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Durability Enhancement of Cement Mortar by Using Electro Kinetic Principles

S. Antony Sujina[1], R. Selvaraj[2], B. Deepa[3]

[1]Post Graduate Student, Kamaraj College of Engineering and Technology, Madurai, Tamil Nadu, India

[2]Senior Principal Scientist, CMPD, CSIR-CECRI, Karaikudi, Tamil Nadu, India

[3]Assistant Professor-, Civil Department, Kamaraj College of Engineering and Technology, Madurai, Tamil Nadu, India

Abstract: Applying electrokinetic principles for enhancing durability of cementing material is one of the recent advanced techniques. In this technique all the surface defects are filled with cations from the electrolytic solutions. Applied direct current (DC) is the driving force for migration of cations from the electrolytic solution. Outside anode and embedded cathode in cement mortar with cationic oxide solutions such as Calcium hydroxide, Potassium hydroxide, Nano silica solution, etc, forms electrolyte. The migrated cations travel into the mortar through the pores, cracks, fissures and other surface defects of mortar and fill the empty spaces and thereby a dense, durable, pore free mortar specimen is obtained, this will prevent the entry of aggressive ions when exposed in the field. The concept of electrokinetic principles and its applications are explained neatly.

Keywords: Electrolyte, Durability, Electrokinetic, Migration, Surface defects, Cations

1. Introduction

Concrete is a antique material in the universal. It encounters the durability and corrosion difficulties. These problems are affected to reinforced concrete structures [1]. Durability of concrete is connected to the porosity and permeability. Durability of concrete can be upgraded using the some techniques. The Electro Kinetic technique is an emerging new technology that improves durability of concrete. This technique is previously done in soil extraction for heavy metals and desalination of bricks. Using this Electro Kinetic principle, for enhancing durability of concrete, that is emigration of ions from the electrolytes with selected voltage and duration [5]. The emigration of ion fills into the pores, voids, fissures, cracks and other defects of Concrete.

2. Electro Kinetic Principle

Electro Kinetic principles, the charge particles are moving to the electrode. This principle includes the ionic conduction, electro phoresis and electro osmosis[10]. Electro osmosis is the flow of water in porous medium. Electro phoresis is the movement of solid particles. The Electro Kinetic technique is similar to electrolysis. Using the Electro Kinetic principles, to enhance the durability of concrete, that is electro emigration of ions from the electrolytic solutions with selected voltage.

3. Experimental Investigation

3.1 Electro Kinetic Treatment

The Electro Kinetic treatment as shown in fig.1 involves connection of Copper plate with telephone wire in the specimen which is the cathode to the negative terminal of power source [7]. A counter electrode is placed outside which is the anode is connected to the positive terminal of power source. The entire setup is immersed in electrolyte solution. Schematic representation of electro kinetic setup is shown in fig.2.The specimens were immersed in containers with electrolyte solution namely Calcium Hydroxide, Sodium Hydroxide, Potassium Hydroxide and Nano Silica [9]. Varying duration and potential were used in the study. Potentials used for study are 6V, 12V, 18V and 20V with varying durations 4hours, 6hours and 8hours shown in table 2.The Electro Kinetic treatment was carried out carefully and current readings in every 30 minutes was noted using ammeter [8]. The current was taken to confirm the diffusion of ions into the specimen. The electrolytic solution details are shown in Table 1.

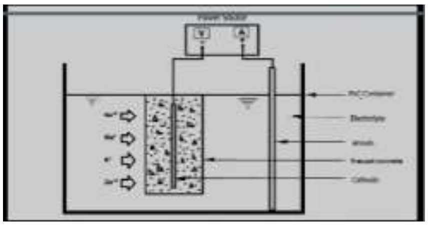

Figure 1: Electro Kinetic Treatment

Table 1: Electrolytic Solutions Details

Eletrolytic Solution	Molecular Weight	Element	Ionic Radius (pm)
$Ca(OH)_2$	74.093	Ca^{2+}	100
NaOH	40.00	Na^+	102
KOH	56.11	K^+	138
Nano Silica	-	Si^-	111

Figure 2: Electro Kinetic Treatment setup

3.2 Cationic Migration Test

This test determines the rapid indication of its resistance to the penetration of cation ions. The test method consists of monitoring the amount of electrical current as shown in fig.3 through at 83mm diameter and 50mm depth disc specimens and 60mm diameter and 120mm depth specimens during a period of 4 hours, 6 hours and 8hours. A potential difference of 6V, 12V, 18V and 20V direct current is maintained across the ends of the specimens one of which immersed in a Sodium Hydroxide, Potassium Hydroxide, Calcium Hydroxide and Nano Silica solutions [3].

Figure 3: Cationic migration test

The total charge passed in coulombs, has been found to be related to the resistance of the specimen to cation penetration. After every 30 minutes for about 4 hours, 6 hours and 8 hours, the current is monitored and recorded.

3.3 Tafel Extrapolation Test

The lollipop specimens of size 60mm diameter and 120mm height were made with placing steel rods and Copper Plates in the centre. These specimens were treated with Electrolytic solution [4]. These casted specimens were exposed to 3.5% Sodium Chloride solution. Then all the lollipop specimens were subjected to Tafel Extrapolation test for 1st, 7th, 14th, 21st and 28th day.

Tafel extrapolation as shown in fig.4 is another method of calculating corrosion rate. The curve obtained from this test consists of three regions: Anodic polarization curve, cathodic polarization curve and linear region called "Tafel region".

Figure 4: Tafel extrapolation test setup

4. Results from Experiment

4.1 Cationic Migration Test

Ionic Migration test has been carried out on mortar specimens with a help of plastic containers in which circular specimen with a stainless steel mesh embedded centrally with a electric lead in placed. On either side of the circular disc stainless steel anodes (-ve) plates to the size of specimens are placed. These two plates are connected units positive terminals. The electrolytes selected as $Ca(OH)_2$, NaOH, KOH and Nano Silica. The electric terminals are connected to DC power supply source and the voltages were applied 6V, 12V, 18V and 20Volts for each test with duration of test 4, 6 and 8 hours. Once the power supply source is switched on, the ionic movements are started. The concentration of electrolytic solutions were saturated $Ca(OH)_2$, 0.1 M NaOH, 0.1M KOH and Nano Silica solutions was prepared with 1.5 gram Nano Silica powder in 1litre of water. For Nano Silica electrolyte, the polarity was changed. During the test at every half-an-hour interval, the circuit current was measured in each cell for calculating the cationic charge passed into the specimen [2] and the cationic charge passed are presented in Tables.

1) It is observed that as the voltage is increased from 6V to 20V, gradual increase in charge passed was also increased for all electrolytic solution.
2) As the duration of application of voltage is increased from 4hours to 8hours, charge passed was also increased for all electrolyte solutions.

A maximum charge passed was observed for 20V-8hours power supply for all electrolytic cells [6]. It can be concluded that maximum voltage and maximum duration permits cationic passing to the maximum. Highest cationic passing has occurred for $Ca(OH)_2$ solutions.ie Ca ions penetrate with higher rates and next to this sodium ions and next to Na, potassium ions and finally nano silica into the specimens. This is quite in good agreement with the size of ions which are given in table. The diffusion of Ca ions are move because the ionic radius of Ca^{++} is smaller than others. Though the K^+ ionic radius is slightly higher the ionic mobility in high as its valancy is unity. The mobility of Nano Silica is slow since its form is SiO_2.

Therefore, a maximum cationic migration for disc specimen is obtained for $Ca(OH)_2$ electrolyte i.e. 11,306 coulombs, followed by NaOH 8571 and this is followed by KOH 8017,and finally for Nano Silica for which 3997 was obtained for 20V-8hours as shown in tables 2 to 5.

A maximum cationic migration for cylindrical lolli-pop specimen is obtained for $Ca(OH)_2$ electrolyte i.e. 16616 coulombs, followed by NaOH 14356 and this is followed by KOH 7849,and finally for Nano Silica for which 2504 was obtained for 20V-8hours as shown in tables 6 to 9.

Table 2: Cationic migration test for 6V

Electrolytic Solution	Voltage	Duration	Charge Passed (coulombs)
$Ca(OH)_2$	6	4	719
	6	6	1615
	6	8	2675
KOH	6	4	660
	6	6	1615
	6	8	2452
NaOH	6	4	1143
	6	6	2209
	6	8	2294
Nano Silica	6	4	143
	6	6	228
	6	8	262

Table 3: Cationic migration for 12V

Electrolytic Solution	Voltage	Duration	Charge Passed (coulombs)
$Ca(OH)_2$	12	4	2263
	12	6	4668
	12	8	7026
KOH	12	4	1544
	12	6	3431
	12	8	5057
	12	4	5116

NaOH	12	6	6371
	12	8	4894
Nano Silica	12	4	1072
	12	6	1992
	12	8	2075

Table 4. Cationic migration for 18V

Electrolytic Solution	Voltage	Duration	Charge Passed (coulombs)
$Ca(OH)_2$	18	4	2193
	18	6	4079
	18	8	5699
KOH	18	4	1674
	18	6	3891
	18	8	5324
NaOH	18	4	3926
	18	6	3961
	18	8	4323
Nano Silica	18	4	1674
	18	6	3584
	18	8	4904

Table 5: Cationic migration for 20V

Electrolytic Solution	Voltage	Duration	Charge passed (Coulombs)
$Ca(OH)_2$	20	4	4503
	20	6	7840
	20	8	11306
NaOH	20	4	2304
	20	6	5399
	20	8	8517
KOH	20	4	3513
	20	6	6802
	20	8	8071
Nano Silica	20	4	1250
	20	6	2594
	20	8	3997

Table 6: Cationic diffusion for 6V

Electrolytic Solution	Voltage	Duration	Charge passed (Coulombs)
$Ca(OH)_2$	6	4	2405
	6	6	3281
	6	8	6400
NaOH	6	4	2800
	6	6	3118
	6	8	5899
KOH	6	4	3597
	6	6	6278
	6	8	4721
Nano Silica	6	4	424
	6	6	814
	6	8	1173

Table 7: Cationic migration for 12V

Electrolytic Solution	Voltage	Duration	Charge passed (Coulombs)
$Ca(OH)_2$	12	4	2880
	12	6	3957
	12	8	8579
NaOH	12	4	3092
	12	6	4209
	12	8	5834
KOH	12	4	2685
	12	6	3481
	12	8	4951
Nano Silica	12	4	1279
	12	6	1465
	12	8	1534

Table 8: Cationic diffusion Test 18V

Electrolytic Solution	Voltage	Duration	Charge Passed (Coulombs)
$Ca(OH)_2$	18	4	15896
	18	6	17867
	18	8	18682
NaOH	18	4	11841
	18	6	12685
	18	8	15859
KOH	18	4	11802
	18	6	12045
	18	8	14673
Nano Silica	18	4	1696
	18	6	1743
	18	8	1963

4.2 Cylinder Compression Strength (ASTM C109/C109M):

Compression test was carried out for control specimens and all treated specimens. Compressive strength of control specimen was 28.732MPa. Specimens treated using 20V-8hours was showing better results in compression test as compared to other potential treatments. Maximum duration was also found to be effective as per compression strength results. Maximum compressive strength was found to be36.128 MPa for $Ca(OH)_2$ treated specimens with 20V and 8 Hours of treatment. Lowest value of compressive strength was for 31.945MPa Nano Silica treated specimen is shown in table 10.

Table 9: Cationic diffusion for 20V

Electrolytic Solution	Voltage	Duration	Charged Passed (Coulombs)
$Ca(OH)_2$	20	4	6130
	20	6	14534
	20	8	16616
NaOH	20	4	6023
	20	6	7633
	20	8	14356
KOH	20	4	4156
	20	6	5873
	20	8	7849
Nano Silica	20	4	1911
	20	6	2394
	20	8	2504

4.3 Split Tensile Test

Split tensile strength has been conducted for all specimens. A higher tensile strength of Mpa is shown by $Ca(OH)_2$ treated specimens. The tensile strength of various treated specimens are shown in table 10.

Table 10: Compression and Split tensile Strength Test

Specimen	Cylinder Compressive Strength (N/mm^2)	Split tensile Strength(N/mm^2)
Control	28.732	2.902
$Ca(OH)_2$ 20V-8Hours	36.128	3.814
NaOH 20V-8Hours	34.778	3.567
KOH 20V-8Hours	32.680	3.384
Nano Silica 20V-8Hours	1.945	3.268

4.4 Chloride Diffusion Test (ASTMC 1202-12)

This test is carried out to measure how much charge is passed into cement mortar specimen (or) the amount of chloride passed/penetrated into specimen. This test is conducted with a help of a specially fabricated PVC cells and mortar specimen is placed between two cells or containers. One part of cell with contains 3.5% NaCl and the other part filled with 0.1M NaOH solution.

In both the cells Titanium mesh is placed as electrode and a constant electricity of 60Volt DC is applied with the half of power supply source of capacity 0-60V DC and 0-5 Amps. The negative terminal is connected to NaCl solution and the positive terminal is connected to NaOH solution. When the power source supply is switched on, 60V, DC is applied and the corresponding electric circuit current is measured. Simultaneously few more cells can be connected usually 6 or 8 numbers but the total integrated current shall not exceed 4 or 4.5 A. The duration of the test is six hours, the circuit current is measured for each unit and every half-an-hour are noted. The total charge passed is calculated using the formula given in ASTMC 1202

$$Q=900[I_0+2(I_{30}+I_{60}+I_{90}\ldots+I_{330})+I_{360}]$$

The computed charge passed in terms of coulombs is presented in tables 11 to 15. The test setup is shown in fig.5. From the test results, it is found that $Ca(OH)_2$ treated sample has lowest charge passed. It means, the chloride penetration is very less. NaOH treated specimens stands too and KOH as third rank. The specimen treated with nano silica is the last one. This is quite good in agreement with earlier cationic diffusion cell. i.e. the Ca^{++} ions penetrate at higher amount and blocks all the pores, Voids, fissures etc and thus presents entry of chloride ions. However, the Nano Silica treated specimens show higher chloride penetration due to poor mobility of SiO_2 molecules in Cationic diffusion test.

Table 11: Chloride diffusion for Control Specimen

Specimen	Charge Passed (Coulombs)
Control	2916

Figure 5: Chloride diffusion Test

Table 12: Chloride diffusion for 6V

Electrolytic Solution	Voltage	Duration	Charge Passed (coulombs)
$Ca(OH)_2$	6	4	710
	6	6	594
	6	8	495
KOH	6	4	686
	6	6	573
	6	8	517
NaOH	6	4	663
	6	6	516
	6	8	418
Nano Silica	6	4	718
	6	6	598
	6	8	484

Table 13: Chloride diffusion for 12V

Electrolytic Solution	Voltage	Duration	Charge Passed (coulombs)
$Ca(OH)_2$	12	4	509
	12	6	463
	12	8	334
KOH	12	4	564
	12	6	496
	12	8	412
NaOH	12	4	516
	12	6	427
	12	8	268
Nano Silica	12	4	578
	12	6	411
	12	8	309

Table 14: Chloride diffusion for 18V

Electrolytic Solution	Voltage	Duration	Charge Passed (coulombs)
$Ca(OH)_2$	18	4	496
	18	6	403
	18	8	267
KOH	18	4	519
	18	6	463
	18	8	392
NaOH	18	4	473
	18	6	394
	18	8	247
Nano Silica	18	4	508
	18	6	302
	18	8	299

Table 15: Cationic diffusion for 20V

Electrolytic Solution	Voltage	Duration	Charged Passed (Coulombs)
$Ca(OH)_2$	20	4	6130
	20	6	14534
	20	8	16616
NaOH	20	4	6023
	20	6	7633
	20	8	14356
KOH	20	4	4156
	20	6	5873
	20	8	7849
Nano Silica	20	4	1911
	20	6	2394
	20	8	2504

4.5 X-Ray Fluorescence (XRF)

X-Ray Fluorescence as shown in fig.6 analysis of powder specimens were carried out using “Horiba” Machine Japan. The samples were control and specimens treated with $Ca(OH)_2$,NaOH,KOH and Nano Silica subjected to 20Volt DC for 8hours duration. The result of elements and oxide analysis are shown in Table 16. It can be infered from the table that, after electro kinetic study the elements absorbed turns into oxide form in presence of oxygen present. It is formed that the Nano-Silica treated specimens found to be the best as it has 96.902% Oxide Composition and the given value of 91.318% was obtained for NaOH. The KOH found to be next to Nano Silica with 95.948% Oxides. The reason for the best performance of Nano Silica is the penetration capacity of SiO_2 which is 35.367% is the particle size. Due to its nano size easy penetration into Voids, Capillaries, Fissures and Cracks present in mortar specimens. From this study it in concluded that Nano-Silica electrolyte acts as best for Electro Kinetic treatment.

Table 16: Oxide Composition of materials by XRF Analysis

Specimen	Control	$Ca(OH)_2$	NaOH	KOH	Nano Silica
Ca^{2+}	37.026	34.389	37.515	38.34	32.215
CaO	51.806	48.117	52.491	53.65	45.076
Si^-	13.008	9.124	11.433	8.600	16.533
SiO_2	27.827	19.518	24.458	18.39	35.367
Fe^{2+}	10.960	11.644	9.192	16.33	10.843
Fe_2O_3	15.670	16.648	13.142	23.36	15.503
K^+	Trace	7.340	1.018	0.449	0.793
K_2O	Trace	8.842	1.227	0.540	0.956
Element mass Percentage (%)	-	53.373	47.725	55.133	48.748
Oxide mass Percentage (%)	-	93.925	91.318	95.948	96.902

Figure 6: X-Ray Fluorescence

4.6 Tafel Extrapolation

This test has been carried out with a help of electrochemical apparatus called 'AUTOLAB' which is nothing but Potentiostat/ Galvanonicstat instrument, which is attached with three electrode system of electrochemical cell. The three electrodes are Working Electrode (WE), Counter Electrode (CE) and a Reference Electrode (RE). A cylindrical mortar specimen having centrally placed 10mm diameter TOR steel this acts as working electrode. A perforated stainless steel plate surrounding the mortar specimen acts as counter electrode and Silver/Silver Chloride (Ag/AgCl) electrode acts as reference electrode. A 3.5% NaCl [equal to sea water] acts as electrolyte. All the three electrodes are given connection to the respective terminals of the 'AUTOLAB'. When the 'AUTOLAB' is switched on, the build in software is open which registers the electrochemical reactions and as a result it delivers in the form of anodic and cathodic curves with current density and corrosion rate in the computer monitor. The tangents are drawn for the given anodic and cathodic curves and corresponding E_{Cor} and I_{Cor} values are obtained.

This test has been carried out for all the specimens and the results are presented in tables. It can be seen this results specimens treated with $Ca(OH)_2$ found to give the best results and this is followed by NaOH and this is followed by KOH and finally the Nano Silica. The current densities and the Corrosion rates are good in agreement. The Control specimen found to be more corrosive than the treated one. This specimens which are treated for 20Volts-8Hours duration found to give the best results, which is 1.321×10-4, 1.732×10-4, 1.894×10-4 and 2.713×10-4 for Ca(OH)2,NaOH,KOH and Nano Silica respectively. It is understood upto14days a mixed response was obtained, and after 14days clear results are come. Higher the voltage and duration of application of current as yield at very good results as given in tables 17 to 21. Tafel curve as shown in fig.7.

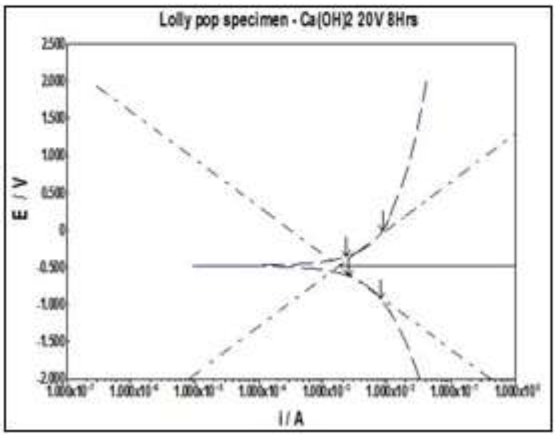

Figure 7: Tafel Curve

Table 17: Corrosion Rate for Control Specimen

DAY	Corrosion Density (A/cm2)	Corrosion Rate (mm/year)
1st Day	1.324	2.933
7th Day	4.876	2.869
14th Day	2.671	1.788
21st Day	2.596	1.699
28th Day	2.632	1.732

Table 18: Corrosion Rate for Ca(OH)2 treated specimen

DAY	Specimen	Corrosion Density (A/cm_2)	Corrosion Rate (mm/yr)
1st Day	6V-4Hour	2.382×10^{-5}	7.793×10^{-1}
	6V-6Hour	4.346×10^{-5}	1.422×10^{-1}
	6V-8Hour	7.14×10^{-6}	2.336×10^{-2}
	12V-4Hour	5.274×10^{-5}	1.726×10^{-1}
	12V-6Hour	3.226×10^{-5}	1.055×10^{-1}
	12V-8Hour	2.351×10^{-5}	7.691×10^{-2}
	20V-4Hour	6.81×10^{-5}	1.631×10^{-1}
	20V-6Hour	4.486×10^{-6}	1.13×10^{-2}
	20V-8Hour	3.540×10^{-6}	1.061×10^{-2}
7th Day	6V-4Hour	7.577×10^{-5}	7.843×10^{-1}
	6V-6Hour	4.929×10^{-5}	6.441×10^{-1}
	6V-8Hour	5.084×10^{-5}	2.114×10^{-2}
	12V-4Hour	4.296×10^{-5}	1.632×10^{-1}
	12V-6Hour	4.117×10^{-5}	1.102×10^{-1}
	12V-8Hour	4.393×10^{-5}	6.99×10^{-2}
	20V-4Hour	3.171×10^{-5}	1.543×10^{-2}
	20V-6Hour	8.58×10^{-6}	8.145×10^{-3}
	20V-8Hour	7.564×10^{-6}	7.167×10^{-3}
	6V-4Hour	7.631×10^{-5}	9.810×10^{-2}
	6V-6Hour	8.411×10^{-5}	9.732×10^{-2}

14th Day	6V-8Hour	3.914×10^{-5}	9.12×10^{-2}
	12V-4Hour	3.914×10^{-5}	4.93×10^{-2}
	12V-6Hour	2.709×10^{-4}	5.01×10^{-2}
	12V-8Hour	1.969×10^{-4}	4.11×10^{-2}
	20V-4Hour	7.016×10^{-5}	2.145×10^{-2}
	20V-6Hour	6.167×10^{-5}	1.010×10^{-2}
	20V-8Hour	7.011×10^{-5}	9.32×10^{-3}
21st Day	6V-6Hour	8.11×10^{-5}	7.931×10^{-2}
	6V-6Hour	8.67×10^{-5}	7.842×10^{-2}
	6V-8Hour	4.11×10^{-5}	6.947×10^{-2}
	12V-4Hour	4.14×10^{-5}	4.731×10^{-2}
	12V-6Hour	5.15×10^{-5}	4.567×10^{-2}
	12V-8Hour	6.15×10^{-5}	4.321×10^{-2}
	20V-4Hour	6.78×10^{-5}	3.110×10^{-2}
	20V-6Hour	5.967×10^{-5}	3.132×10^{-2}
	20V-8Hour	5.011×10^{-5}	9.211×10^{-3}
28th Day	6V-4Hour	7.683×10^{-5}	7.136×10^{-2}
	6V-6Hour	7.511×10^{-5}	7.001×10^{-2}
	6V-8Hour	7.501×10^{-5}	6.943×10^{-2}
	12V-4Hour	5.011×10^{-5}	4.516×10^{-2}
	12V-6Hour	4.81×10^{-5}	4.412×10^{-2}
	12V-8Hour	4.71×10^{-5}	4.112×10^{-2}
	20V-4Hour	7.011×10^{-5}	4.321×10^{-4}
	20V-6Hour	6.93×10^{-5}	1.435×10^{-4}
	20V-8Hour	5.11×10^{-5}	1.321×10^{-4}

Table 19: Corrosion Rate for NaOH treated specimen

DAY	Specimen	Corrosion Density (A/cm2)	Corrosion Rate (mm/yr)
1st Day	6V-4Hour	1.299×10^{-4}	4.249×10^{-1}
	6V-6Hour	4.644×10^{-4}	1.519×10^{-1}
	6V-8Hour	7.996×10^{-4}	1.501×10^{-1}
	12V-4Hour	1.967×10^{-5}	2.616×10^{-1}
	12V-6Hour	6.457×10^{-6}	6.435×10^{-2}
	12V-8Hour	4.883×10^{-6}	6.435×10^{-2}
	20V-4Hour	3.474×10^{-6}	2.017×10^{-2}
	20V-6Hour	2.981×10^{-6}	1.988×10^{-2}
	20V-8Hour	2.711×10^{-6}	1.598×10^{-2}
7th Day	6V-4Hour	1.177×10^{-4}	3.243×10^{-1}
	6V-6Hour	6.834×10^{-5}	2.141×10^{-1}
	6V-8Hour	7.135×10^{-5}	1.593×10^{-1}
	12V-4Hour	5.547×10^{-5}	3.191×10^{-1}
	12V-6Hour	9.069×10^{-5}	7.431×10^{-2}
	12V-8Hour	8.281×10^{-5}	6.491×10^{-2}
	20V-4Hour	7.893×10^{-5}	3.914×10^{-2}
	20V-6Hour	6.711×10^{-5}	2.816×10^{-2}
	20V-8Hour	3.432×10^{-5}	1.481×10^{-2}
14th Day	6V-4Hour	1.899×10^{-5}	9.912×10^{-2}
	6V-6Hour	5.917×10^{-6}	9.141×10^{-2}
	6V-8Hour	9.110×10^{-6}	8.631×10^{-2}
	12V-4Hour	4.932×10^{-6}	5.931×10^{-2}
	12V-6Hour	4.211×10^{-6}	4.732×10^{-2}
	12V-8Hour	2.178×10^{-6}	4.011×10^{-2}
	20V-4Hour	7.993×10^{-6}	3.921×10^{-2}
	20V-6Hour	4.661×10^{-6}	2.671×10^{-2}
	20V-8Hour	4.219×10^{-6}	1.001×10^{-3}
21st Day	6V-4Hour	9.741×10^{-5}	8.932×10^{-2}
	6V-6Hour	9.113×10^{-5}	8.634×10^{-2}
	6V-8Hour	8.945×10^{-5}	8.394×10^{-2}
	12V-4Hour	8.956×10^{-6}	8.001×10^{-2}
	12V-6Hour	8.43×10^{-6}	7.962×10^{-2}
	12V-8Hour	8.14×10^{-6}	7.631×10^{-2}
	20V-4Hour	7.482×10^{-6}	7.432×10^{-2}
	20V-6Hour	4.218×10^{-6}	5.435×10^{-3}
	20V-8Hour	3.944×10^{-6}	4.114×10^{-3}
28th Day	6V-4Hour	8.463×10^{-5}	8.114×10^{-2}
	6V-6Hour	8.186×10^{-5}	7.912×10^{-2}
	6V-8Hour	7.945×10^{-5}	7.314×10^{-2}
	12V-4Hour	6.616×10^{-5}	7.009×10^{-2}
	12V-6Hour	5.814×10^{-5}	6.76×10^{-2}
	12V-8Hour	5.010×10^{-5}	6.178×10^{-2}
	20V-4Hour	5.790×10^{-5}	6.325×10^{-4}
	20V-6Hour	5.312×10^{-5}	5.022×10^{-4}
	20V-8Hour	5.932×10^{-5}	1.894×10^{-4}

Table 20: Corrosion Rate for KOH treated Specimen

DAY	Specimen	Corrosion Density (A/cm2)	Corrosion Rate (mm/yr)
1st Day	6V-4Hour	3.581×10^{-5}	1.172×10^{-1}
	6V-6Hour	5.499×10^{-4}	1.799×10^{-1}
	6V-8Hour	1.710×10^{-4}	5.595×10^{-2}
	12V-4Hour	4.985×10^{-4}	4.960×10^{-2}
	12V-6Hour	8.553×10^{-5}	4.632×10^{-2}
	12V-8Hour	8.290×10^{-5}	4.117×10^{-2}
	20V-4Hour	7.28×10^{-5}	4.865×10^{-2}
	20V-6Hour	5.939×10^{-6}	4.751×10^{-2}
	20V-8Hour	4.902×10^{-6}	4.021×10^{-2}
7th Day	6V-4Hour	6.915×10^{-5}	1.671×10^{-1}
	6V-6Hour	5.489×10^{-5}	1.710×10^{-1}
	6V-8Hour	5.094×10^{-5}	4.93×10^{-2}
	12V-4Hour	1.021×10^{-4}	5.97×10^{-2}
	12V-6Hour	4.701×10^{-5}	5.63×10^{-2}
	12V-8Hour	9.62×10^{-5}	5.110×10^{-2}
	20V-4Hour	7.424×10^{-5}	5.916×10^{-2}
	20V-6Hour	4.11×10^{-5}	5.134×10^{-2}
	20V-8Hour	5.158×10^{-5}	4.211×10^{-2}
14th Day	6V-4Hour	8.178×10^{-5}	8.114×10^{-2}
	6V-6Hour	5.160×10^{-5}	8.402×10^{-2}
	6V-8Hour	4.910×10^{-5}	8.462×10^{-2}
	12V-4Hour	1.099×10^{-6}	7.932×10^{-2}
	12V-6Hour	2.110×10^{-6}	7.814×10^{-2}
	12V-8Hour	2.01×10^{-6}	7.632×10^{-2}
	20V-4Hour	7.421×10^{-6}	7.002×10^{-2}
	20V-6Hour	4.391×10^{-6}	3.124×10^{-3}
	20V-8Hour	4.112×10^{-6}	3.021×10^{-3}
21st Day	6V-4Hour	9.133×10^{-5}	8.171×10^{-2}
	6V-6Hour	8.96×10^{-5}	8.321×10^{-2}
	6V-8Hour	8.031×10^{-5}	8.060×10^{-2}
	12V-4Hour	9.45×10^{-6}	4.841×10^{-2}
	12V-6Hour	8.12×10^{-6}	7.631×10^{-2}
	12V-8Hour	8.01×10^{-6}	7.31×10^{-2}
	20V-4Hour	7.402×10^{-6}	6.934×10^{-2}
	20V-6Hour	4.210×10^{-6}	3.946×10^{-3}
	20V-8Hour	4.033×10^{-6}	3.110×10^{-3}
28th Day	6V-4Hour	7.993×10^{-5}	7.943×10^{-2}
	6V-6Hour	7.632×10^{-5}	7.404×10^{-2}
	6V-8Hour	7.486×10^{-5}	7.234×10^{-2}
	12V-4Hour	5.012×10^{-5}	6.451×10^{-2}
	12V-6Hour	4.812×10^{-5}	5.93×10^{-2}
	12V-8Hour	4.632×10^{-5}	5.99×10^{-2}
	20V-4Hour	5.74×10^{-5}	5.32×10^{-4}
	20V-6Hour	5.93×10^{-5}	3.417×10^{-4}
	20V-8Hour	5.71×10^{-5}	1.732×10^{-4}

Table 21: Corrosion Rate for Nano Silica treated specimen

Day	Specimen	Corrosion Density (A/cm2)	Corrosion Rate (mm/yr)
1st Day	6V-4Hour	9.867×10^{-5}	3.228×10^{-1}
	6V-6Hour	3.571×10^{-5}	1.169×10^{-1}
	6V-8Hour	3.225×10^{-5}	1.055×10^{-1}
	12V-4Hour	8.167×10^{-5}	3.018×10^{-2}
	12V-6Hour	4.010×10^{-5}	3.114×10^{-2}
	12V-8Hour	4.117×10^{-5}	2.141×10^{-2}

	20V-4Hour	1.795×10^{-6}	5.873×10^{-2}
	20V-6Hour	1.617×10^{-6}	4.712×10^{-2}
	20V-8Hour	1.443×10^{-6}	3.168×10^{-2}
7th Day	6V-4Hour	7.791×10^{-5}	2.961×10^{-1}
	6V-6Hour	5.057×10^{-5}	1.841×10^{-1}
	6V-8Hour	7.731×10^{-5}	1.321×10^{-1}
	12V-4Hour	6.914×10^{-5}	2.981×10^{-2}
	12V-6Hour	5.813×10^{-5}	3.011×10^{-2}
	12V-8Hour	4.732×10^{-5}	2.943×10^{-2}
	20V-4Hour	2.743×10^{-5}	4.932×10^{-2}
	20V-6Hour	7.610×10^{-5}	4.617×10^{-2}
	20V-8Hour	7.236×10^{-5}	4.11×10^{-2}
14th Day	6V-4Hour	4.321×10^{-6}	3.145×10^{-2}
	6V-6Hour	3.912×10^{-6}	3.010×10^{-2}
	6V-8Hour	2.892×10^{-6}	4.01×10^{-2}
	12V-4Hour	4.391×10^{-6}	5.86×10^{-2}
	12V-6Hour	2.110×10^{-6}	5.71×10^{-2}
	12V-8Hour	1.98×10^{-6}	4.88×10^{-2}
	20V-4Hour	8.910×10^{-6}	6.110×10^{-2}
	20V-6Hour	7.843×10^{-6}	5.121×10^{-2}
	20V-8Hour	6.120×10^{-6}	3.145×10^{-3}
21st Day	6V-4Hour	9.841×10^{-5}	8.984×10^{-2}
	6V-6Hour	9.741×10^{-5}	8.668×10^{-2}
	6V-8Hour	9.211×10^{-5}	8.432×10^{-2}
	12V-4Hour	9.761×10^{-6}	8.912×10^{-2}
	12V-6Hour	9.321×10^{-6}	8.241×10^{-2}
	12V-8Hour	8.94×10^{-6}	7.936×10^{-2}
	20V-4Hour	7.944×10^{-6}	7.943×10^{-2}
	20V-6Hour	8.431×10^{-6}	4.932×10^{-3}
	20V-8Hour	4.932×10^{-6}	4.321×10^{-3}
28th Day	6V-4Hour	8.873×10^{-5}	8.792×10^{-2}
	6V-6Hour	8.214×10^{-5}	8.562×10^{-2}
	6V-8Hour	8.001×10^{-5}	7.934×10^{-2}
	12V-4Hour	7.618×10^{-5}	7.849×10^{-2}
	12V-6Hour	6.817×10^{-5}	7.324×10^{-2}
	12V-8Hour	6.026×10^{-5}	7.167×10^{-2}
	20V-4Hour	6.894×10^{-5}	7.432×10^{-4}
	20V-6Hour	5.719×10^{-5}	6.915×10^{-4}
	20V-8Hour	5.987×10^{-5}	2.713×10^{-4}

5. Conclusion

- Electro Kinetic treatment was found to be effective in increasing the durability and increasing corrosion rate by filling up the pores. It is expected that the ions used for treatment was successful in flocculating into Mortar pores.
- The best electrolyte for Electro Kinetic treatment was found to be Calcium Hydroxide ($Ca(OH)_2$) followed by Sodium Hydroxide (NaOH). Due to the greater size of Nano Silica, it was not showing satisfactory results as compared to other three electrolytes.
- It was confirmed that Higher voltage and Higher duration was found to be most effective for Electro Kinetic treatment. From the test results, treatment using 20V and 8 hours duration was found to be most effective.
- For all specimens as voltage increased, resultant current also increased, which indicates more diffusion of ions into specimens.
- When duration increased, current also increasing for treated specimens.
- As per Chloride ion penetration and Compression test, Calcium Hydroxide ($Ca(OH)_2$) treated specimens found to be best among other three electrolytic solutions for Electro Kinetic treatment.
- Corrosion studies also confirmed Calcium Hydroxide ($Ca(OH)_2$) treated specimens as most resistant to corrosion. Followed by Sodium Hydroxide (NaOH) treated specimen and finally Nano Silica treated specimens.
- Corrosion Current for the best specimen that is Calcium Hydroxide ($Ca(OH)_2$) treated specimen was having lesser corrosion current as compared to control specimen. Corrosion rate reduced almost as compared to control specimen.
- The ranking and performance can be explained by followed equation Nano Silica< KOH<NaOH< $Ca(OH)_2$).

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