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ACCELERATED CORROSION STUDIES ON REINFORCED CONCRETE SAMPLES USING VOLTAGE IMPRESSED TEST

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Abstract: There are many causes of deterioration in reinforced concrete structures, but corrosion is the main culprit. Reinforced concrete is the most used material in construction. Concrete structures as infrastructures are prone to losing performance over time as a result of the environmental conditions to which they are subjected. Steel embedded in concrete is normally subjected to an alkaline environment which subsequently passivates the steel. Any condition which disrupts the environment around the steel can result in disruption of the passive film and initiate corrosion process. The phenomenon of corrosion of reinforcement bar in concrete is a time dependant process, it takes years for the steel reinforcement to be corroded and to cause deterioration of reinforced concrete (RC) structures. Salt injury to reinforced concrete (RC) structures, freezing and thawing damage in cold climate zones, carbonation owing to carbon dioxide, chemical attack by acid solution, and so on are all examples of deterioration phenomena. One of the main global issues with steel reinforced concrete constructions deteriorating is chloride-induced steel corrosion. Key structural elements including beams, slabs, and the supporting columns are susceptible to corrosion attack, particularly when de-icing salts are used in cold temperature locations. However, If the corrosion time is too lengthy, the reinforced concrete structure components will be corroded for a long period, reducing the dependability of the reinforced concrete structure's function and perhaps causing safety issues. when it becomes imperative to evaluate the relative performance of different types of steel and binder in a short time, the accelerated corrosion test can be adopted. Corrosion was developed by artificially using an impressed voltage approach according to the ASTM B117-which had low connection with air corrosion testing. Reinforcing bar bonding in concrete is critical for reinforcing bar anchorage and reinforced concrete crack prevention. on the other hand, produce different test findings. Impressed current can cause non-uniform, growth of localised corrosion on steel reinforcement. the corrosion parameters are mild to severe in steel specimen used. The result is further supplemented by the observations made in IVT curves. Observable damage is indicative of decreased durability of concrete and ductility of steel.

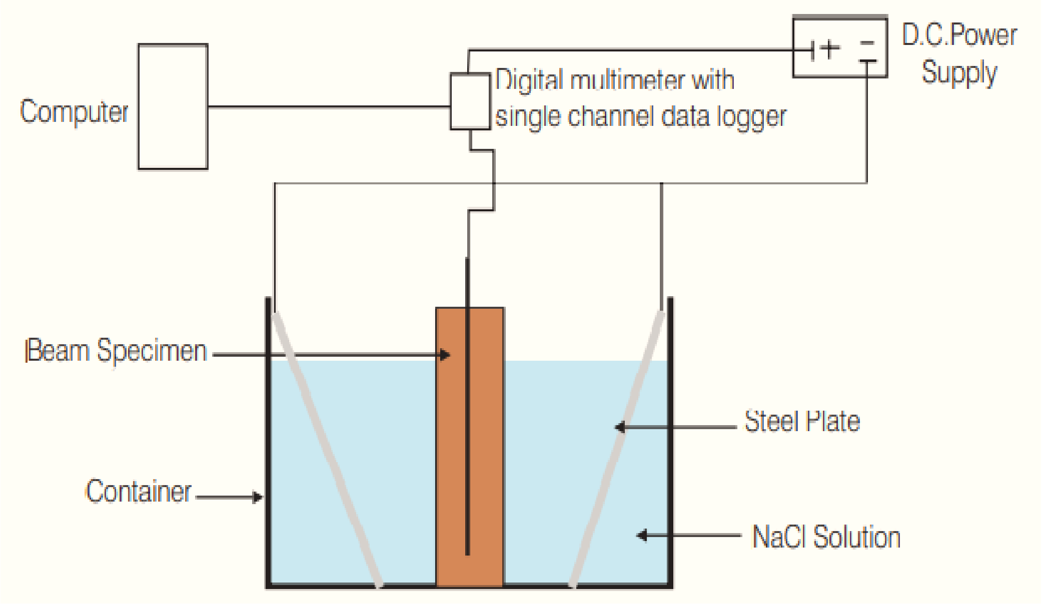
Keywords: Reinforced Concrete Structures, Corrosion, Voltage Impressed Test, Chloride.

I. INTRODUCTION

The majority of the materials used in building are reinforced concrete. Usually exposed to an alkaline environment, steel that is embedded in concrete begins to passivate. The passive film may be disturbed by any circumstance that disturbs the steel's surroundings, which will start the corrosion process. Reinforcing bar corrosion in concrete is a process that depends on time. Even in extreme environmental circumstances, reinforced concrete (RC) constructions deteriorate and steel reinforcement corrodes over time. One of the most important problems that steel reinforced concrete structures face globally is chloride-induced steel corrosion. Key structural components, such as supporting columns, are prone to corrosion attack, especially in cold temperature locations where de-icing salts are used. Saline water could also be a source of chloride contamination in structures. Saltwater contamination of aggregate components in concrete or water used in concrete batching are two further origins for chloride contamination in structures, as well as exposure to the marine environment directly or indirectly. On the other hand, the accelerated corrosion test can be used to quickly examine the overall relative efficiency performance of various types of steel and binders.

Accelerated Corrosion Test

Figure depicts the setup for an accelerated corrosion test (also referred to as voltage impressed test). A DC power source, two stainless steel plates, a data logger, a test specimen, and a jar that holds the required amount of NaCl solution make up the system. For the accelerated corrosion test, Concrete beam specimens with a steel bar implanted in the centre are employed. After preparation, specimens are tested at the requisite age. The positive terminal of the DC power supply is linked to the specimen's steel bar , while the negative terminal is connected to the stainless steel plates. A continuous voltage is applied to the system to start the corrosion process. The data logger continuously monitors and records the current reaction. The specimens are also visually inspected every day for the emergence of cracks. The data logger is programmed to record the circuit's corrosion current at a sampling frequency of 1 minute. When the specimen cracks and the rate of growth of corrosion current with time is insignificant, the accelerated corrosion test is terminated.



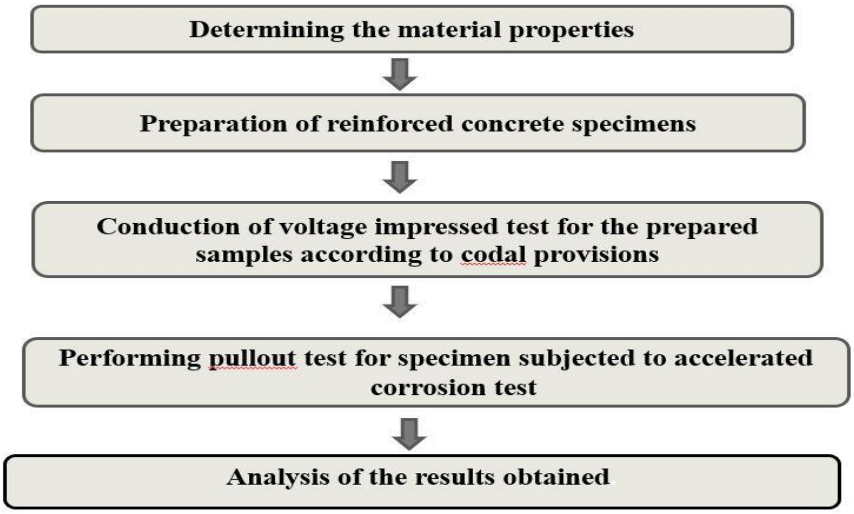
Setup diagram for an accelerated corrosion test

II. OBJECTIVES AND METHODOLOGY

3.1 OBJECTIVES OF STUDY

1. To determine the resistance of materials to corrosion under certain environmental conditions.
2. To determine the percentage ingression of corrosion product in the concrete.
3. To study the rate of deterioration of reinforced concrete using voltage impressed test.

3.2 METHODOLOGY



III. EXPERIMENTAL STUDIES

Ingredients in Reinforced Concrete

1. Cement
2. Aggregate
    a) coarse aggregate
    b) fine aggregate
3. Water
4. Steel

Normal Consistency of Cement

"The Standard Consistency of a cement paste defined as the **Consistency** which will permit the vicat plunger to penetrate to a point 5 to 7mm from the bottom of the vicat mould. apparatus"**.**

Table: Normal Consistency of Cement.

% age of Water	26%	28%	30%
Quantity of water	104	112	120
Initial Reading [IR]mm	0	0	0
Final Reading [FR]mm	18	13	6
Depth of Un-penetration in mm	18	110	6

Result: Standard Consistency of a cement sample is **28%**

Setting Time of Cement

"Initial setting time duration is required to delay the process of Hydration or Hardening. Final setting time is the time when the paste is completely losses its plasticity. It is the time taken for the cement paste or cement concrete to harden sufficiently and attain the shape of the mould in which it is cast."

a) Initial Setting Time of Cement (should not be less than 30 min):
b) Final Setting Time (should not be less than 600min)

Specific Gravity Test

The specific gravity of cement is defined as the ratio between the mass of given volume of cement and mass of an equal volume of kerosene. One of the methods of determining the specific gravity of cement is by use of liquid such as kerosene free from water to doesn't react with cement.

. **Table: Specific Gravity of cement**

Sl no	**Observation**	**Trial1**	**Trial2**	**Trial3**
1	Weight of empty bottle W1 in gram	52	52	52
2	Weight of bottle + water W2 in gram	154	154	154
3	Weight of bottle+ kerosene W3in gram	130	130	130
4	Weight of bottle+ kerosene+ cement W4in gram	176	175	176
5	Weight of cement W5 in gram	60	60	60
6	Specific gravity of cement	3.2	3	3.2

Result: Specific gravity of cement is: **-3.133**

Test on Fine aggregate

. **Specific gravity** (as per IS 2386 part 3- 1963).
Fine aggregate's specific gravity is defined as the ratio between the mass of a given volume of fine aggregate and the mass of an identical amount of water. This ratio is expressed as a percentage.

Table 9- Specific gravity test by pycnometer method

Sl. No.	Observation	Trail-1 (gm)	Trail-2 (gm)	Trail-3 (gm)
1	Weight of Empty pycnometer	615	615	615
2	Weight of pycnometer and dry sand	1111	1169	1136
3	Weight of pycnometer (sand+water)	1745	1820	1780
4	Weight of pycnometer and water	1460	1460	1460
5	Specific gravity	2.35	2.85	2.60
6	Average specific gravity	2.6		

Moisture Content of Fine Aggregate

Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture). Water content is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation. It can be given on a volumetric or mass (gravimetric) basis.

Table : Moisture Content

Weight of empty pycnometer (W1) gm	608
Weight of pycnometer + Sand (W2) gm	1078
Weight of pycnometer + Sand + Water (W3) gm	1792
Weight of pycnometer + Water (W4) gm	1498

Result: The percentage of moisture content of Fine Aggregate is**1.62%**

Test on Coarse aggregate

Specific gravity. (As per IS 2386 part 3- 1963) For 20mm aggregate
The ratio of the mass of a given volume of coarse aggregate to the mass of an equivalent amount of water is the definition of the specific gravity of coarse aggregate. This ratio is expressed as a percentage

Table : Specific Gravity Of Coarse Aggregate

Weight of coarse aggregate in gm	2000
Weight of basket + aggregate in water A1 gm	3060
Weight of basket immersed in water A2 gm	1806
Weight of aggregate in water A=A1-A2 in gm	1254
Weight of aggregate after dry surface B gm	1986
Loss of weight of aggregate in water B-A in gm	732
Weight of oven dry Coarse aggregate C	1966

Result: The Specific gravity of coarse aggregate is **2.685**

Unit Weight (Bulk Density) & %age of Voids of Coarse aggregate

We will get %**age voids** by comparing loose state and compacted state.

Table : Unit Weight & %age of Voids

Diameter of the cylinder ‘d’ in cm	15
Height of the cylinder ‘h’ in cm	17
Volume of the cylinder ‘V’ $\pi d^2/4 \times h$ cm^3	3004.14
Weight of empty cylinder (W1) gm	4386
Weight of cylinder + Compacted QD (W2) gm	9314
Weight of cylinder + Loosely QD (W3) gm	8792

Results

a. **Compacted State:**
  - Unit weight of Compacted state is **1.64 gm/cm^3**
  - The percentage of voids in compacted state is **36.92%**

b. **Loosely Filled State:**
  - Unit weight of loosely filled state is **1.46 gm/cm^3**
  - The percentage of voids in loosely filled state is **43.84%**

Steel

Table 12- Properties of steel

Sl.no	**Property**	**Value**
1	Aspect ratio	50
2	Diameter (mm)	16
3	Length (mm)	210
4	Tensile strength (Mpa)	841 (Carbon steel)

Fresh Concrete

Slump Test on Concrete

The concrete is used for the measurement of a property of fresh concrete. The test is an empirical test that measures the workability of fresh concrete. The stiffness of the concrete mix should be matched to the requirements for the finished product quality.

Table: Slump Test

w/c ratio	Initial height (h_1) in mm	Final height (h_2) in mm	Slump $(h_1 - h_2)$ in mm
0.5	300	196	104
0.5	300	193	107

Compacting Factor Test

The Compacting factor = weight of partially compacted concrete/weight of fully compacted concrete.

- ✓ **Slump cone test**
- ✓ **Compaction factor test**

M25 Grade concrete
Slump value : 104
Compacting factor : 0.92

M30 Grade concrete
Slump value : 107
Compacting factor : 0.93

4.5 Hardened Concrete

The most important qualities of hardened concrete, in terms of their use, are its strength; its stress-strain characteristics; its shrinkage and creep deformation; its sensitivity to variations in temperature; its permeability; and its durability. Of these, the strength of the concrete is considered to be of the utmost importance.

Compressive Strength:

Different kinds of concrete's tensile strengths Because concrete is mainly intended to endure compressive loads, determining its compressive strength has garnered a significant amount of interest. This is due to the fact that concrete can be measured to determine its compressive strength. Compression test specimens may take the form of cubes, cylinders, or prisms, and all three of these shapes are employed to measure a material's compressive strength. The standard size for a cube is either 100 or 150 millimetres on a side, while the standard size for a cylinder is 150 millimetres in diameter and 300 millimetres in height. In France, the standard size for a prism is 100 millimetres on all three sides and 150 millimetres in height. The specimens are then tested according to the standards that have been specified for such testing after being cast and cured. Before the test can begin, any cylinders that will be used need to have the appropriate cap placed on them.

Table : Compressive Strength Test of 28 days Cubes (M20)

Sl. no.	Grade of concrete	Weight of the cube (kg)	Compressive Strength(N/mm^2)	Average strength (N/mm2)
1.	M25	8.016	24.68	24.91
		7.996	25.14	
2.	M30	8.314	30.22	30.035
		8.269	29.85	

Grade of concrete	Split Tensile Strength(N/mm2)		
	7 days	14 days	28 days
M 25	2.06	2.34	2.75
M30	1.56	2.12	2.83

IV. RESULT AND DISCUSSION

Voltage impressed test

Figure depicts the setup for an accelerated corrosion test (also referred to as voltage impressed test). A DC power source, two stainless steel plates, a data logger, a test specimen, and a jar that holds the required amount of NaCl solution make up the system. For the accelerated corrosion test, Concrete beam specimens with a steel bar implanted in the centre are employed. After preparation, specimens are tested at the requisite age. The positive terminal of the DC power supply is linked to the specimen's steel bar , while the negative terminal is connected to the stainless steel plates.

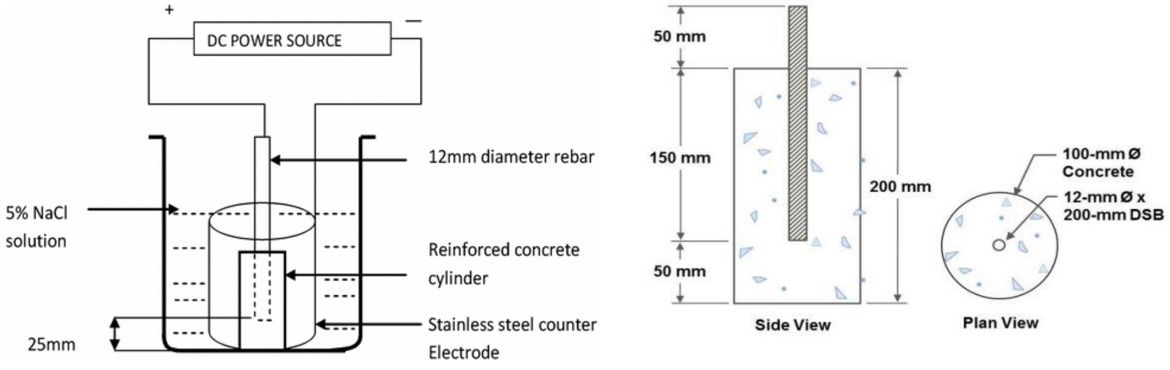


Fig. 2 schematic representation for Setup of impressed voltage test & RC test specimen

A continuous voltage is applied to the system to start the corrosion process. The data logger continuously monitors and records the current reaction. The specimens are also visually inspected every day for the emergence of cracks. The data logger is programmed to record the circuit's corrosion current at a sampling frequency of 1 minute. When the specimen cracks and the rate of growth of corrosion current with time is insignificant, the accelerated corrosion test is terminated. Rebar samples are Grade 500 with 0.5-in. (12 mm) diameter, cut into 8-in. (200 mm) lengths. Commercially available rock salt was used to prepare the 5% salt water concentration (Nacl) by weight.

Prior to casting, workability of specimens was tested using slump test under ASTM C 143 standard. The test samples were then allowed to set under room temperature for 24 hours, and moistcured for an additional 28 days in a water bath as per ASTM C 192. Impressed voltage technique was carried at the end of 28-day curing period. Chloride-contaminated water was prepared by mixing sea salt and purified water at 5% concentration by weight of solution I,e.,(Nacl solution) Corrosion process was accelerated by impressing a constant 3-V DC to RC cylinders immersed in 5% NaCl solution. The setup was configured such that the positive terminal of power supply is connected to the embedded rebar (anode) and the negative terminal to cylindrical stainless steel (cathode) of size 8-1/2 in. high, and 6 in. diameter. To prevent entry of oxygen to rebar-concrete junction, an epoxy coating has been applied n the said location. A 10-ohm resistor was also soldered somewhere in the protruded part of each rebar to act as the primary load of the circuit. The current flowing through the bars was recorded using an external ammeter (data-logger) connected across the resistor that can measure one current reading per second.

Corrosion Damage Measurement

Faraday's law of electrolysis

$$m=Qw_a/nF \text{ ………..…..………Eq.(1)}$$

where Q is the total charge passed, wa is atomic molar mass (wa= 55.847 g/mol for Fe), n is the number of electrons transferred per iron atom ($z = 2$ for $Fe \rightarrow Fe^{2+} + 2e^{-}$), and F is the Faraday's constant parameter (F = 96,487 C/mol). The total amount of electric charge Q resulting from electric current was calculated by getting the area under the curve of current-time relationship. Thus, the percentage of corrosion damage is given in Eq. (2)

$$C_t=(m/m_t)x100 \text{……………………..Eq.(2)}$$

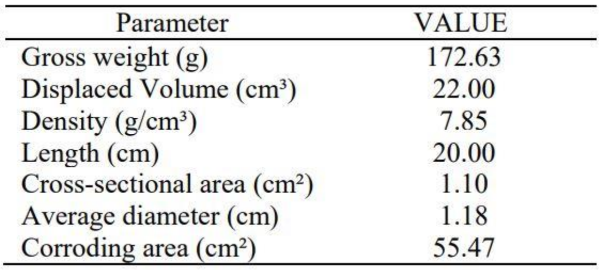
where mi is the mass of original metal. The mean corrosion rate (mm/year), can be obtained as shown in Eq. (3) by rearranging the mass loss equation,

$$r=iw_a/npF \text{………………………..Eq.(3)}$$

where r is the corrosion rate, i is the corrosion current density which is the ratio of average current to the original area corroding; and wa, n, ρ, and F as defined earlier.
Average current passed unto the bars was obtained by dividing the amount of charge liberated in Eq. (1) by the total time duration T of test as indicated in Eq. (4),

$$I_{av}=Q/T \text{…………………...…….Eq.(4)}$$

Table. Measurements obtained to compute for average corroding area.



Parameter	VALUE
Gross weight (g)	172.63
Displaced Volume (cm³)	22.00
Density (g/cm³)	7.85
Length (cm)	20.00
Cross-sectional area (cm²)	1.10
Average diameter (cm)	1.18
Corroding area (cm²)	55.47

Current-time relationship

Current values for all RC specimens generally level off at initial stage of test and may be attributed to the resistance provided by the concrete. It was argued that the decrease is due to the temporary protection given by the passive oxide film formed at earlier stage of current application. Past studies also mentioned that passivation may take effect even while concrete undergoes moist-curing. Presently available chloride caused the FeOOH or FeO-layers in the passive film to break down into more porous and weaker iron-oxide (Fe2O3) and thus protection lasts much faster than normal.

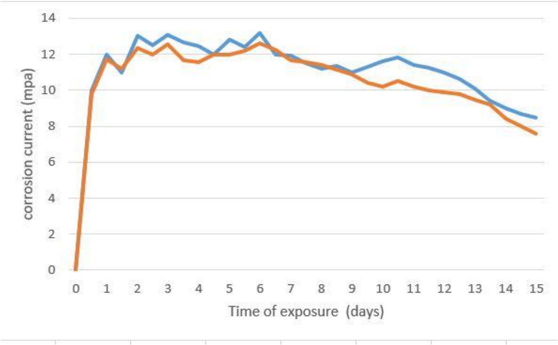
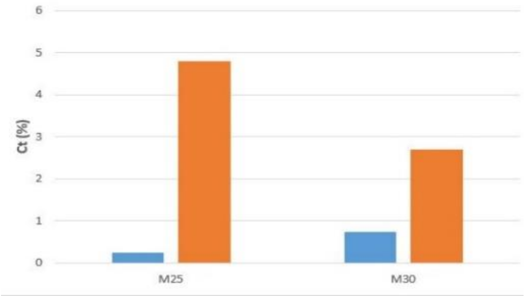


Fig. 4 Comparison of current values (mA) through time

Corrosion Damage



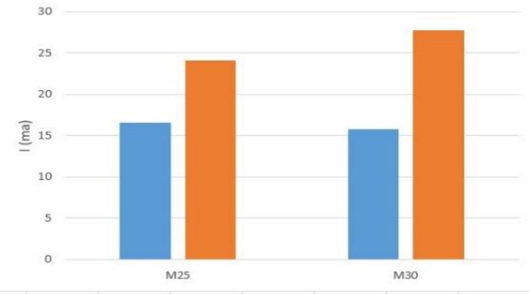


Fig. 5 Average percent corrosion

Fig. 6 Current measured in IVT per treatment.

Parameters of corrosion (percent mass loss, maximum, and average current applied) were averaged for triplicate samples and graphed in Fig. 5. The amount of current measured in IVT per treatment is also shown in Fig. 6. Applied current is a measure of concrete's ability to allow flow of electrons, which is an indication of susceptibility to corrosion, while corrosion rate measures the propagation of mass loss in steel under damage.

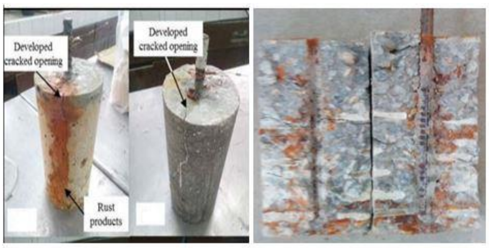


Figure 30. Concrete and steel surface observation after IVT

V. CONCLUSION AND FUTURE SCOPES

Real structures that are exposed to moisture may occur in environments with freshwater or saltwater. The experimental evaluation carried out aids in comprehending trends and determining the requirement for further study. The findings of corrosion ingression in the reinforced concrete structure subjected to accelerated corrosion utilising voltage impressed test can be the subject of research.

The objective of this study is to simulate steel corrosion in RC specimens under such conditions in an accelerated manner. This was done by applying an external constant voltage, and monitoring the corrosion current within a reasonable time period. Based on the analysis made, the following general conclusions can be drawn:

In general, the corrosion parameters are mild to severe in steel specimen used. The result is further supplemented by the observations made in IVT curves. Observable damage is indicative of decreased durability of concrete and ductility of steel. This study also demonstrated that using accelerated corrosion, clean water solution can still cause weight loss.

However, Faraday's law becomes inefficient in estimating the damage, indicating that iron hydrolysis is not the lone reaction occurring in the anodic metal.

Future scope

This test can be used to determine a variety of concrete durability factors. This test can also be used to compare different types of construction materials. This test can be used to simulate a variety of harsh field situations by altering the chloride content, grade of concrete, and voltage applied. Most corrosion experiments are done in laboratory conditions considering uniform corrosion on small and artificial samples. However, the properties of the steel–concrete interface may not be representative of natural corrosion. In addition, the corrosion process is affected by a size effect. Therefore, it remains difficult to extrapolate laboratory results from a small structure with a single rebar to a large structure with linked rebars. To acquire useful information for field application, particular care must be given in the sample design and preparation.

REFERENCES

[1] Coppola L, Beretta S, Bignozzi MC, Bolzoni F, Brenna A, Cabrini M, Candamano S, Caputo D, Carsana M, Cioffi R, Coffetti D. The Improvement of Durability of Reinforced Concretes for Sustainable Structures: A Review on Different Approaches. Materials. 2022 Apr 7;15(8):2728.
[2] Deb S. Accelerated Short-Term Techniques to Evaluate Corrosion in Reinforced Concrete Structures. The Master Builder. 2012:248-55.
[3] Kanazu T, Matsumura T, Nishiuchi T, Yamamoto T. Effect of simulated acid rain on deterioration of concrete. InAcid rain 2000 2001 (pp. 1481-1486). Springer, Dordrecht.
[4] Hussain RR, Ishida T. Enhanced electro-chemical corrosion model for reinforced concrete under severe coupled action of chloride and temperature. Construction and Building materials. 2011 Mar 1;25(3):1305-15.
[5] Altoubat S, Maalej M, Shaikh FU. Laboratory simulation of corrosion damage in reinforced concrete. International Journal of Concrete Structures and Materials. 2016 Sep;10(3):383-91.
[6] Benito EK, Madlangbayan MS, Tabucal NM, Sundo MB, Velasco PP. Corrosion damage measurement on reinforced concrete by impressed voltage technique and gravimetric method. GEOMATE Journal. 2017 Nov 30;13(39):198-205.
[7] Alhawat M, Zinkaah OH, Araba A. Study of corrosion products induced under different environmental conditions. InIOP Conference Series: Materials Science and Engineering 2021 Mar 1 (Vol. 1090, No. 1, p. 012050). IOP Publishing.
[8] Satish VL, Ravindra V. Evaluation of corrosion resistance of corrosion inhibitors in concrete structures by Impressed voltage test. InIOP Conference Series: Materials Science and Engineering 2021 (Vol. 1025, No. 1, p. 012002). IOP Publishing.
[9] Said Mahmoud., Hussein, Amgad, Hassan, Assem A and Gillis (2018)"Comparison Of Different Accelerated Corrosion Techniques" Civil Engineering Department, Memorial University, Canada , SNC Lavalin Inc, Canada. Building Tomorrow's Society
[10] Antunes RA, Ichikawa RU, Martinez LG, Costa I. Characterization of corrosion products on carbon steel exposed to natural weathering and to accelerated corrosion tests. International Journal of Corrosion. 2014 Jun 15;2014.
[11] Chu SH, Kwan AK. A new method for pull out test of reinforcing bars in plain and fibre reinforced concrete. Engineering Structures. 2018 Jun 1;164:82-91.
[12] Nguyen TH, Tran VM, Cao NT, Pansuk W, Jongvivatsakul P. Verifying the reliability of impressed current method to simulate natural corrosion in reinforced concrete. Engineering Journal. 2021 Mar 31;25(3):105-16.