International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7, Issue-6C2, April 2019

Service Life Prediction of High Performance Concrete Incorporated with GGBS and Silica Fume

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Abstract: As known that, every structure has an estimated life span. Due to various problems, the life span of structures gradually decreases due to the passage of time. One of the major problems is corrosion of reinforcement as we all facing now a days. Corrosion mainly occurs due to penetration of chloride ions. By partially replacing of Ground granulated blast furnace slag (GGBS) with different percentages (50%, 60%, 70%, 80%, 90%) and by adding 5% of silica fume to the cement results in the reduction of heat of hydration, as well as leads to high strength, high durability, corrosion resistance and pore reducing capacity in the structures. It is mostly useful for durability point of view when concrete is exposed to marine conditions, etc. The experiment is conducted by replacing cement with GGBS on different mixes of similar workability with three water binding ratios of 0.3, 0.4 and 0.5. For this research, around 72 cubes of standard size (150mm X 150mm X 150mm) were tested for compressive strengths which is for both plain concrete and different slag replacements in concrete at the ages of 28 days, 56 days and 90 days. For CPT test, around 48 cubes were cast in determining chloride penetration. The specimens were immersed in 3.5% of sodium chloride solution by weight of water and then left for curing for 28 days, 56 days and 90days and then drill the specimens to certain depths of for chemical analysis. The amount of penetration is checked and the chloride impact is estimated on the concrete, which helps in estimation of life of concrete. Hence, the results were concluded by chemical results.

Index Terms: Chloride penetration, Corrosion, Durability, GGBS, Service life prediction, Silica fume and Water-cement ratio.

I. INTRODUCTION

Concrete was introduced in the year 1853; at that time concrete was one of the best construction materials for Civil Engineers. Concrete has many advantages like high strength, durability, serviceability, low maintenance, resistant to heat, wind, and water. After the discovery and proper use of concrete, later it was found with some drawbacks. Durability and strength issues are the major concerns in concrete. Engineers and Scientists mainly concentrated on these problems and found very reliable alternative solutions to those problems and also seriously concentrated to improve the nature of concrete. In this process they identified that the major structural failures are due to the service life of reinforced concrete.

Every civil engineer treats structure is like a human, as human has 3 stages in his or her life, like that structure is also having 3 stages. Birth, Young and Old age. In the first stage concrete has no strength we take care at this age like selection of materials, quality of materials, mix proportion, structure design, execution and etc.

If concrete is perfect at this stage, then the service life of a structure will gradually increase. In the young stage concrete gain its strength, we take care about the surrounding environmental impacts around the building because if environmental impact is high, then structure life span reduces. Just like humans suffer from various health issues in the final stage or old age, structure is becoming old it suffers from steel corrosion problems, deterioration of concrete and etc. These all three stages impact on reducing the life span of the concrete. So if the starting stage is perfect the entire concrete will be perfect**.**

The entire project runs based on a single quotation "Prevention is always better than Cure" if one element in the structure fails, then we have to do repair and rehabilitation many times but it does not get to its original strength and shape. So the birth of concrete is perfect, then we don't require any repairs to the concrete.

The service life of reinforced concrete, Most of the structural failures and life span of structure decreases due to corrosion problems.

The present paper mostly concentrated on chloride ion penetration because major failure of a structure is due to this chloride ion penetration. Decrease in the permeability of concrete leads to the increase in the structure service life. Fine material like Ground granulated blast furnace slag (GGBS) and silica fume are used. They will fill the pores present in the concrete and make it very thick concrete mix. When concrete is thick, the penetration of any gases or liquids into the concrete will be very less. If Penetration is less then chloride ion penetration is restricted, then corrosion problems will become a very time taking process. Life of a structure is gradually increases.

II. METHODOLOGY

A. Chloride Penetration in Concrete

Corrosion is the major cause of decreasing the service life of reinforced concrete. Mainly the corrosion problem occurs due to penetration of chloride ion into the concrete [1].

The service life of reinforced concrete, Most of the structural failures and life span of structure decreases due to corrosion problems. Corrosion may occur when reinforcement in concrete is exposed to the surface. Low permeability and water-cement ratio minimizes the

Revised Manuscript Received on April 09, 2019.

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penetration of corrosion inducing agents such as sulfate attack, chloride ion penetration, carbonation, acid attacks and moisture etc [2].

B. Mechanism of Corrosion of Reinforcing Steel and Deterioration of Concrete

Consumption of steel implanted in cement is an oxidation-decrease response bringing about oxidation of iron present in steel. The response continues by methods for an electrochemical mechanism, which include both Micro cell and Macro cell corrosion [3].

The electrochemical potential required to form these corrosion cells might be produced in RCC in two different ways.

Arrangement cells are shaped due to non-consistency in the surface attributes of the strengthening steel.

Fixation cells are framed because of contrasts in groups of breaking up particles in the region of steel.

As an aftereffect of making about these potential contrasts some part of the implanted steel becomes anodic where as some other part becomes cathodic and an electrochemical current appears.

III. RESEARCH SIGNIFICANCE

By studying all the literatures, one thing is mostly observed the life span of every structure and damage of the structure is caused due to structure failures like various affects such as material properties, mix design, water-cement ratio, quality of material not only these environmental impacts around the structures also plays a major role of structural failure. Concrete containing only cement, then it has pores, so by replacing the cement with fine material like GGBS it will fill the pores in concrete and also find a lot of difference in structure. Strength, durability if durability increases, then service life of the structure is also increasing both are interlinked.

IV. MATERIALS USED

The material utilized for specimens were Portland slag cement (OPC), coarse aggregate, fine aggregate, super plasticizers and tap water and other than this concrete materials two more materials are added there are granulated blast-furnace slag (GGBS) and silica fume.

The main advantages of using GGBS are listed as follows:

GGBS is a fine material when we use in concrete, it will Reduce permeability and Pore refinement.

When pores are filled penetration of liquids and gases into the concrete will be very less than concrete and it will take a long time for steel to get corroded which is present in concrete.

Reduce heat of hydration, Chemical resistance increases, Reduce chloride ion penetration, High resistance of sulphate attack, Low emission of CO_2. [4].

Silica fume is a byproduct of producing ferrosilicon or silicon metal alloys. Its chemical and physical properties are very reactive pozzolan. Silica fume is also very fine material and is helpful to fill the pores present in concrete. By adding 3-7% of silica fume is the one of the most beneficial to the concrete it will makes the very thick concrete [5]. It is highly resistant of corrosion, chloride, carbonation, sulfate attack.

Ground Granulated Blast-Furnace Slag

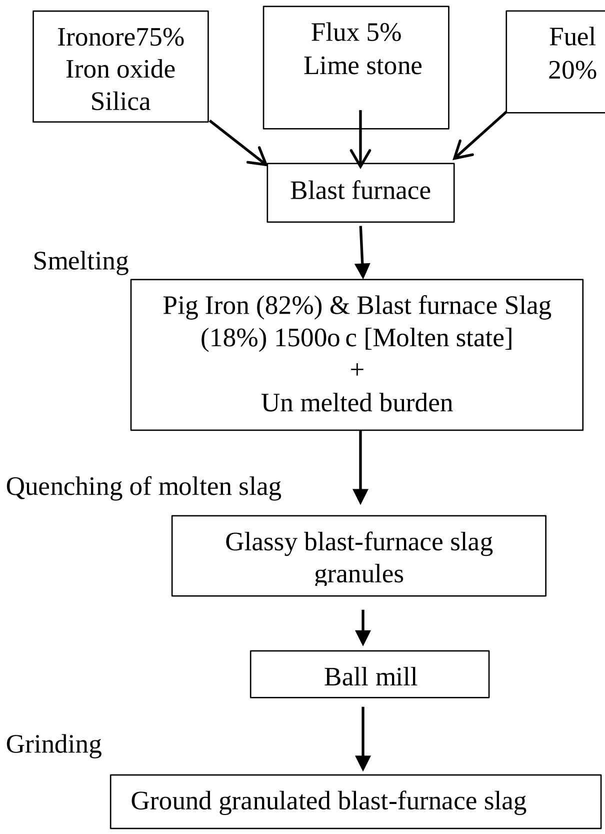

Fig. 1: Manufacturing Process of GGBS

Fig. 1 gives the information about the GGBS manufacturing process.

Partial replacement of Ground granulated blast furnace slag (GGBS) with different percentages and by adding 5% of silica fume to the cement results in the reduction of heat of hydration, as well as lead to high strength, high durability, corrosion resistance and pore reducing capacity in the structures. It is mostly useful for durability point of view when concrete is exposed to marine conditions, etc.

V. EXPERIMENTAL PROCESS

Table I: Outline of the experimental program

Parameters	Values Chosen
Water-binder ratio	0.3, 0.4, 0.5
Slag replacement levels	50, 60, 70, 80, 90
Age at compressive strength test (days)	28, 56, 90
Age at test for chloride penetration (days)	28, 56, 90
Concentration of NaCl	3.50%

In order to increase service life of reinforced concrete, a total number of 138 cubes with different water-cement ratios and different binder's replacement percentages were casted.

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Plain concrete cubes were also casted for comparison purpose of these plain and GGBS replaced concrete cubes.

Partially replacement of Ground granulated blast furnace slag (GGBS) with different percentages (50%, 60%, 70%, 80%, and 90%) and by adding 5% of silica fume to the cement has been carried out. Experimental investigation is conducted by replacing cement with GGBS on different mixes of similar workability with three water binding ratios of 0.3, 0.4 and 0.5. For this research, around 72 cubes of standard size (150mm X 150mm X 150mm) were tested for compressive strengths which are for both plain concrete and different slag replacements in concrete at the ages of 28 days and 90 days. For a clear understanding of these cubes details follow the, Table I.

Table II: Plain concrete cube details

w/c	Total cubes	No of Cubes	Curing Days	Curing	After curing
0.3	12	3	28	Normal Water curing	Compression test
		3	90		
		2	28		NaCl expose for extra 28, 50, 90 days
		2	28		
		2	28		
0.4	12	3	28	Normal Water curing	Compression test
		3	90		
		2	28		NaCl expose for extra 28, 50, 90 days
		2	28		
		2	28		
0.5	12	3	28	Normal Water curing	Compression test
		3	90		
		2	28		NaCl expose for extra 28, 56, 90 days
		2	28		
		2	28		

After completion of 28 days and 90 days of curing that cubes were tested for the compression values. Then remaining cubes are exposed to sodium chloride solution. 3.5% of sodium chloride solution is added by weight of water for those NaCl exposed cubes. After exposing to NaCl solution these cubes were also cured for 28 days, 56 days and 90 days in that solution.

Then casted 108 cubes with replacing cement with GGBS and also adding 5% of silica fume with weight of cement, In this total, 108 cubes were divided into 54 and 54 cubes, 54 cubes were cast for compression testing and remain 54 cubes for chloride penetration test (CPM).

Out of 100% of binding material, only 10% is cement and the remaining 90% is GGBS. Like this the percentages of GGBS are changed to 80%, 70%, 60% and 50% and cement is also varied to 20%, 30%, 40% and 50%, silica fume is same for all mixes only adding 5%, Added 0.5% of Superplasticizers in the concrete mix for better workability nature. For all these combinations casting of the cubes is carried out. For clear understanding cube details follow Table

A. Chloride Ion Penetration

The main reason behind exposure of the cubes to the NaCl solution is that, in coastal areas salt content in the moisture will be very high when this salt enters into the concrete, corrosion of steel will take place due to the reactions in between the chloride ions and steel. Due to the corrosion steel becomes very weak and further failure may also take place. So the main target is to find out the amount of salt penetration and at what time it will be penetrating into the concrete.

B. Sampling of Concrete Powder

A cube of each different mixes was taken out from the NaCl solution. After completion of NaCl curing for 28 and 90 days, the surface of cubes were cleaned with a dry cloth. Drilling the cube is carried out on each side with different depths of 5 mm, 10 mm, 15 mm, 20 mm, 25 mm. Powder was collected from the same hole at different depths on each side. By using Time and Depth method, penetration of chloride ions into the concrete at different depths is calculated after exposing the cubes to the NaCl solution for 28 and 90 days and the same were tested to find out the penetration of chloride ion into the concrete.

C. Chemical Analysis Process

After collecting powder at different samples weigh each depth sample. It should be around 4 to 5 grams. The main aim is to convert this sample from solid state to liquid state. For this take this sample into a 250 ml capacity conical flask.

Add 40 ml of distilled water to it and stir well with a mixing rod till solid become liquid. When the concrete powder is dissolved into the distilled water, it takes all the properties present in the concrete powder. Conversion of powder to liquid form is completed. Stack it to about one hour without disturbing. After completion of 1 hour collect the liquid present above the bowl. Titrate only 10ml of this liquid taking into the conical flask against the 0.1N of $AgNo_3$ Silver nitrate ($AgNo_3$) by adding the 2 to 3 drops of Potassium Chromate ($K_2Cr_2O_4$). When color changes from yellow to brick red titration is over. By taking the burette readings chloride content will be calculated using the formula.

D. Percentage of Chloride Ion Penetration

The percentages chloride ion penetration in the concrete powder was finally calculated using the formula;

% of chloride in concrete powder = $K * N * V/W$

Where,

K = a constant depending upon total volume of solution made and the volume of solution taken for titration

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N = normality of $AgNO_3$ solution, here taken 0.01
V = volume of $AgNO_3$ reach the end point.
W = weight of the concrete drilling powder sample.

VI. TESTS AND RESULTS

Firstly, we test the specific gravity of various materials compression test results of the cubes after completion of 28 days and 90 days for plain concrete.

Table III detail about the specific gravity for various materials such as cement, GGBS, silica fume, fine aggregate and coarse aggregate these materials used in preparation of concrete cubes.

Table III: Specific gravity of various materials

Materials	Specific gravity
Specific gravity of cement	3.15
Specific gravity of GGBS	2.9
Specific gravity of Silica fume	2.2
Specific gravity of fine aggregate	2.54
Specific gravity of coarse aggregate	2.89

Fig. 2: Compressive strength

Fig. 2 shows the compression strength obtained for cubes casted and tested for 28 days and 90 days.

Table IV and Table V gives the information about plain concrete cubes with 0.3, 0.4, 0.5 W/C compressive strength and 28 days and 90 days respectively. Average of 3 cubes values taken in the last column.

Table IV: Compression values for plain concrete cubes after 28 days

w/c	1st cube	2nd cube	3rd cube	Average
0.3	62.22	53.33	74.66	63.407
0.4	59.11	40.44	44.44	47.99
0.5	28.44	27.11	22.22	25.923

Table V: Compression values for this plain concrete cube after 90 days.

W/C	1st cube	2nd cube	3rd cube	Average
0.3	63.55	49.77	60.44	57.92
0.4	61.33	52.44	67.55	60.44
0.5	35.11	29.33	34.66	33.03

Table VI and Table VII gives the information about replaced cement with different percentages of GGBS and silica fume compressive strength for 28 days and 90 days.

Table VI: Compression test values for GGBS and silica fume after 28 days

w/c	GGBS %	1st cube	2nd cube	3rd cube	Average
0.3	90%	31.33	28.88	33.77	31.25
	80%	42.22	44.88	37.33	41.47
	70%	44.88	47.11	51.11	41.47
0.4	80%	23.55	27.55	32.11	27.7
	70%	30.22	27.55	30.22	29.33
	60%	29.33	24.88	27.11	27.1
0.5	70%	21.33	14.22	16.88	17.47
	60%	23.11	22.22	22.66	22.66
	50%	33.77	31.11	20.44	28.44

Table VII: Compression test values for GGBS and silica fume after 90 days of curing.

w/c	GGBS %	1st cube	2nd cube	3rd cube	Average
0.3	90%	41.77	39.11	44.88	41.92
	80%	41.77	47.11	51.55	46.81
	70%	53.33	51.55	47.11	50.66
0.4	80%	40.88	40.88	27.11	36.29
	70%	38.22	33.33	32	34.51
	60%	34.66	38.66	37.77	37.03
0.5	70%	25.77	23.11	23.11	23.99
	60%	35.55	35.55	34.66	35.25
	50%	43.55	48	49.77	47.1

Fig. 3 drilling the cubes by using a drilling machine at different depths powder collected at all 6 sides of same cube and weighs the powder and pack carefully, it is a very fine powder during drilling without any water use the powder will be taken only dry material will collected as shown in Fig.3.

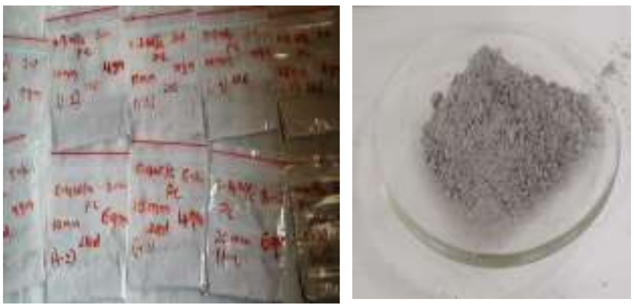

Fig. 3: Drilling powder

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Table VIII: Plain concrete drilling depths values

W/C	Immersion Age	Average depth of drilling & respective chloride concentrations				
		5	10	15	20	25
		mm	mm	mm	mm	Mm
0.3	28	0.11	0.1	0.09	0.08	0.06
	56	0.15	0.08	0.08	0.07	0.06
	90	0.21	0.15	0.12	0.1	0.09
0.4	28	0.14	0.12	0.11	0.1	0.09
	56	0.14	0.1	0.08	0.08	0.07
	90	0.19	0.17	0.14	0.11	0.09
0.5	28	1.16	1.15	0.12	0.11	0.09
	56	0.13	0.11	0.11	0.1	0.09
	90	0.2	0.19	0.17	0.12	0.1

Table VIII shows the Cubes were drilled at different depths 5mm, 10mm, 15mm, 20mm, and 25mm respectively and the corresponding chloride ion penetration results for plain concrete.

Fig. 4: Cube drilling at various depths

Fig. 4 Shows about the drilling of cubes at different depths by using drilling machine the diameter of drilling machine bit is 10 mm drilled at all 6 sides of same cube with different depths 5, 10, 15, 20, 25mm.

Fig. 5: Colour changes yellow to brick red colour

Fig. 5 Shows about the after collecting the concrete powder, powder it will convert to solid to liquid by using distilled water and these samples titrate against the AgNo3 solution then colour changing of concrete sample yellow colour to brick red as shown in fig. 5.

Table IX shows the details about the chloride ion penetration for concrete cubes with different water to cement ratios and variation in GGBS replaced with cement percentages. NaCl exposing days 28 days, 56 days, and 90 days and various depths 5mm, 10mm, 15mm, 20mm, 25mm

Table IX: Replaced concretechloride ion penetration details

w/c	GGBS	NaCl Age	Average depth of drilling & Respective chloride concentrations (%)				
			5	10	15	20	25
	%		mm	mm	mm	mm	mm
0.3	90	28	0.11	0.05	0.02	0	0
		56	0.16	0.07	0.04	0.03	0
		90	0.12	0.08	0.07	0.05	0.02
	80	28	0.02	0.02	0.01	0	0
		56	0.04	0.03	0.02	0.01	0
		90	0.06	0.05	0.05	0.04	0.02
	70	28	0.02	0.01	0.01	0	0
		56	0.04	0.02	0.02	0.01	0
		90	0.06	0.05	0.04	0.04	0.02
0.4	80	28	0.04	0.03	0.02	0	0
		56	0.07	0.03	0.02	0.01	0
		90	0.07	0.05	0.04	0.04	0.02
	70	28	0.02	0.02	0.01	0	0
		56	0.05	0.04	0.04	0.01	0.01
		90	0.09	0.08	0.07	0.05	0
	60	28	0.03	0.02	0.01	0	0
		56	0.04	0.03	0.03	0.02	0.01
		90	0.08	0.06	0.05	0.05	0.05
0.5	70	28	0.03	0.03	0.02	0.01	0
		56	0.04	0.04	0.03	0.02	0.01
		90	0.09	0.08	0.06	0.05	0.04
	60	28	0.05	0.04	0.03	0.02	0
		56	0.08	0.03	0.02	0.02	0.01
		90	0.07	0.06	0.06	0.05	0.04
	50	28	0.05	0.04	0.03	0.02	0
		56	0.07	0.04	0.04	0.03	0.01
		90	0.09	0.08	0.07	0.06	0.05

Fig. 6-8 Shows the pain concrete chloride ion penetration results for 0.3, 0.4, 0.5 w/c ratios.

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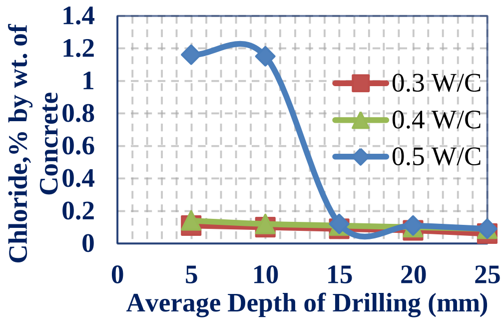

Fig. 6: Chloride ion penetration for 28 days

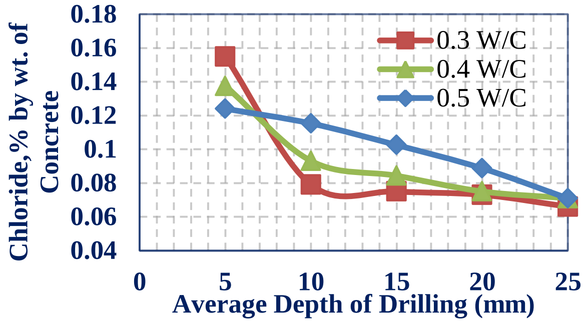

Fig. 7: Chloride ion penetration for 56 days

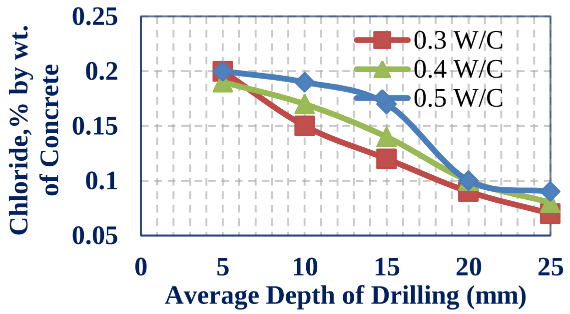

Fig. 8: Chloride ion penetration for 90 days

28 days NaCl exposed cube results

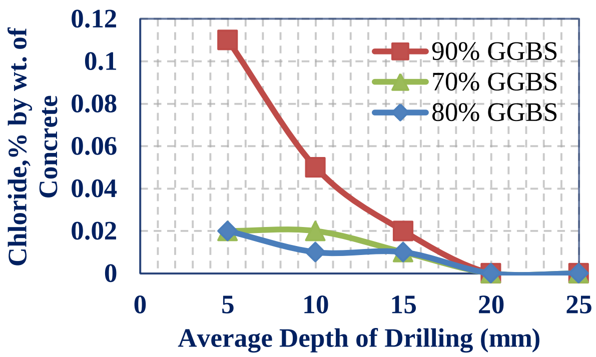

Fig. 9: Chloride ion penetration for 28 days 0.3 w/c

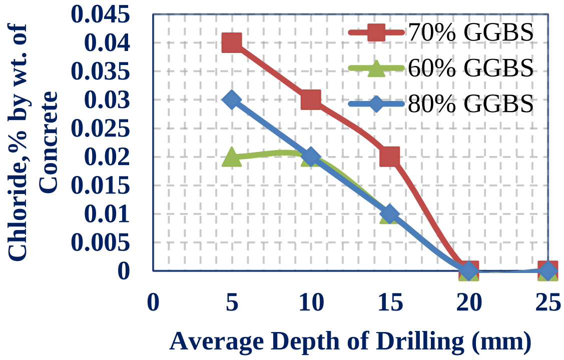

Fig. 10: Chloride ion penetration for 28 days 0.4 w/c

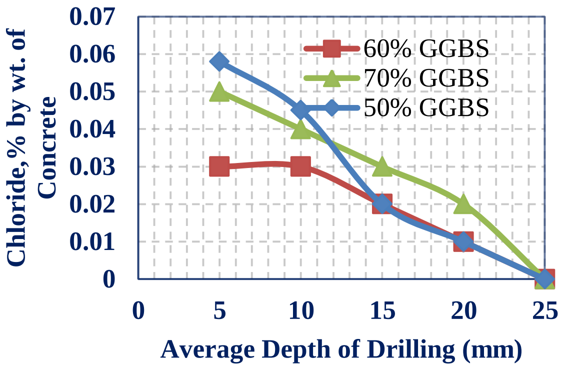

Fig. 11: Chloride ion penetration for 28 days 0.5 w/c

Fig. 9-11 shows the replaced concrete chloride ion penetration details with different depths for 28 days of NaCl curing.

Fig. 12-14 shows the replaced concrete chloride ion penetration details with different depths for 56 days NaCl curing.

Fig. 15-17 shows the replaced concrete chloride ion penetration details with different depths for 90 days NaCl curing.

56 days NaCl exposed cube results

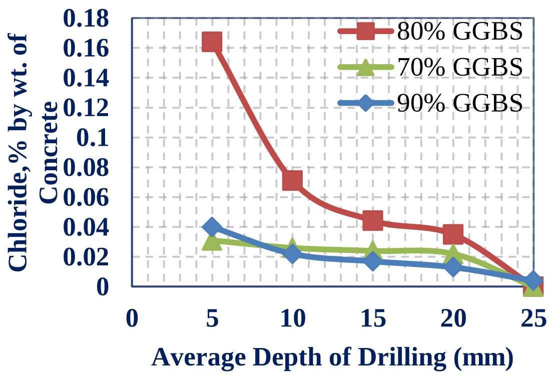

Fig. 12: Chloride ion penetration for 56days 0.3 w/c

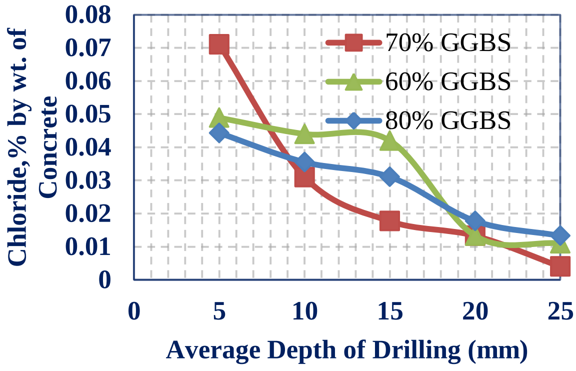

Fig. 13: Chloride ion penetration for 56 days 0.4 w/c

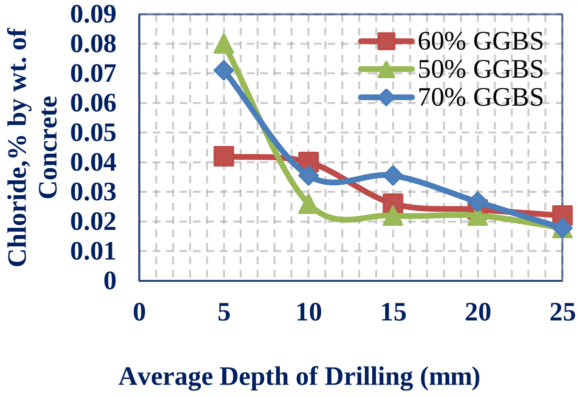

Fig. 14: Chloride ion penetration for 56 days 0.5 w/c

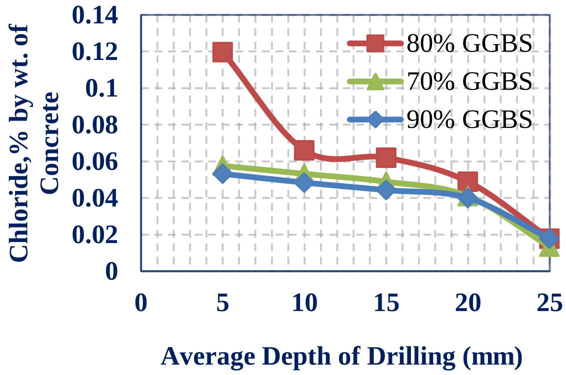

Fig. 15: Chloride ion penetration for 90 days 0.3 w/c

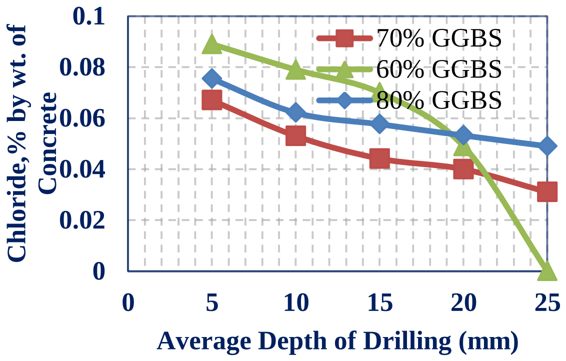

Fig. 16: Chloride ion penetration for 90 days 0.4 w/c

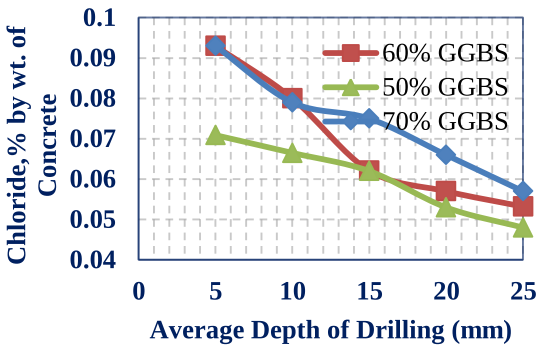

Fig. 17: Chloride ion penetration for 90 days 0.5 w/c

By following the 28 days, 56 days and 90 days of cubes after exposing NaCl solution results, then clearly understand the penetration of chloride ion percentages in concrete for each and every 5 mm depths. Starting surface contains high chlorides then it slowly penetrated into the concrete sample is started. So every 5mm depths results is must be taken, by following these graphs 5mm the penetration is high, then 10mm the penetration is less than 5mm like that at last 25 mm the penetration is very negligible the graphs is in the shape of decreasing order, that means penetration of chloride ion is also decreasing, by using these GGBS and silica fume in concrete is less penetration of chloride ion when comparing the sample with plain concrete.

VII. CONCLUSTION

1. Usage of fine materials like ground granulated blast furnace slag (GGBS) and silica fume in concrete leads to low permeability and penetration of chloride ion into concrete. If penetration of chloride ions is less, then the corrosion of steel present in the concrete will also be low. And it will take more time to get corroded. From the results one can understand the amount of chloride ion penetration in relation to both time and depth.
2. Both GGBS and silica fume are efficient to resist the penetration of chloride ions. Moreover they will also resist the penetration of the sulphate, carbonates, and other material which are toxic to the concrete.
3. From the results it is clear that the chloride ion penetration in the NaCl cured cubes for 28 days and 56 days is zero at the depths of 20mm and 25mm. i.e., there is no chloride ion penetration at that depth. For 90days cube it is only 0.01% i.e., very negligible. For plain cube chloride ion penetration is nearly 0.1%. Compared to plane concrete cubes, a cube with GGBS and silica fume has low chloride ion penetration. It is observed from the experiment that for 70% replacement of GGBS and silica fume at 25mm depth, the penetration of chloride ion decreases by 0.99 percent approximately for 90 days which substantially increases the life span of structure.

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