

Analytical Study of Influence of pH and weight Loss on Steel Corrosion Embedded in Reinforced Concrete: A Review Paper

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Abstract

The present review paper discusses an aspect of influence of pH and weight loss of steel embedded in reinforced cement concrete. Fe415 steel is the widely used steel in construction industry because of its low carbon content and good mechanical properties. To make an analytical study, the Linear Polarization Resistance (LPR) measurement technique has been used for measurement of pH and weight loss in 0.5M NaOH Solution. The pH has been varied from 7-10 by a difference of 0.5. An equation which relates the pH and corrosion rates has also been dictated in the present paper. A wide literature review has also been conducted in the present paper. Temperature and the electrode voltage relationship have been shown in the text according to the Nernst equation.

Keywords: pH, Temperature, Corrosion, Weight Loss

1. Introduction

Reinforced concrete has the potential to be very durable and capable of withstanding the variety of adverse environmental condition. The effect of temperature on steel corrosion in concrete can be quite complex and it is due to many parameters. In reinforced concrete, steel provides the tensile properties which are needed in structural concrete. Concrete normally provides high degree of protection to the reinforcing steel against corrosion by the virtue of high alkalinity (pH>13.5) of the pore solution. The weight and Linear polarisation methods of evaluating the corrosion rate were used with 0.5M concentration of NaOH solution for experimental work. Corrosion rate increases with increment in temperature for almost all chemical process. Arrhenius equation relates these two parameters as shown in eq.1. From this equation, it can be concluded that with increases in temperature corrosion rates increases exponentially. While with variation in temperature pH value also varies.

$$i_c = Ae^{-E/RT} \quad (1)$$

Where

- i_c is the corrosion rate
- A is the Arrhenius pre-exponential factor
- E is the activation energy
- R is the universal gas constant
- T is the absolute temperature

Equation 2 represents the relation between pH and corrosion current. The value of constant 'A' obtained by different researchers has been shown in Table 1.

$$\log i_c = -A \times \text{pH} + B \quad (2)$$

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Table 1. Value of Constant ‘A’ by Different Researcher

Researcher	A	Mechanism Considered
Mukhtar et al [1]	1.0	Anodic reaction does not depend on pH
Bockris et al [2]	0.5	Anodic reaction inversely proportional to H ⁺ concentration
Raphel [3]	1.2	Hydrogen ion concentration with acidic solution

1.2. Electrode Slope Dependence on Temperature

Nernst Equation which relates the temperature with voltage of an electrode for half-cell and full-cell cases. Eq. 4 and 5 shows the Nernst equation for two cases half-cell and full-cell respectively.

$$E_{half-cell} = E_{half-cell}^o + \frac{RT}{zf} \ln \frac{a_{ox}}{a_{oy}} \quad (4)$$

$$E_{cell} = E_{cell}^o - \frac{RT}{zf} \ln Q_r \quad (5)$$

Where

- $E_{half-cell}$ is the potential for half-cell at the interest temperature
- $E_{half-cell}^o$ is the standard potential for half-cell
- E_{cell} is the potential for full cell at the interest temperature
- E_{cell}^o is the standard potential for half-cell
- T is the absolute temperature
- a_{ox} is an-oxidizing agent
- a_{oy} is the reducing agent
- R is the universal gas constant (6.023×10^{23})
- Z is the no. moles in reaction
- f is the faraday's constant
- Q_r is the reaction quotient

2. Literature Review

Ghaz *et al.*, [5] studied the high-temperature effect on the corrosion of steel through simulate polarization resistance test and model development by using Laplace equation to study corrosion rate temperature and concrete resistivity. Escudero and Macias [6] studied the effect of fluoride on corrosion of reinforcing steel in alkaline solutions by means of electrochemical techniques in saturated solution of Ca(OH)₂ and pH of NaOH solution with additions of NaF and came to conclusion that the corrosion behaviour of reinforced steel in concrete made with cement manufactured employing fluorides cannot be very different from that in concrete made with traditional cement. Apostolopoulos and Papadakis [7] studied the consequences of steel corrosion on the ductility properties of reinforcement bar for the initiation mechanism leading to steel de-passivation *i.e.*, carbonation and chloride penetration and they form loss in steel mass increases.

Mechanical	Plastic shrinkage							
	Plastic settlement							
		Direct loading						
		Imposed deformations						
Physical		Temperature differences						
		shrinkage	Early	frost action	late			
Chemical					Acid sulphate Reinforcement corrosion			
Biological					Microgrowth			
					H ₂ S attack			
		HO	UR	DAY	WEEK	MONTH	YEAR	CENTURY

Figure 1. Concrete Deterioration Mechanisms and Possible Time of Appearance of Cracking or Damage

Song and Saraswathy [8] studied the corrosion monitoring of reinforced concrete structures by electrochemical and non destructive techniques and their application to buildings bridges and other structures by different methods in their review paper and reported that the electrical resistivity of concrete as an effective parameter to evaluate the risk of reinforcing steel corrosion and their details are shown in Table 2.

Table 2. Corrosion Risk from Resistivity

Resistivity (Ohm.cm)	Corrosion risk
Greater than 20,000	Negligible
10000-20000	Low
5000-10000	High
Less than 5000	Very high

A number of electrochemical rebar corrosion measurement and techniques available are reviewed. Each technique is reviewed to possess with certain advantages and limitations and communicated finally in his paper that sensors are also used on structures exhibiting corrosion as a part of rehabilitation energy to assess the effectiveness of repairs. Arredondo *et al.*, [9] studied the carbonation rate and reinforcing steel corrosion of concretes with recycled concrete aggregates and supplementary cementing materials. Concrete carbonation is one of the main causes of reinforcement electrochemical corrosion. The corrosion rate of steel embedded in concrete has been measured by the linear polarisation resistance technique. Due to the significant environmental impact that the concrete production causes, and as sustainability contribution for this industry; presently some improvements are being implemented in its durability and its components are being replaced for alternative recyclable materials and came to conclusion that to use 100% RCA increases in 20% the total porosity and decreases the compressive strength in 15% respect to reference mixture.

Suo, Stewart *et al.*, [10] studied the corrosion cracking prediction updating of deteriorating RC structures using inspection information. It is well known that the corrosion-induced cracking of reinforced concrete (RC) structures vary in time and space due to the inherent spatial variability of concrete cover, concrete strength, surface chloride concentration and other material, environmental and dimensional properties and came to conclusion that how to reduce the uncertainties when predicting future corrosion damage by utilizing visual inspection findings. The influence of different inspection findings and inspection intervals on the likelihood and extent of corrosion damage (cover cracking) is studied by numerical simulation using a spatial time-dependent reliability analysis.

Cleland *et al.*, [11] studied the corrosion of patch reinforcement repair in concrete structures. They show how the repair material influences the resistance to corrosion of reinforcement by experimentally investigating the provide data on the performance of repair materials in preventing corrosion of both coated and uncoated reinforcing bars and concluded that epoxy mortar exhibit small shrinkage compared to the cementitious material and also concluded that high permeability was measured at the interface of the cementitious mortars and surrounding concrete but not at the interface between the epoxy or flowing concrete and surrounding concrete.

Xiang *et al.*, [12] studied the corrosion behaviour of X70 steel in the CO₂/SO₂/O₂/H₂O environment affected by high temperature.

Table 3. Represents Researchers Work about Temperature Effect on Corrosion Rate

Author's	Material use	Environment	Temperature
Shariff et al [22]	AISI 304	CO ₂	700 °C
Fazal et al [23]	Mild steel	Palm Biodiesel	Room temp., 50 & 80 °C
Anderson [14]	AISI 304 and Alloy 600	Water-O ₂	25-288 °C
Truman [18]	AISI 304	NaCl	20,40, 60 & 100 °C
Xiang et al [12]	X70 steel	CO ₂ /SO ₂ /O ₂ /H ₂ O	25, 50, 75 & 94 °C
Mesa et al [24]	AISI 420 & High nitrogen martensitic steel	Ocean water & Quartz particles	0, 25 & 70 °C
Xin et al [13]	Aluminium 3003 alloy	Ethylene glycol	30-80 °C
Ismail et al [17]	X70	ATCC 7757	5, 20, 37 & 60 °C
Qi et al [20]	Carbon steel (A350LF2)	Hydrogen Sulphide	25, 40, 60 & 90 °C
Kairi & Kassim [15]	Mild steel	HCL	30-55 °C
Escudero and Macias [6]	Ca(OH) ₂ , NaOH and NaF	pH 12-23	Nil
Apostolopoulos [7]	Ca(OH) ₂ +CSH and NaCL steel grade BSt 420	pH around 12.6-9	35 ⁰ C
Cleland et al. [11]	Mild steel bar	Epoxy	20 ⁰ C
Qinghui Suo and Mark G. Stewart [10]	NaCL	Monte carlo simulation	Nil
Rea Arredondo S. P. et al [9]	Recycled concrete aggregate	pH=13 for thermodynamic stability	28 ⁰ ±1

Xin *et al.*, [13] studied 3003 aluminium alloy corrosion in ethylene glycol-water solution affected by temperature. Andresen [14] studied the temperature effect on the growth of crack for 304 stainless steel and 600 alloys.

Kairi and Kassim [15] studied the corrosion inhibition of mild steel affect by high temperature in 1M HCL solution. Table 3 represents the work conducted by researchers around the globe to see the effect of temperature.

Clarelli *et al.*, [16] developed a mathematical model for copper corrosion detection due to sulphur dioxide SO₂. The partial differential model developed by them can describe the damage evolution. In their experiments, they considered a bronze sample which was open to sulphur dioxide pollution (SO₂). The mathematical equation for saturated vapour density (SVD) as a function of temperature developed by them has been shown in equation 6. While the results obtained by them for the behaviour of corrosion has been shown in Figure 2.

$$SVD(T) = 5.018 + 0.32321T + 0.0081847T^2 + 0.00031243T^3 \quad (6)$$

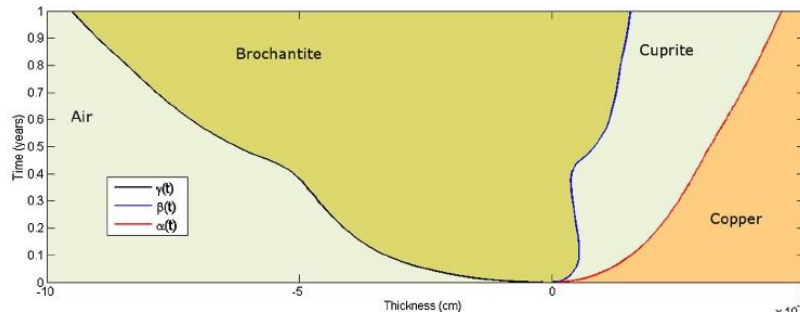


Figure 2. Behaviour of Corrosion with Environment

Ismail [17] studied the pH and temperature effect of SRB on steel corrosion. The variation of corrosion rates for carbon Steel with pH variation measured by them has been shown in Table 4.

Table 4. Variation of Corrosion Rate with pH [17]

pH values	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
CR (mm/year)	0.013	0.084	0.066	0.012	0.074	0.092	0.011	0.013	0.014

Trumen [18] studied temperature, pH and chloride content effect with austenite stainless steel.

Chen and Brantley [19] studied the dissolution rate dependency on pH and temperature in acidic medium.

Table 5. Effect of Temperature and Flow Velocity on CR (Corrosion Rate)

Author	Flow velocity (m/s)	CR (Temp): mm/year (°C)	CR (Temp): mm/year (°C)	CR (Temp): mm/year (°C)	CR (Temp): mm/year (°C)
Qi [20]	-	0.56 (25)	0.905 (40)	0.28 (60)	0.224 (90)
Nesic et al [21]	13	3.26 (20)	11.15 (40)	17.2 (60)	18.6 (90)

Table 5 represents the effect of flow velocity and temperature on the corrosion rate. First row represents the work done by Qi [20] which has been conducted at the low flow rate while Nesic [21] has conducted the work on low flow velocity as well as for large velocity. It can be observed that the for low-velocity corrosion rate increases then decreases with increases in temperature while for large velocity it continuously increases up to 90°C Table 6 represents the effect of the pH values.

Table 6. Represents Researchers Work about pH Effect on Corrosion Rate

Author's	Material use	Environment	Temperature
Roy et al [25]	Waste container materials	Aqueous	2, 3, 6, 7, 10 & 11
Tam & Elefsiniotis [26]	Lead and Cu	Alkaline and orthophosphate	7,7.5, 8 & 9
Arjmand & Adriaens [27]	Unalloyed Cu	NaCl	3, 7 & 11
Muslim et al [28]	Al & Cu	Water	4.7, 7 & 8.2

2.1. Mild Steel Compositions

It is also known as low carbon steel or plain carbon steel. It is the most extensively used because of its low cost. Its low carbon amount makes it suitable for low carbide

precipitation during heat temperature treatment zone. It has upright mechanical properties in respective of the construction industries. Table 7 obtained from Indian standard code shows the general purpose composition of mild steel. Carbon percentage varies from 0.05 to 0.25%. LPR measurement technique dictated below has been used in the present study to measure the corrosion rate.

Table 7. Mild Steel Compositions

Material	Carbon	Manganese	Silicon	Phosphorous	Sulphur
Amount (wt. %)	0.05-0.25	0.7-0.9	0.4% max	0.04 max	0.04 max

3. Experimental Methodology:

Linear polarization method has been used to measure the corrosion rates of mild steel samples prepared. In this method one can use either three electrodes or two electrodes. Three electrodes method is used for measuring lower resistance and thus appropriate for solution with low thermal conductivity. In three electrode methods, one is working electrode, one is reference electrode and the last one is the conventional counter electrode. Figure 3 illustrates the three electrode method. A two electrodes measurement technique has been shown in Figure 4. In this technique no reference electrode is necessary. Where AUX=Auxiliary Electrode, WE=Working Electrode, REF=Reference Electrode.

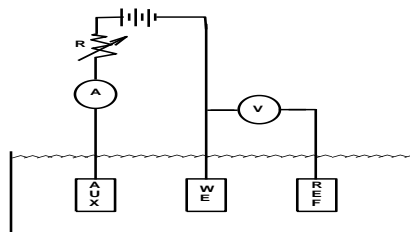


Figure 3. Three Electrode LPR Measurement Technique

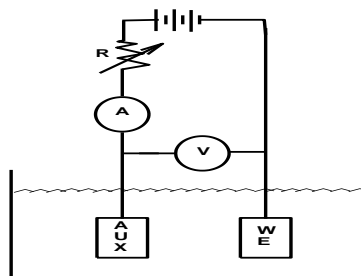


Figure 4. Two Electrode LPR Measurement Technique

3.1. Weight Loss Measurement of Steel Embedded in Concrete

To evaluate pH and weight loss in Fe415 steel bars, seventy two concrete mixes are prepared in $150 \times 150 \times 150 \text{ mm}^3$ mould and a 12mm ϕ TMT steel bar of 200mm length has been taken for experimental work which digitally weighed was embedded in concrete cube by keeping 20 mm cover on each side. The weight of each bar was found in grams up to three digits by using advance digitally weighing machine as shown in the figure 6 and their weights are recorded initially and after 28 days. The loss of weight of bar in gram is measured and tabulated below in Table 8. The loss in weight is represented graphically in Figure 7. The specimens were de-moulded after 24 hours and kept in NaOH solution of 0.5M concentration to study the rate of corrosion as well as loss in weight of

bar after initiation and 28 days respectively. After that, all samples were taken out and dried.



Figure 5. Shows Corrosion of Steel Bar Embedded in Reinforced Cement Concrete after 28 Days of Exposure



Figure 6. Weight of Steel Bar taken by Advance Digitally Weighing Machine

Table 8. Weight Loss of Steel Bars in Different Samples after 28 Days of Exposure

Sample	Original weight of steel bars in gram	weight of bars after the 28 days of exposure	Loss of weight (gram)	Average Loss of weight (gram)
Sample 1	179.54	179.51	.03	0.028
	179.77	179.75	.02	
	179.65	179.61	.04	
	179.76	179.73	.03	
	179.60	179.57	.03	
	179.52	179.50	.02	
Sample 2	179.56	179.54	0.02	0.018
	179.59	179.57	0.02	
	179.59	179.57	0.02	
	179.86	179.85	0.01	
	179.66	179.64	0.02	
	179.84	179.82	0.02	
Sample 3	179.52	179.50	0.02	0.02
	179.79	179.77	0.02	
	179.78	179.76	0.02	
	179.65	179.63	0.02	
	179.59	179.56	0.03	
	179.70	179.69	0.01	
Sample 4	179.43	179.41	0.02	0.022
	179.76	179.74	0.02	
	179.59	179.57	0.02	
	179.90	179.88	0.02	

	179.24	179.21	0.03	
	179.55	179.53	0.02	
Sample 5	179.67	179.65	0.02	0.02
	179.74	179.72	0.02	
	179.66	179.64	0.02	
	179.64	179.62	0.02	
	179.57	179.55	0.02	
	179.50	179.48	0.02	
Sample 6	179.66	179.64	0.02	0.018
	179.60	179.58	0.02	
	179.61	179.59	0.02	
	179.66	179.64	0.02	
	179.50	179.49	0.01	
	179.58	179.56	0.02	
Sample 7	179.77	179.73	0.04	0.048
	179.87	179.82	0.05	
	179.79	179.74	0.05	
	179.65	179.58	0.07	
	179.90	179.86	0.04	
	179.62	179.58	0.04	
Sample 8	179.63	179.59	0.04	0.043
	179.63	179.6	0.03	
	179.79	179.74	0.05	
	179.14	179.09	0.05	
	179.92	179.87	0.05	
	179.05	179.01	0.04	
Sample 9	179.31	179.11	0.2	0.183
	179.19	179.004	0.186	
	179.22	179.03	0.19	
	179.37	179.18	0.19	
	179.33	179.17	0.16	
	179.69	179.52	0.17	
Sample 10	179.57	179.55	0.02	0.02
	179.52	179.50	0.02	
	179.56	179.54	0.02	
	179.72	179.70	0.02	
	179.53	179.51	0.02	
	179.61	179.59	0.02	
Sample 11	179.68	179.66	0.02	0.02
	179.44	179.42	0.02	
	179.53	179.51	0.02	
	179.48	179.46	0.02	
	179.58	179.56	0.02	
	179.61	179.59	0.02	
Sample 12	179.77	179.73	0.04	0.025
	179.48	179.46	0.02	
	179.63	179.6	0.03	
	179.74	179.72	0.02	
	179.90	179.88	0.02	
	179.84	179.82	0.02	

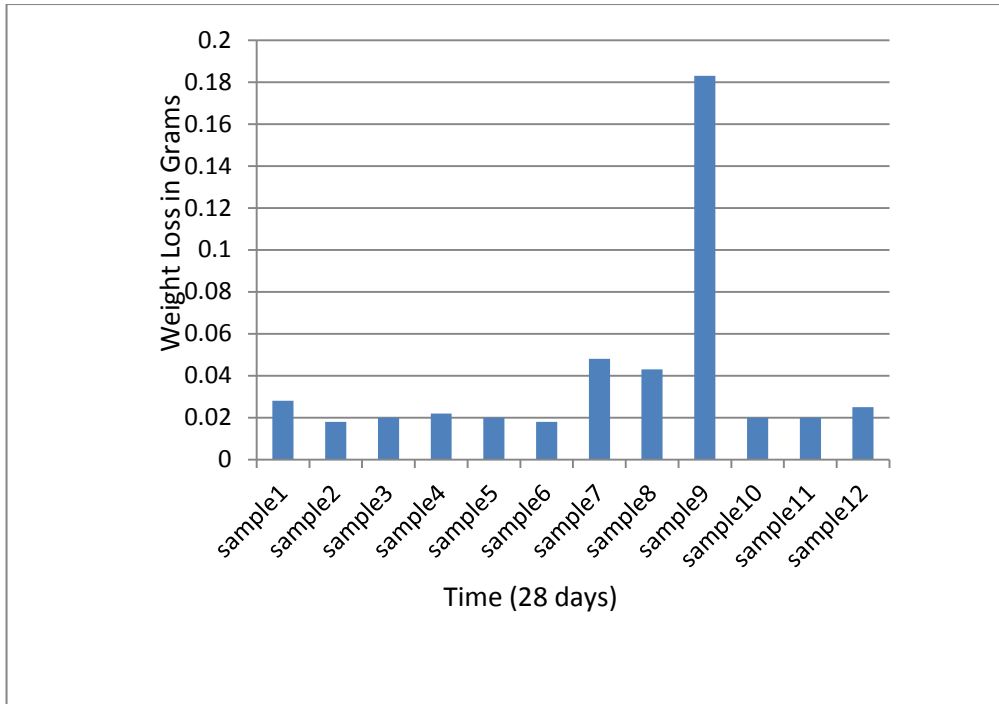


Figure 7. The Loss in Weight of Steel Bar with Time

4. Result and Discussion

A Sample of $3 \times 1 \times 0.15$ cm has been cut from a sheet. A hole has been bored at the end of the sample for stress-free hanging. From Figure 8 it can be noticed that weight loss decreases with increment in pH value. While Figure 9 shows the relationship between the pH and the corrosion rate of the mild steel.

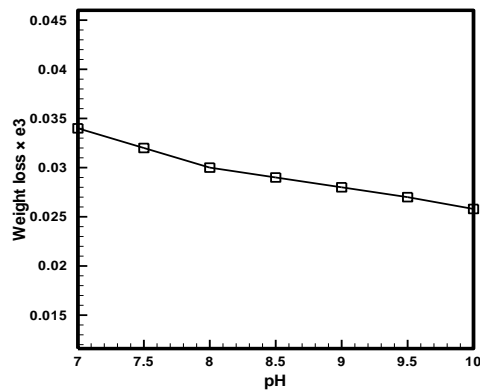


Figure 8. Effect of pH on Weight Loss

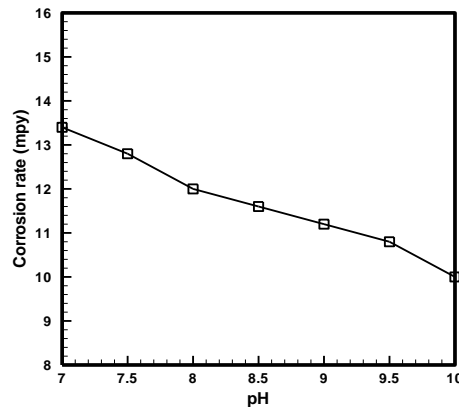


Figure 9. Effect of pH on Corrosion Rate

5. Conclusion

The corrosion of stainless steel (Fe415) in basic solution has been studied using weight loss by linear polarisation and electrochemical methods. The corrosion rate was found to increase with increasing temperature. It is necessary to take care of corrosion due to the pH related problem especially in the warm cities where the temperature is always around 35°C because rate of evaporation increases and water droplet stick to the surface of steel or concrete structure.

1. Corrosion rate increases with increment in the pH values.
2. Weight loss found to increases with pH.
3. Arrhenius is the eq. which relates temperature and corrosion rate.
4. Material and solution properties also affect the rate of corrosion

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