



(RESEARCH ARTICLE)



Comparative study of corrosion behavior of Aluminum, Zinc and Babbit coatings deposited by Value Arc Technique for protection of subsea structures

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International Journal of Science and Research Archive, 2025, 17(02), 430-437

Publication history: Received on 30 September 2025; revised on 08 November 2025; accepted on 12 November 2025

Article DOI: <https://doi.org/10.30574/ijrsra.2025.17.2.2878>

Abstract

Steel structures are significantly degraded owing to corrosion especially in sea water environments. To mitigate the corrosion problem of steel used in sea water environments by the application of sacrificial metallic coatings (such as Aluminum, Zinc and alloys). In the current study, the corrosion behavior of Al, Zinc and Babbit coating deposited by value arc technique was observed by electrochemical measurements and immersion of coatings for 10 weeks in 3.5% NaCl solution. The results show that zinc and aluminum coatings are best solution for protection of steel structures from corrosion in submarine environments being utilized as sacrificial anodic coatings.

Keywords: Sacrificial; Corrosion Mechanism; Electrochemical Measurements; Immersion; Thermal Spray; Subsea Structures

1. Introduction

The corrosion protection of structures operating in seawater environments is very important issue. The most common corrosion mitigation methods for the protection of offshore structures that are made of steel (usually mild or low-alloyed) involve the application of cathodic protection and/or protective coatings [1]. One of the methods involves the application of sacrificial metallic coatings (for example; Zinc, Aluminum and their alloys) on steel structures. Depending on the electrode potential with respect to the substrate metal (usually steel), metallic coatings can be formed either anodic (e.g. aluminum and zinc) or cathodic (e.g., nickel and copper). The primary function of protective coatings is their barrier properties.

Surface Engineering is an area of engineering technology which deals with altering the properties of surface and sub-surface of metals to achieve the desirable properties by creation of new layer on substrate material by coating process. By this process the surface of metal can be protected against wear, erosion, friction, abrasion, corrosion, fretting, damping and etc. in different working environments under different loading conditions [1,2].

There are so many surface engineering techniques/methods being used to produce different types of thin and thick films on the surface of metals to enhance the surface properties. PVD and CVD technology is used to produce thin films of few microns to improve surface hardness and other mechanical properties of small machine tools. By applying Thermal Spraying technology thick films of microns to millimeters can be produced to protect the base material and this technology can also be used for reclamation purposes.

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Thermal Spraying involve the production of metallic, ceramics, cermets and some polymeric material coatings in the form of powder, rod and wire fed to gun or torch with which they heated to near or above the melting point to create the plasma. The resulting molten and near to molten material can be deposited on substrate material and solidify to produce a hard layer.

Thermal spraying technology has a wide range of techniques like; flame, High Velocity Oxy-Fuel (HVOF), Low Velocity Oxy-Fuel (LVOF), D-Gun, Plasma, Electric Wire Arc and Plasma Transferred Arc (PTA) technique [4].

Among these techniques, Electric Wire Arc process holds very favorable process from stand point of so many applications. The process is using only electric current and no any gases for atomizing of air are required. The produced coatings are characteristically more clean and machinable than those produced by thermal spray process. Electric Wire Arc process is more economical and very simple to operate and maintain with very low number of operating parameters. The quality of produced coatings is very reliable and robust. These systems are simple to work in-house and on-site coatings also [3].

In the current study, the corrosion behavior of sacrificial anodic (Aluminum, Zinc and Babbit) coating on MS substrate developed by wire arc technique was studied in 3.5% NaCl solutions [2,5].

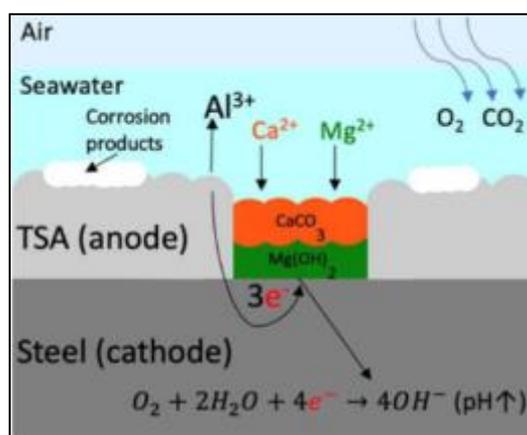


Figure 1 Sacrificial protection mechanism of Aluminum coatings

2. Experimental work

2.1. Materials and Coating Deposition

The substrate material was Mild Steel and coating material was Aluminum, Zinc and Babbit (Sn, Sb & Cu). Five batches of samples having dimensions (3"x 1.5"x0.196") were selected and shot blasted with Alumina Grit (particle size 5µm) to achieve the adequate surface roughness. The coating was deposited by applying the parameters like; voltage of 21-24 V, current/feed rate was set of 5kW/hr and air pressure was set at 50-60 psi with spraying distance of 4 inch.

2.2. Characterization of Coatings

After deposition of coating the different characterization techniques were utilized to analyze characteristics of the coating. The coating thickness was measured by using the optical microscope Nikon (UFX-DX) Japan varied from 100 to 250µm. The microstructure analysis of coated samples was assessed by using Image Analyzer (LEICA DM4000M). The morphology of coating was analyzed by using Scanning Electron Microscope (SEM/EDS) S-3700N Hitachi, Japan. Hardness profile was generated by vicker (Ogava, Japan) & micro-vicker hardness tester (Wilson Walper, China). Electrochemical measurements were analyzed by using Potentiostat (AutoLab, Netherlands) in NaCl solutions. The Immersion test of 10 weeks was performed at room temperature for the coating in 3.5% NaCl solution in sealed glass bottles. The coated surface of sample was exposed to corrosive environment [7,8].

3. Results and Discussion

3.1. Microstructural analysis

Fig. 2 shows the microstructure of surface as well cross sectional aluminum coated samples by using scanning electron microscope. The images show the basic structure of aluminum coating and the splat formation of coating in cross sectional image. The splats are proper and wavy in shape. The image also shows the adhesion of coating with base material (steel). In Fig. 3, the porosity level is also highlighted images also show the porosity level in both images (surface and cross section) is also seen, which is very low.

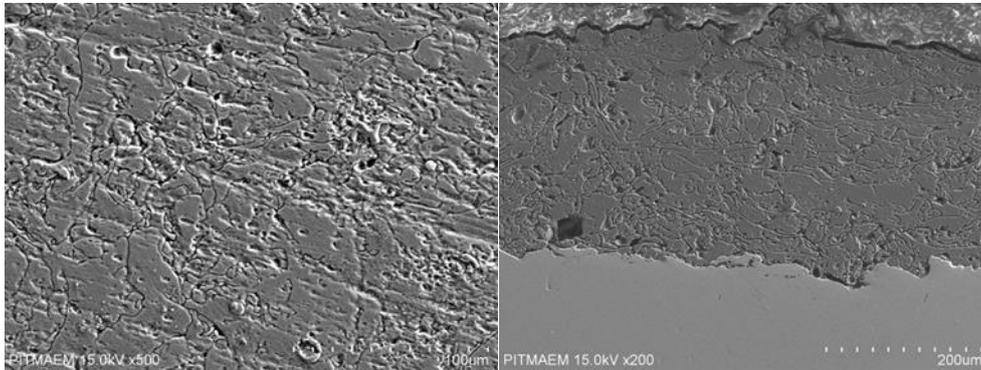


Figure 2 Microstructures of Aluminum coating (surface & cross sectional)

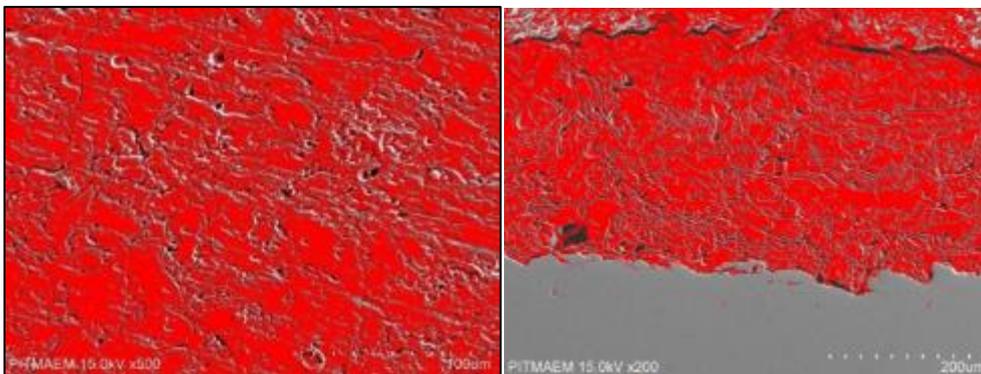


Figure 3 Porosity measurement of Aluminum coating (surface & cross sectional)

Fig. 4 shows the selected surface and cross sectional photographs of the microstructures of Zinc coating made by using optical microscope/SEM. The microstructure shows the basic structure of enriched zinc needle-shaped and nearly globular-shaped. In Fig. 5, the images also shows the porosity level in both (surface and cross sectional), which is very low as compared to aluminum coating.

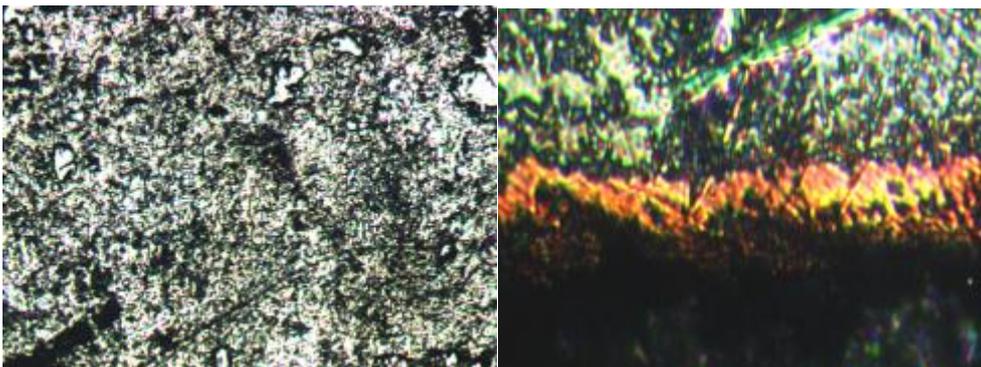


Figure 4 Microstructures of Zinc coating (surface & cross sectional)

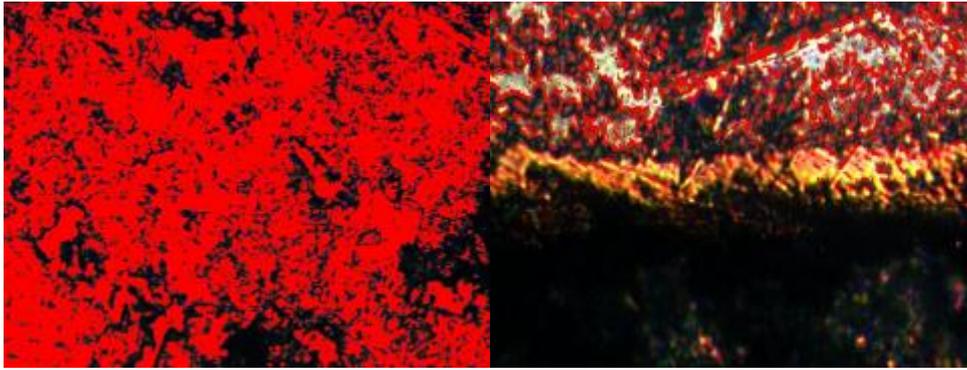


Figure 5 Porosity measurement of Zinc coating (surface & cross sectional)

Fig. 6 shows the selected surface and cross sectional photographs of the microstructures of Babbit coating made by using optical microscope/SEM. The microstructure of investigated alloy consists of large hard cubic crystals of the Sn Sb phase and precipitates of the Cu₆Sn₅ phase, both needle-shaped and nearly globular-shaped dispersed in a softer tin-rich matrix. In Fig. 7, the images also shows the porosity level in both (surface and cross sectional), which is higher than aluminum and zinc coating. The reason of increased porosity level may be due to voltage variation.

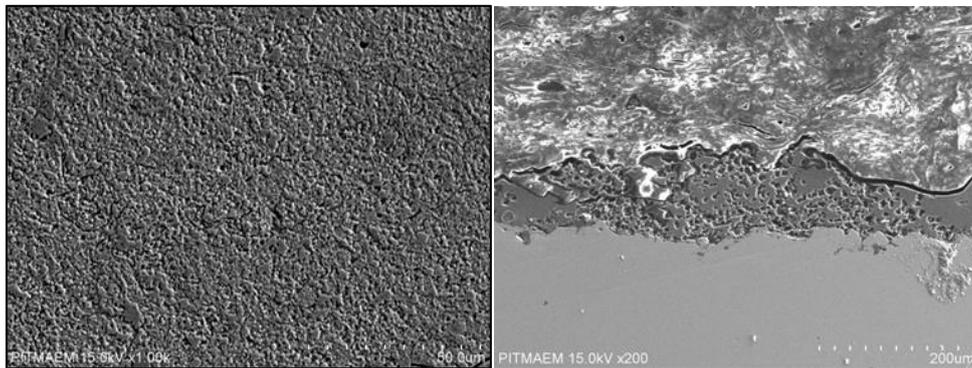


Figure 6 Microstructures of Babbit coating (surface & cross sectional)

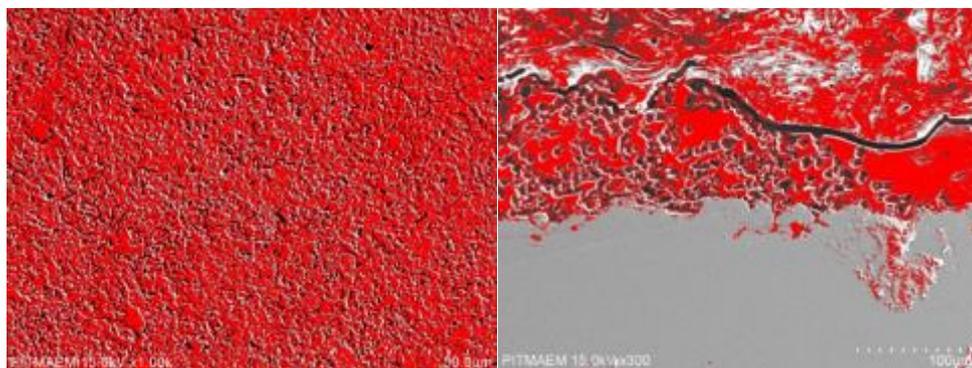


Figure 7 Porosity measurement Babbit coating (surface & cross sectional)

3.2. Hardness Profile

For measurement of hardness, the surface and cross sectional samples were analyzed by using micro-vicker hardness tester by applying load of 100gms on surface coated and 300gms on cross sectional coated samples. Five readings were taken to create a profile of hardness for surface coated and two readings were taken on cross section coated samples of Aluminum, Zinc and Babbit. The average hardness of surface coating of Aluminum was observed 38.7 Hv_{0.1} and cross sectional was 39.85 Hv_{0.3}. The surface coatings hardness values of Zinc coating was observed 65.82 Hv_{0.1} and cross sectional was 133.80 Hv_{0.3}. The surface coatings hardness values of Babbit coating was observed 19.1 Hv_{0.1} and cross sectional was 150.50 Hv_{0.3}. Table. 1 shows the hardness results. The increase in hardness values of cross section of

Babbit coatings is because these coatings are wear resistant and due to lamellae structure hardness of coating is increased.

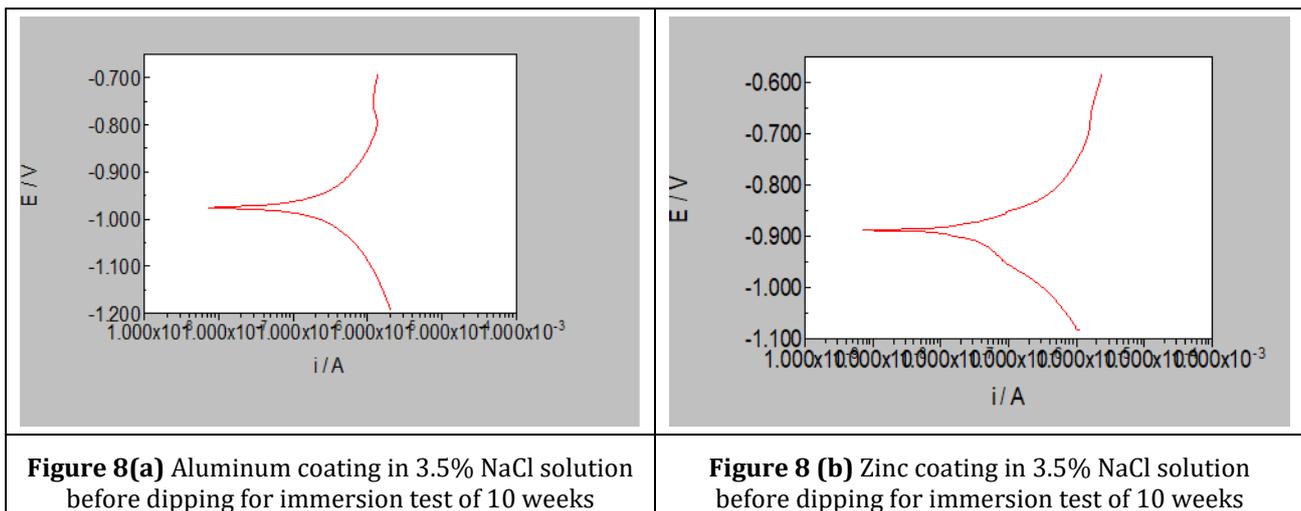
Table 1 The hardness values of surface as well as cross sectional coated samples of Aluminum, Zinc & Babbit

Sr. No.	Aluminum coating		Zinc coating		Babbit coating	
	Surface	Cross Sectional	Surface	Cross Sectional	Surface	Cross Sectional
	38.7 Hv _{0.1}	39.85 Hv _{0.3}	65.82 Hv _{0.1}	133.80 Hv _{0.3}	19.1 Hv _{0.1}	150.5 Hv _{0.1}

3.3. Corrosion Study: Electrochemical Measurements:

The corrosion resistance of coated samples (Aluminum, Zinc and Babbit) was evaluated by cyclic anodic polarization in 3.5 wt.% NaCl solution are shown in Fig. 8 (a, b & c), respectively. The voltage potential is very important factor in galvanic series of metals in sea water. The curves show the almost same behavior without any major variation. The smooth appearance of the curves measured for the coated specimens may indicate corrosion rate of these coatings is (Al Corrosion rate: $1.3E^{-2}$ (0.01) mm/year), (Zinc: $9.078E^{-3}$ (0.009) mm/year) and (Babbit: $9.226E^{-5}$ (0.0001) mm/year) respectively. The difference in voltage potential (E/V) of three coatings is also shown in these graphs -0.90, -1.0 and -0.42 respectively.

The difference in the behavior of corrosion rate of coatings is remarkably seen in curves. The Babbit coating is more corrosion resistant with low voltage potential as compared to Zinc and Aluminum respectively. As per previous research work done by different researchers and available literature, the Aluminum and Zinc coatings are most likely used as sacrificial anode in corrosive environments for protection of steel structures especially in submarine environments. While the Babbit coatings are widely used as wear resistant and corrosion resistant by applying on different bearings and other machine parts. Therefore, the Babbit coating shows the lowest corrosion rate than aluminum and zinc coatings. Hence, the zinc and aluminum coatings are being utilized as sacrificial anodic coatings for protection of steel structures in sea water due to their voltage potential difference.



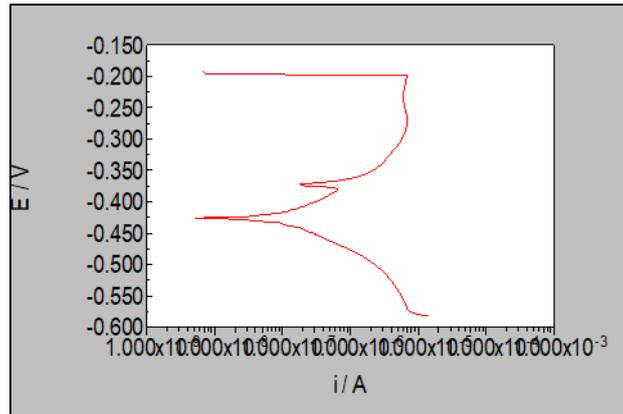


Figure 8(c) Babbit coating in 3.5% NaCl solution before dipping for immersion test of 10 weeks

3.4. Immersion Test Results:

After ten weeks of immersion in 3.5 wt.% NaCl solution, all specimens had some visible signs of corrosion on the corners but the surface of coating was clear from any sign of corrosion. These corrosion signs on the corners may be due to reaction of salt water between mounting material and steel. The all three coated samples were analyzed for corrosion resistance behavior by cyclic anodic polarization in 3.5 wt.% NaCl solution as shown in Fig. 9 (a, b & c), respectively. The curves show some slightly increase in carrion rate. The smooth appearance of the curves measured for the coated specimens may indicate corrosion rate of these coatings is (Al Corrosion rate: $5.176E^{-2}$ (0.05) mm/year), (Zinc: $1.078E^{-2}$ (0.01) mm/year) and (Babbit: $7.082E^{-3}$ (0.007) mm/year) respectively.

The slight increase in corrosion rate of all three samples was observed. As already discussed in results of before immersion test, almost same behavior of all three samples is seen in the curves. The Babbit coating is more corrosion resistant as compared to Zinc and Aluminum respectively. Aluminum and Zinc coatings are most likely used as sacrificial anode in corrosive environments for protection of steel structures. While the Babbit coatings are widely used as wear resistant and corrosion resistant by applying on different bearings and other machine parts. Therefore, the Babbit coating shows the higher corrosion rate than aluminum and zinc coatings. Hence, the zinc and aluminum coatings are corrosion resistant with varying the voltage potential difference being utilized as sacrificial anodic coatings.

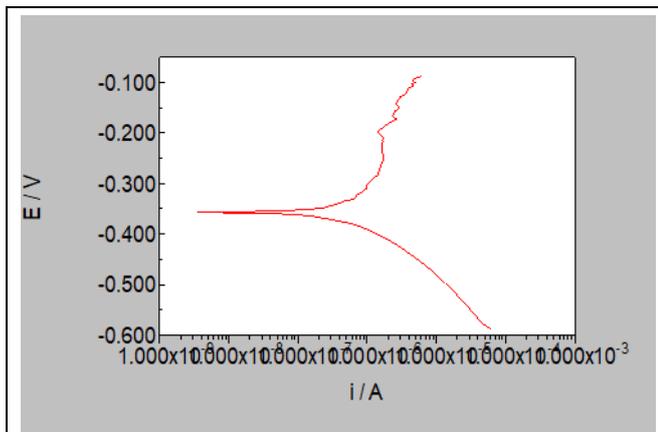


Figure 9 (a) Aluminum coating in 3.5% NaCl solution after dipping for immersion test of 10 weeks

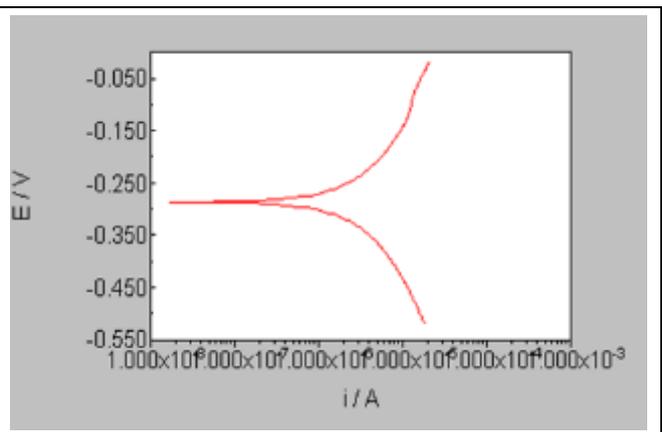


Figure 9 (b) Zinc coating in 3.5% NaCl solution after dipping for immersion test of 10 weeks

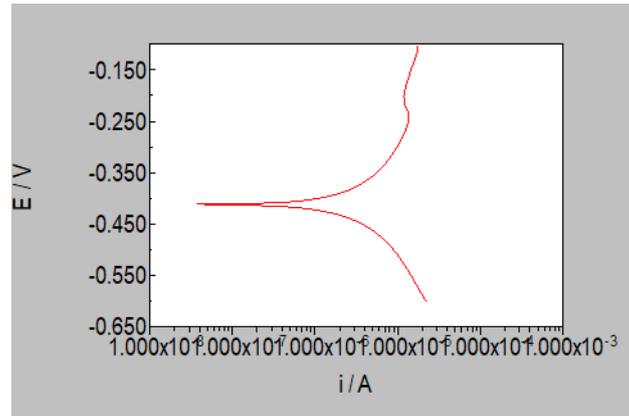


Figure 9 (c) Babbit coating in 3.5% NaCl solution after dipping for immersion test of 10 weeks

4. Conclusion

In this study, the corrosion performance of thermally sprayed Aluminum, Zinc and Babbit coatings was studied by means of open-circuit potential measurements, cyclic anodic polarization measurements, and immersion tests. In addition, the comparative study of corrosion resistant and sacrificial anodic behavior of the coatings was discussed. The following conclusions were made from this study:

- All coatings were dense enough to prevent the penetration of the chlorine ions to the coating-substrate interface
- The coatings tend to passivate in the aqueous NaCl environment.
- The Babbit coating had better corrosion resistance than the Zinc and Aluminum coatings.
- The sacrificial anodic behavior of Zinc and aluminum coatings in NaCl environment is higher than babbit coating with voltage potential difference.

On the basis of above results, it is concluded that Zinc and aluminum coatings are best solution for protection of steel structures from corrosion in submarine environments being utilized as sacrificial anodic coatings.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have no any conflict of interest.

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