Corrosion Resistance of Sn-Zn Coated on Low Carbon Steel Material in Wet Gas Pipeline

Roni Hadi Wijaya and Bambang Soegijono
Department of Physics, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia
E-mail: naufal@ui.ac.id

Abstract. Low carbon steel pipeline material is usually to transport wet gas. The presence of water in gas may lead corrosion and leakage. To enhance corrosion resistance of this material, we investigated electrodeposited of Sn-Zn on various composition Zn. Microstructure, structure, thermal properties and corrosion behaviour were analysed with Scanning Electron Microscopy (SEM), X-ray diffraction (XRD), Differential Scanning Calorimetry (DSC) and Potentiodynamic Polarization. Electrodeposited Sn-Zn with smallest Zn content shows highest corrosion rate. With various composition, XRD pattern shows tetragonal crystal structure. The various Zn content have changed the melting point and the enthalpy. Electrodeposited Sn-Zn on low carbon steel pipeline material enhance the corrosion resistance.

1. Introduction
The pipeline has transport wet gas from well head to the gas station is serious problem when using low carbon material. The presence of CO₂, H₂O, H₂S and Chloride may lead localize corrosion on material API 5L grade B that used in pipeline onshore.

The Indonesian natural gas with high CO₂ causing the failure of material especially in the presence of water or CO₂ dissolved in water or aqueous media can cause corrosive environment (carbonic acid / H₂CO₃) and accelerate the corrosion process on carbon steel material. In the pipeline, formation water that containing chloride ions is medium to distributed and can caused a uniform corrosion. The failure or success of corrosion resistance material is based on selection proper materials and their application such as identify chemicals will be present in environment (acid, neutral, or alkaline), the minimum and maximum temperature used, and fabrication and installation process.

Many researchers already published failure analysis corrosion on carbon steel pipeline and flowline. The aim of this paper was to enhance the corrosion resistance of low carbon steel pipeline with coated Sn-Zn on the surface material. Half the world’s used zinc to protect steel from the corrosion for a wide application with the reason; low prices, supply zinc available and good cathodic protection with makes the coating layer when the substrate exposed to the corrosive environments. Zinc is protected the substrate by galvanic action as a sacrificial metal. Combined zinc and thin is interested to observe how both Sn-Zn protected the carbon steel from the corrosion. Most commonly used for coating is; hot dipping, electroplating, mechanical coating, sherardizing, thermally sprayed coating and dust painting. Electrodeposition was chosen in this proses due to good adhesion, the coating is uniform with limitation the power of the bath. Sn-Zn coating with high content of tin is good protection against oxidation and uniform corrosion of metals. [22]
2. Material and Methods

2.1. History of the Pipeline

This gas pipeline located in the onshore through rice field from production well to the gas station. The flow line operated since 2009, protected by external coating and ICCP (Impressed Current Cathodic Protection). This pipeline material is low carbon steel (API 5L grade B) and leak in 2016 and 2018. The operational data record show average water cut 96%, pH 7.5, gas temperature 83-110°F, CO$_2$ content 1.91% and partial pressure 3.57 Psi or operation below the design pressure.

2.2. Visual Inspection

The pipeline failure has been visual inspection, the external was in good condition with coated by 3 LPE shown in figure 1(b) and internal found general and localized corrosion in the bottom of the pipe as shown in figure 1(a).

![Internal of the Pipe](image1)

![External of the Pipe](image2)

**Figure 1.** Visual Inspection of the Pipeline

2.3. Wall Thickness Measurement

Wall thickness measurement was conducted on the gas pipeline using ultrasonic testing and calculated for a corrosion rate described in table 1.

| Pipeline Measurement, Corrosion Rate & Remaining Life |
|------------------------------------------------------|
| **Onshore Pipeline** | **Position** | **Thickness Year 2006** | **Thickness Year 2018** | **Corrosion Rate (mm per year)** |
| Well X | 12 o’clock | 7.1 mm | 6.8 mm | 0.023 |
| To | 03 o’clock | 7.1 mm | 5.3 mm | 0.138 |
| Gas Station | 06 o’clock | 7.1 mm | 3.2 mm | 0.325 |
| | 09 o’clock | 7.1 mm | 5.5 mm | 0.123 |

Bottom of pipe has significant corrosion rate 0.325 mm per year shown in table 1. and need inspection strategies to mitigate the cause of failure or enhance the corrosion rate resistance of low carbon steel.

2.4. Analysis of Surface Corrosion Pipeline

From the figure 2 result, it can be seen that the intergranular corrosion of low carbon steel began on transition grain boundary when the steel polarized to the active passive transition zone. [11]. Figure
2(a)(b) general corrosion of surface low carbon steel shown IGC observed. Figure 2(c)(d) pitting corrosion of surface low carbon steel shown similar intergranular corrosion observed.

(a) General Corrosion

(b) General Corrosion

(c) Pitting Corrosion

(d) Pitting Corrosion

(e) EDX on Pitting Corrosion

(f) Pitting Corrosion EDX Result

**Figure 2.** SEM-EDX Morphologies on surface corrosion low carbon steel material

### 3. Result and Discussion

#### 3.1. Experimental

Low carbon steel material with dimensions 10mm x 10mm mechanically polished on silicon carbide abrasive paper (500 grit) and the substrate were deposited by tin-zinc coating with different composition of Zn shown in table 2. After electrodeposition, samples were characterized by SEM (Scanning Electron Microscopy), XRD (X-ray Diffraction) and DSC (Differential Scanning Calorimetry). Corrosion
behaviour was conducted by potentiodynamic polarization at solution 3.5% NaCl to determine the corrosion currents (Icorr) by tafel plot.

### Table 2. Sample Sn-xZn weight composition.

| Composition (wt%) | Sn    | Zn    | Total  |
|-------------------|-------|-------|--------|
| Sn-0%Zn           | 25 gram | 0 gram | 25 gram |
| Sn-4%Zn           | 25 gram | 1.01 gram | 26.01 gram |
| Sn-9%Zn           | 25 gram | 2.24 gram  | 27.24 gram |
| Sn-10.5%Zn        | 25 gram | 2.624 gram | 27.62 gram |

3.2. XRD Analysis

Sample coating of Sn-xZn on low carbon steel substrate was identify by X-ray diffraction (XRD) with weight composition shown in table 2. Diffraction pattern show peak the hexagonal Zn phase and the tetragonal β-Sn phase on 9% Zn and up. [22] The analysis used to identify the phase and structure crystal surface coating of Sn-Zn shown that no significant Zn peak observed as shown in figure 3.

![XRD Patterns](image)

**Figure 3.** XRD patterns of the Electrodeposition Sn-Zn metallic coating for various Sn-xZn: Sn-0%Zn, Sn-4%Zn, Sn-9%Zn and Sn-10.5%Zn

3.3. SEM – EDS Analysis

Metallographic of Sn-Zn was analysis by Scanning Electron Microscope (SEM) to get the morphology the metal surface coating deposits and corrosion products after polarization test in 3.5 % NaCl are shown in figure 4. respectively various composition of Zn. The microstructure hypoeutectic present of 2 phases is observed; β-Sn phase in figure 4(a) shown like a crack grain in pure Sn. Sn-4%Zn majority of the microstructure shown like a pure Sn and β-Sn plus eutectic was observed in figure 4(b), the Sn-9%Zn alloy shown in figure 4(c) has elliptical morphology with light gray colour and only eutectic phase was observed which describes as fine nedles Zn (black colour). Increasing of Zn in alloy to the eutectic composition shown needles black colour disappear, Zn rich island occurred is observed in figure 4(d) because the phase is at hypereutectic zone. [22]
Figure 4. Micrographics (a) Pure Sn-0Zn, (b) Sn-4%Zn, (c) Sn-9%Zn, and (d) Sn-10.5%Zn

3.4. DSC (Different Scanning Calorimetry)

DSC analysis to observed thermal behaviour of Sn-Zn alloy and the result shown in figure 5 where increase of % Zn weight affected decrease melting point or in pure Sn shown the highest melting point up to 230°C. The Sn-4%Zn has a highest enthalpy shown in table 3.

Figure 5. DSC curve for sample Sn and alloy; pure Sn, Sn-4%Zn, Sn-9%Zn and Sn-10.5%Zn
### Table 3. Melting Point and enthalpy from the sample.

| No | Sample | Sn (wt %) | Zn (wt %) | Melting Point (°C) | Delta H (J/g) | Onset Point | Endset Point | Different |
|----|--------|-----------|-----------|--------------------|---------------|-------------|-------------|-----------|
| 1  | Sn-0Zn | 100       | 0         | 230,8              | 54,1          | 229,1       | 238,8       | 9,7       |
| 2  | Sn-4Zn | 96        | 4         | 210,7              | 60,7          | 196,9       | 211,1       | 14,2      |
| 3  | Sn-9Zn | 91        | 9         | 200,9              | 59,6          | 197,0       | 207,9       | 10,9      |
| 4  | Sn-10.5Zn | 89,5    | 10,5      | 202,1              | 57,9          | 195,7       | 208,2       | 12,5      |

3.5. Potentiodynamic Polarization

Linear polarization resistance (LPR) measurement curve are generally used to characterize corrosion behaviour of sample alloy. This potentiodynamic polarization can be used to analysis of the electrochemical, electrical and mass-transport processes in the corrosion mechanism of electrochemical reactions [4]. This electrochemical measurements performed at room temperature, 3.5 wt% NaCl solutions and SCE (Saturated Calomel Electrode) was used as reference. Table 4 shows, the addition of Zn resulting increase the corrosion rate due to Zn electrochemically more active than Sn [3].

![Linear Polarization tafel plot](image)

**Figure 6.** Linear Polarization tafel plot

### Table 4. Effect of Zn addition to corrosion rate in 3.5% NaCl Solution at ambient temperature

| Sample   | E_{corr} (V) | I_{corr} (A) | Corrosion Rate (mm/year) |
|----------|--------------|--------------|--------------------------|
| Sn-0Zn   | -0,939       | 1,117E-4     | 0,0019                   |
| Sn-4%Zn  | -1,296       | 5,130E-4     | 0,0195                   |
| Sn-9%Zn  | -1,397       | 1,442E-4     | 0,0024                   |
| Sn-10.5%Zn | -1,320    | 3,769E-4     | 0,0038                   |
The cyclic voltammetry observed at Sn-Zn coating various weight (%) composition tested with solution 3.5% NaCl as shown in figure 7 (a) (b) (c) and (d).

![Cyclic Voltammetry](image)

Figure 7. Cyclic Voltammetry Polarization on Sn-Zn in 3.5% NaCl Solution at ambient temperature, scan rate 0.05 V/sec

4. Conclusion
Sn-Zn coated on surface carbon steel substrate by method electroplating or electrodeposition was successfully increase resistance corrosion rate. Potensiodynamic measurement on 3.5% NaCl solution measurement shown the best corrosion rate is Sn0Zn, followed by Sn-9%Zn, Sn-10.5%Zn and Sn-4%Zn.

Coated substrate with various composition of Sn-Zn also increased resistance corrosion rate from 0.325 mm per year based on actual measurement to maximum 0.0195 mm per year.

Each metal has protect steel with a different mechanism and Tin is nobler than steel and under ordinary atmospheric exposure, protects steel by forming corrosion resistant envelop around it [4].

Acknowledgement
The authors would like to show appreciation to the Research of Center of Material Science (RCMS) and CMPFPA (Center for Material and Processing Failure Analysis) universitas Indonesia for supporting the research activity for providing data XRD and SEM-EDX. This study also funded by universitas Indonesia through Hibah PITTA B No. NKB-0617/UN2.R3.1/HKP.05.00/2019.

References
[1] O.P. Oladijo, M.H. Mathabatha, A.P.I. Popoola, T.P. Ntsoanec, Characterization and corrosion behaviour of plasma sprayed Zn-Sn alloy coating on mild steel, Surfcaes & Coating
[2] Z. Ahmad, "CHAPTER 2 - BASIC CONCEPTS IN CORROSION," in Principles of Corrosion Engineering and Corrosion Control, Washington, Butterworth-Heinemann, 2006, pp. 9-56.

[3] S. Dubent, M. Mertens, M. Saurat, Electrodeposition, characterization and corrosion behaviour of tin-20wt% zinc coatings electroplated from a non-cyanide alkaline bath, Mater. Chem. Phys. 120 (2010) 371–380.

[4] Y. Salhi, S. Cherrouf, M. Cherkaoui, K. Abdelouahdi, “Electrodeposition of nanostructured Sn–Zn coatings”, Applied Surface Science. 367 (2016) 64–69.

[5] Edition, T. (2002) ‘CORROSION ENGINEER’ S REFERENCE Third Edition’

[6] Arici, M., Nazir, H. and Aksu, M. L. (2011) ‘Investigation of Sn – Zn electrodeposition from acidic bath on EQCM’, 509, pp. 1534–1537. doi: 10.1016/j.jallcom.2010.10.161.

[7] Salhi, Y. et al. (2016) ‘Applied Surface Science Electrodeposition of nanostructured Sn – Zn coatings’, 367, pp. 64–69.

[8] Dini, J. W. (1993) The Materials Science of Coatings and Substrates..

[9] Ashiru, O. A. and Shirokoff, J. (1996) ‘Electrodeposition and characterization of tin-zinc alloy coatings’.

[10] Javidi, M., Chamanfar, R. and Bekhrad, S. (2019) ‘Investigation on the efficiency of corrosion inhibitor in CO2 corrosion of carbon steel in the presence of iron carbonate scale’, Journal of Natural gas Science and Engineering, 61(June 2018), pp. 197–205.

[11] Zhou, Y. and Zuo, Y. (2015) ‘The Intergranular Corrosion of Mild Steel in CO2 + NaNO2 Solution’, Electrochimica Acta, 154, pp. 157–165.

[12] Edition, T. (2002) ‘CORROSION ENGINEER’ S REFERENCE Third Edition’.

[13] Xu, S. et al. (2017) ‘Failure analysis of a carbon steel pipeline exposed to wet hydrogen sul fi de environment’, Engineering Failure Analysis, 71, pp. 1–10.

[14] Abdel Salam, M. A. (2015) Handbook of Material Failure Analysis With Case Studies from the Oil and Gas Industry.

[15] Mansoori, H. et al. (2017) ‘Pitting corrosion failure analysis of a wet gas pipeline’, 82(August), pp. 16–25.

[16] Oladijo, O. P. et al. (2018) ‘Surface & Coatings Technology Characterization and corrosion behaviour of plasma sprayed Zn-Sn alloy coating on mild steel’, Surface & Coating Technology, 352, pp. 654–661.

[17] Javidi, M. and Bekhrad, S. (2018) ‘Failure analysis of a wet gas pipeline due to localised CO 2 corrosion’, Engineering Failure Analysis. Elsevier, 89(December 2017), pp. 46–56. doi: 10.1016/j.engfailanal.2018.03.006.

[18] Yavas, D. et al. (2018) ‘Electrochimica Acta Morphology and stress evolution during the initial stages of intergranular corrosion of X70 steel’, Electrochica Acta, 285, pp. 336–343.

[19] Benamor, A. et al. (2018) ‘E ff ect of temperature and fl uid speed on the corrosion behavior of carbon steel pipeline in Qatari oil fl i eld produced water’, 808(December 2017), pp. 218–227. doi: 10.1016/j.jelechem.2017.12.009.

[20] Peng, S. et al. (2010) ‘Applied Surface Science Morphology and antimony segregation of spangles on batch hot-dip galvanized coatings’, Applied Surface Science. Elsevier B.V., 256(16), pp. 5015–5020. doi: 10.1016/j.apsusc.2010.03.046.

[21] Wu, K. et al. (2019) ‘International Journal of Greenhouse Gas Control Understanding the corrosion behavior of carbon steel in amino- functionalized ionic liquids for CO 2 capture assisted by weight loss and electrochemical techniques’, International Journal of Greenhouse Gas Control, 83(August 2018), pp. 216–227.

[22] Me, C. M., Kociubczyk, A. I. and Ares, A. E. (2018) ‘Electrochemical behavior of Sn-Zn alloys with different grain structures in chloride-containing solutions’, pp. 1084–1096.