Accelerated Corrosion Test as a Method to Evaluate Corrosion of Rebar

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Abstract— **Corrosion of steel reinforcement leading to deterioration of concrete is caused by an electrochemical due to the formation of small anodes and cathodes, resulting in ion movement between the two electrodes. Under marine environment, the inclusion of chloride into concrete is the primary reasons of reinforcement corrosion. In the present study, 150mm x 150mm x 150mm concrete cube specimens and 8mm steel bar conforming to Bureau of Indian standard specifications was used to assess corrosion of rebar in concrete under simulated marine water immersion. A constant voltage accelerated corrosion technique was used to induce corrosion to assess the factors governing the distribution and growth of corrosion products at the steel-concrete contact that were quantitatively examined. Use of gravimetric analysis indicated that the weight of the rebar in concrete under simulated marine environment decreased by 4.4% after 62 days of exposure under accelerated corrosion testing. XRD analysis indicated highest percentage of iron oxide in corroded specimens.**

Keywords— Corrosion, Steel–Concrete Interface (SCI), steel bars, corrosion rate, reinforced concrete

I. INTRODUCTION

Reinforcement corrosion cause early deterioration in sea-exposed structures. Structural components corrode faster due to inadequate concrete covering over the reinforcement, a high water/cement ratio, and minute cracks that allow moisture, oxygen, and chlorides to reach the steel surface. Structures severely deteriorate by chloride-induced reinforcing corrosion. This mechanism leads to cracking and spalling of reinforced concrete cover [1]. Chloride threshold decreases with the distance between the rebar surface and the concrete particles. In the case of horizontal rebar, the chloride threshold decreased with Steel-concrete interface (SCI) thickness as well. SCI thickness influences the chloride threshold of the horizontal rebar only: as SCI thickness decreases, the threshold increases [2]. Several studies indicated that the corrosion products are non-uniform around the steel-concrete interface, with maximum at the bottom side of the steel bar and the amount of corrosion products increases with the increase in concrete's water to cement ratio [3]. The steel-concrete interface becomes anodic due to gaps/voids. These locations have increased microcell corrosion. Due to voids/gaps at the steel-concrete interface, considerable macro-cell and microcell corrosion causes a localized pit. Thus, steel-concrete surfaces must be gap-free for marine reinforced concrete structures to last [4].Several factors influence the corrosion rate of a concrete structure, including moisture content, oxygen availability, and temperature, because of which, it is required to repeat corrosion rate tests at regular time intervals for better results [5]. Studies also indicated that quantifying the steel-concrete contact is easy and accurate with the backscattered electron (BSE) imaging technique. The distribution and mineral composition of corrosion products, namely chloride-induced corrosion and accelerated corrosion in carbonated mortar, can be examined using SEM/BSE, EDX, and Raman spectroscopy. The distribution of corrosion products is observed to be highly non-uniform and influenced by ion concentration, local steel characteristics, the microstructure of mortar around the rebar, the presence of oxygen, etc. Corrosion products often form precipitates in voids and bleed water zones at the steel surface [6].By taking into account the effect of the porosity of the steel-concrete interfacial zone, a simple and direct model for predicting the corrosion rate of steel bars in concrete is possible. The anode-cathode ratio for the electrochemical corrosion process, the chloride threshold value, and the resistivity of concrete are determined by the porosity of steel-concrete interfacial zone [7]. The Ground Penetrating radar (GPR) data

demonstrates that corrosion can be identified, but it must first be processed using image processing and discriminant analysis before being studied and understood **[8].** The thermal technique can be used to divide the by-products of corrosion into oxygen oxides and hydroxyl-oxides, which can then be used to carry out quantitative examination of the compositions and expansion coefficients for rust samples **[9].** The only therapy for chloride-induced corrosion that effectively controls reinforcement corrosion over a long period of time is impressed current cathodic protection (ICCP) **[10].** The objective of the present study is to induce corrosion of steel re-bars using accelerated corrosion test under simulated marine condition. The present study helps to understand the process involved in accelerating corrosion of re-bars under simulated marine conditions by supply of constant voltage.

II. MATERIALS AND METHODS

A. MATERIALS

In the present experimental study, 53-grade ordinary Portland cement, M-Sand of 4.75mm passing, as per IS 383:1970 confirming to Zone II. Coarse aggregate with sizes 20 mm downside is used confirming to IS 383-1970 is used. No chemical super plasticizer was used in this experiment, as it may affect the consistency of cement paste and the slump of concrete. HYSD bar of 8 mm in diameter and 410 mm in length was used, which has characteristic yield strength of 500 MPa. Table 1 shows properties of materials used.

TABLE 1: PROPERTIES OF CEMENT USED

Materials	Tests conducted	Results
Cement	Normal	30%
	Initial Setting	45min
	Final Setting	600 min
	Specific	3.10
M sand	Fineness	4.6
	Bulking	12%
	Specific	2.56
Coarse aggregate	Fineness	5.03
	Water	1%
	Specific	2.60

B. METHODOLOGY
Sample preparation
Mix design for Grade M40 in accordance with IS: 10262-2009 was implemented. The proportions of

cement, fine aggregate, and coarse aggregate in the mix were determined to be 1:2.25:3.36 respectively. A higher w/c ratio of 0.45 was used to investigate the possible effect on the distribution and growth of corrosion products. In accordance with IS:2514, the specimen was compacted on the vibration table for ten seconds before being subjected to a water curing for 28 days in a laboratory with a constant temperature of 23^0C.

In order to verify the design mix proportion, six concrete cube specimens were cast and to determine the concrete's compressive strength. Table 4 summarizes the percentage of average compressive strength of concrete for design mix proportion of grade M40. It can be seen that the average compressive strength for 28 days of curing for design mix proportion for M 40 grade of concrete is equal to 48.21MPa which is within the tolerance limit of 5% standard deviation as per IS:456-2000.

TABLE 2: COMPRESSIVE STRENGTH OF SAMPLES

Sl. No	Sample Number	Compressive strength after 28 days of curing (MPa)
1	S1	46.11
2	S2	48.12
3	S3	48.53
4	S4	48.59
5	S5	48.67
6	S6	48.71
Average compressive		*48.21*

III. EXPERIMENTAL SET UP

Laboratory investigation on the factors governing the rate of inductive corrosion in rebar embedded in a concrete cube specimen under a simulated marine environment was carried out. For the purpose of this investigation, six concrete cube specimens each measuring 150 mm x 150 mm x 150 mm and conforming to IS: 456- 2000 with a single HYSD steel bar as per IS:1786 of diameter 8 mm embedded in concrete were used. To remove mill scales that had accumulated on the surface of the rebar, the bar was pre-treated with distilled white vinegar before it was embedded in the concrete as reinforcement. To fulfil the minimum requirement for concrete cover specified in IS: 456-2000, a steel bar was embedded into the concrete cube at the appropriate place, as shown in Fig. 1.

(a)Schematic diagrams of RC Specimen (b) Typical Test specimen

Fig 1: Typical Reinforced Concrete Specimen Used in the Study

Accelerated corrosion test

Set-ups used for inducing reinforcement corrosion through impressed current consist of a DC power source, a counter electrode, and an electrolyte. The positive terminal of the DC power source is connected to the steel bars (anode) and the negative terminal is connected to the counter electrode (cathode). The current is impressed from counter electrode to the rebars through concrete with the help of the electrolyte (simulated marine water). The accelerated corrosion test setup schematically represented in Figure 2(a). Fig 2(b) shows the experiment under progress.
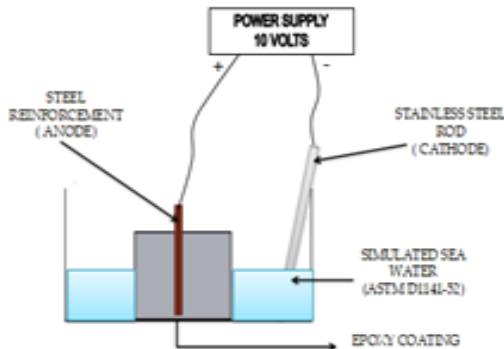
(a) Schematic presentation of the accelerated corrosion test set- up

(b) Accelerated corrosion test Set-up used
Fig 2: Accelerated Corrosion Test Set up

The specimen was partially immersed in artificially simulated seawater prepared as per ASTM D1141-98 shown in Table.5 with salinity similar to that of natural seawater. A constant voltage of 10 volts through DC power supply was supplied to the reinforcement to account for the effect of corrosion rate on rust expansion and deposition. The bottom of the specimen was sealed with epoxy resin to prevent the Sodium Chloride (NaCl) solution from entering through the bottom surface and rust from spreading beyond the concrete and steel interface. Figure 2b depicts the accelerated corrosion test in progress.

TABLE 3 ARTIFICIAL SEAWATER "ASTM D1141-98 COMPOSITION.

Compounds	Chemical name	Weight (g/l)
Sodium Chloride	NaCl	24.53
Magnesium Chloride	MgCl2	5.20
Sodium Sulfate	Na2SO	4 4.09
Calcium Chloride	CaCl2	1.16
Potassium Chloride	KCL	0.695
Sodium Bicarbonate	NaHCO3	0.201
Potassium Bromide	KBr	0.101
Boric Acid	H3BO3	0.027
Strontium Chloride	SrCl2	0.0025
Sodium Fluoride	NaF	0.003
Water	H2O	988.968

To evaluate the rate of corrosion at the steel-concrete interface and the effect of rust on the concrete surface, the following visual observations were made after the initiation of accelerated corrosion test, which are as shown in Fig 3. Fig.3a depicts the specimen prior to the onset of corrosion. During the first week of testing, deposition of corrosion, products were observed on the specimen's top surface at the steel-concrete interface. In addition, rust eventually began spreading/flowing vertically upwards, around the steel bar, and gathered on the top surface at the steel-concrete interface, resulting in a reduction in the steel bar's cross-section, as shown in Fig.3b.

(a) Specimen prior to corrosion (b) Rust deposition at steel concrete interface (c) Outer Concrete Surface Subjected to Spalling

Fig.3: Stages in Deterioration of Specimen during Accelerated Corrosion Test

Due to the diffusion of rust on the bottom surface of the concrete specimen following a 20-day immersion period, the epoxy layer at the specimen's base became weak after 20 days. Rust deposited at the steel-concrete interface exerted pressure on the surrounding concrete, resulting in an increase the concrete's porosity around the bar. It was found that the outside concrete surface was prone to spalling as shown in the Fig 3c.

After 62 days of immersion, the steel reinforcing bar was removed, cleaned of rust using a stiff metal brush, and weighed to establish its real mass loss. Using a diamond core cutting tool, a 40mm diameter core sample together with the reinforced bar was removed from the cube specimen. The samples of concrete were then broken to reveal the steel concrete interface. Gravimetric method and X-ray diffraction was used to identify the presence of corrosion products and also to quantify corrosion products in various fractured samples near SCI.

IV. RESULTS AND DISCUSSIONS

Gravimetric method

Accelerated corrosion test lasted for 62 days. Corroded bars were extracted from cylindrical concrete and were cleaned from concrete debris. The bars were cleaned using vinegar liquid, Cleaned bars were finally reweighed in analytical balance with 0.01g precision.

The initial weight and initial area of the steel rebar was measured before its immersion into simulated sea water solution. After the elapse of its exposure under accelerated corrosion test, and removal of rust, the reduced area and its final weight was meeasured. The actual area of corroded rebar was evaluated using Eq.(1)

$$A_{cs} = W_f / (L \times \gamma \text{ iron}) \qquad \dots\dots\dots\text{Eq (1)}$$

Where: A_{cs} = actual area of corroded reinforcement bar (mm^2), W_f = weight of reinforcement after corrosion, and rust removed (g) L = length of the specimen (mm) and γ_{iron} = 0.00785 g/mm^3 (steel).

The actual mass of rust per unit surface area on rebar extracted from the concrete specimen after the accelerated corrosion test by gravimetric test is computed using Eq (2)

$$M_{ac} = ((W_i-W_f))/\pi DL \qquad \dots\dots\dots\text{Eq (2)}$$

Where: M_{ac} = actual mass of rust per unit surface area of the bar (g/cm^2), W_i = initial weight of the bar before corrosion (g), W_f = initial eight after corrosion (g) for a given duration of induced corrosion, D = diameter of the rebar (cm), and L = length of the rebar sample (cm).

The average weight of the rebar before corrosion was 160gms. Actual area of reinforcement bar is 50.24 (mm^2), The average weight of the actual corroded bar of all the samples was found to be 153gms and area reduction can be determined using Eq (1).

XRD Analysis

X ray diffraction (XRD) analysis is carried out for phase identification of a crystalline material and to identify the compounds present in the corroded sample as shown in the Fig.4.
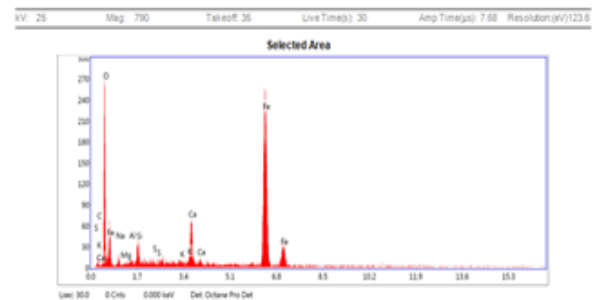

Fig.4 XRD analysis of corroded sample

Figure 4 reveals the presence of a higher percentage of iron oxides, which suggests that more rust has diffused away from the steel-concrete contact. According to the results of elemental analysis, the distribution of corrosion products in deeper layers is not uniform. Before concrete cracking begins, rust only diffuses into the cement paste around the steel-concrete interface. As rust accumulates, the confinement of concrete degrades and surface fissures may spread.

V. CONCLUSIONS

On the basis of present experimental study, it was found that the accelerated corrosion test was used to induce corrosion of steel re-bars embedded under concrete and subjected to simulated marine submergence. After undergoing 62-days of accelerated corrosion test, it was determined that the rebar had lost 4.4% of its weight. After 62 days of immersion in a salt water solution, the actual mass of rust per unit surface area on rebar extracted from the concrete specimen was determined to be $0.067 g/cm^2$. The XRD analysis of the sample showed that it contains 62.46 percent Fe2O3. Hence accelerated corrosion test can be conveniently used to assess the extent of corrosion a rebar undergoes under simulated marine submergence in the laboratory.

ACKNOWLEDGMENT

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