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INFLUENCE OF W/C RATIO, TYPES OF CEMENT & POZZOLONIC MATERIALS IN CHLORIDE PERMEABILITY TO CONCRETE

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Abstract

The chloride permeability in concrete is one of the primary reason for corrosion of reinforcement steel in concrete. Thus chloride permeability in concrete is one of the important durability problem in concrete. Hence many research work were carried out in past regarding mitigation of chloride ions in concrete either internal treatment during mixing stage or externally by using protective coating on the hardened concrete surface. In the present paper the methods which are usually adopted during mixing stage like using of optimum w/c ratio in the mix, selection of proper cement type and addition of pozzolonic material as a partial substitute of normal Portland cement in concrete were studied in details. The present paper investigate the influence of w/c ratio in concrete, Cement type in the mix and presence pozzolonic material in concrete chloride permeability. The investigation was carried out with w/c ratio from 0.35 to 0.55, different types of cement like CEM-I, CEM-II/A-M, CEM-II/B-M, CEM-III/A as per BSEN-197-1 & PPC as per IS-1489-P-1 and pozzolonic materials such as low Calcium oxide Fly ash (F-type) & high alumina (>11%) GGBS in concrete for chloride penetrability test of Concrete as per ASTM C1202.The outcome of this research work shows that concrete higher w/c ratio shows higher amount of chloride penetration in concrete & vice versa, the investigation also shows that chloride permeability in concrete significantly reducing with cement CEM-II/B-M , CEM-III/A and PPC than mix with normal Portland cement. The research investigation also shows that concrete high Alumina GGBS in concrete shows significant reduction in chloride permeability in concrete and low Calcium oxide Fly ash in concrete also shows significant reduction in chloride permeability to concrete. Thus resistance of chloride permeability to concrete with different types of cement is of following decreasing order PPC >CEM-III/A > CEM-II/B-M > CEM-II/A-M > CEM-I.

***Key words* - CEM-I, CEM-II/A-M, CEM-II/B-M, CEM-III/A, PPC, Chloride, Fly Ash, GGBS, RCPT.**

I. INTRODUCTION

The chloride induced Corrosion of steel reinforcement in reinforced concrete structure is one of the most important durability problem for reinforced concrete structures in marine environment. Typically, the pore solution of concrete has a pH-value above 12.6 due to the presence of $Ca(OH)_2$, and even higher values can be observed for concrete rich in NaOH and KOH. The highly alkaline environment of the pore solution favors the formation of a passive oxide film of Iron oxide on the surface of the steel reinforcement and a high pH-value is therefore an important inhibiting factor with regard to corrosion initiation of reinforced steel in Concrete. The free chloride ions entered in concrete may cause depassivation of the protective Iron oxide film layer of reinforcement steel leading to corrosion of steel in concrete & it results increasing of steel volume & thus spalling of cover concrete. The chloride resistance is depends on the permeability of the concrete and the thickness of clear cover to the reinforcement steel. So durability of the reinforced concrete structure against chloride attack is mainly depend on the chlorides penetrability resistance of concrete. In this research work a detail experimental study has been conducted on penetrability of chloride ions in concrete by using Rapid Chloride Permeability test (RCPT) method as per AASHTO T277 & ASTMC1202. In this research work a control concrete mix M1 of C-30/37 grade was used by using normal Portland cement CEM-I with w/c ratio 0.4 & other samples mixes were prepared by changing the w/c ratio , changing the type of cement CEM-I with other types of cement CEM-II/A-M, CEM-II/B-M ,CEM-III/A as per BSEN-197-1 & PPC as per IS-1489, P-1, and also partial replacement of normal Portland cement CEM-I with pozzolonic materials low Calcium oxide Fly ash 15%, 20% ,25%, 30% & GGBS 30% ,40%, 50%. 60% in the mix keeping all other ingredients of concrete remain same as per design mix design of control mix C-30/37. The outcome of this research work shows that concrete higher w/c ratio shows higher amount of chloride penetration in concrete & vice versa, the investigation also shows that chloride permeability in concrete significantly reducing with cement CEM-II/B-M , CEM-III/A and PPC than mix with normal Portland cement. The research investigation also shows that concrete high Alumina GGBS in concrete shows significant reduction in chloride permeability in concrete and low Calcium oxide Fly ash in concrete also shows significant reduction in chloride permeability to concrete. Thus resistance of chloride permeability to concrete with different types of cement is of following decreasing order PPC >CEM-III/A > CEM-II/B-M > CEM-II/A-M > CEM-I.

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.

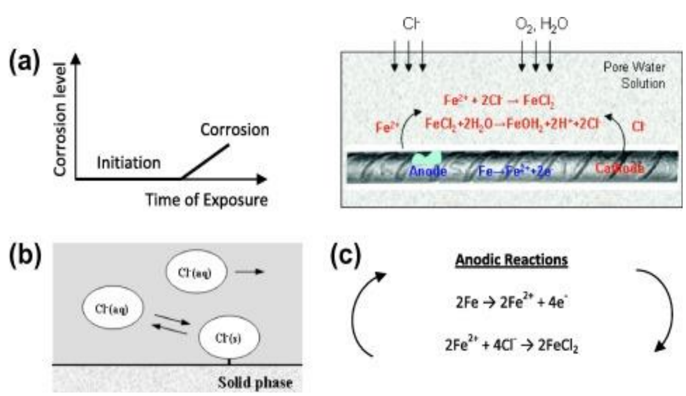

Figure 1: Mechanism of chloride induced corrosion of reinforcement steel in concrete

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.

Figure-2: RCPT test of concrete as per ASTMC1202

Table-1: 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

The different material used in the experimental investigation are different types of cement like CEM-I, CEM-II/A-M, CEM-II/B-M , CEM-III/A as per BSEN-197, P-1 and PPC as per IS-1489, P-1 and Pozzolonic materials low Calcium oxide Fly ash , high Alumina GGBS . The coarse aggregate used for this experimental work was crushed Basalt rock & Fine aggregate of river sand having FM of 2.7. The superplasticizer used in this research work was Poly carboxylate ether based product. The control mix used in the experimental work was C-30/37 grade with cement content (CEM-I) 438 Kg/m3 , coarse aggregate content 1142 kg/m3 , Fine aggregate content 685 kg/m3 , water content 175 kg/m3 and Superplasticizer 3.5

kg/m3. The different mix used in the experiment other than control mix with cement CEM-I and w/c ratio 0.4 were changing the w/c ratio in the mix , cement type and addition of Pozzolonic materials Fly ash and GGBS at various dosage as a partial substitute of normal Portland cement CEM-I in the mix. The test results of all the materials used in the experimental investigation are tabulated.

Table-2: Physical properties of different types of cement & Pozzolonic materials used in the experiment.

Test Parameter	CEM-I	CEM-II/A-M	CEM-II/B-M	CEM-III/A	PPC	Fly Ash	GGBS
Sp. gr	3.15	2.72	2.84	2.93	2.86	2.24	2.85
Fineness (Cm2 /gm.)	3557	3638	3735	4286	3832	3724	3462

Table-3: Chemical composition of different types of cement and pozzolonic materials used in the experiment.

Component %	CEM-I	CEM-II/A-M	CEM-II/B-M	CEM-III/A	PPC	Fly Ash	GGBS
CaO	63.28	55.49	57.9	53.62	44.38	1.87	34.4
SiO_2	21.4	25.24	26.23	24.48	29.21	61.28	36.32
Al_2O_3	5.06	8.29	9.15	8.98	11.51	27.61	17.31
Fe_2O_3	3.79	3.37	3.68	2.24	3.51	5.42	1.04
MgO	2.12	1.85	1.38	2.97	1.96	0.16	7.22
SO_3	2.86	2.68	2.34	2.84	2.78	0.12	0.34
Na_2O	0.175	0.337	0.099	0.284	0.296	0.142	0.573
K_2O	0.442	1.08	1.09	0.665	1.07	1.441	0.174

Table-4: Physical properties of Coarse Aggregate.

Test Parameter	Test Results
Sp Gravity	2.86
Dry rodded Bulk Density in Kg/cum	1675
Water absorption in %	0.48
Aggregate Impact value in %	12.31
Loss Angel Abrasion in %	0.73
Flakiness Index in %	18.62
Elongation Index in %	16.4
Magnesium Sulphate Soundness in %	13
Grading Requirement (19-4.75 mm)	Satisfactory as per ASTMC33

Table –5: Physical properties of Fine Aggregate

Test Parameter	Test Results
Sp Gravity	2.58
75 micron passing in % by weight	1.62
Fineness Modulus	2.74
Water absorption in % by weight	1.52

Table-6: Properties of mixing water.

Test Parameter	Test Results
pH	7.6
Chloride Content in mg/l	232
Sulphate content (S04-2) in mg/l	1.92
Total solids in mg/l	759
Total Alkalinity as $CaCO_3$ in mg/l	312

Table-7: Mix details of different sample ID in kg/m3 used in the experimental work

Mix Details	w/c Ratio	Cement	SCM	CA	FA	Superplasticizer
M, CEM-I, 52.5N (100%)	0.4	438	NA	1142	685	3.5
M2, CEM-II/A-M (100%)	0.4	438	NA	1142	685	3.5
M3, CEM-II/B-M (100%)	0.4	438	NA	1142	685	3.5
M4, CEM-III/A (100%)	0.4	438	NA	1142	685	3.5
M5, PPC (100%)	0.4	438	NA	1142	685	3.5

M6, W/C-0.45	0.45	438	NA	1142	685	3.5
M7,W/C-0.50	0.50	438	NA	1142	685	3.5
M8, W/C-0.55	0.55	438	NA	1142	685	3.5
M9, CEM-I (85%) + FA (15%)	0.4	372.3	65.7	1142	685	3.5
M10, CEM-I (80%) + FA (20%)	0.4	350.4	87.6	1142	685	3.5
M11, CEM-I (75%) + FA (25%)	0.4	328.5	109.5	1142	685	3.5
M12, CEM-I (70%) + FA (30%)	0.4	306.6	131.4	1142	685	3.5
M13, CEM-I (70%) + GGBS (30%)	0.4	306.6	131.4	1142	685	3.5
M14, CEM-I (60%) + GGBS (40%)	0.4	262.8	175.2	1142	685	3.5
M15, CEM-I (50%) + GGBS (50%)	0.4	219	219	1142	685	3.5
M16, CEM-I (40%) + GGBS (60%)	0.4	175.2	262.8	1142	685	3.5

V. RESULTS & DISCUSSION

The chloride permeability to different concrete sample as per the Table-7 with different types of cement CEM-I, CEM-II/A-M, CEM-II/B-M, CEM-III/A, PPC & different w/c ratio and partial replacement of Portland cement with Fly ash & GGBS at various proportion is hereby tabulated below in Table-8.

Table-8: Average RCPT value in Coulombs

Mix ID	Av RCPT (Coulombs)
M1	1420.3
M2	1052.28
M3	712.98
M4	930.42
M5	509.4
M6	937.34
M7	1644.84
M8	2385.72
M9	759.96
M10	945.90
M11	1324.08
M12	848.7
M13	482.04
M14	414.18
M15	273.7
M15	252.53

From the above results it has been observed that Chloride penetrability to concrete with w/c ratio 0.55 is maximum than with other lower level of w/c ratio like 0.40, 0.45 and 0.50, it has also noticed that chloride permeability in the mix 0.4 w/c shows minimum chloride penetration in concrete than other w/c ratio in concrete, thus lower the w/c higher is the resistance against chloride penetration in concrete. The increase in w/c ratio in concrete is simply make the concrete more permeable due to formation bigger pore size in concrete & it result concrete become more permeable & become easy for transport of external ions to concrete . The experimental results also shows that concrete with blended cement PPC, CEM-III/A and CEM-II/B-M [3] shows more resistant against chloride permeability to concrete. The blending cement protect chloride ions to concrete due to its higher fineness which support the blockage of pore and at the same time due to presence of higher amount of Alumina in these cement CEM-II/B-M, CEM-III/A, PPC they shows the chloride binding capability in concrete. In addition to that due to pozzolonic materials presence in blending cement & their pozzolonic reaction in concrete the densification of pore structure occurs due to formation of secondary C-S-H in concrete which will block the pore structure [12]. The

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experimental results also shows that concrete made with partial replacement of Portland cement CEM-I with Fly ash shows reduction in chloride permeability than control mix, however it also observed that up to 20% there is no significant improvement in chloride resistance, but with further increase in dosage up to 25-30% % in mix shows significant reduction in chloride penetration to concrete. The research work also shows that concrete with high Alumina GGBS in the mix shows significant improvement in reduction of chloride penetration to concrete due its capability of both chloride binding because of high Alumina in it and also due to high fineness it will also act as a filler in pore structure & thus helps to reduce chloride penetration to concrete. The research work also shows that higher the GGBS in concrete higher is the resistance of chloride ions penetration to concrete.

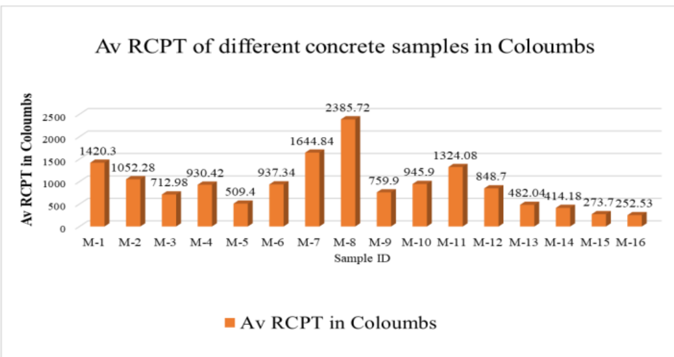

Figure-3: RCPT value in Coulombs

VI. Conclusion

From the experimental research work on chloride permeability to concrete made with different types of cement, w/c ratio & also concrete made with partial replacement of Portland cement with pozzolonic materials Fly ash & GGBS at various proportions. The followings are the outcome of the research work.

1) The blended cement PPC and Portland composite cement CEM-II/B-M and Blast furnace slag cement shows more resistant against Chloride ions penetration to concrete than normal Portland cement CEM-I.
2) The w/c ratio of concrete also plays an important role in Chloride permeability to concrete, higher the w/c ratio in concrete higher is the chloride penetration in concrete and vice versa.
3) The low Calcium Fly ash in concrete up to 20% shows insignificant reduction in chloride penetration to concrete , however on further increase in dosage 25-30% Fly ash shows significant reduction in Chloride penetration to concrete.
4) The research work also shows that concrete with high Alumina GGBS shows significant reduction in Chloride penetration to concrete and also with increase in dosage it shows significant reduction in chloride penetration to concrete.

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