

Effect of Soil Composition on Electrochemical Corrosion Behavior of Steel: A Review

Vishal Bansode¹, Sandesh Solepatil², Aniket Kolekar³

^{1, 2, 3} Dept of Mechanical Engineering

^{1, 2, 3} DYPIEMR. Ak Pune

Abstract- Corrosion by soil is a complex phenomenon due to the number of variables involved. In principle, steels should be in the passive state in soils but the presence of water and aggressive chemical species such as chloride ions, sulphates as well as different types of bacteria and stray current can cause localised corrosion. Soils constitute the most complex environment known to metallic corrosion. Corrosion of metals in soil can vary from relatively rapid material loss to negligible effects, depending on soil environment. Soil engineering properties and soil contents are important parameters that influence soil corrosivity and level of corrosion dynamic.

Keywords- Corrosion, Soil properties, Soil Parameters, Soil resistivity, Soil pH

I. INTRODUCTION

Corrosion is defined as degradation of material or its properties due to a reaction with environment. Soil corrosion is a complex phenomenon with number of factors involved. Chaker and Palmer defined soil corrosion as deterioration of metal or other material brought about by chemical, mechanical and biological action by the soil environment. [8]

Metals have a natural tendency to revert to their oxidized form given the proper environment and opportunity. The appropriate circumstances necessary for the degradation of metals can vary greatly between environments. Free hydrogen ions found in all waters, soils and some gases can provide a means of removing the excess electrons from metals. In addition, oxygen in the air can accelerate the oxidation of most metals and alloys. The electrical conductivity of water also increases with its dissolved mineral concentration. Therefore highly mineralized waters or soils readily conduct the electrical currents of electrolytic cells and can accelerate the corrosion process. The same can also be said for exposed atmospheric conditions where moisture is present in the form of vapor water or can condense and fall as rain concentrating the collection of salts, chemicals and other pollutants. The environment for many structures provides conditions that favor the formation of natural corrosion cells. The metals of a structure can serve as the anode, cathode and

as the necessary conductor between any two metal components of the building. Free water, or as moisture in soil or air, provides the electrolyte required to complete the cell circuit

In case of steel pipeline, corrosion is common form of structure degradation that reduces both static and cyclic strength. Due to degradation of steel pipeline causes serious problem human, environmental and financial losses.

Corrosion of buried steel pipe in soil mainly depends on soil properties such as soil resistivity, soil redox potential, soil pH, soil organic content, and chemical composition also by microbial activity. Fig.1 shows 3 phase boundaries that arise at the soil to pipe interface. [1]

Effect of Ca⁺⁺, Mg⁺⁺, K⁺ on carbon steel:

The material used for this study is carbon steel whose chemical composition as shown in table (1) below. And simulated soil solution was prepared based on soil composition used for study. 0.01 M NaCl solution was used as electrolyte and other cations and anions are added into it in order to study their effect on corrosion behavior. [3]

Table:1. Chemical compositions of the carbon steel studied (wt. %). [3]

Steel	C	S	P	Mn	Si	Cu
Q235	0.176	0.023	0.019	0.057	0.233	0.033

Table:2. Corrosion electrolyte type and compositions used in this test. [3]

Electrolyte type	Compositions
1	0.01MNaCl
2	0.01MNaCl + 0.01M _{Ca} Cl ₂
3	0.01MNaCl + 0.01MM _{Mg} Cl ₂
4	0.01MNaCl + 0.01MKCl
5	0.01MNaCl + 0.01MNa ₂ SO ₄
6	0.01MNaCl + 0.01MNaHCO ₃
7	0.01MNaCl + 0.01MNaNO ₃

The potentiodynamic polarization measurement were carried out in a conventional three electrode glass cell with

platinum a counter electrode and saturated calomel electrode as a reference electrode. [3]

Fig.6 shows potentiodynamic polarization curve and EIS diagram showing effect of Ca⁺⁺, Mg⁺⁺, K⁺ on Q235 carbon steel in NaCl solution. Potentiodynamic polarization curve were recorded by a constant sweep rate 10 mV/min and before polarization test open circuit potential was done to stable the potential for 30 min. EIS measurement were performed in a frequency range of 10⁵ – 10⁻² Hz.

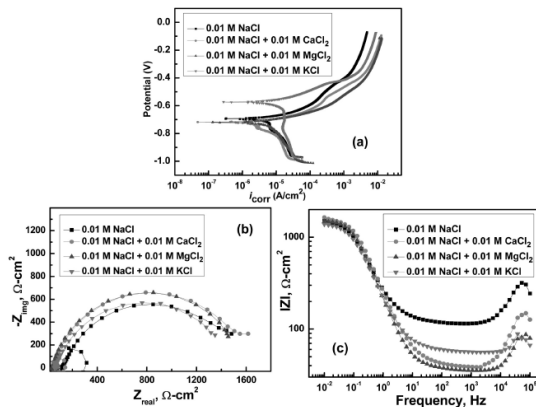


Fig.1. Potentiodynamic polarization curves and EIS diagram about effect of Ca²⁺, Mg²⁺, K⁺ on Q235 carbon steel in NaCl solution. [4]

Fig.1(a) showing the result of potentiodynamic polarization curve. Fig.1 (b) and (c) shows result of Nyquist and Bode plots for EIS respectively. [4] In order to analyse the effect of Ca²⁺, Mg²⁺, K⁺ on corrosion behavior of carbon steel in simulated soil solution. The solutions were prepared by adding 0.01 M CaCl₂, 0.01 M MgCl₂ and 0.01 M KCl in 0.01 M NaCl solution respectively. Polarization curves shows that the cathodic processes are all controlled by reduction of dissolved oxygen. While anodic processes are all controlled by dissolution of carbon steel electrode.

For the addition of CaCl₂, it reduces cathodic current density and increases anodic current density. For the addition of MgCl₂, it reduces cathodic current density slightly but greatly increases anodic current density and for addition of KCl it increases cathodic current density and in case of anodic current density it will first increases and then decreases. From this polarization curve it can be concluded that aggressiveness of these three added composition are in order of KCl > MgCl₂ > CaCl₂ and as anions are same that is Cl⁻ then aggressiveness of cation is in order of K⁺ > Mg²⁺ > Ca²⁺. [3]

For the Nyquist and Bode plot, it can be seen from fig (b) the size of high frequency semicircle decreased in order of CaCl₂> MgCl₂>NaCl>KCl. It means that for NaCl

electrolyte solution the aggressiveness of three added composition are in order of KCl > MgCl₂ > CaCl₂.

The EIS fitting result of Q235 in simulated soil solution shown in table (3). From this result it is clear that the addition of KCl, MgCl₂, CaCl₂ in 0.01 M NaCl decreases the corrosion resistance. [3]

Table:3. EIS fitting results of Q235 carbon steel in all the simulated soil solutions. [3]

Solutions	Equivalent circuit	Rs (ohm/cm ²)	Capacitance Q		Rt (ohm/cm ²)
			Q-Yo (ohm/cm ² /s)	Q-n	
0.01MNaCl	R(QR)	118.1	0.001084	0.7925	1522
0.01MNaCl + 0.01M CaCl ₂	R(QR)	40.08	0.0008365	0.8278	1684
0.01MNaCl + 0.01M MgCl ₂	R(QR)	36.61	0.000976	0.8579	1586
0.01MNaCl + 0.01M KCl	R(QR)	57.82	0.001126	0.8011	1496
0.01MNaCl + 0.01M Na ₂ SO ₄	R(QR)	44.50	0.001532	0.8179	1296
0.01MNaCl + 0.01M NaHCO ₃	R(QR)	61.12	0.0004054	0.7229	1374
0.01MNaCl + 0.01M NaNO ₃	R(QR)	44.66	0.001107	0.8058	1459

Effect of anions SO₄²⁻, HCO₃⁻, NO₃⁻ on carbon steel:

In order to analyse the effect of SO₄²⁻, HCO₃⁻, NO₃⁻ on corrosion behavior of carbon steel in simulated soil solution. The solutions were prepared by adding 0.01 M Na₂SO₄, 0.01 M NaHCO₃, 0.01 M NaNO₃ into 0.01 M NaCl solution respectively. Fig.7 shows potentiodynamic polarization curve and EIS diagram, showing effect of HCO₃⁻ on Q235 carbon steel in NaCl solution. [3]

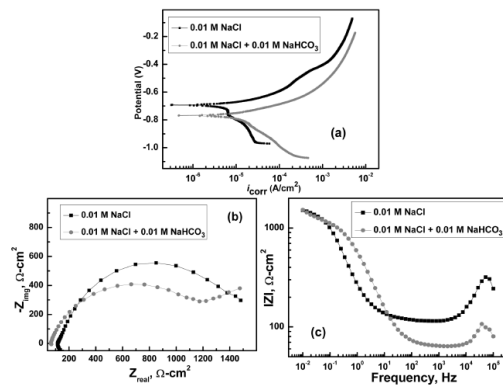


Fig.2. Potentiodynamic polarization curves and EIS diagram about effect of HCO₃⁻ on Q235 carbon steel in NaCl solution.[3]

For the addition of NaHCO₃ in 0.1M NaCl solution it can increase both cathodic and anodic current density of carbon steel as shown in fig.2 (a). The diffusion impedance in low frequency range indicates that diffusion process is a step control process. Fig.2 (c) also indicates that addition of NaHCO₃ can decrease solution resistance. Higher corrosion current density and lower charge transfer resistance indicate corrosivity of NaHCO₃ on corrosion behavior of carbon steel. For Nyquist diagram, the presence of low frequency diffusion impedance shows that mass transfer of dissolved oxygen plays an important role in carbon steel corrosion and whole corrosion process is mixed controlled by activation and diffusion steps and this may be due to emission of CO₂.

Similarly result of addition of NaNO₃ in NaCl solution can slightly increase corrosion current density, decrease charge transfer resistance and decreases solution resistance. Fig. 8 shows polarization curves and EIS diagram about effect of NO₃⁻ on Q235 carbon steel. From these results corrosivity of addition of chemicals are in order of Na₂SO₄ > NaHCO₃ > NaNO₃ and as cations are same that is Na⁺, the aggressiveness of anions are in order of SO₄²⁻ > HCO₃⁻ > NO₃⁻.

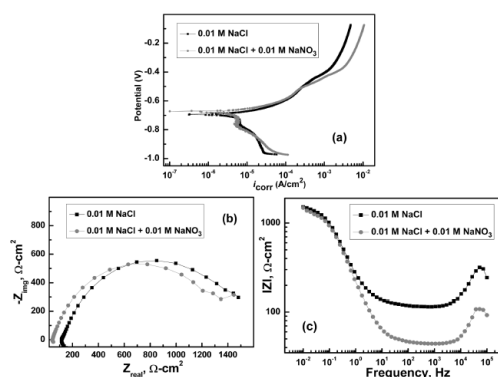


Fig.3. Potentiodynamic polarization curves and EIS diagram about effect of NO₃⁻ on Q235 carbon steel in NaCl solution. [3]

REFERENCES

- [1] I.S. Cole, D. Marney, “The science of pipe corrosion: A review of the literature on the corrosion of ferrous metals in soils”, *Corrosion Science* 56 (2012) pp.5–16.
- [2] Nordin Yahaya, “New technique for studying soil corrosion of underground pipeline”, *Journal of Applied Science* 11(9): (2011) pp.1510-1518.
- [3] T. M. Liu, Y. H. Wu, S. X. Luo, C. Sun, “Effect of soil compositions on the electrochemical corrosion behavior of carbon steel in simulated soil solution”, *Mat.-wiss. u. Werkstofftech.* 2010, 41, No. 4.
- [4] Z. Liang, LI Xiao-gang, DU Cui-wei, “Effect of Environmental Factors on Electrochemical Behavior of X70 Pipeline Steel in Simulated Soil Solution”, *JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL.* 2009, 16(6): pp.52-57.
- [5] A.I.M. Ismail, A.M. El-Shamy, “Engineering behavior of soil materials on the corrosion of mild steel”, *Applied Clay Science* 42 (2009) pp.356–362.
- [6] D. de la Fuente, I. Díaz, J. Simancas, B. Chico, M. Morcillo, “Long-term atmospheric corrosion of mild steel”, *Corrosion Science* 53 (2011) pp. 604–617.
- [7] C.W. Du, X.G. Li, P. Liang, Z.Y. Liu, G.F. Jia, and Y.F. Cheng, “Effects of Microstructure on Corrosion of X70 Pipe Steel in an Alkaline Soil”, *Journal of Materials Engineering and Performance* Volume 18(2) March 2009, pp.216–220.
- [8] M.N. Norhazilan, Y. Nordin, K.S. Lim, R.O. Siti, A.R.A. Safuan, M.H. Norhamimi, “Relationship between Soil Properties and Corrosion of Carbon Steel”, *Journal of Applied Sciences Research*, 8(3), 2012 pp.1739-1747.
- [9] M. G. Fontana “Corrosion Engineering” Tata MacGraw Hill Education Private Ltd., New Delhi, Third Edition 2005, pp. 4, 296, 306.
- [10] M. Barbalat, “Electrochemical study of the corrosion rate of carbon steel in soil: Evolution with time and determination of residual corrosion rates under cathodic protection”, *Corrosion Science* 55 (2012) pp.246–253.
- [11] C. Sun, J. Xu, F.H. Wang, C.K. Yu, “Effect of sulfate reducing bacteria on corrosion of stainless steel 1Cr18Ni9Ti in soils containing chloride ions”, *Materials Chemistry and Physics* 126 (2011) pp.330–336.
- [12] X. Wang, J. Xu, C. Sun, “Effects of Sulfate-Reducing Bacterial on Corrosion of 403 Stainless Steel in Soils Containing Chloride Ions”, *Int. J. Electrochem. Sci.*, 8 (2013) pp.821 – 830.
- [13] Vanessa de Freitas Cunha Lins, Mitchel Leonard Magalhães Ferreira, Patrícia Alves Saliba, “Corrosion Resistance of API X52 Carbon Steel in Soil Environment”, *Journal of Materials Research and Technology* (2012) 1(3) pp.161-166.

- [14] B. Jegdic, S.Polić-Radovanovic, S. Risti, A. Alil, “Corrosion Processes, Nature and Composition of Corrosion Products on Iron Artefacts of Weaponry” Scientific Technical Review, 2011, Vol.61, No.2, pp.50-56
- [15] Z. Liu, Y. Kleiner, “State of the art review of inspection technologies for condition assessment of water pipes”, Measurement 46 (2013) pp.1–15