International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

Durability Assessment of Concrete by using Electrical Resistivity & Rapid Chloride Permeability Technique

Abdullah Ahmed Laskar, Partha Ghosh,

Abstract: The durability of concrete is generally evaluated by many NDT technique, among the different NDT technique RCPT is one of the popular NDT method used by many researchers & practicing Engineers for evaluation of concrete durability. However the RCPT technique has some limitation on field test of concrete, considering the limitation of the RCPT technique a new technique has been intr oduced called Electrical resistivity technique is used for evaluation of concrete durability in both field & lab test. Durability of concrete is mainly depends on the properties of concrete microstructure i.e. pore size distribution, shape & connectivity of the microstructural pores in concrete. In general smaller pore size, with lesser connectivity results lower permeability & shows more durability, while concrete with porous microstructure having larger pore size distribution along with larger degree of interconnections results in higher permeability and shows poor durability. In this paper an experimental studies were conducted for evaluation of concrete durability on different types of concrete samples by using electrical resistivity & RCPT technique. From the experimental results it has been observed that concrete with lower level of Chloride permeability shows higher Electrical resistivity. Thus Electrical resistivity of concrete is directly influencing the durability of concrete.

Keywords: CEM-I, CEM-II/A-M, CEM-II/B-M, CEM-III, PPC, Fly Ash, GGBS, Pore size. Microstructure, ERT, RCPT

I. INTRODUCTION

The Rapid Chloride Permeability & Electrical resistivity technique are one of the two popular NDT method among researchers and practicing Engineers of construction industries for quality control and durability assessment of concrete. The acceptance of the methods are already taken into standards with regards to durability assessment of concrete and the guidelines has explained in AASHTO-TP95 for electrical resistivity of concrete & ASTM C1202 for rapid chloride permeability technique of concrete. In this experimental work different types of concrete samples with various types of cement, partial replacement of Portland cement with Pozzolonic materials, samples with varying w/c ratio & with varying cement content in the mix were tested for durability assessment of concrete after 28-days of normal water curing condition by using electrical resistivity & Rapid Chloride permeability technique. From the experimental results it has been observed that concrete with lower level of Chloride permeability shows higher Electrical resistivity. Thus the chloride permeability & Electrical resistivity of concrete is depend on the microstructural properties of concrete such as pore size distribution and the shape of the interconnections. A smaller pore network, with less connectivity shows lower chloride permeability & higher electrical resistivity, while concrete with porous microstructure having larger pore size distribution with larger interconnections shows higher chloride permeability and reduced resistivity. The primary idea behind electrical resistivity & RCPT technique is to somehow quantify the conductive properties of the microstructure of concrete. So electrical resistivity & RCPT technique of concrete can be expressed as the ability of concrete to resist the transfer of ions permeability to concrete. So in this research work different types of concrete samples were used to evaluate the durability of concrete by using RCPT & Electrical Resistivity technique. The results of the experiment shows that concrete samples with lower chloride permeability is having higher electrical resistivity of concrete. Thus by using Electrical Resistivity & RCPT technique the durability of concrete can be evaluated as this technique is based on the capability of resisting transportation of ions through concrete microstructural pores.

II. MEASUREMENT TECHNIQUES FOR ELECTRICAL RESISTIVITY OF CONCRETE

The electrical resistivity of concrete is measured by Wenner Four-probe technique. The basic principle involved in this method is to apply current (I) through outer two probes and the potential difference (V) is measured between two inner probes. The current is generally carried by ions in the pore fluid of concrete. The resistivity of concrete is calculated by the equation below.

$$\text{Resistivity } \rho = 2\pi\, aV/I\ [k\Omega cm]$$

Where "a" is the distance between the probe.

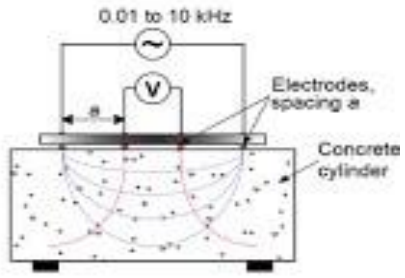

Fig. 1. Wenner four point probe arrangement for ERT.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Abdullah Ahmed Laskar*, PhD-Scholar, Construction Engineering Department, Jadavpur University, Kolkata, WB, India.
Dr Partha Ghosh* , Associate Professor, Construction Engineering Department, Jadavpur University, Kolkata, WB, India.

III. MEASUREMENT TECHNIQUE FOR RAPID CHLORIDE PERMEABILITY OF CONCRETE.

Rapid chloride permeability test (RCPT) of concrete is as per ASTM C 1202. According to ASTM C1202 test, a water-saturated concrete specimen of 50 mm thick & diameter 100 mm is subjected to DC voltage of 60 V for a period of 6 hours using the apparatus and the cell arrangement as shown in Fig-3. In the apparatus arrangement there are two reservoir in both side of specimen. Out of the two reservoir one reservoir is with 3.0 % NaCl solution while the other reservoir is filled with 0.3 M NaOH solution. The total charge passed through concrete is determined at the end of 6hrs and this result is used to rate the concrete durability as per Table-I.

IV. STANDARD RECOMMENDATIONS

Table 1: Chloride penetrability level established for standard based on electrical resistivity as per AASHTO T-95 & RCPT as per ASTMC 1202.

Chloride Ion Penetrability level	Electrical Resistivity range in KΩcm as per AASHTO T-95	RCPT in Coulombs as per ASTMC-1202
High	< 12	>4000
Moderate	12-21	2000-4000
Low	21-37	1000-2000
Very Low	37-254	100-1000
Negligible	>254	<100

V. MATERIALS

The different types of cement used for this research work was 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-197-1. & Fly ash based PPC as per IS-1489, Part-I. The pozzolonic materials used in the research experiment as a partial replacement of Portland cement for this research work was Pulverized Fly ash (F-type) & Ground granulated Blast furnace slag (GGBS) .The coarse aggregate used for this experimental work is of crushed Basalt rock & Fine aggregate used in the experiment was of river sand having FM of 2.7. The super plasticizer used in this research work was of Polycarboxylate ether based product of BASF. The reference grade of concrete used for this experimental work was C-30/37 grade with Portland cement (CEM-I as per BSEN-197, Part-I) content 438 kg/cum, w/c ratio 0.4, Coarse Aggregate content 1142 kg/cum, Fine Aggregate content 685 kg/ cum & Superplasticizer content 3.50kg/cum .The test results of all the materials used in the experimental work is tabulated below.

Table-2: Physical properties of cement, fly ash & GGBS

Cement	Sp Gravity	Fineness in cm2/gm.	% Residue on 45 Micron
CEM-I	3.15	3550	3.87
CEM-II/A-M	3.12	3635	4.28
CEM-II/B-M	3.08	3727	4.55
CEM-III/A	2.98	4282	5.56
PPC (Fly Ash)	3.01	3825	2.92
Fly Ash	2.145	3704	8.7
GGBS	2.909	3443	7.83

Table-2: Chemical properties of different types of cement.

Component	CEM-I	CEM-II /A-M	CEM-I I/B-M	CEM-III/A	PPC
CaO	63.25	55.47	51.6	53.59	44.3
SiO_2	20.97	25.22	26.23	24.45	29.1
Al_2O_3	5.02	8.27	9.11	8.97	11.4
Fe_2O_3	3.73	3.36	3.66	2.22	3.49
SO_3	2.95	2.64	2.33	2.83	2.75
MgO	2.02	1.85	1.29	2.95	1.94
Na_2O	0.190	0.220	0.270	0.282	0.22
K_2O	0.530	0.510	0.870	0.661	0.64

Table-3: Chemical properties of Fly ash & GGBS

Component	Fly Ash	GGBS
CaO	1.87	34.2
SiO_2	61.08	36.03
Al_2O_3	27.58	17.15
Fe_2O_3	5.36	1.03
SO_3	0.11	0.32
MgO	0.14	7.21
Na_2O	0.572	0.140
K_2O	0.172	1.435

Table-4: Physical properties of coarse aggregate.

Test Parameter	Test Results
Sp Gravity	2.87
Dry rodded Bulk Density in Kg/cum	1678
Water absorption in %	0.43
Impact value in %	11.41
Loss Angel Abrasion in %	0.424
Flakiness Index in %	21.22
Elongation Index in %	23.5
Magnesium Sulphate Soundness in %	14
Grading Requirement (19-4.75 mm)	Confirming ASTMC-33

Table-5: Physical properties of fine aggregate.

Test Parameter	Test Results
Sp Gravity	2.54
75 micron passing in % by weight	1.75
Fineness Modulus	2.70
Water absorption in % by weight	1.54

Table-6: Properties of mixing water

Test Parameter	Test Results
pH	7.5
Chloride content in mg/L	250

Retrieval Number: A1848109119/2019©BEIESP
DOI: 10.35940/ijeat.A1848.109119
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Sulphate content in mg/L	1.8
Total Solid in mg/L	750
Total Alkalinity as $CaCO_3$ in mg/L	285

VI. EXPERIMENTAL SETUP

The samples used for ERT of concrete was 200mm x 100 mm x 100mm plain concrete block of different concrete mix as explained in Table-8 & the samples used for RCPT was circular disc of 100 mm diameter & 50 mm thick . The casted samples were cured for 28-days. & then after the samples were tested for Electrical Resistivity by using Wenner four probe electrical resistivity meter as per AASHTO T-95 & RCPT as per ASTM C1202. The mix details of different concrete samples used for experiment is tabulated below.

Table-8: Mix details of different concrete mix used for experiment.

Mix ID	Mix Details	Cement Kg/m3	w/c Ratio	Coarse Agg in Kg/m3	Fine Agg in Kg/m3
S_0	CEM-I	438	0.40	1142	685
S_1	CEM-I	438	0.35	1142	685
S_2	CEM-I	438	0.45	1142	685
S_3	CEM-I	438	0.50	1142	685
S_4	CEM-I	438	0.55	1142	685
S_5	CEM-I	350	0.40	1142	685
S_6	CEM-I	375	0.40	1142	685
S_7	CEM-I	400	0.40	1142	685
S_8	CEM-I	425	0.40	1142	685
S_9	CEM-I	450	0.40	1142	685
S_{10}	CEM-II/A-M	438	0.40	1142	685
S_{11}	CEM-II/B-M	438	0.4	1142	685
S_{12}	CEM-III/A	438	0.4	1142	685
S_{13}	PPC	438	0.4	1142	685
S_{14}	CEM-I 90%+10%FA	394.2	0.4	1142	685
S_{15}	CEM-I 85%+15%FA	372.3	0.4	1142	685
S_{16}	CEM-I 80%+20%FA	350.4	0.4	1142	685
S_{17}	CEM-I 75%+25%FA	328.5	0.4	1142	685
S_{18}	CEM-I 70%+30%FA	306.6	0.4	1142	685
S_{19}	CEM-I 70%+30% GGBS	306.6	0.4	1142	685
S_{20}	CEM-I 60%+40% GGBS	262.8	0.4	1142	685
S_{21}	CEM-I 50%+50% GGBS	219	0.4	1142	685
S_{22}	CEM-I 40%+60% GGBS	175.2	0.4	1142	685

Fig. 2. Samples for ERT of concrete.

Fig-3: RCPT of concrete samples.

VII. RESULT AND DISCUSSION

After the samples were removed from curing tank after 28-days of curing all the concrete samples durability were evaluated through Electrical Resistivity technique by using Wenner four probe electrical resistivity meter & Rapid chloride permeability testing method as per ASTMC1202. From the experimental results shows in Table-9, that concrete sample (S21) having lower chloride permeability shows higher Electrical resistivity & concrete sample (S5) with higher chloride permeability shows lower level of Electrical resistivity of concrete. Thus from the experimental results it is clear that lower the chloride permeability to concrete higher is the resistivity & more the durability of concrete. The results of various concrete mix used for experiment also give us durability behaviors of different types of concrete. From the results it shows concrete mix (S21) with 50% GGBS shows minimum chloride penetration & at the same time it shows maximum electrical resistivity. The GGBS used in the mix helps to fill the pore structure & also due to high content of Alumina in GGBS it has the maximum capability of Chloride binding [4] which results maximum resistance of chloride penetration to such concrete. Among the different types of Cement Fly Ash based Portland Pozzolana cement as per IS-1489, P-1 based concrete sample (S13) & Portland composite cement CEM-II/B-M based sample (S11) shows higher Electrical resistivity & lower Chloride permeability due to better filling of microstructural pore of concrete due to pozzolonic action in PPC & Portland composite cement CEM-II/B-M along with chloride binding capability of pozzolonic materials.

The concrete mix (S4) with higher w/c ratio shows higher chloride penetration & lower resistivity due to larger pore structure in concrete with higher w/c ratio ,while concrete mix (S1) with lower w/c ratio shows lower chloride penetration & higher Electrical resistivity due to finer pore structure in concrete with lower w/c ratio. Thus durability of concrete is directly depend on Electrical resistivity of concrete i.e. more the resistivity of concrete more the concrete is durable.

Table -9: Electrical resistivity, compressive strength & RCPT of different types of concrete mixes

Mix ID	Compressive strength at 7-days	Compressive Strength at 28-days	ERT in KΩcm	RCPT in Coulombs
S_0	52.73	54.33	16	1234.56
S_1	50.80	55.02	20.3	937.36
S_2	39.82	43.02	14.8	1468.56
S_3	36.64	42.13	12.4	1644.84
S_4	34.44	36.6	9.6	2385.72
S_5	39.27	45.36	7.9	2797.22
S_6	40.87	48.33	8.4	2487.60
S_7	43.13	50.11	9.3	1956.02
S_8	48.76	51.33	10.6	1616.58
S_9	52.51	59.27	12.3	1419.66
S_{10}	42.02	46.29	26.1	1052.28
S_{11}	45.29	48.98	32.6	712.98
S_{12}	41.82	47.09	20.9	930.42
S_{13}	35.36	48.06	46.3	509.4
S_{14}	40.42	43.87	19.4	1376.24
S_{15}	41.22	47.87	24.1	832.45
S_{16}	43.82	52.89	33	759.96
S_{17}	38.98	45.69	19.7	1324.08
S_{18}	35.71	44.18	25.6	808.7
S_{19}	45.20	51.22	58.2	482.04
S_{20}	46.42	52.35	59.1	414.18
S_{21}	48.16	54.51	89.7	272.7
S_{22}	43.24	50.24	61.5	329.94

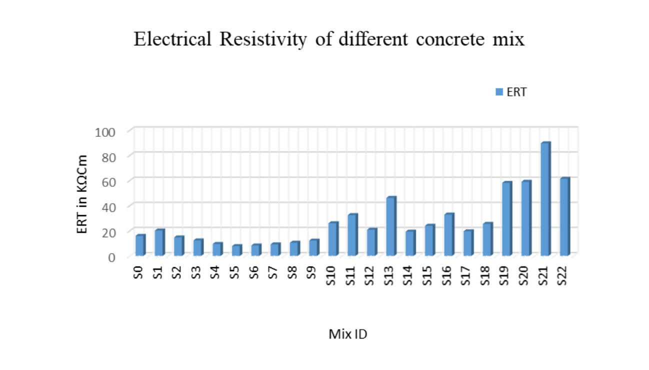

Fig-4: Electrical Resistivity of different types of Concrete mix.

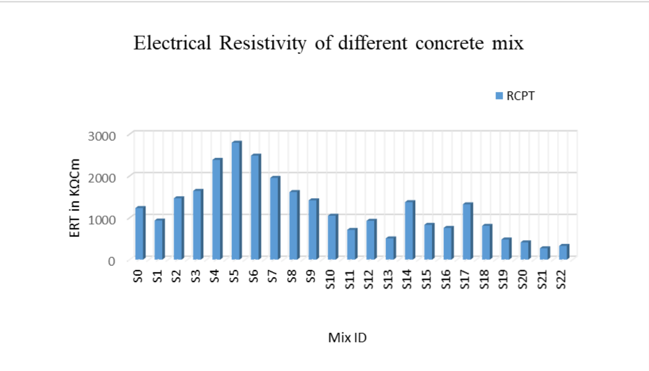

Fig-5: RCPT of different types of concrete mixes.

VIII. CONCLUSION

The following are the outcome of this research work.

I. The Electrical resistivity of concrete is higher when the penetration of ions in concrete is lower & it is vice-versa.

II. Concrete mix with partial replacement of normal Portland cement CEM-I with GGBS shows minimum penetration of Chloride ions & maximum electrical resistivity.

III. Concrete mix with Portland Pozzolana Cement (Fly ash based) as per IS-1489, P-1 & also mix with Portland Composite Cement CEM-II/B-M as per BSEN-197 ,P-1 shows higher level of electrical resistivity & lower level of Chloride permeability than normal Portland cement CEM-I.

IV. Concrete mix with lower w/c ratio shows higher level of Electrical resistivity & lower chloride permeability, while concrete with higher level of w/c ratio shows lower electrical resistivity & higher chloride permeability.

V. There is no significant improvement in concrete resistivity by increasing normal Portland cement CEM-I in the mix.

VI. Addition of GGBS in concrete mix along with normal Portland cement shows maximum resistivity of Chloride ions penetration to concrete due to better filling up of microstructural pore of GGBS based concrete & better chloride binding capability of GGBS due to higher % of Aluminum oxide in GGBS.

VII. The durability of concrete is directly depend on the Electrical resistivity of the concrete.

REFERENCES

1. ASTM C1202-12, “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”
2. AASHTO TP 95, “Standard Test Method for Surface Resistivity of Concrete’s Ability to Resist Chloride Ion Penetration,” American Association of State Highway and Transportation Officials, Washington, DC, 2014, 10 pp.
3. ASTM C1760-12, “Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete,” ASTM International, West Conshohocken, PA, 2012, 5 pp.
4. Menéndez,G.,Bonavetti, V. and Irassar, E.F., Strength development of ternary blende cement with limestone filler and blast-furnace slag, Cement and Concrete Composites 25 (2003), 61-67
5. Rajabipour, F.; Weiss, J.; and Abraham, D.M., “In-situ Electrical Conductivity Measurements to Assess Moisture and Ionic Transport in Concrete,” International RILEM Symposium on Concrete Science and Engineering: A Tribute to Arnon Bentur, K. Kovler, J. Marchand, S. Mindess, and J. Weiss, eds., RILEM Publications SARL, 2004, 260 pp.
6. AASHTO T 277, “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride,” American Association of State Highway and Transportation Officials, Washington, DC, 2007, 12 pp.
7. AASHTO T 259, “Method of Test for Resistance of Concrete to Chloride Ion Penetration,” American Association of State Highway and Transportation Officials, Washington, DC, 2006, 3 pp.
8. Morris, W.; Moreno, E.I.; and Sagüés, A.A., “Practical Evaluation of Resistivity of Concrete in 433 Test Cylinders Using a Wenner Array Probe,” Cement and Concrete Research, V. 26, No. 12, 1996, pp. 1779-1787.
9. Electrical Resistivity of Concrete Concepts, applications, and measurement techniques by Hamed Layssi, Pouria Ghods, Aali R. Alizadeh, and Mustafa Salehi
10. Sherif Yehia, Sharef Farrag, Kareem Helal, and Shahinaz El-Kalieand P. Rakic, “Effects of Fly Ash, Silica Fume, and Ground-Granulated Blast Slag on Properties of Self-Compacting High Strength Lightweight concrete ,” GSTF Journal of Engineering Technology (JET) Vol.3 No.3, October

11. Book "Concrete Microstructure, properties & Materials "by P. Kumar & Paulo J. M. Monteiro.
12. BS EN-197, Part-1. Composition, Specifications and conformity criteria for common cements.
13. IS-1489. Part-1. Specification for Portland Pozzolana Cement, Fly ash based.
14. Zhuqing Yu1and Guang Ye2 "Chloride Penetration and Microstructure Development of Fly Ash Concrete" Second International Conference on Microstructural-related Durability of Cementitious Composites, 11-13 April 2012, Amsterdam, The Netherlands.
15. Menéndez,G.,Bonavetti, V. and Irassar, E.F., Strength development of ternary blende cement with limestone filler and blast-furnace slag, Cement and Concrete Composites 25 (2003), 61-67
16. Claisse, P.A., "Letter: Using Electrical Tests as Durability Indicators," Concrete International, V. 36, No. 10, Oct. 2014, p.17.

AUTHORS PROFILE

Abdullah Ahmed Laskar, PhD-Scholar, Jadavpur University , Construction Engineering Department , Saltlake Campus Kolkata, India, Email: aal@bhel.in

Dr Partha Ghosh, Associate Professor, Jadavpur University, Construction Engineering Department , Saltlake campus , Kolkata, India, Email: parthaghosh78@yahoo.co.in