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Effect of different types of Cement in Concrete Chloride Permeability

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Abstract: This research paper presents the effect of different types of cement CEM-I, CEM-II/A-M, CEM-II/B-M, and CEM-III/A in concrete as per BSEN-197-1 on chloride permeability to Concrete. Chloride permeability in concrete is one of the major reasons for corrosion of embedded steel reinforcement in concrete & it results deterioration of concrete structure due to internal volume expansion of reinforced steel as because of corrosion in reinforcement steel. So in this research work a detail experimental work was conducted on penetrability of chloride ions in concrete made with different types of Cement CEM-I, CEM-II/A-M, CEM-II/B-M and CEM-III/A through RCPT as per ASTM C-1202 & calorimetric test by using 1% AgNO3 solution. The research work shows that concrete made with Blast furnace slag cement CEM-III/A shows minimum permeability of chloride ions while concrete made with normal Portland cement CEM-I shows maximum permeability of chloride ions. Thus resistance of chloride permeability to concrete with different cement is of the following decreasing order CEM-III/A > CEM-II/B-M > CEM-II/A-M > CEM-I. This research work revealed that cement with higher amount of pozzolonic materials [3] like shows minimum chloride ion penetration in concrete due to higher capability of Chloride binding for Pozzolonic materials present in cement.
Keywords: CEM-I, CEM-II/A-M, CEM-II/B-M, CEM-III/A, Pozzolona, Fly Ash, GGBS.

I. INTRODUCTION

Corrosion of reinforcement steel in concrete structure in marine environment is a serious concern in construction industries due to chloride permeability in concrete. Considering this durability problem in concrete with regards to corrosion of embedded steel reinforcement in concrete, selection of cement in concrete plays an important role in durability of concrete. So in this research work Chloride permeability of concrete with different types of Cement of mostly available in market like Portland Cement CEM-I, Portland Composite cement CEM-II/A-M & CEM-II/B-M , Blast furnace slag cement CEM-III/A as per BSEN-197-I ,was studied through RCPT as per ASTMC-1202 & calorimetric test by using 1% AgNO3 solution. The research work shows that concrete made with Blast-furnace slag cement CEM-III/A shows minimum permeability of chloride ions in concrete while concrete made with normal Portland cement CEM-I shows maximum penetration of chloride ions in concrete. The experimental work also shows that concrete with cement having higher % of pozzolonic materials [2] shows minimum permeability of chloride ions in concrete due to Chloride binding capability of pozzolonic materials present in cement.

II. MECHANISM OF CHLORIDE INDUCED CORROSION

The corrosion of embedded reinforcement Steel in concrete is an electrochemical process .The embedded steel reinforcement is inherently protected against corrosion by passivation of the steel surface due to the high alkalinity (pH > 12.5) of the concrete. The major two cause of corrosion of steel is either due to reduction of concrete pH due to carbonation or by damaging of thin passivizing layer of Iron oxide on embedded steel reinforcement due to ingress of chloride ions in concrete. The schematic representation of corrosion mechanism of embedded reinforcing steel is hereby explained.

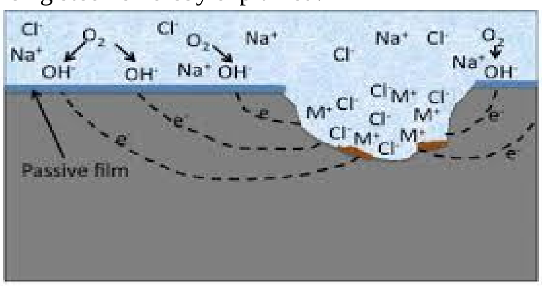

Figure 1: Mechanism of chloride induced corrosion of steel reinforcement

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III.EXPERIMENTAL SETUP

Standardized testing procedures adopted as Rapid chloride permeability test (RCPT) of concrete as per AASHTO T277 & ASTM C 1202. According to ASTM C1202 test, a water-saturated, 50 mm thick, 100 mm thick diameter concrete specimen is subjected to a 60 v applied DC voltage for 6 hours using the apparatus and the cell arrangement as shown in Figure-2. In one reservoir is a 3.0 % NaCl solution and in the other reservoir 0.3 M NaOH solution is used. The total charge passed is determined and this is used to rate the concrete as per Table-I & resistivity of chloride ions penetrability in concrete. After the sample is removed from the cell at the end of the 6 hours the sample is again using for chloride penetrability test by calorimetric method using 0.1M AgNO3 solution. In addition to the RCPT of concrete as per ASTMC1202 the compressive strength of concrete with different types of cement & partial replacement of Portland cement with pozzolonic materials Fly ash & GGBS at various proportion has been studied here. The size of sample used for evaluation of concrete compressive strength at different age is 150mm x 150mm x 150mm cube samples. The sample used for RCPT was cured for 28-days & the test was conducted after 28-days of curing only.

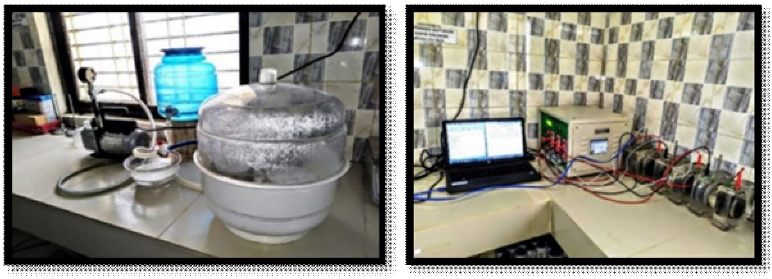

Figure-2: RCPT test of concrete as per ASTMC1202

TABLE I
RCPT rating as per ASTMC1202

Charge Passed (Coulombs)	Chloride Ion Penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

IV.MATERIALS

In this research experimental work a reference concrete grade was used of C-30/37 grade with normal Portland cement CEM-I. The different concrete samples was prepared by changing the normal Portland cement CEM-I with different other types of cement CEM-II/A-M, CEM-II/B-M & CEM-III/A keeping all other ingredients of Concrete including w/c ratio was remain same as per design mix of reference concrete grade C-30/37. The physical & chemical properties of all the materials used in this experiment are tabulated here.

TABLE II
Physical properties of different types of cement

Test Parameter	CEM-I	CEM-II /A-M	CEM-II /B-M	CEM-III /A
Sp. gr	3.15	2.72	2.8	2.92
Fineness (Cm2 /gm.)	3630	3230	3670	4282
Soundness mm	0.65	1.8	1.6	1.38
Compressive strength at 7 Days	48.5	39.3	37.5	28.2
Compressive strength at 28-days 28 Days	56.4	49.2	48.2	43.2

TABLE III
Chemical properties of different types of cement

Component %	CEM-I	CEM-II/ A-M	CEM-II/ B-M	CEM-III /A
CaO	63.8	62.4	57.8	53.52
SiO_2	21.6	20.7	23.6	24.42
Al_2O_3	5.2	4.32	6.41	8.96
Fe_2O_3	3.92	3.22	3.55	2.15
MgO	1.82	2.42	1.46	2.92
SO_3	1.22	3.2	2.35	2.82
Na_2O	0.171	0.334	0.096	0.284
K_2O	0.432	1.03	1.06	0.662

TABLE IV
Physical properties of Coarse Aggregate

Test Parameter	Test Results
Sp Gravity	2.86
Dry rodded Bulk Density in Kg/cum	1672
Water absorption in %	0.44
Aggregate Impact value in %	12.21
Loss Angel Abrasion in %	0.426
Flakiness Index in %	20.24
Elongation Index in %	22.25
Magnesium Sulphate Soundness in %	13
Grading Requirement (19-4.75 mm)	Satisfactory as per ASTMC33

TABLE V
Physical properties of Fine Aggregate

Test Parameter	Test Results
Sp Gravity	2.62
75 micron passing in % by weight	1.73
Fineness Modulus	2.72
Water absorption in % by weight	1.58

TABLE VI
Test report of mixing water

Test Parameter	Test Results
pH	7.5
Chloride Content in mg/l	250
Sulphate content (S04-2) in mg/l	1.8
Total solids in mg/l	750
Total Alkalinity as $CaCO_3$ in mg/l	285

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TABLE VII
Design mix of Reference concrete C-30/37

Name of the Ingredient	Quantity in Kg/Cum
Cement content	438
Water content	175
Water Cement Ratio (W/C)	0.4
Total amount of Coarse aggregate	1142
Coarse Aggregate 19 mm [60%]	685.2
Coarse Aggregate 12.5 mm[40%]	456.8
Fine Aggregate	685
Super plasticiser @ 0.8 % by weight of cement	3.5

TABLE VIII
Design mix of Reference concrete C-30/37

Sample Details	w/c Ratio	Cement	CA	FA	Superplasticiser
S_1 CEM-I, 52.5N (100%)	0.4	438	1142	685	3.5
S_2 CEM-II/A-M (100%)	0.4	438	1142	685	3.5
S_3 CEM-II/B-M (100%)	0.4	438	1142	685	3.5
S_4 CEM-III/A (100%)	0.4	438	1142	685	3.5

V. RESULTS & DISCUSSIONS

A. Compressive Strength of Concrete.

The average compressive strength of concrete at 7-days for sample mix S1 with normal Portland cement CEM-I & Sample mix S2 with Portland composite Cement of type CEM-II/A-M shows slightly higher strength at early age of 7-days as compared with other two types Sample mix S3 & S4 with Portland Composite cement of type CEM-II /B-M & Blast furnace slag cement CEM-III /A. The experimental works also shows that at 28-days concrete mix S1 with normal Portland cement CEM-I (M1) shows maximum strength , however mix with Portland composite cement of type CEM-II/A-M also shows slightly higher strength than sample mix S3 & S4 with other two types of cement like Portland composite cement of type CEM-II/B-M & Blast-furnace slag cement CEM-III/A .The strength gaining of concrete at both 7-days & 28-days are in lower side with cement CEM-II/B-M & CEM-III/A due to lower part of clinker & increased part of pozzolonic materials for both CEM-II/B-M(Clinker-65-79% & Pozzolonic materials part-21-35%)[2] & CEM-III/A(Clinker-35-64% & Blast furnace slag part-36-65%)[2]. Hence, for cement with higher the part of Pozzolonic materials & lower part of clinker shows lower strength at 7-days & 28-days but at the same time strength gaining after 7-days is prominently higher in cement with CEM-II/B-M & CEM-III/A.

TABLE IX
Compressive Strength of concrete at 7-days & 28-days

Sample Mix	7-Days Strength in N/mm2	28-Days Strength in N/mm2
S1	56.4	68.2
S2	52.2	66.2
S3	44.2	62.4
S4	37.2	48.6

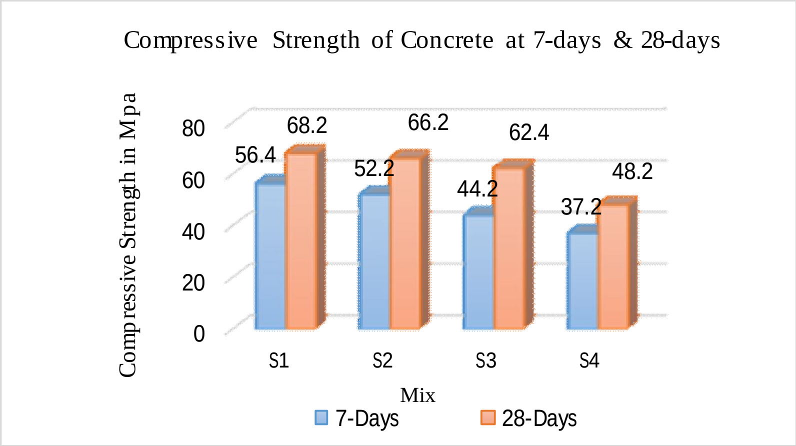

Figure-3: Compressive strength of different concrete mix at 7-days & 28-days.

B. *Chloride Permeability to Concrete.*

The experimental work on Chloride penetrability to concrete through RCPT as per ASTMC-1202 & also through Calorimetric test by using 0.1M $AgNO_3$ solution shows that concrete mix S4 made with Blast-furnace slag cement CEM-III/A & mix S3 with Portland composite cement CEM-II/B-M shows minimum permeability of Chloride ions than concrete mix S1 & S2 made with normal Portland cement CEM-I & with Portland composite cement of type CEM-II/A-M. The results indicate that cement with higher % of clinker part shows maximum penetration of chloride ions due to lower binding of Chloride ions, while in cement CEM-II/B-M (Clinker-65-79% & Pozzolonic mix part-21-35%) [2] & cement CEM-III/A (Clinker-35-64% & Blast furnace slag part-36-65%) [2] Shows minimum chloride penetration due to higher % of pozzolonic materials present in cement & its higher capability of chloride binding through pozzolonic materials present in cement CEM-II/B-M & CEM-III/A. Even the chloride permeability in concrete with Blast-furnace slag cement shows minimum but at the same time the negative effect of such cement is pH reduction in concrete & it is again a prominent condition for damaging of passivizing layer on steel reinforcement. So by using Slag cement CEM-III/A & composite cement CEM-II/B-M in marine environment is having other negative effect of reduction in pH than concrete with normal Portland cement CEM-I which is a good condition for corrosion of steel reinforcement.

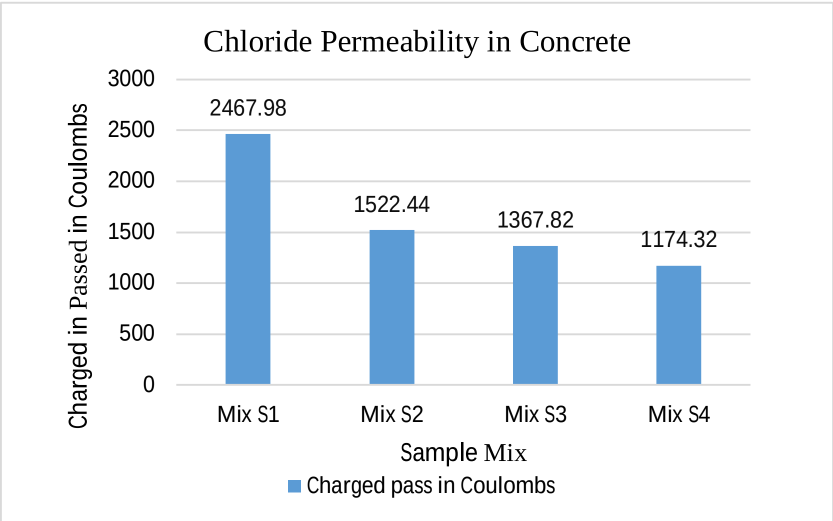

Figure-4: RCPT value in Coulombs as per ASTMC-1202

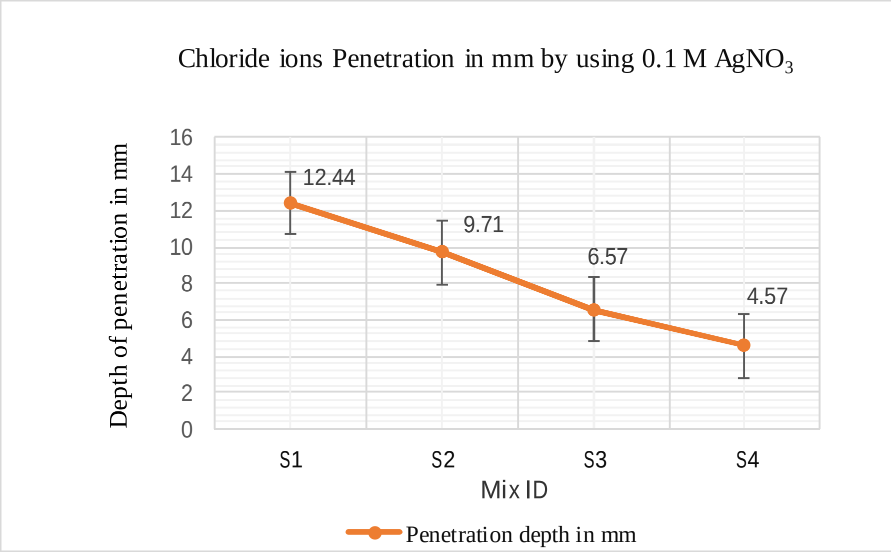

Figure-9: Average depth of chloride ions penetration in mm.

Figure-10: Silver Nitrate test for Chloride permeability in concrete for all four types of cement mix S1 to S4 (left to Right).

VI.CONCLUSIONS

The chloride permeability of concrete made with cement having higher % pozzolonic material shows minimum penetration of chloride ions due to increased level of chloride binding capacity of pozzolonic materials present in cement CEM-III/A & CEM-II/B-M due to presence of high composition of Al_2O_3 in Pozzolonic materials used in cement, while concrete made with normal Portland cement shows maximum penetration of Chloride ions with same w/c ratio. It is also concluded that even normal Portland cement CEM-I shows maximum penetration of chloride ions but still the pH of the pore fluid is maximum with normal Portland cement CEM-I & with high pH the passivizing layer on steel is stable enough to protect steel from corrosion phenomenon. So cement with high content of pozzolonic materials even it restrict the chloride penetration through mechanism of chloride binding capability of pozzolonic materials due to its rich content of Al_2O_3 but at the same time it lower the pH of the concrete in other way, which is again vulnerable situation for corrosion of steel.

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