SSRG International Journal of Civil Engineering
ISSN: 2348-8352 / https://doi.org/10.14445/23488352/IJCE-V9I11P107

Volume 9 Issue 11, 50-55, November, 2022
© 2022 Seventh Sense Research Group®

Original Article

Prediction of Moment Strength of Steel Reinforcement Concrete Bar in NaCl Environment

Suparjo[1], Yuli Panca Asmara[2]

-[1]Engineering Faculty, University of Mataram, West Nusa Tenggara, Indonesia
[2]INTI International Universiti, Faculty of Engineering and Quantity Surveying, Nilai Negeri Sembilan, Malaysia

Received: 07 October 2022 Revised: 09 Novemer 2022 Accepted: 20 November 2022 Published: 30 November 2022

Abstract *- Designing concrete infrastructure in seawater conditions is a challenge for engineers. Seawater contains aggressive chemicals such as chlorine ions and* CO_2 *gas, influencing steel-reinforced concrete (RC) strength. The strength of RC reduces gradually as the effect of steel corrosion. Corrosion on reinforcing steel bars continuously increases over a specific time before the collapse. Factors influencing the corrosion rate are concrete porosity, the concentration of chlorine ions, and the humidity of the concrete. This research studies the remaining moment strength of rebar as effects of chlorine ion concentration, temperature, pH, and dissolved oxygen. The moment strength of concretes is determined mathematically using mathematics models referred to as ACI 318-14 standard. The models calculate corrosion based on references and model software predictions. The research was to study empirical corrosion rate models for NaCl solutions representing seawater conditions. Investigation parameters determining the rate of corrosion on reinforcement steel in NaCl solution can be used to predict the service life of concrete structures.*

Keywords *- Corrosion rate, Carbon steel, Rebar, Seawater environment.*

1. Introduction

The corrosion process occurring in reinforcing steel in concrete structures determines the live service of concrete structures in seawater environments (1-10). The corrosion process attaches steel to the concrete causing significant deterioration in structural concrete. Factors influencing the corrosion process in seawater are chlorine ions, temperatures, pH, and oxygen. They react with steel through an electrochemical reaction in the steel surface exposed to the seawater (11-20). Concretes immersed in seawater are passive electrochemically immune steel from the corrosion process. However, due to cracks and porosity, ions such as Cl, CO_2 and O_2 can reach the steel in the concrete [15-20]. Once these elements reach the reinforcing steel, the concretes become electrolytes for the steel. It will create differential potential, which initiates corrosion reaction locally. The corrosion increase and create volume expansion in the concrete. The electrochemical reaction on the steel destroys the passive film covered on the surface of the steel (8,9,10). The alkaline environment in concrete becomes acidic, causing corrosion reactions will be faster [6-7]. The growth of the product of corrosion reactions makes cracks simultaneously and enlarges the porosity of the concrete. Thus, it will reduce the adhesion force between concrete and steel and weaken the moment strength of the concrete.

To date, many methods have been developed to monitor the quality of concrete in order to prevent corrosion problems. The severity crack index, hummer test, resistance polarization test and contamination indicators are examples of methods to assess concrete quality. The index of crack severity is commonly used to detect crack length on the concrete surface. The severity crack is indicated by the size of the crack, which can be a hairline or micro-crack on the concrete. A rebound hammer is a tool to record the strength of concrete when concrete is under impact load. The electrical resistance of concrete is essential in understanding electron transfer in the concrete, which shows corrosion behavior. Testing pollutant compositions in the concrete are essential to detect the integrity of the concrete.

Concrete integrity indicates the severity of the corrosion process (30-40). Corrosion reaction is higher when the integrity of concrete is poor. With the steel corrosion rate in concrete data, the life of concrete can be determined [8]. Life concrete prediction can be conducted indirectly by investigating binder conditions, amount of moisture, electrical resistivity, porosity, solution pH and gas contaminations. These factors determine the steel corrosion rate in concretes [9,10].

1.1. Calculation of Moment Strength of the Reinforced Concrete Beam

The concrete beam is designed according to ACI 318-14 (1). The standard guide to calculating tension, compression, and shear reinforcement to meet safety considerations. Analytical equations per the ACI 318-14 standard, including

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

moment strength. Moment strength is calculated based on equations which assume that compression steel does not yield: $\varepsilon'_s < \varepsilon_y$ and $f'_s = E_s \cdot \varepsilon'_s$. Tensile steel does yield: $\varepsilon_s \geq \varepsilon_y$ and $f_s = f_y$. Analyzing the stress and strain diagram of the beam, the neutral axis is found in the equation below. The equation is set that the compression forces equal the tension forces in order to satisfy equilibrium:

$$T_s = C'_s + C_c \rightarrow A_s \cdot f_y - A'_s \cdot f'_s - 0.85 \cdot f'_c \cdot a \cdot b = 0 \quad (1)$$

Utilizing the equations, moments strength is calculated with Formula 2.

$$Mn = A'_s \, E_s \varepsilon_{cu} \left(\frac{C_{NA-d\prime}}{C_{NA}}\right)\left(\frac{a}{2} - d'\right) A_s f_y \left(d - \frac{a}{2}\right) \quad (2)$$

Where, Mn is the nominal moment, Cs is concrete in compression, ε'_s is the compression steel, and ε_y is yield strain.

1.2. Corrosion Rate Measurements

Various methods which are used to measure corrosion rate are Tafel extrapolation, linear polarisation resistance (LPR), electrochemical spectroscope impedance (EIS) and noise of electrochemical indicating (ECN). They apply electrochemical reactions to identify the corrosion process. The corrosion process also can be modelled using mathematical expression. Researchers use fundamental theories to model the corrosion process. Using the corrosion model, they simulate the corrosion process under various conditions such as chemical composition, reactions of electrochemical, corrosion kinetics, typical corrosion and thermodynamics reactions. The data from theories can be validated with experimental results.

Corrosion monitoring is used to investigate the corrosion process based on its mechanism. The corrosion data is essential in the maintenance program used for system integrity. The corrosion data can be used to predict failure behavior before the sudden collapse of infrastructure. LPR was applied to measure the rate of corrosion. The potential was scanned from corrosion potential (E_{corr}) at ± 10 mV at the rate of 10 mV/minutes. Tafel constants 25 mV (15) were used to measure the corrosion rates.

The corrosion rate calculation measured the steel's polarization resistance (Rp). Rp is a resistance to the corrosion reaction of steel with concrete. It was obtained with the scanning potential of steel in the area close to E_{corr}. The current density versus voltage indicated a straight line at the E_{corr} position. The formula of Stern-Geary is presented below (10):

$$R_p = \frac{B}{i_{corr}} = \frac{(\Delta E)}{(\Delta i)_{\Delta E \to 0}} \quad (3)$$

$$CR = I_{corr} \, 3272 \, EW/\rho A \quad (4)$$

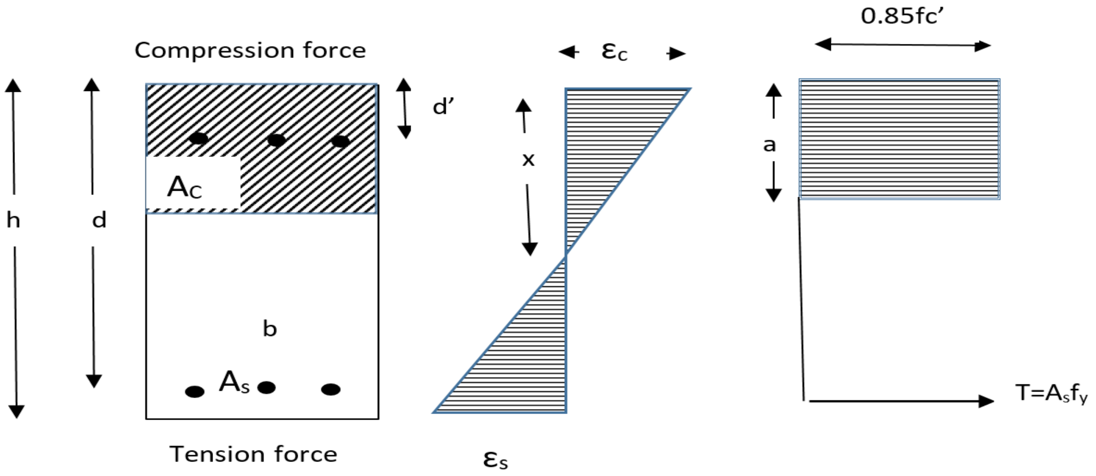
Where:
CR : Rate of Corrosion (mm/y),
I_{corr} : Current flows (amps),
K : A constant number for unit conversion.
EW : The equivalent weight.

2. Experimental Setup

The studies were conducted in two steps. The first step was conducted by calculating the corrosion rate, while the next step was determining the moment strength of RC. The corrosion rate calculated refers to the kinds of literature (Alisina, Ernesto, villaescusa, guasave) (30-34) to apply in RC. Calculating the moment strength of rebar was used rebar designed as indicated in Table 1. The constant numbers refer to ACI (American Concrete Institute). Designing the model of the strength of concrete was calculated based on ACI. The calculations used the concept of Whitney's stress block. Materials used were low-carbon steel, and it assumed seawater was contaminated in the concretes. The assumptions used based on ACI (American Concrete Institute) are described as follows: compressive strain ultimate in concrete was assumed at 0.003, while the tensile strength of the concrete is neglected, the strain curve varies linearly over the depth of the cross-section, the stress of steels vary linearly until to the yield was constant. The force of compressive in the concrete was calculated to refer to Whitney's equivalent stress block.

Table 1. Data of rebar design used in the models and loading condition.

Description	Unit	Value
Beam width	mm	1000
Beam depth effective	mm	500
Compr. Strength of concrete	Mpa	60
Tension steel yield	Mpa	3000
Number of steel tension	Nos.	10
Yield stress of compressed steel	Mpa	3000
Number steel in compression	Nos	10
Compression steel cover	mm	100



(a) **(b)** **(c)**

Fig. 1 Reinforcing steel bar configuration: Reinforcement concrete beam in one layer of tension steel bar. Cross section of RC (a), strain diagram (b), stress diagram (c).

3. Results and Discussion

3.1. Effects of Oxygen Dissolved in Concrete on Moment Strength of RC

The oxygen that is present in seawater can increase corrosion reactions on reinforcing steel in RC, as presented in Figure 2. The corrosion process as electrons produced by steels reduces oxygen gas to ions OH. The electron produced by steels is located in an anode. Potential differences govern the electron transfers as effects of local aeration in the concrete. At the cathode site, electrons react in a thin layer of steel surface based on the following reactions.

The process occurs at the cathode under alkaline conditions.

$$O_{2(g)} + 2H_2O_{(l)} + 4e^- \rightarrow 4OH^-(aq) \qquad (5)$$

In an acid solution, an oxygen reduction process will occur.

$$O_{2(g)} + 4H^+ + 4e^- \rightarrow 2H_2O_{(aq)} \qquad (6)$$

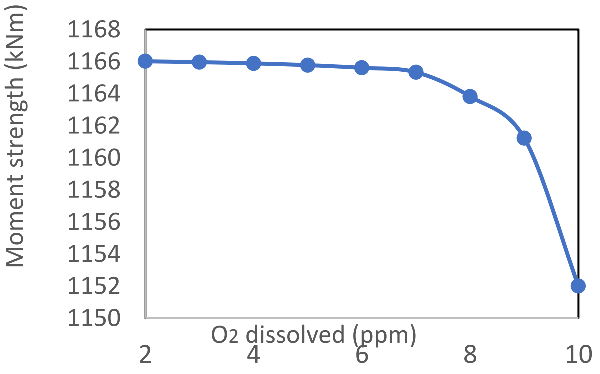


Fig. 2 Effects of oxygen on moment strength of RC

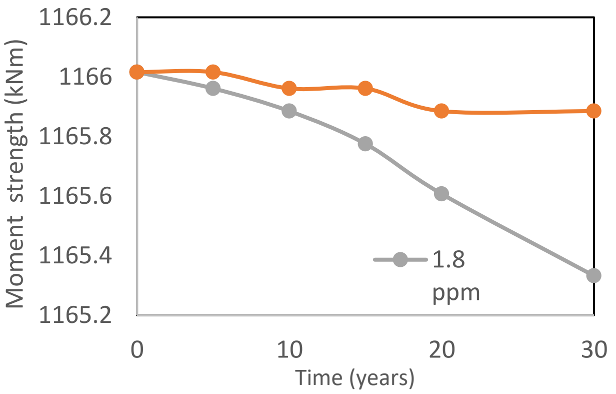


Fig. 3 Effects of oxygen on moment strength of RC over 30 years.

Figure 2 presents the relationship between the concentration of oxygen on concrete moment strength. It showed that the corrosion rate increased if the was more oxygen concentration. The effect of oxygen concentration was also verified using the software Freecorp, Norsok (15,18), which indicated a similar trend. Figure 3 is the prediction of reduced moment strength over 30 years. At 1.8 ppm, oxygen dissolved in seawater decreased the moment strength of concrete insignificantly. At the concentration of oxygen 2%, the strength of concrete reduced sharply.

3.2. Effects of pH on Moment Strength of RC

pH is a factor for corrosion reaction. Figure 4 shows that the corrosion rate will decrease when pH increases which cause the moment strength of RC to reduce slowly. Microorganisms and sea biota produce the pH in seawater. The pH value indicates the number of ions H^+ dissolving in the solution. The effects of pH in determining corrosion rate depend on the concentration of ions, temperature, pressure, and ionic strength [28]. However, H^+ ions are known as specie which is dominant in promoting corrosion. The ability of H^+ ions to penetrate the concrete governs the acceleration of corrosion. The corrosion process involving H^+ ions occurs through a hydrogen evolution reaction. The steps of hydrogen reactions contributing to corrosion can be explained in Formula 7-9.

$$H^+ + e^- \rightarrow H_{(ads)} \tag{7}$$

$$H_{(ads)} + H_{(ads)} \rightarrow H_{2(ads)} \tag{8}$$

Those reduction reactions are followed by oxidation reactions which produce Fe^{2+} ions (Formula 9).

$$Fe \rightarrow Fe^{2+} + 2e^- \tag{9}$$

The films become thicker, denser, and more protective when pH increases. The presence of high pH makes it easier for metal ions to form a metal-alkaline layer on the surface of concrete, which causes the concrete to become passive. Hoffmeister (35) showed in his experiment that the corrosion rate at pH 5.8 did not decrease significantly. This suggested that the scale is relatively porous and detached, which is not protective. It may be able to relate to the rapid growth of the scale.

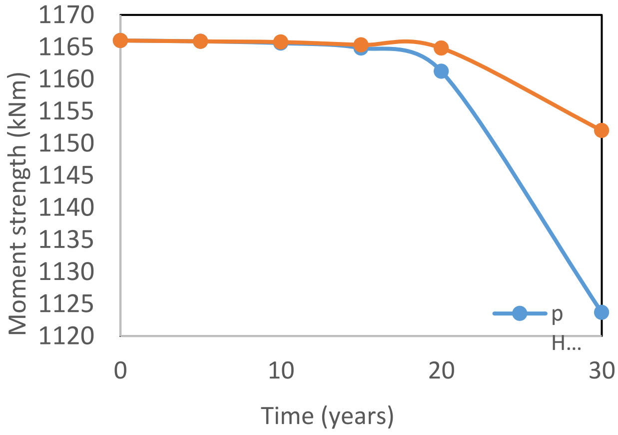


Fig. 4 Effects of pH on moment strength of RC over 30 years.

3.3. Effects of Chlorine Ions on Moment Strength of RC

The presence of Cl ions in reducing rebar strength is presented in Figure 5. The models' calculated Cl ions concentration at 0.6 and 0.9 ppm. It can be seen that the more Cl ions concentration, concrete strength reduced significantly. The presence of Cl^- ions affects the conductivity of concrete, which accelerates corrosion [22]. Cl^- the diffusion process determined the ion's reaction with steels in RC. Cl ions migrate in the concretes as an effect of the electric field. The rate of migration increased when there was more crack and porous. Dissolving chloride in reinforced concrete was suspected in both corrosion uniform and pitting. Chlorine ions influence concrete structures' disintegration, causing crack extension on the concrete. The behavior of chlorine ions in the corrosion process can be expressed in Equations 10-12. As can be seen from the equations, chlorine ions can be able to react with steel many times to corrode steel. At a small amount of chloride, the corrosion process is slower. Free chloride acts as a catalyst to initiate further corrosion process. Chlorine ions reaction in concrete leads to loss of total moment strength.

$$Fe^{2+} + Cl^- \rightarrow FeCl_2 \tag{10}$$

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2Cl^- \tag{11}$$

$$6FeCl_2 + O_2 + 6H_2O \rightarrow 2Fe_3O_4 + 12H^+ + 12Cl^- \tag{12}$$

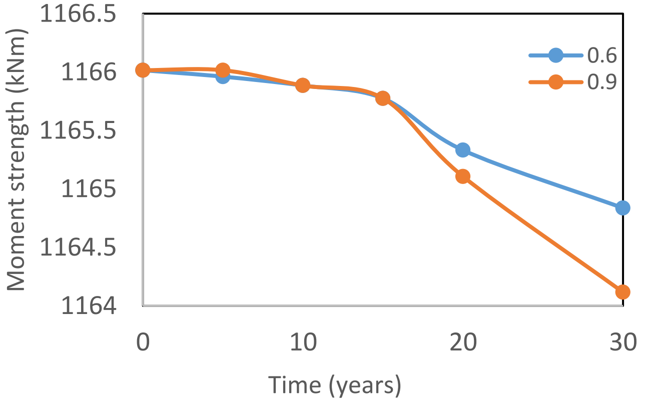


Fig. 5 Relationship of chlorine ions concentration on moment strength of reinforcing steel bar over 30 years exposure time.

3.4. Effects of Temperature on Moment Strength of RC

Temperature determined corrosion rate as its role in forming of alkaline film. At temperatures less than 60°C, FeOH is soluble, and the precipitation rate is low. Thus, there was no protective film formation until pH increased to reach FeOH solubility. When the temperature reached 60ºC, iron carbonate's solubility decreased, and the layer's protectiveness became thicker, which decreased the corrosion rate. The corrosion rate was higher at a temperature of 40ºC, which caused the moment strength of the RC to weaken. At temperatures of 30ºC, the effects of film formation on steel can be ignored. Many researchers (10 - 20) have agreed that corrosion rates remain high due to the interaction between steel and water.

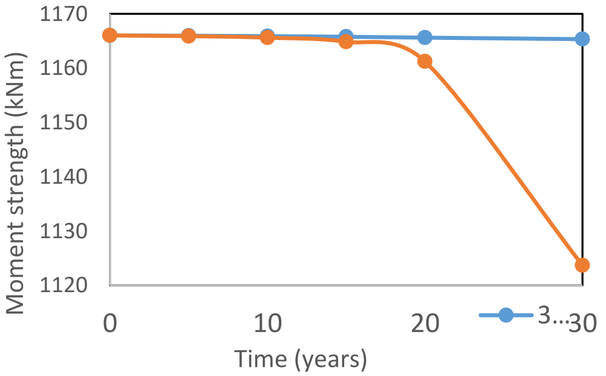


Fig. 6 Effects of temperature on moment strength of RC over 30 years.

4. Conclusion

Based on mathematic models studies, there were several findings which can be concluded as follows:

- The corrosion models, which include the effects of temperature, Cl, Oxygen, and pH, have shown reduced RC moment strength. The results have been confirmed well with other researchers' findings.
- Reducing moment strength was insignificant at low temperatures, low oxygen concentration and high pH. The dominant effect influencing reducing RC strength were chlorine ions and oxygen.
- Designing RC for 30 years using a range of values parameters was satisfied in building construction.

References

[1] ACI 318-14, "Building Code Requirements for Structural Concrete and Commentary,"

[2] Ahmad Beng Hong Kueh Xiao-Hui Wang, Yu Chen and Shi-Jie Gui, "Contesting crack modes modeling of reinforced concrete structure threatened by the progressive rust expansion in rebars in the presence of external load," *Construction and Building Material*, vol. 263, pp. 120127, 2020. Crossref, https://doi.org/10.1016/j.conbuildmat.2020.120127

[3] Asma, R., YP Asmara, and C. Mokhtar, "Study on the Effect of Surface Finish on Corrosion Of Carbon Steel In Co_2 Environment*," Journal Of Applied Sciences*, vol. 11, no. 11, pp. 2053-2057, 2011. Crossref, https://doi.org/10.3923/jas.2011.2053.2057

[4] Asmara Y P, Juliawati, J. Jaafar, K. Azuar, J.P. Siregar and Kurniawan T, 2014, "Effects Pre-strain of Carbon Steel on Stress-Strain Diagram in CO_2 Environment with the Presence of H2S," *International Journal of Material Science Innovations (IJMSI)*, vol. 2, no. 3, pp. 52-58, 2014.

[5] Asmara, Y. P and Ismail. M, "Study Combinations Effects of HAc in H2S/CO_2 Corrosion," *Journal of Applied Sciences*, vol. 11, pp. 1821-1826, 2011. Crossref, https://doi.org/10.3923/jas.2011.1821.1826

[6] Asmara, YP and M. Che Ismail, "A Statistics Approach for the Prediction of CO_2 Corrosion in Mixed Acid Gases. Corrosion and materials", 2009. 34(4): p. 25-30.

[7] Asmara, Y.P., A. Juliawati, and A. Sulaiman. "Mechanistic Model of Stress Corrosion Cracking (Scc) of Carbon Steel in Acidic Solution with the Presence of H_2S," *IOP Conference Series: Materials Science and Engineering*, vol. 50, 2013. *Crossref*, https://doi.org/10.1088/1757-899X/50/1/012072

[8] Y P. Asmara, Athirah, J P. Siregar, T. Kurniawan and D. Bachtiar "Application of Response Surface Methodology Method in Designing Corrosion Inhibitor," *IOP Conference Series: Materials Science and Engineering*, 2017. *Crossref*, https://doi.org/10.1088/1757-899X/257/1/012090

[9] Y. P. Asmara, M. F. Ismail, L. Giok Chui and Jamiludin Halimi, "Predicting Effects of Corrosion Erosion of High Strength Steel Pipelines Elbow on CO_2-Acetic Acid (HAc) Solution," *IOP Conference Series: Materials Science and Engineering*. 2016. *Crossref*, https://doi.org/10.1088/1757-899X/114/1/012128

[10] Asmara, Y. P. Juliawati, Alias J., Jaafar K., Azuar J. P., Siregar and Kurniawan, "Effects Pre-Strain of Carbon Steel on Stress-Strain Diagram in CO_2 Environment with the Presence of H_2S," *International Journal of Material Science Innovations*, vol. 2, no. 3, pp. 52-58, 2014.

[11] Yuli Panca Asmara, Januar Parlaungan Siregar, Tezara Cionita and Juliawati Alias, "Electrochemical Behaviour of High-Stress Steel (AISI 4340) in CO2 Environments with the Presence of H2 Gas," *Applied Mechanics and Materials*, vol. 695, pp. 98-101, 2014. *Crossref*, https://doi.org/10.4028/www.scientific.net/AMM.695.98

[12] Yuli Panca Asmara, Yap Chun Wei, Mohd Fazli Ismail and Khairi Yusuf, "Flow Assisted Erosion-Corrosion of High-Speed Steel (HSS) in Nanofluid Coolant," *Applied Mechanics and Materials*, vol. 695, pp. 143-146, 2014. *Crossref*, https://doi.org/10.4028/www.scientific.net/AMM.695.143

[13] Asmara, Y.P., N.A.A. Razak, and Salwani. "Analysis of Corrosion Prediction Software for Detection Corrosion in Oil and Gas Environment Containing Acetic Acid, CO_2 and H2S Gases," *International Symposium on Corrosion & Materials Degradation* , 2014.

[14] De Waard, C., Milliam, D., E., "Carbonic Acid Corrosion of Mild Steel", Corrosion, 31, 5, 1975, pp. 131 - 135.

[15] FREECORP *V1Technical Book*, I.f.C.a.M.T., Ohio University Research Park, Athens, Ohio

[16] Joosten, Michael. W, Kolts, Juri, Hembree, Justin. W and Mohsen Achour. "Organic Acid Corrosion In Oil And Gas Production." *CORROSION 2002*, 2002.

[17] R.B.A. Nor Asma, P.A. Yuli and C.I. Mokhtar, "Study on the Effect of Surface Finish on Corrosion of Carbon Steel in CO2 Environment," *Journal of Applied Sciences*, vol. 11, no. 11, pp. 2053-2057, 2011. *Crossref*, https://doi.org/10.3923/jas.2011.2053.2057

[18] Norsok M-506 Standard, N.S, "CO_2 Corrosion Rate Calculation Model," Norwegian Technology, Standards Institution, Oslo, Norway.

[19] Videm, K., "The Effects of Some Environmental Variables on The Aqueous CO_2 Corrosion of Carbon Steel", The Institute of Material, No. 13, 1994

[20] Sun Wei, Nesic Srdjan, and Sankara Papavinasam, "Kinetics of Iron Sulfide and Mixed Iron Sulfide/Carbonate Scale Precipitation in CO_2/H_2S Corrosion," *NACE - International Corrosion*, 2006.

[21] T.N.Guma, James A.Abu, "A Field Study of Outdoor Atmospheric Corrosion Rates of Mild Steel around Kaduna Metropolis," *SSRG International Journal of Mechanical Engineering*, vol. 5, no. 11, pp. 7-21, 2018. *Crossref*, https://doi.org/10.14445/23488360/IJME-V5I11P102

[22] Khoa Tan Nguyen, Jaehong Lee, Kangsu Lee and Namshik Ahn, "An Experimental Study of the Effects of Chloride Ions on the Corrosion Performance of Polymer Coated Rebar in Concrete Pavement," *Journal of Asian Architecture and Building Engineering*, vol. 11, no. 1, 2012.

[23] Utkarsh Roy, Shubham Khurana, Pratikshit Arora, Vipin "Strength of Concrete-Filled Carbon Fiber-Reinforced Polymer Columns," *International Journal of Engineering Trends and Technology*, vol. 68, no. 5, pp. 62-66, 2020. *Crossref*, https://doi.org:10.14445/22315381/IJETT-V68I5P211S

[24] Jianhua Jiang and Yingshu Yuan, "Prediction Model for the Time-Varying Corrosion Rate of Rebar Based on Micro-Environment in Concrete," *Construction and Building Materials*, vol. 35, pp. 625-632, 2012. *Crossref*, https://doi.org/10.1016/j.conbuildmat.2012.04.077

[25] Y. P. Asmara, J. P. Siregar, C. Tezara, W. Nurlisa and J. Jamiluddin, "Long-Term Corrosion Experiment Of Steel Rebar in Fly Ash-Based Geopolymer Concrete in NaCl Solution," *International Journal of Corrosion*, 2016. *Crossref*, https://doi.org/10.1155/2016/3853045

[26] Yakun Zhu, Digby D. Macdonald, Jie Yang a, Jie Qiu a and George R. Engelhardt, "Corrosion of Rebar in Concrete. Part II: Literature Survey and Statistical Analysis of Existing Data on Chloride Threshold," *Corrosion Science*, vol. 185, pp. 109439, 2021. *Crossref*, https://doi.org/10.1016/j.corsci.2021.109439

[27] Szweda Zofiaa and Zybura Adamb, "Theoretical Model and Experimental Tests on Chloride Diffusion and Migration Processes in Concrete," *Procedia Engineering*, vol. 57, pp. 1121-1130, 2013. *Crossref*, https://doi.org/10.1016/j.proeng.2013.04.141

[28] Yuanzhan Wang, Xiaolong Gong and Linjian Wu, "Prediction Model of Chloride Diffusion in Concrete Considering the Coupling Effects of Coarse Aggregate and Steel Reinforcement Exposed to Marine Tidal Environment," *Construction and Building Materials*, vol. 216, pp. 40-57, 2019. *Crossref*, https://doi.org/10.1016/j.conbuildmat.2019.04.221

[29] Alisina Toloei, Sanam Atashin and Mahmood Pakshir, "Corrosion Rate of Carbon Steel Under Synergistic Effect of Seawater Parameters Including Ph, Temperature and Salinity in Turbulent Condition," *Corrosion Reviews*, vol. 31, no. 3-6, pp. 135-144, 2013. *Crossref*, https://doi.org/10.1515/corrrev-2013-0032

[30] Ernesto villaescusa, Rhett Hassell and A.G. Thompson "Development of a Corrosivity Classification for Cement Grouted Cable Strand in Underground Hard-Rock Mining Excavations," Journal of the Southern African Institute of Mining and Metallurgy, vol. 108, no. 6, pp. 301-308, 2008.

[31] Shuhong Wang, Wen Yan and Haibin song, "Mapping the Thickness of the Gas Hydrate Stability Zone in the South China Sea," *Terrestrial Atmospheric and Oceanic Sciences*, vol. 17, no. 4, Crossref, http://dx.doi.org/10.3319/TAO.2006.17.4.815(GH)

[32] Xuanqi yan, yingrui wang, qingzhen du, weiqi jiang, fang shang, and ran li, "Research Progress on Factors Affecting Oxygen Corrosion and Countermeasures in Oilfield Development," *Web of Conferences*, vol. 131, pp. 01031, 2019. *Crossref*, https://doi.org/10.1051/e3sconf/201913101031

[33] Zeng, r.s. Lillard, and hongbo cong, "Effect of Salt Concentration on the Corrosion Behavior of Carbon Steel in CO_2 Environment," *Corrosion*, vol 72, no. 6, pp. 805-823, 2016. Crossref, https://doi.org/10.5006/1910

[34] Héctor Peinado, Carlos Green-Ruíz, Jaime Herrera-Barrientos, Oscar Escolero-Fuentes, Omar Delgado-Rodríguez, Salvador Belmonte-Jiménez, and María Ladrón de Guevara, "Relationship Between Chloride Concentration and Electrical Conductivity in Groundwater and its Estimation From Vertical Electrical Soundings (VESs) in Guasave, Sinaloa, Mexico". *Environmental and Ecology Research Note*, vol.39 no.1, pp. 229-239, 2012. Crossref, http://dx.doi.org/10.4067/S0718-16202012000100020

[35] Hoffmeister, Hans and Gerald Scheidacker, "Effect of Chloride Contents, pH and Temperature on Crevice Corrosion of Alloy 33 as Determined by Remote Crevice Assembly (RCA) Testing," Corrosion Proceeding, 2004.

[36] Nur Azhani Abd Razak, Yuli Panca Asmara and Mohamad Khairuazlan Kamaruzaman, "Influences of H_2SO_4 and NaCl Concentrations on Stress Corrosion Cracking of AISI 304 Stainless Steel," *Advanced Materials Research,* vol. 893, pp. 410-414. 2014. *Crossref*, https://doi.org/10.4028/www.scientific.net/AMR.893.410

[37] Gabriel Samson a, Fabrice Deby a, Jean-Luc Garcia and Mansour Lassoued, "An Alternative Method to Measure Corrosion Rate of Reinforced Concrete Structures," *Cement and Concrete Composites*, vol. 112, pp. 103672, 2020. *Crossref*, https://doi.org/10.1016/j.cemconcomp.2020.103672