BEM application for thin electrolyte corrosion problem

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Abstract

BEM methods were applied for a thin electrolyte problem. Al-2%Zn alloy thermal spray coatings are used for seawater heat exchanger made of Al-Mg alloy for LNG process utility. We investigated the remaining service life of the coating. The sprayed coating was acting as a sacrificial anode. The integrity of the coating degraded with time by peeling-off and thinning. The expected life of the coating is a crucial data for maintenance scheduling. The distribution of the corrosion potential and current were calculated with BEM analysis with BEASY CP 7.0 module. The anodic behavior of the coating was changed significantly by polymer sealing over-coating and the resultant remaining service life. The viscosity of the sealant determined the degree of impregnation and pore structure. The resin with lower viscosity value decreased the anodic current density and resulted in longer service life and narrow coverage over exposed substrate. We could estimate the coverage of the cathodic protection from the corrosion potential distribution and remained life of the coating from the current distribution at each case.

1. Introduction

The structure studied was vertical heat exchanging panel, ORV(Open Rack Vaporizer) used for LNG (liquefied natural gas) vaporization. Heat source for the vaporization is seawater that flows from the top of the panel to the bottom. The panel was made of Al-Mg alloy (AA 5083). The Al-Mg alloys corrode in pitting form in seawater. To protect the panel from pitting, Al-2%Zn film was flame-spray coated as sacrificial anode. The flowing seawater forms a thin electrolyte film of 1 ~ 5 mm thickness according to supplied seawater flow rate. Al-2%Zn layer has porous microstructure and corrodes rapidly in seawater. Usually, epoxy sealant was applied for maximum service life.

Sacrificial anode coating has been applied for many industrial process equipments[1-3]. The function of the coating is to protect the substrate by preferential dissolution of the coating. The coating degrades with time. The degradation of the coating happens usually in two modes, partial peeling-off and thinning. As the uncoated fraction becomes large, it is more likely that the protection current from remained coating could not cover whole disbonded area and consumption rate of the coating which provide cathodic current increase sharply as the current density increases on their surface. Eventually recoating is required to restore the protective coating function. Early recoating increases the operation cost and delayed recoating could provide the chance of pitting corrosion on the substrate.

In this work, we estimated the remaining coating life from disbonded area fraction and remained thickness, and tried to develop diagnosis criteria for the seawater heat exchanger coating problem with BEM simulation method.

2. Methods

2.1 Electrochemical behavior measurements

To obtain the polarization data for the Al-Mg alloy and coating, the small plate are prepared with normal process for the heat exchanger. The plate of 100x200x5mm dimension was blast cleaned by alumina grit. The substrates are thermal-spray coated with Al-2%Zn alloy to 200μm thickness. The epoxy sealant was applied with brush. The prepared samples were wired and masked with thick insulating epoxy resin excepts $1cm^2$. A three-electrode electrochemical cells with saturated calomel electrode(SCE) as reference electrode and graphite electrode as counter electrode was used for electrochemical test. The measurements were conducted in synthetic seawater of 3.5wt% NaCl solution with continuous air blowing at a scan rate of 0.5mV after aging of more than 67 hrs to stabilize the surface.

2.2 Numerical analysis

The corrosion potential of the sprayed coating is several hundred mV negative to that of the substrate alloy The current flows from the cathodic coating to disbonded area. The disbonded area distributed at random sites with a random shape. The panel has corrugated surface to enhance heat exchange efficiency. As the thickness of electrolyte, seawater film, are rather uniform over the panel, we modeled the problem with simple flat geometry(Fig. 1). The thickness of the film is ignored as it is negligible compared to usual disbonded area size, several to hundreds mm. The conductivity of the electrolyte was 0.236 S/cm.

The analysis was using a secondary model considering iR drop and active polarization. The analysis was conducted using commercial BEM package

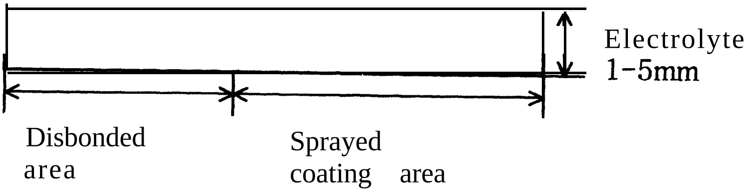

Fig. 1. Schematic diagram of the model

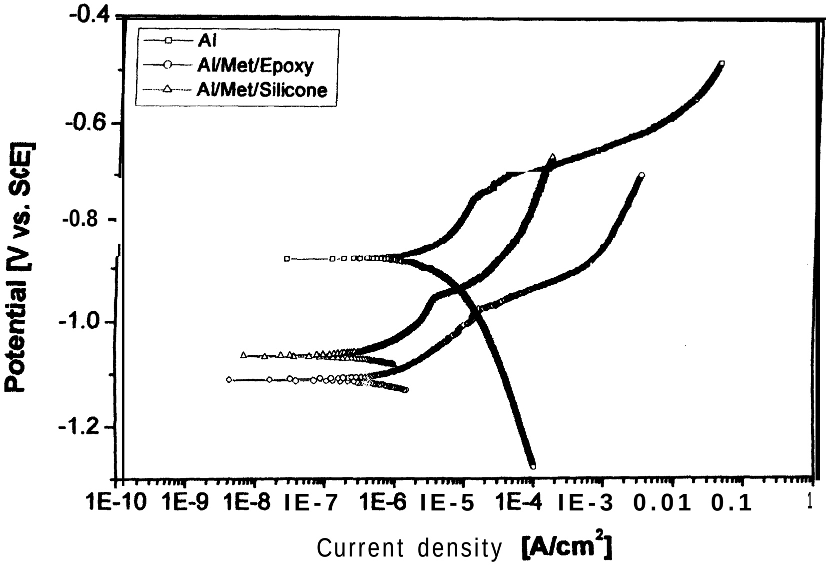

Fig. 2: Polarization curves of thermal sprayed coating system in synthetic seawater (3.5 wt% NaCl); reference electrode – saturated calomel electrode(SCE).

(BEASY version 7.0 CP 2-D module, Computational Mechanics). The corrosion analysis with BEM method had been conducted by many researchers because of the speed and accuracy of the results[4-6].

3. Results

3.1. Polarization data

The measured polarization behavior of the substrate and coating were shown in Fig. 2. Corrosion potential of the substrates was about –880mV(vs.SCE) which is about 200mV higher than coating. We could clearly identify sacrificial anodic function of the coatings. Coating with epoxy sealant had lower corrosion potential and higher current level than coating with silicon sealant at the same potential. We believe this difference comes from the viscosity. Silicon sealant with high fluidity gives more thorough coverage.

3.2. Calculation results

The potential distributions and current profile were calculated at various coating disbonded fraction, form 50% to 95% for epoxy sealed coating and silicon sealed coating. The electrolyte thickness was 5mm for both coating and 1 mm case was solved for epoxy coating. The typical results are shown in Fig. 3 and 4. Horizontal axis represents distance from center of the disbonded area. In Fig. 4. positive current should be interpreted as cathodic current and negative as anodic current.

The potential was maximum at the center of the defect as shown in Fig 3. The maximum potential was decreasing with the increase of disbonded area. The variation of the potential at the center of the defect was plotted in Fig. 5. The average current density was increased with the disbonded area(Fig. 6).

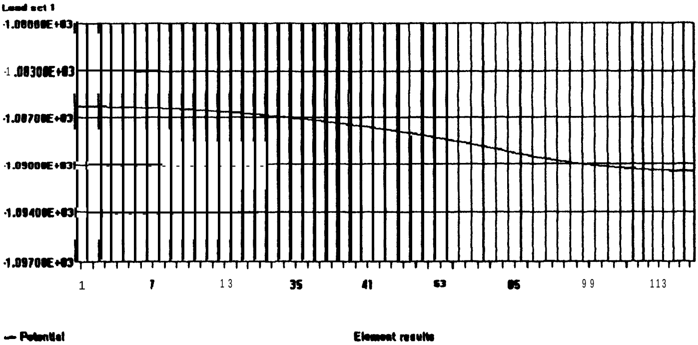

Fig 3: Potential Profile (Epoxy coated panel, disbonded area 70%, sea water layer 5mm)

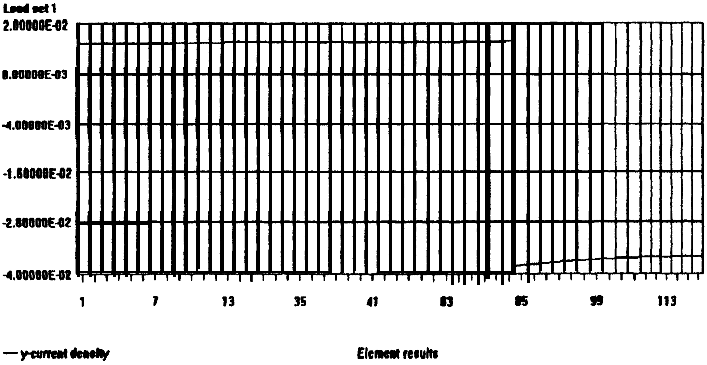

Fig 4. Current Profile (Epoxy coated panel, disbonded area 70%, sea water layer 5mm)

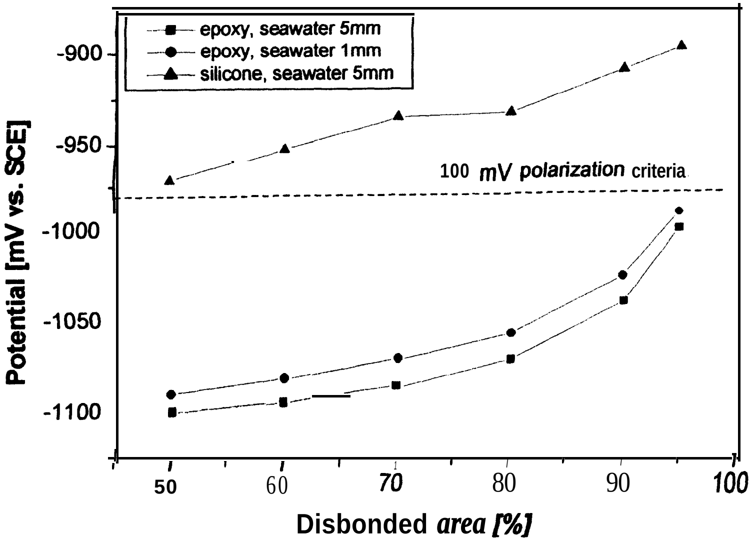

Fig. 5: The changes of corrosion potential according to various disbonded area of the coating.

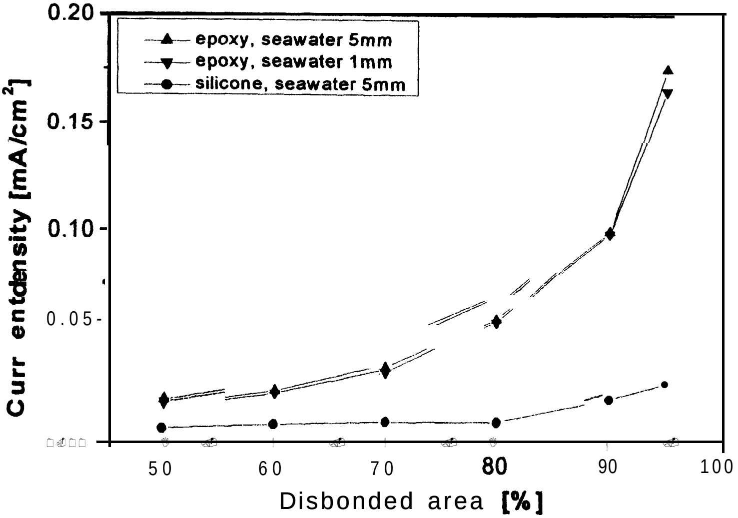

Fig. 6: The changes of current density flowed from coating for protection of substrate according to various disbonded area of the coating.

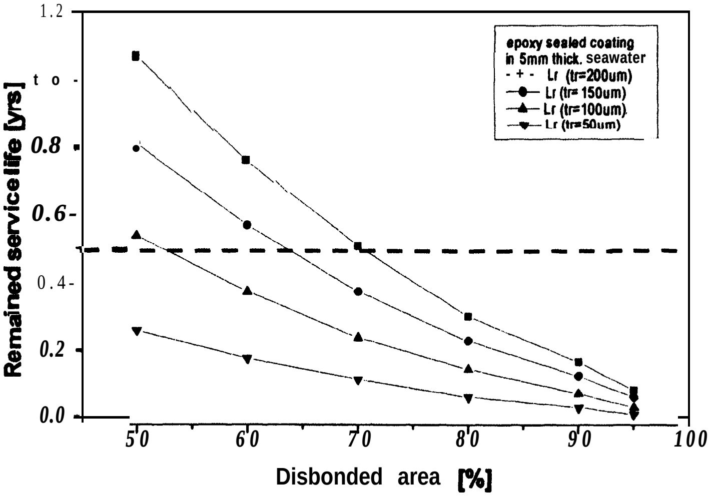

Fig. 7: The estimation of remained service life

4. Discussion

We tried to establish a relationship between the disbonded area and effectiveness of cathodic protection. The corrosion protection criteria for the aluminum alloy was not well established like –850mV(vs. Copper sulfate electrode) of steel structure. Maximum cathodic potential varied from -830 to –850mV(vs.SCE) at various literature[7]. Another popular protection criteria is 100mV from the corrosion potential. As the corrosion potential of the substrates are –880mV(vs.SCE), the criteria is –980mV(vs. SCE) as shown in Fig 5. The corrosion potential of the silicon sealed coating was higher than the criteria already at 50% of the disbonded area. The potential of the epoxy sealed coating satisfied the criteria even at 95% disbonded area. This difference comes from the difference in polarization behavior. From the continuous change of the mixed potential with disbonded area, we can conclude that the measurement of the panel potential will gives the estimation of the average disbonded fraction. However these potential could be influenced severely by the polarization behavior. So we concluded that only the continuous monitoring of the potential could give the meaningful understanding of the coating condition.

As the current coating thickness could be determined by NDT method, we can calculate the remained life of the coating. Using Faraday law, the current density on the coating surface gives the consumption rate of the coating. The estimated remained life was shown in Fig. 7.

5. Conclusion

We could estimated the effectiveness and coverage of the cathodic protection from BEM modeling of the corrosion potential distribution. From the current density calculation, the remained life of the coating could be estimated.

6. References

[1] R.H.Unger, Thermal Spray: *Pro. of Advances in Coatings Technology*, Orlando, Florida, USA, (1987), ASM International Materials: Park, Ohio, USA, pp. 399-406, 1988.

[2] K.J.Altorfer, *Pro. of Atmospheric Corrosion*, (1980), John Wiley and Sons, Inc., p.645-650, 1982.

[3] S. Kawahara, R. Sumida, Nippon Yosha Kyokai Shi *(Journal of Japan Thermal Spraying Society) 3* 1(l), pp.37-42, 1994.

[4] J.O.Dukovic and C. W.Tobias, *J. Electrochem.Soc.*, p.33 1, 1987

[5 3 N.G.Zamani,J.M.Chuang and C.C.Hsiung: *Int.J. Numer.Methods Eng., 24,* p. 1479, 1987.

[6] Danson, D.J., Warne,M.A. :Current density/Voltage Calculations using Boundary Element Techniques, NACE Conference, Los Angeles, USA, 1983.

[7] John Wagner: *Cathodic Protection Design* I, NACE International, Houston, TX, 1993.