test Results:

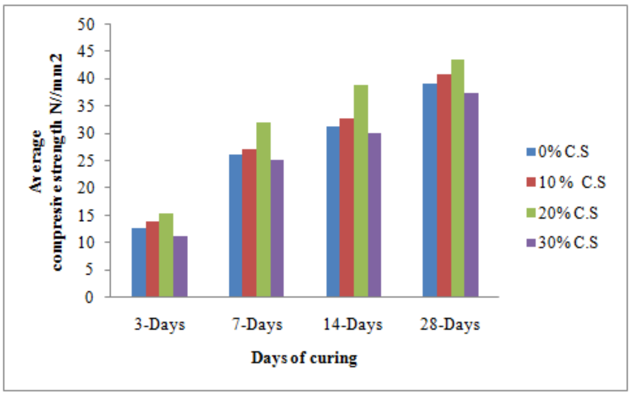

Fig .1: Average compressive strength of HPC with 40 % GGBS and various replacement level of crusher sand

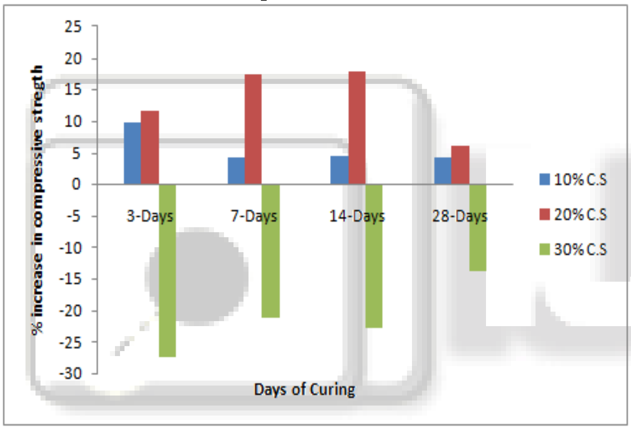

Fig. 2: Representation of variation in compressive strength

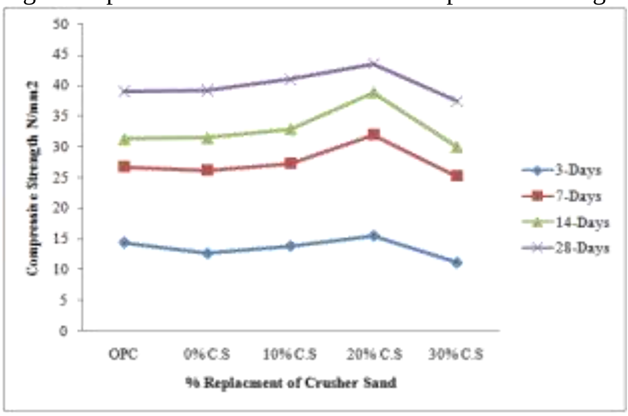

Fig. 3: Compressive Strength of HPC with various replacement level of Crusher Sand

From fig.1, fig.2 and fig.3, it is observed that the compressive strength for 40% GGBS and 20% crusher sand specimen have highest compressive strength.

C. Carbonation Test Results:

The fig.4 shows that value of carbonation depth for OPC concrete is much higher as compared to GGBS blended concrete. The carbonation depth of 20 % crusher sand replaced concrete is 0.9 mm, which is very low and thus, it makes the concrete more durable against carbonation.

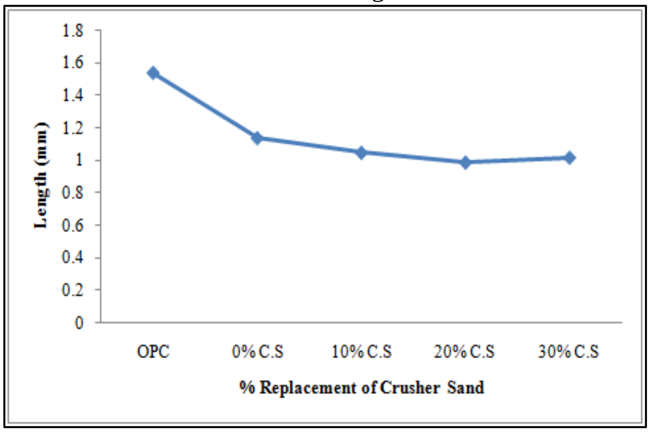

Fig. 4: Carbonation test result of HPC with various replacement level of Crusher Sand

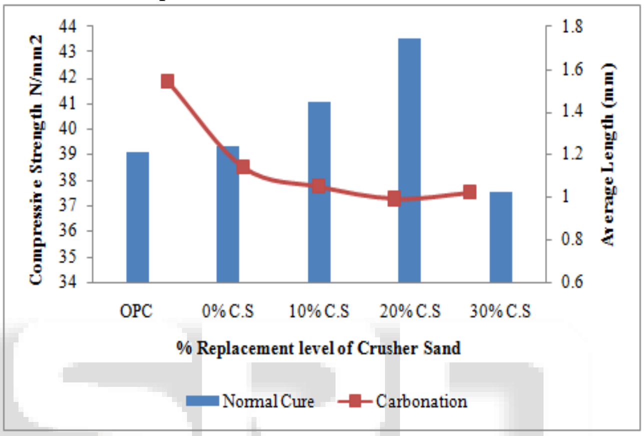

Fig.5: Comprehensive result of Normal Curing and carbonation of HPC with various replacement level of Crusher Sand

Fig.5 shows the compressive strength with % replacement of crusher sand which shows higher increase with increase in crusher strength, also reducing the carbonation depth, thereby showing better resistance to carbonation.

D. Acid Attack Test Results:

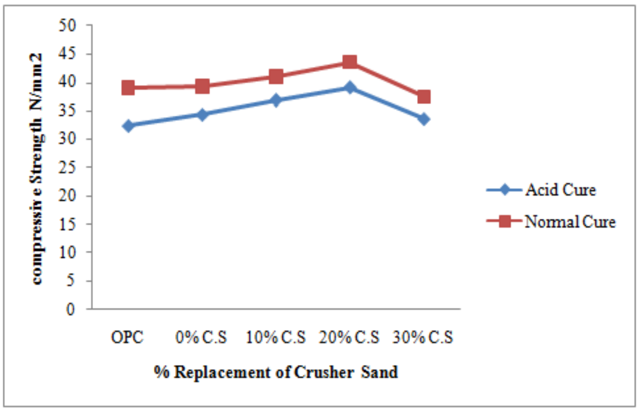

Fig. 6: Acid Attack test result of HPC with various replacement level of Crusher Sand

Fig.6 shows that there is decrease in compressive strength, when the GGBS and crusher sand containing concrete is expose to sulphuric acid (pH = 5). The percentage decrease in compressive strength after 28 days acid curing is 10 to 12 %.

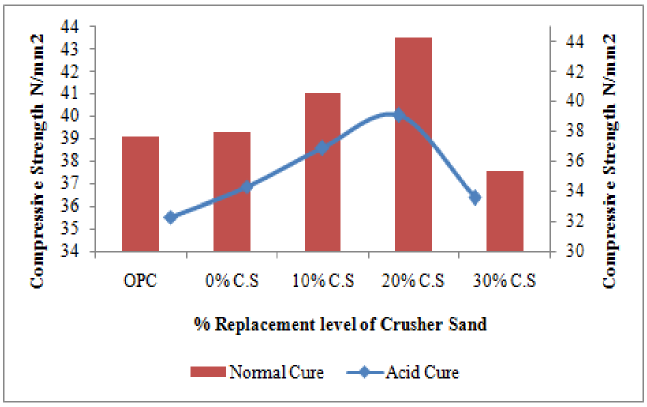

Fig. 7: Comprehensive result of Normal curing and Acid Attack of HPC with various replacement level of Crusher Sand

From fig.7, it is observed that compressive strength decreases due to acid attack. But as compared to OPC, GGBS blended concrete has higher resistance to acid attack.

E. Rapid chloride penetration test (RCPT) results:

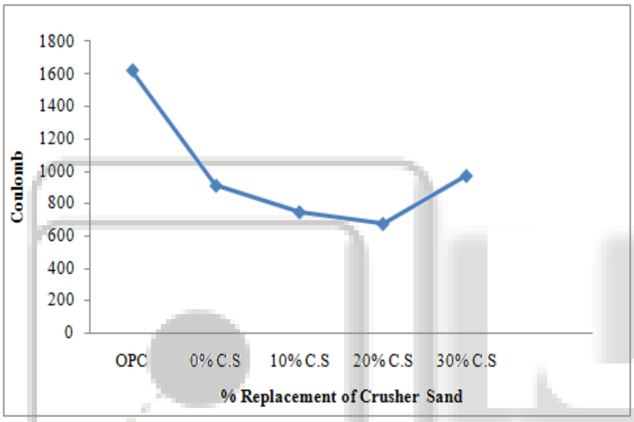

Fig. 8: RCPT test result of HPC with various replacement level of Crusher Sand

From fig.8, it is evident that the concrete specimen which contains 40% GGBS and 20% crusher sand has low permeability. It is due to the fineness of GGBS and crusher sand. It influences cement hydration, due to more refined pore structure in cementitious system. This leads to low permeability in concrete and hence the enhancement of the mechanical properties, high strength and durability of concrete like high resistance to weathering.

F. Water Absorption test results:

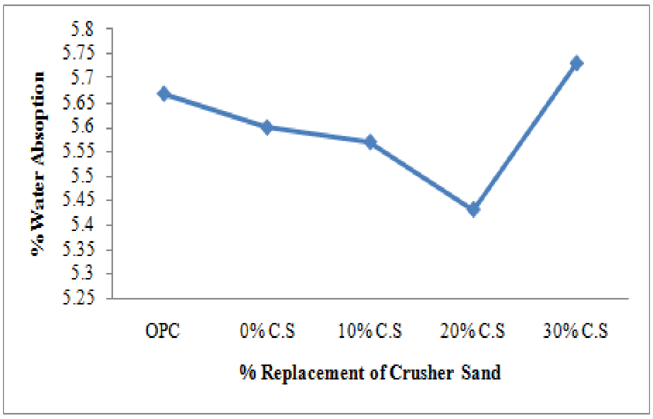

Fig. 9: Water Absorption test result of HPC with various replacement level of Crusher Sand

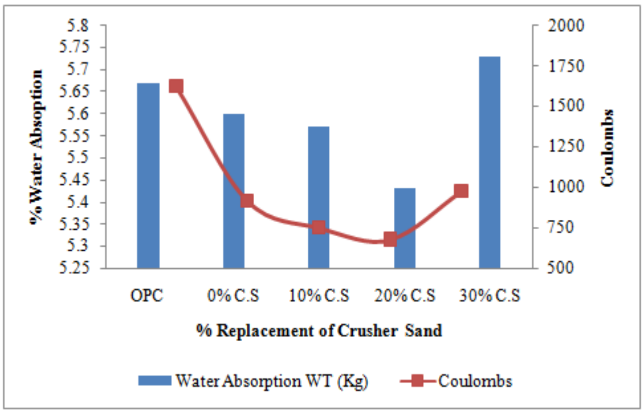

Fig. 10: Comprehensive result of water absorption and RCPT of HPC with various replacement level of Crusher Sand

Water absorption deals with capillary flow and micro pores in concrete specimen, while RCPT talks about the chloride resistivity and conductivity of concrete specimen. The figure shows that concrete specimen with 40% GGBS and 20% crusher sand had lowest water absorption. RCPT results indicate that the concrete specimen had very low permeability. Thus, the concrete specimen has better durability and performance quality.

G. Alkalinity Test Results:

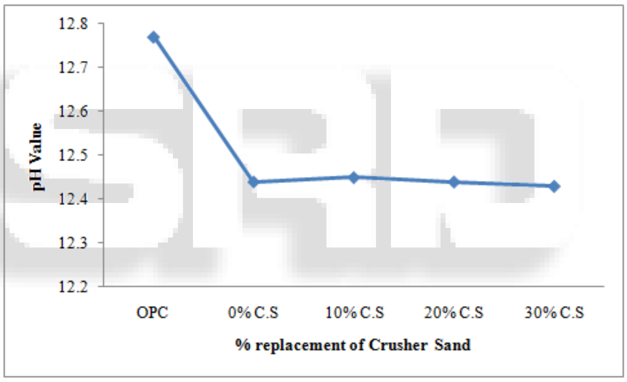

Fig.11: Alkalinity test result of HPC with various replacement level of Crusher Sand

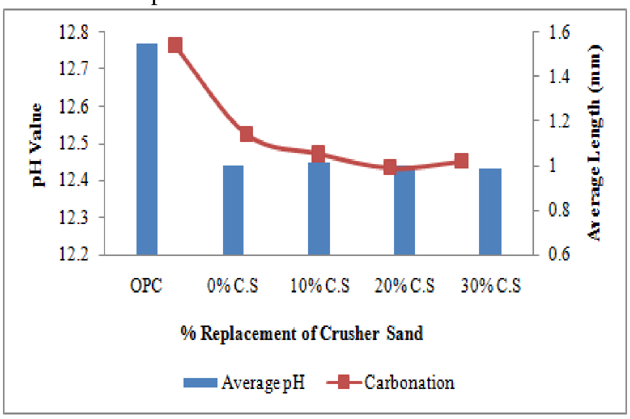

Fig.12: Comprehensive result of average pH and carbonation of HPC with various replacement level of Crusher Sand

From fig.11 and fig.12, it is clear that the pH value for the concrete specimen with OPC has higher alkali value, while the concrete with the GGBS blended has similar value near to each other, but lower than OPC. Thus, the potential of corrosion of concrete is very low.

H. Wetting - Drying Test Results:

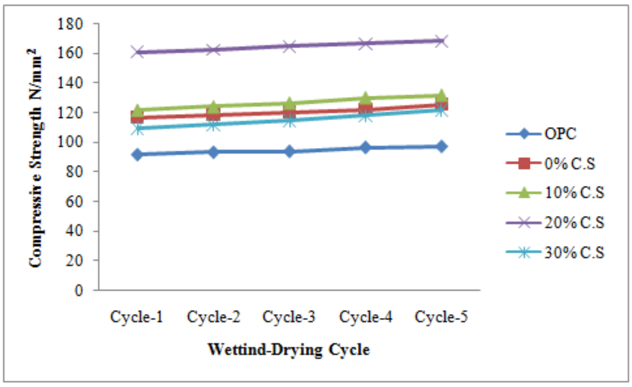

Fig. 13: Wetting - Drying test result of HPC with various replacement level of Crusher Sand

The wetting and drying exposure leads to capillary flow of water through micro pores of concrete specimen. From fig.13, it is seen that the compressive strength is constantly increasing by 2.5 % with each cycle. This remarks that the anhydrate cement and GGBS produce the C-S-H gel, react with water and release heat of hydration. The advantage of GGBS blended concrete is that it gains higher compressive strength at later age.

I. Freezing – Thawing test results:

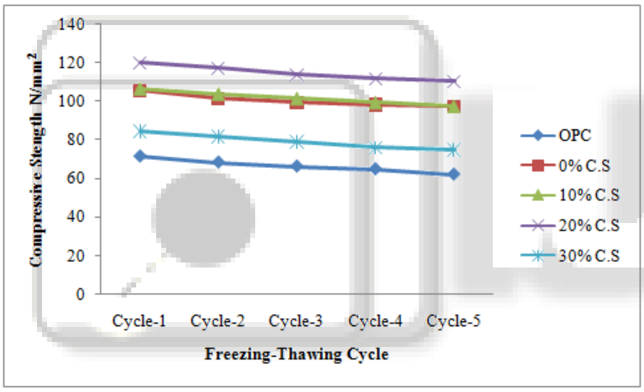

Fig. 14: Freezing - Thawing test result of HPC with various replacement level of Crusher Sand

Water below the 0ºC temperature changes its volume and occupies a solid state with 10% greater volume than the initial. But when concrete is exposed to freezing and thawing, the scaling of concrete indicates that there is a constant decrease in the compressive strength of the concrete specimen. The study shows that the freezing slows down the hydration process of cement and thawing leads to development of pores inside the micro structure of concrete specimen, i.e. frozen water melts and produces pores. As the hydration process of GGBS blended concrete is low, there is ultimate reduction in strength of concrete specimen.

V. CONCLUSION

- High Performance Concrete (HPC) always has a higher strength than normal concrete. The results of 7-Days and 28-Days compressive strength with various percentage of replacement of crusher sand with ordinary sand are used to get the optimum mix proportion.
- The optimum amount with which the sand can be replaced by crusher sand is 20 %. The percentage increase in the 28 days strength is 11%. Further increase in percentage of replacement crusher sand will decrease the compressive strength of HPC as the amount of crusher sand exceeds the quantity that is required to fill the micro pores.
- The durability and service life of concrete exposed to weather is related to the permeability of the cover concrete protecting the environment. The High Performance Concrete (HPC) has very low permeability to chloride ions and water respectively.
- When the test specimen of HPC were exposed to severe acidic curing condition i.e. H2SO4 for 28 days, results of compressive strength test did not show remarkable fall in the strength of HPC. This is because of low permeability of HPC due to its dense pore structure, which makes it more durable.
- High Performance Concrete (HPC) has very good resistance to carbonation due to its low permeability. The average depth to which HPC (considering all proportions of Crusher sand) has carbonated is 1.05 mm whereas OPC has shown 1.54 mm penetration after 28 days which is approximately 32 % more than the HPC. Hence, HPC cover concrete is immune to carbonation to a depth that would cause corrosion. The 20 % crusher sand replacement showed least depth of penetration i.e 0.9 mm.
- Reactivity between certain siliceous aggregate and alkali hydroxides can affect the long term performance of the concrete. Hence in order to minimize the effect of alkali-silica reactivity the following precaution were taken:
- Low w/c ratio (0.41) was taken for the mix as at very low w/c ratio, HPC can self desiccate to a level that does not allow ASR to occur.
- The slag was used as a supplementary cementing material as it has the ability to control alkali-silica reactivity.
- Due to low water cement ratio it is believed that concrete is highly resistant to physical break up due to freezing and thawing. But the results showed decrease in the compressive strength. This shows that HPC can be further improved either by reducing W/C ratio (≤ 0.25) or by adding air-entrained admixtures.
- Cyclic wetting and drying causes continuous moisture movement through concrete pores. Since the result of RCPT and other test showed that HPC has relatively low permeability, the cyclic effect of wetting and drying on the durability is minimized. The test results showed, HPC with 20 % replacement of sand with crusher sand, offers better resistance to the cyclic effect.
- Under the adequate reactive material and moist curing condition, the strength of GGBS blended concrete increases at a later age.

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