Corrosion of Steel Casing in Cement Placed in Salt Solution

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Abstract
This study is on the corrosion of steel casing in cement and 3.5% saline water solution monitored for 540 days. Using the Vipulanandan Impedance model to optimize the parameters, the changes in cement resistivity with the steel and contact corrosion parameters were quantified. For the corrosion of steel casing in cement and 3.5% saline water solution the corrosion parameters including the RC index variation with time were quantified. The corrosion index RC for the steel-cement interface is increasing with time.

1. Introduction

Construction industry is heavily impacted by the effects of corrosion as the corrosion of steel bars could cause deterioration of the concrete structures, thus results in failure (Kashani, et al., 2013). Corrosion of reinforcement results in fracture cracking, spalling of concrete cover, reduction of flexural and shear strength and reduction of ductility of the material (Kashani et al. 2013). As per U.S Corrosion study conducted between 1999-2001, around $276 billion was related to the direct cost on metallic corrosion and this was 3.1% of U.S. Gross Domestic Product (GDP) of 1998 (Koch, et al., 2002). The global cost of corrosion was estimated as US$ 2505 Billion, and this was 3.4% of global Gross Domestic Product (GDP) in 2013 (Koch, et al., 2016).

For corrosion monitoring, corrosion coupon weight loss method, electrical resistance probe method, electrochemical sensors, Ultrasonic testing of wall thickness method, magnetic flux leakage method, electromagnetic sensors, passive wireless sensors, optical fiber sensors and pipe inspection gauge are used (Wright, et al., 2019)

Non-destructive electrical method was developed to study the degree of corrosion in the structures. The electrical properties of the materials were used to develop Vipulanandan corrosion index (Vipulanandan, 2021). The contact resistance (R) and contact capacitance (C) can be used to quantify the corrosion of the steel casing and bars.

2. Objective

The overall objective was to measure and quantify the corrosion of steel casing in cement. The specific objectives are as follows.

1. Measure the changes in the cement using the two wire probes and A/C current
2. Measure the changes in the steel and interface

3. Methodology

A cylindrical mold of height 4 in and 4 in diameter was used. For the molds, four insertions were made for the wire probes as shown in Figure 1. A bottom cutout was made for the steel bar to go through. The cement slurry was prepared using a water-to-cement ratio of 0.4. Commercially available oil well cement (Class-H cement) and tap water were used. The mixing method adopted was hand mixing.

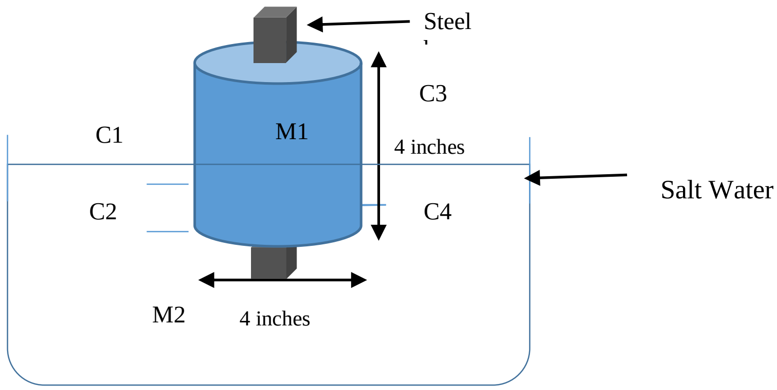


Figure 1 Cement Steel Casing wire configuration

On demolding the specimen after one day, the specimen was placed inside a bucket containing 3.5% salinity NaCl solution. The measurement of the resistance values were taken using LCR device for the frequency range of 20 Hz to 300 kHz for 540 days. The specimen was placed inside a bucket with 3.5% saline water. The resistance and reactance measurements were taken for 11 different wire probe combinations.

Based on the measured impedance-frequency plots a suitable equivalent circuit was chosen. The equivalent circuit is shown in Figure 2.

Here the bulk material is taken as resistance only while the two contact points are taken as a resistor and capacitor in parallel.

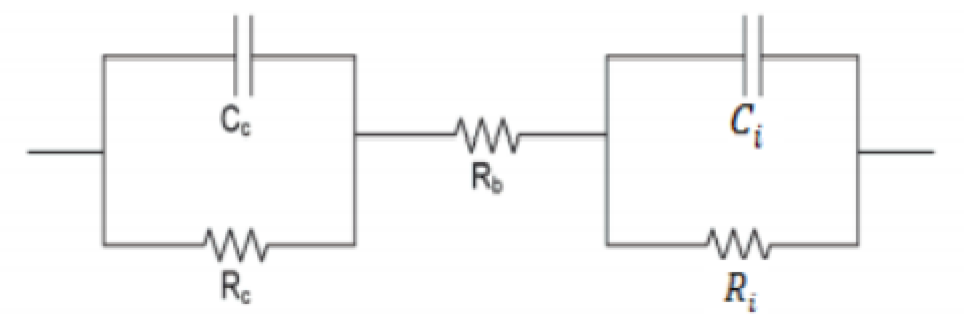


Figure 2 Equivalent circuit diagram of corrosion model

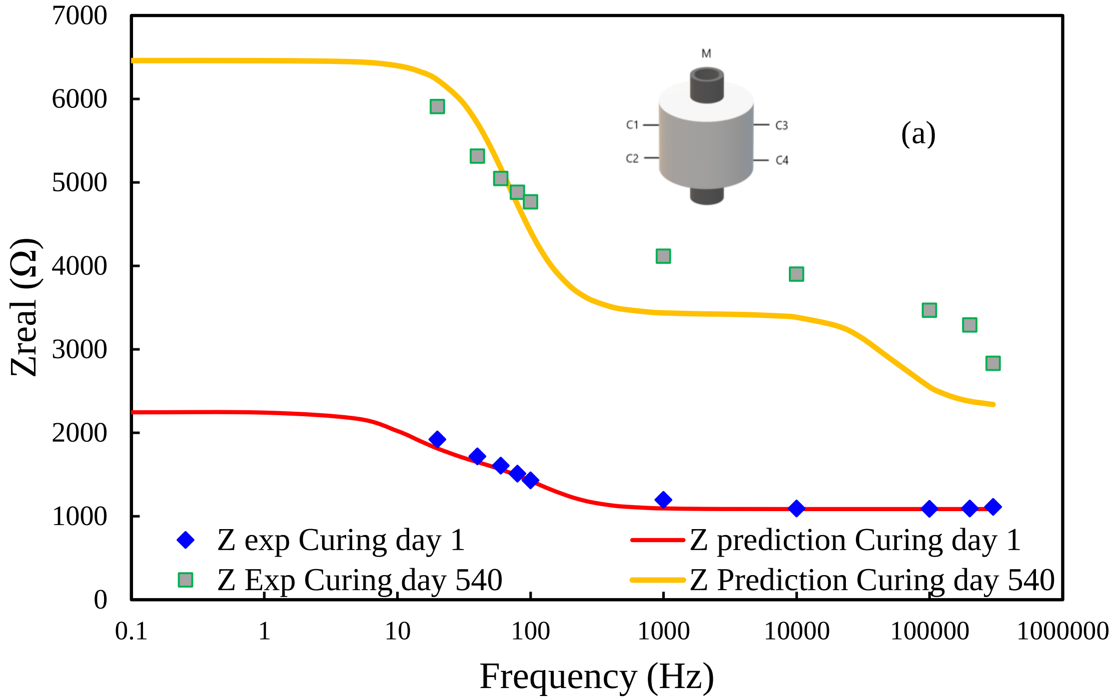
Impedance equation for given equivalent circuit diagram of corrosion model.

$$Z = R_b + \frac{R_c}{1+\omega^2 R_c^2 C_c^2} + \frac{R_i}{1+\omega^2 R_i^2 C_i^2} \quad \text{---(1)}$$

The above circuit equation can be used and the bulk resistance, contact resistance and contact capacitance values for all the probe configurations were computed by optimizing the model impedance data points.

4. Results

From the impedance model the collected data was optimized. The bulk resistance (Rb), contact resistance (Rc) and contact capacitance (Cc), interface Resistance (Ri) and interface capacitance (Ci) were calculated from the model optimization. The impedance curves of C3-C4 and M1-C1 configuration on day 1 and 540 are shown in Figure 3



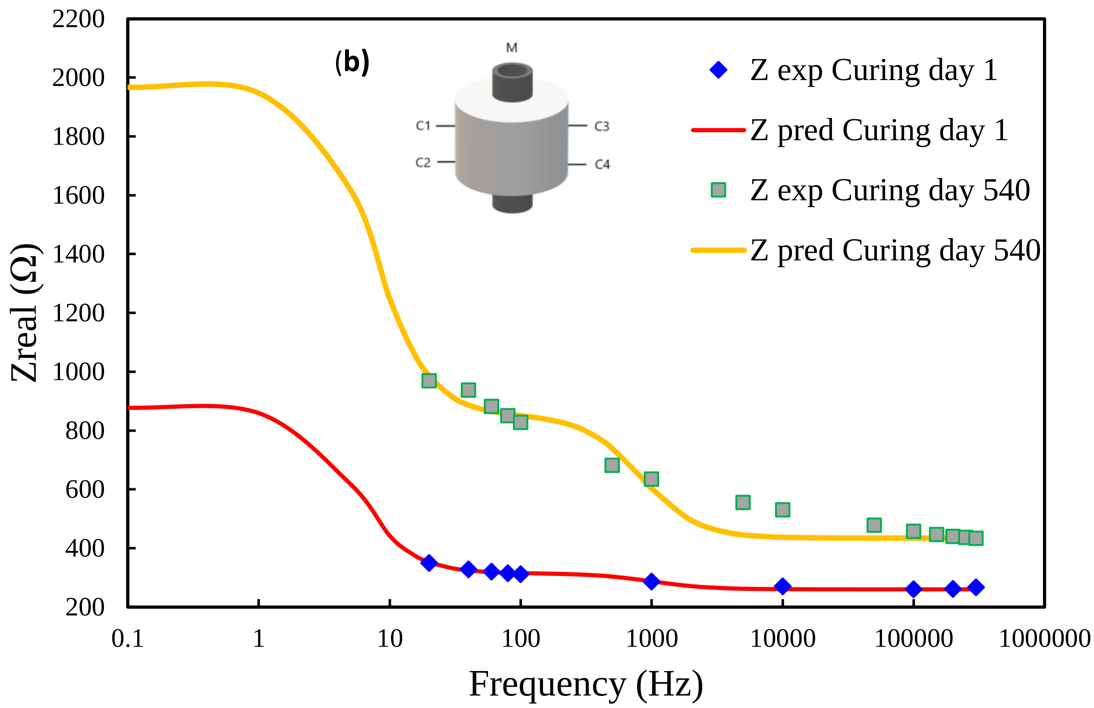


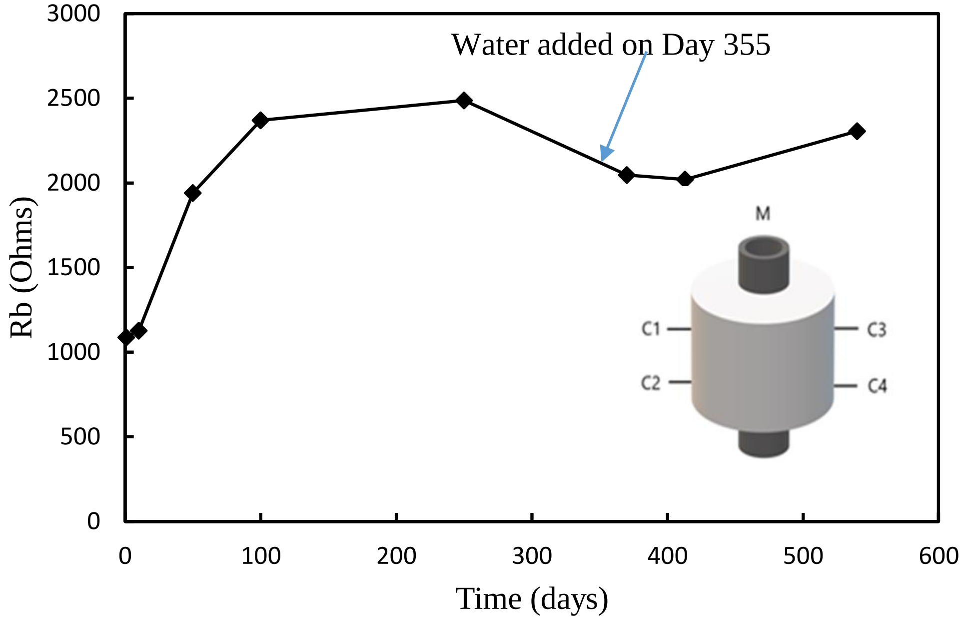
Figure 3 Comparing the impedance responses (a) C3-C4 and (b) M1-C1 configuration after 1day and 540 days

Based on the Figure 3, contact resistance, Contact capacitance, interface resistance, interface capacitance, R_{bulk} are tabulated for C3-C4 and M1-C1 combinations in Table 1.

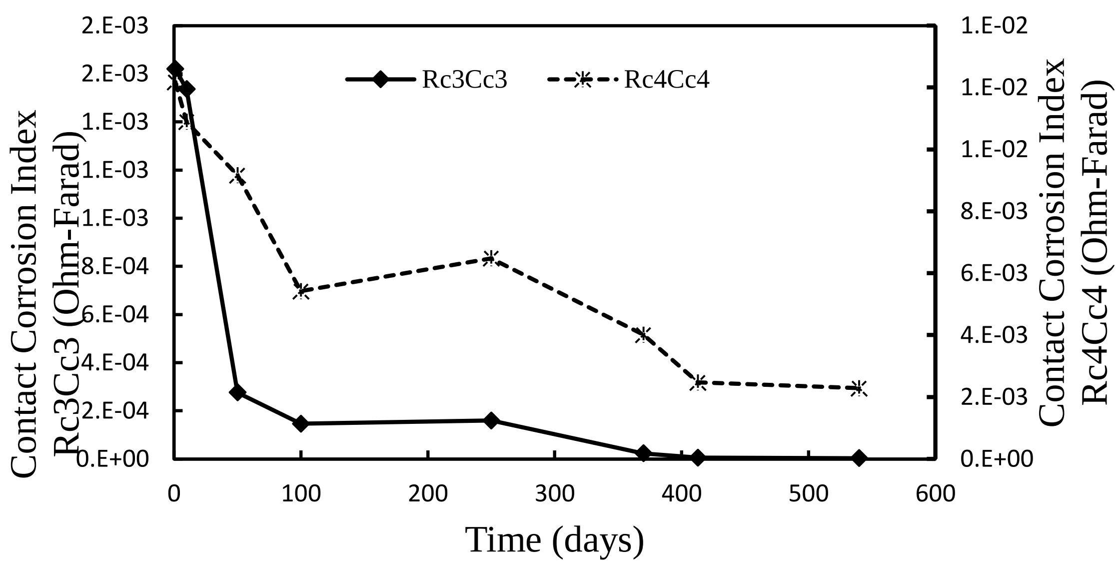
Table 1 Corrosion parameters for C3-C4 and M1-C1 configurations for curing days 1 and 540

Curing days	Combination	R^2	RMSE (ohm)	Rc3 (ohm)	Cc3 (F)	Rc4 (ohm)	Cc4 (F)	Rb (ohm)
1	C3-C4	0.96	53.58	563.50	2.4 E-06	595	2.05E-05	1086.65
540	C3-C4	0.95	265.50	1117	2.7 E-09	3037	7.62 E-07	2306.29
Curing days	**Combination**	**R^2**	**RMSE (ohm)**	**Rci (ohm)**	**Cci (F)**	**Rc1 (ohm)**	**Cc1 (F)**	**Rb (ohm)**
1	M1-C1	0.97	4.31	54.15	2.94 E-06	563.50	5. 22E-05	260.26
540	M1-C1	0.95	45.89	416.09	4.63 E-07	1117	1.92 E-05	434.11

The Plots for Rb and RcCc over time for the vertical configuration (C3-C4) and Plots for Rb, RiCi and RcCc over time for the M1-C1 configuration are shown in Figure 4 and 5.

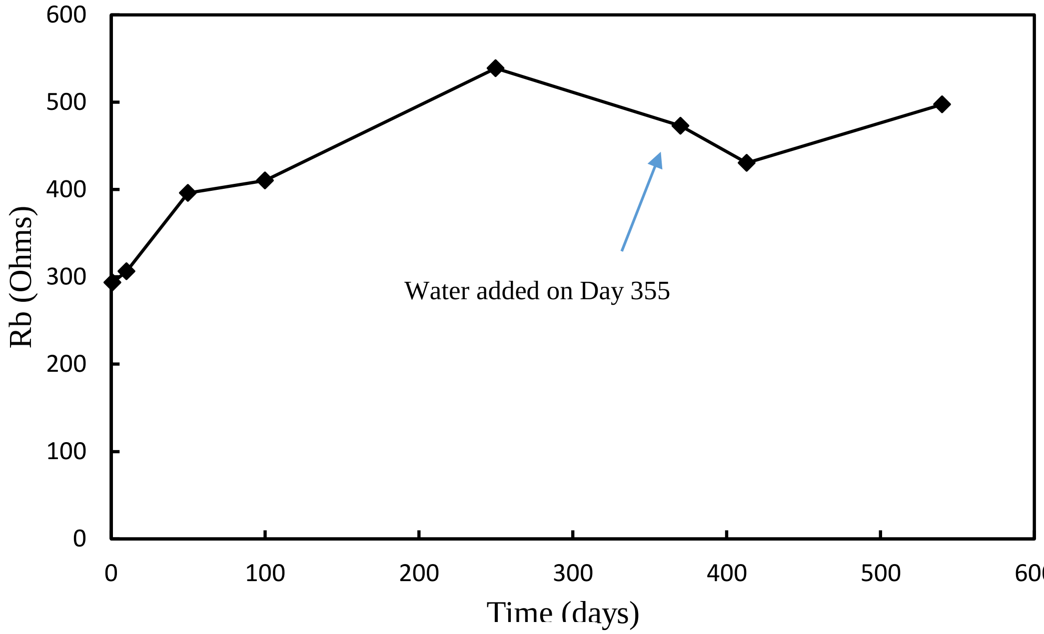


(a)

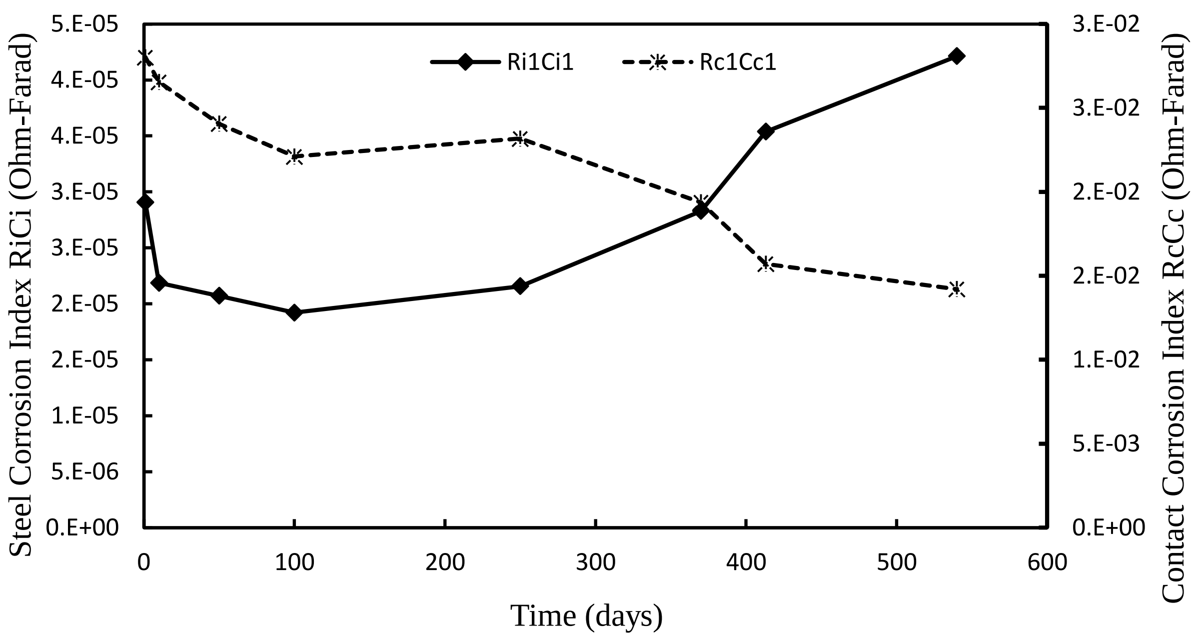


(b)

Figure 4 Variation of corrosion parameters (a) Rb and (b) RcCc over time for bottom (C2-C4) horizontal configuration



(a)



(b)

Figure 5 Variation of corrosion parameters (a) Rb and (b) RcCc and RiCi over time for M1-C1 configuration

Base on Figure 4 and 5, the following observations were made.

1. For both configurations, with the addition of water bulk resistance reduced immediately. Overall Bulk resistance (Rb) increased with time.
2. RcCc is decreasing overtime for both configurations whereas RiCi is increasing over 540 days.

5. Conclusions

1. The impedance values are decreasing from 20 Hz to 100 kHz. Beyond this frequency, the impedance value becomes nearly constant. This implies that the impedance value is influenced by resistance of cement. This follows case 2.
2. Same decreasing trends of Impedance values were observed for Cement-Steel configuration.
3. The equivalent circuit for case 2 can be used for cement-steel casing, where the bulk is represented by resistor and contacts were represented by two parallelly connected resistors and capacitors.
4. The bulk resistance, contact resistance and contact capacitance of all wire configurations were determined by optimizing the circuit formula. For Steel -wire configuration, the bulk resistance, contact resistance, contact capacitance, interface resistance and interface capacitance were determined using optimization of the circuit formula.
5. With the addition of water bulk resistance reduced immediately. Bulk resistance (Rb) is increasing in long term
6. Steel Corrosion Index (for cement steel interface) - RiCi is increasing and Contact Corrosion Index - RcCc is decreasing over time.

6 Acknowledgement

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7. References

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