International Journal of Engineering & Technology, 7 (4.35) (2018) 194-197

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Effect of Epoxy/Al_2O_3/CeO_2 Coating on Corrosion Rate and Mechanical Properties of Mild Steel

M.N. Nasih[1], W.V. Vicki[2*]

[1,2] Centre for Advanced Material, Universiti Tenaga Nasional, Malaysia
**Corresponding author E-mail: vignesh@uniten.edu.my*

Abstract

In any industry like a power station, corrosion is a natural process that commonly happens and one of the problems that need to be considered. The example is in the underground pipeline where sea water is transported for cooling purposes. This study mainly on corrosion rate and mechanical properties of coating material on mild steel. Theoretically, Metal can get the higher rate of corrosion when exposed to the surrounding environment. Corrosion can cause to a lot of unwanted conditions, including failures in functions and higher maintenance cost as well as it is too risky for safety. The objective of this project is to study the corrosion rate and mechanical properties of the coating material of pure epoxy, aluminum oxide (Al_2O_3) and cerium oxide (CeO_2) on mild steel. Different composition of epoxy/ Al_2O_3/CeO_2 coating tested on mild steel specimen. There is three experimental conduct which is a Gamry test for corrosion rate and impact and hardness test for mechanical tests. As a conclusion, the results from the tests show that the coated mild steel of Al_2O_3-CeO_2-epoxy obtained the best value in term of corrosion resistance and mechanical properties.

Keywords: *Corrosion rate; Mechanical Properties; Epoxy coating; Aluminum oxide; Cerium oxide.*

1. Introduction

A protective coating is one of the methods that act as a corrosion protection in the underground pipeline. Underground pipelines that have no protected barrier when contacted with water, can cause the corrosion. The disintegration will occur in every pipeline without a right maintenance. Corrosion will make the pipeline structural become weak and it is not safe for the application system in the industry. However, there are technologies that exists to increase the lifetime of the pipeline structure if applied and maintained in the right way [1].

Organic coatings are commonly used in industry for corrosion prevention on metallic surfaces. However, water and oxygen can infiltrate organic coatings to a few points of confinement. The advanced material, for example, lightweight, splendid appearance and boundary properties, have influenced the aluminum pigment as an appealing material for the analysts [2]. Nowadays, the addition of a small percentage of metal particles to an organic material like epoxy can improve the corrosion resistance and mechanical properties [3]. Al_2O_3 particles, specifically, have pulled in impressive consideration and their application in the corrosion inhibitive coatings has turned into an examination field of intrigue. Moreover, Al_2O_3 particles can influence the boundary and mechanical properties of the organic coatings. High electrochemical reactivity and inclination of Al_2O_3 particles for response with oxygen and moisture can reduce the formation of oxide layer and increase the resistance of the base metal against corrosion [4].

Even though the modified Al_2O_3 particles into epoxy coating can improve the corrosion rate, but the layer is still unstable at some pH value that bringing about detached layer disintegration which decreases its lifespan and protective characteristics in corrosive conditions [5]. Hence, surface modification of Al_2O_3 particles is an imperative issue due to their characteristically high electrochemical and chemical reactivity. Other than organic and inorganic materials counting CeO_2 have been the subject for modification of Al_2O_3. Generally there are many different type of surface treatment techniques. One of the technique that widely researched is surface treatments using composition of polymer and metal nanoparticles such as Al_2O_3 and CeO_2. The CeO_2 is a stable layer that covers the metal surface giving effective corrosion protection through obstructing the dynamic destinations from forceful particles access. Furthermore, the self-healing part of Ce4+ is another parameter influencing its corrosion defensive performance [6].

2. Materials and Methods

2.1. Specimen Preparation

In this research, there is fifteen mild steel that had been used for experimental conduct. These mild steels are used as the base metal surface for coating materials of pure epoxy, aluminium oxide (Al_2O_3) and cerium oxide (CeO_2). The pure epoxy acts as an organic material while Al_2O_3 and CeO_2 act as a inorganic material. Modified Al_2O_3 and CeO_2 are adding to pure epoxy by a certain amount of percentage (wt%). Table 1 is the theoretical mixing ratio for the combination of epoxy resin and hardener to Al_2O_3/CeO_2 particles.

Table 1: The theoretical mixing ratio of Coating material

Specimen	Epoxy		Particles	
	Resin	Hardener	Al_2O_3	CeO_2
Weight Fraction / Specimen	Weight Fraction (wt%)	Weight Fraction (wt%)	Weight Fraction (wt%)	Weight Fraction (wt%)
Epoxy, (A)	66.67	33.33	0.00	0.00

Epoxy/Al_2O_3 (B)	60.00	30.00	10.00	0.00
Epoxy/Al_2O_3 (C)	53.33	26.67	20.00	0.00
Epoxy/Al_2O_3 /CeO_2, (D)	53.33	26.67	10.00	10.00
Epoxy/Al_2O_3/CeO_2 (E)	40.00	20.00	20.00	20.00

Al_2O_3 and CeO_3 have different size of particles. The size for Al_2O_3 is 80 mesh while for CeO_2 is 440 mesh. The CeO_2 particle is un-analytical grade because the purity percentage is around 50-55%. The supplier for these two materials are Irama Canggih Sdn Bhd. Next, about the pure epoxy, it is divided into two which are an epoxy resin and epoxy hardener. The mixing ratio is 2:1. The properties of this material are hard, clear and suitable for industrial application. The pot life for this material is around 80-100 minutes. This epoxy used is BONDITE-8950 supplied by Miracon (M) Sdn **B**hd. Every experiment have different size and dimension of mild steel based on the ASTM standards for testing. The specimen dimension for corrosion test is 70 x 25 x 25mm, for hardness test is 10 x 30 x 30mm and impact test is 10 x 10 100mm. The mild steel surface will be cleaned first before coating process started. The coating was applied by means of a brush and specimen will be placed in an oven with a temperature of 55°C for 24h.

2.2 Pontentiodynamic Testing Using Gamry Instrument

This testing strategy can be used to check the performance of polarization protection estimation hardware including reference electrodes, electrochemical cells, potentiostats, filter generators, measuring and recording gadgets. Polarization protection can be identified with the corrosion rate for metals at or close to their corrosion potential. Polarization protection estimations are an exact and quick approach to gauge the general corrosion rate. Ongoing corrosion observing is a typical application. In order to set up this experiment, the first thing that needs to do is the preparation of the 3.5% NaCl solution.

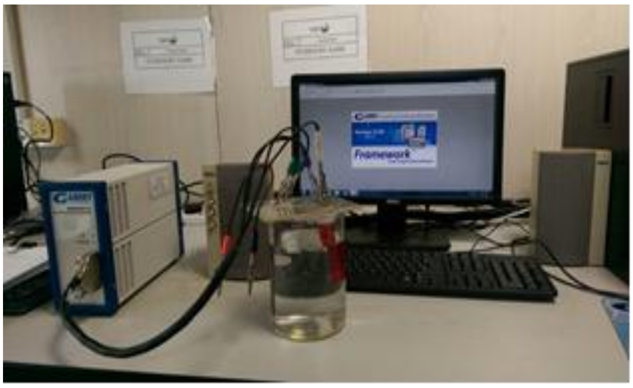

Fig. 1: The setup of Gamry's software instrument for potentiodynamic testing

The solution used in the beaker with the amount of 500ml. Next, the coated metal will be submerged into the NaCl solution in the beaker. Other than that, the reference electrode and counter electrode also need to be submerged in the solution. A counter electrode is made of an inert material which is graphite. The material for a reference electrode is copper sulfate ($CuSO_4$). Fig. 1 shows the setup for potentiodynamic testing and also the Gamry instrument.

2.3 Impact Test

The experiment is used to measure the amount of energy absorbed by a specimen material during fracture. How a material reacts to a sudden tension due to a quick blow or impact is shown by means of an impact tester. The test is conducted according to the model of ASTMD 256-88 IZOD Impact test of notched specimens of mild steel. In this experiment, the starting point will set to zero. It is because of grating and wind protection, the pendulum won't have an indistinguishable striking point from the fall angle. This can be adjusted for by slanting the impact tester marginally. The fall angle will then be bigger and the striking edge less yet the scale is settled and a non-stacked blow. The pointer for the start point will set for 15 joules.

3. Results and Discussion

3.1. Effect of Al_2O_3/CeO_2/Epoxy Coating on the Corrosion Rate of Mild Steel

The value of corrosion rate for all the coated specimen the test using the Gamry's software instrument for potentiodynamic testing are shown in Table 2. The corrosion rate for each specimen was auto-calculated in Mils per year (mpy) by the Gamry's software.

Table 2: Corrosion rate value for all specimens

Specimen	Corrosion Rate (mpy)
A	276.2×10^{-3}
B	732.0×10^{-9}
C	42.31×10^{-9}
D	78.3×10^{-18}
E	7.3×10^{-18}

The Tafel plots for electrochemical corrosion measurement are used to derive the rate of the corrosion for the specimens. There is some analysis has been studied to differentiate the corrosion rate of the specimens. The analysis was obtained based on parameters that will affect the propagation of corrosion like example temperature, wind blows and exposure to the atmosphere. The corrosion rate for all the coated specimen are shown in Fig. 2. Sample A shows the highest corrosion rate of 2.76×10^{-1} mpy and the lowest corrosion rate are observed for specimen E which is 7.3x10-18mpy.

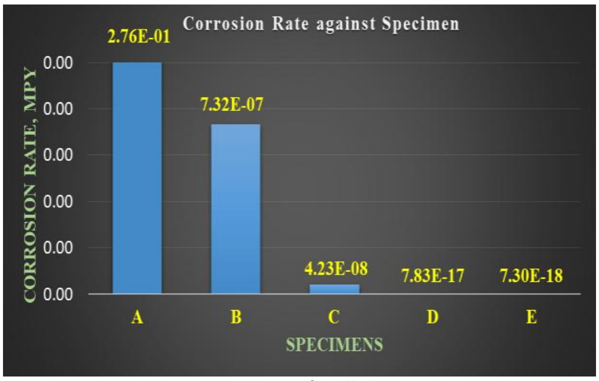

Fig. 2: Corrosion rate for all the specimens

It can be concluded that the result for corrosion rate for the last coated specimen which is modified pure epoxy with Al_2O_3 (20%) and CeO_2 (20%) is the lowest to compare with other specimens. It means that this specimen is the best in term of corrosion prevention. Other than that, the author conducts the experiment in the lab with constant temperature and also there is no wind blows in that lab room. The only affecting parameter that can be discussed is the exposure to the atmosphere. From the previous study conducted by A. Gupta et. al, it shows that the value of corrosion rate for uncoated mild steel is 33.4mpy and for coated mild steel of coal tar epoxy material is 0.0388mpy [7]. From these two values, it can be compared to that specimen E got the lower value. It means that specimen E is the best in term of corrosion resistance

3.2. Effect of Al_2O_3/CeO_2/Epoxy Coating on the Hardness of Mild Steel

The hardness is determined by measuring the depth of penetration of the indenter under a large load. Hardness testing used to assess materials where its hardness material relates to its wear resistance, the material strength, and other mechanical properties. The hardness strength of the coated mild steel was calculated using the formula of Brinell hardness which is HB=0.102(F)/A. For this experiment, the area for all the test specimens is $900mm^2$. The values for the hardness strength of the materials was plotted in Fig. 3. All the hardness strength values of the coated mild steel were analyzed and discussed. The combination of coating material between organic and inorganic material can give effect to the hardness strength of the mild steel. From Fig. 3, the experimental values for hardness strength for coated specimen show a positive trend even though the increase in hardness is in small scale. This is due to the coating which is a single layer. The results show that the modified pure epoxy with $A_{l2}O_3$ and CeO_2 is harder than other specimens.

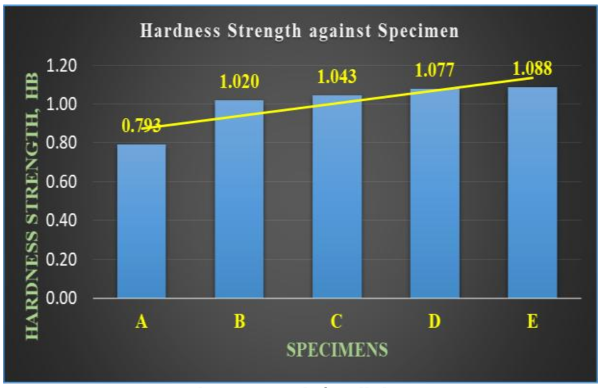

Fig 3: Hardness strength for all the specimens

Hardness and softness is the measure of the resistance of a solid matter when force is applied. The hardness and softness of the material is determined by the strength of the intermolecular bond of the material. For this experiment, it can be concluded that the intermolecular bond of modified pure epoxy with Al_2O_3 and CeO_2 is stronger than only pure epoxy. It is because of the higher value of hardness strength. The other point that should be considered is about interfacial adhesion, in which interfaces between stages or parts are kept up by intermolecular forces, chain entanglements, or both, over the interfaces. Interfacial adhesion also can be called as adhesive strength. The unit for the adhesive strength is Nm^{-2} and the symbol is Fa. From the Brinell hardness equation, it can be concluded that when the applied force is increased, the hardness strength also will increase. It shows that the adhesive strength for modified pure epoxy with Al_2O_3 and CeO_2 is greater than only pure epoxy. From this experiment, it shows that the addition of these metal particles with pure epoxy that applied to the mild steel can strengthen the mechanical properties for hardness strength of the material. Even from one of the previous report, the result shows that the addition of some percentage of inorganic material like Al_2O_3 and iron(II) oxide and results in a higher values of hardness strength compared to coal tar epoxy (only organic material) [8,9].

3.3. Effect of Al_2O_3/CeO_2/Epoxy Coating on the Impact Strength of Mild Steel

The impact strength was calculated taking the energy absorbed (J) dividing with the sample cross-section area (cm^2). Basically the unit for impact strength J/cm^2. Impact strength is one of the mechanical properties of a material which illustrates the measure of crack start leading to fracture because of a certain amount of power that acted upon the surface of the specimen. Composite fracture toughness is based on the interfacial bonding and interlinear strength between the bonds of the epoxy and nanoparticle strength parameter. After the specimens were tested, the value of energy will be recorded from the IZOD impact test machine. From that value, the impact strength can be calculated. The recorded value from the test machine is in Joule (J) which is the unit for energy. From that value, the value for impact strength can be determined using the formula of impact strength. For this experiment, the area for all test specimen is $1cm^2$.

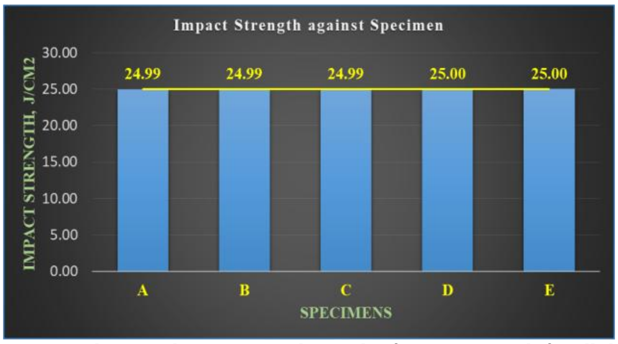

Fig 4: Bar chart graph to compare the result of impact strength for all the specimens

From Fig. 4, it shows that the result for all specimens is same which is 25 J/cm^2. It means that the coating material that applied to mild steel does not give any effect for the value of impact strength. It is because the layer of coating is just very thin, which is one layer only. Therefore, the single layer coating on a mild steel specimen with thickness of 10mm does not have significant effect to the impact strength of mild steel. The interface shear stress, adhesion and interfacial bonding of the coating material does not affect the properties of mild steels specimen because the coating material act as a protective layer on the mild steel and doesn't not influenced the interfacial bonding of mild steel [9]. For sample A, B, and C, there is some reduction in the impact strength with a difference of $0.01J/cm^2$ but this value is very small and relatively does not show a major effect due to coating layer. Moreover, there is one report from the previous study, it just shows that the result for impact test in Joule for coating material of polyethylene and polypropylene is around 9.8J, where both values does not show much difference [10-11].

4. Conclusion

In this research, mild steels were successfully coated with the composition of epoxy, aluminium oxide (Al_2O_3) and cerium oxide (CeO_2) and characterized for its mechanical properties and corrosion rate. A new coating material has been developed from the combination of organic and inorganic material which is epoxy with Al_2O_3 and CeO_2. From the corrosion test, it can be concluded that the coated specimen (E) Al_2O_3(20%)-CeO_2(20%)-epoxy(60%) shows the lowest corrosion rate of $7.3x10^{-18}$ mpy. It can be justified that this composition of coating material has high potential to be used in underground pipeline application because of the good characteristic of corrosion resistance. The value for hardness strength for the combination of Al_2O_3-CeO_2-epoxy is higher than only pure epoxy. However, the effect of coating on the hardness of mild still is not significant due to the coating layer is too thin and its single layer coating. Moreover, it also can conclude that the intermolecular bond and adhesive strength of combination between organic and inorganic is greater for pure epoxy coating. For the impact strength, it can be concluded that the application of coating material on the mild steel does not give any effect to impact strength. The value of impact strength for all the specimens are same which is 25 J/cm^2.

Acknowledgements

The authors thank the technical staffs of the mechanics of material laboratory and Tuan Haji Zainudin from Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional Malaysia for the assistance in the research work. Also, authors would like to acknowledge the financial support provided by Universiti Tenaga Nasional under the BOLD 2025 research grant project code:10289176/13/9/2017/33.

References

[1] "Pipeline Corrosion," [Online]. Available: https://www.nace.org/uploadedFiles/Corrosion_Central/Pipeline%20Corrosion.pdf. [Accessed 15 January 2018].

[2] S. Huang, Y. Zuo, T. Zhou, L. Zhang, H. Wang, "Corrosion resistance of lamellar aluminium pigments coated by SiO2 by sol-gel method," vol. 53, pp. 161-167, 2011.

[3] O.B. Nazarenko, C. S. Chandran, T. V. Melnikova, S. Y. Nazarenko, J.-C. Kim, P.M. Visakh, "Effect of electron beam irradiation on thermal and mechanical properties of aluminum based epoxy composites," vol. 136, pp. 17-22, 2017

[4] M. Rostami, B. Ramezanzadeh, S. Niroumandrad, "Effects of combined surface treatments of aluminium nanoparticle on its corrosion resistance before and after inclusion into an epoxy coating," 2016.

[5] P. Eng, A. Mak, "General Cable Corrosion of Steel, Aluminum and Copper in Electrical Applications," 2002.

[6] E. A, Kulp, W. G, Fahrenholtz, M. J, O'Keefe, S. Joshi, "Dissolution of cerium from cerium-based conversion coatings on Al 7075-T6 in 0.1 M NaCl solutions," pp. 290-295, 2012.

[7] A. Gupta, P. C. Verma, "study of corrosion behaviour of coal tar polymers coated system in different corrosive environment," 2011.

[8] "YD-134 Standard Liquid type Epoxy," [Online]. Available: https://www.kukdo.com/file/goods/YD-134_TDS_.pdf. [Accessed 28 January 2018].

[9] "JFE pipe coating," [Online]. Available: http://www.jfe-steel.co.jp/en/products/pipes/catalog/e1e-009.pdf. [Accessed 28 January 2018.

[10] Mahmud Abdulmalik, "Effect of coating mild steel with CNTs on its mechanical properties and corrosion behaviour in acidic medium," *Adv. Nat. Sci: Nanosci. Nanotechnol*. Vol. 8, No 015016 (14pp), http://iopscience.iop.org/article/10.1088/2043-6254/aa5cf8/meta

[11] B. Vijaya Kumar, G. Madhusudhan Reddy, T. Mohandas, "Influence of process parameters on physical dimensions of AA6063 aluminium alloy coating on mild steel in friction surfacing", *Defence Technology*, Vol. 11, No.3, 2015, pp. 275-281,https://doi.org/10.1016/j.dt.2015.04.001.