Paper Reference ID: UMT/FMSM/MARTEC/MTP-107

SODIUM BENZOATE AS CORROSION INHIBITOR FOR ALUMINUM ALLOY AA 7618 IN TROPICAL SEAWATER

Muzathik A.M.[1,2*], Ahmad M.F.[1], Kamales B.[1] and Wan Nik W.B.[1]

[1]Department of Maritime Technology, Universiti Malaysia Terengganu, Malaysia.
[2]Institute of Technology, University of Moratuwa, Katubedda, Sri Lanka.
*E- mail: muzathik64@yahoo.com

ABSTRACT

Corrosion is chemically induced damage to a material that results in deterioration of the material and its properties. Ships, marinas, pipelines, offshore structures, desalination plants, and heat exchangers are some examples of systems that experienced marine corrosion. Aluminum alloy is commonly used in marine applications. The use of inhibitors is one of the practical methods for protection against corrosion. Sodium benzoate has found considerable application as a corrosion inhibitor in low concentrations. The aim of this study is to analyze corrosion behavior of Aluminum alloy AA 7618 towards tropical seawater with the presence of sodium benzoate as corrosion inhibitor aimed to use in industrial applications. Immersion test and electrochemical test were conducted to measure the corrosion. The immersion period for the Aluminum alloy was 60 days. Seawater sample was collected from South China Sea along Universiti Malaysia Terengganu. This study reports the results of weight loss (%), inhibition efficiency (%), corrosion rate (mm/year), corrosion current densities (i_{corr}), corrosion potential (E_{corr}), polarization resistance,(R_p) and capacitance (CPE). The results showed that addition of sodium benzoate acted as inhibitor and minimize the corrosion of the aluminum alloy in seawater. The inhibition efficiency increases with the increase of immersion time. Electrochemical studies showed that there was a significant increase in overall resistance after addition of sodium benzoate. Inhibition efficiency is increased from 50% to 97% during the immersion period and increases with the immersion time. The result obtained lead to the conclusion that sodium benzoate is suitable to use as a corrosion inhibitor of Aluminum alloy AA 7618 in seawater.

Keywords: Aluminum alloy, corrosion inhibitor, seawater corrosion, sodium benzoate

1. INTRODUCTION

Corrosion is chemically induced damage to a material that results in deterioration of the material and its properties [1]. Moreover corrosion is referred as a process that involves deterioration or degradation of metal as well and as a result of the inherent tendency of metals to revert their more stable compounds which is usually oxides [2]. Ships, marinas, pipelines, offshore structures, desalination plants, and heat exchangers are some examples of systems that experienced marine corrosion. The use of inhibitors is one of the most practical methods for protection against corrosion [3]. Aluminum alloy is commonly used in marine applications. Sodium benzoate has found considerable application as a corrosion inhibitor in low concentrations. Corrosion inhibition has been reported for steel, zinc, copper, copper alloys, soldered joints, aluminum, and aluminum alloys [2]. The aim of this study is to analyze corrosion behavior of aluminum alloy (AA7618) towards tropical seawater with the presence of sodium benzoate as corrosion inhibitor so that it can be used in marine industrial applications in future.

2. METHODOLOGY

The study of sodium benzoate as corrosion inhibitor for aluminum alloy AA7618 in tropical seawater was carried out using weight loss experiment and electrochemical impedance spectroscopy (EIS). The samples were immersed in 2 different solution containing seawater and sodium benzoate + seawater wit concentration of 200mg/l. The samples were tested every 5 days for weight loss experiment and every 10 days for EIS experiment to measure corrosion characteristics. Table 1 showed composition of inhibition solutions.

Sample preparation was most vital procedure in obtaining better results in this experiment. Initially, the specimens (AA7618) were cut into desirable measurements for immersion tests where the dimension of specimens is 2.5cm x 3.0cm x 0.3cm. Before exposure, more than 108 samples polished using number 600, 800 and 1200 emery papers and lubricated using distilled water to remove layer of oxide from the surface of aluminum alloy samples. The polished samples were cleaned with acetone, washed using distilled water, dried in air and stored over a desiccant.

Table 1 Composition of Inhibition Solutions

Solutions	Compositions	Seawater	Inhibitor Concentration
S	Seawater only	14 litre	0 mg/litre
SBS	Sodium Benzoate + Seawater	14 litre	200 mg/litre

Seawater sample was collected from South China Sea along University Malaysia Terengganu and used as test solution. The corrosion inhibitor used was sodium benzoate. There are two tests were conducted to measure the corrosion known as immersion test and electrochemical test [3]. The immersion period for the aluminum alloy was 60 days. Figure 1 shows the process flow of the experiment and self explainer.

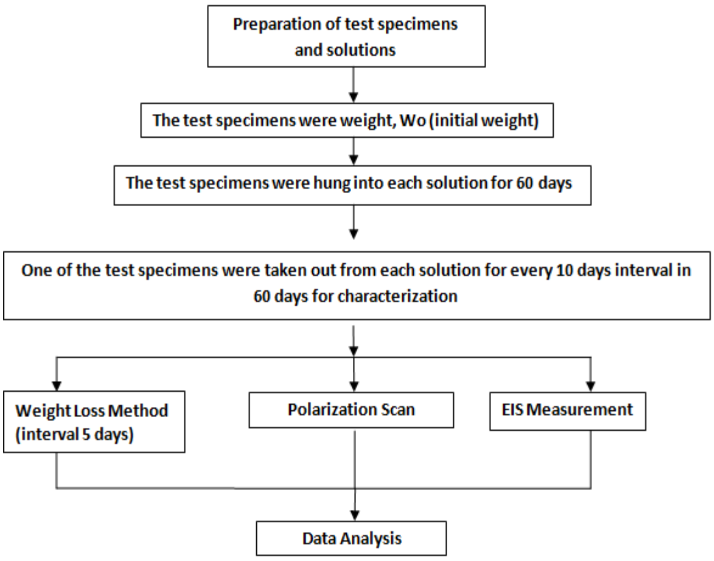

Figure 1 The Flow Chart of the Procedures of the Experiment

Immersion test and electrochemical test were conducted to measure the corrosion. In immersion test, samples weighed for the original weight (w) and then hung by using stick in seawater solution for 60 days. Each specimen measured for its length and breadth. After test period the weight values of samples were recorded in 4 decimal places. The weight loss (Δw) of the metal in the corrosive solution is given by Equation 1, where w and w_o are the weight of metal before and after exposure to the corrosive solution, respectively [4].

$$\Delta w = w - w_o \qquad (1)$$

The inhibitor used was sodium benzoate with 200mg/l concentration in seawater. The samples were checked for every 5 days. The corroded specimens removed from the solutions, cleaned with distilled water and dried, then immersed in a nitric acid (HNO_3) for 2 to 3 min to remove the corrosion products according to the ASTM standard G31. The value of the inhibition efficiency (IE) by presentation from the weight loss test was calculated using the Equation 2.

$$\mathrm{IE}(\%) = 100\left(1 - \frac{w}{w_0}\right) \qquad (2)$$

Like most other chemical reactions, corrosion rates increase as temperature increases. Temperature and pressure of the medium govern the solubility of the corrosive species in the fluid, such as oxygen (O_2), carbon dioxide (CO_2), chlorides, and hydroxides. Corrosion rates are can be calculated from weight loss methods using Equation 3 [5].

$$\text{Corrosion rate (mm /year)} = 87.6 \text{ x } (\Delta w / DAT) \qquad (3)$$

In order to calculate corrosion rate, the parameters involved are weight loss (Δw) in milligrams, exposure time (T) in hours, area of metal (A) in cm^2, and density of aluminum alloy (D) in g/cm^3. The density of aluminum alloy used is 2.7 g/cm^3. This value is constant in calculation of corrosion rate in both conditions which are with and without presence of sodium benzoate in the solution.

Corrosion rates also can be determined by applying a current to produce a polarization curve (the degree of potential change as a function of the amount of current applied) for the metal surface whose corrosion rate is being determined.

When the potential of the metal surface is polarized by the application of the current in a positive direction, it is said to be anodically polarized; a negative direction signifies that it is cathodically polarized. The degree of polarization is a measure of how the rates of the anodic and the cathodic reactions are retarded by various environmental (concentration of metal ions, dissolved oxygen, etc. in solution) and/or surface process (adsorption, film formation, ease of release of electrons, etc.) factors [6].

Electrochemical test is a powerful technique for characterization of electrochemical systems. The potentiodynamic polarization scan and electrochemical impedance spectroscopy (EIS) measurement were made with same setup of equipment and computer but different software. The polarization measurement used general purpose electrochemical system (GPES) software while the EIS measurement is using frequency response analyzer (FRA) software. It is probably the most commonly used polarization testing method for measuring corrosion resistance and is used for a wide variety of functions. Corrosion current densities (i_{corr}) and corrosion potential (E_{corr}) were evaluated from the intersection of the linear anodic and cathodic branches of the polarization curve (PC) as Tafel plots [7-8]. Electrochemical impedance spectroscopy measurements were carried out using AC signal of impedance measurements and conducted at the corrosion potential. The impedance measurements were carried out over a frequency range of 10^3 Hz to 10^{-1} Hz using 10 mV amplitude of sinusoidal voltage and the scanning rate is 10 mVmin^{-1}. Data presented as Nyquist plots. The results were analyzed using the fit program of FRA and GPES.

3. RESULTS AND DISCUSSION

The weight losses of aluminum alloys in two different types of solutions were determined as a function of immersion time. Figure 2 shows the average weight loss versus immersion time with and without inhibitor. The weight losses of aluminum alloy immersed in seawater has greatest value compared with aluminum alloy immersed in solution with inhibitor. There was considerable reduction in weight loss with introduction of inhibitor in corrosive media. The weight loss of test specimen decreased when sodium benzoate was added into the seawater. This reveals that benzoate compounds offer interesting possibilities in minimize corrosion.

The results reveal that for the first 10 days the differences is not very significant due to the presence of bacteria [3]. According to Rosliza *et al*. [3], bacteria can actively react in seawater when the locations are changed. But after a period of time, the bacteria action lowered due to unable to survive in new environment and the result of corrosion data will be more accurate.

The average weight loss is increasing in every interval of 5 days for with and without inhibitor. After the first 5 days, the average weight loss recorded was 0.172 % and the highest weight loss recorded end of the last 5 days period (end of 60 days) as 0.643 % for without inhibitor. The average weight loss at the end of first five days for with sodium benzoate inhibitor was 0.142 %. By compare the result obtained, the difference in average weight loss with and without inhibitor for first 5 days is - 0.03%. The difference for end of 60 days immersion time of metal with and without inhibitor is - 0.244%.

Figure 3 shows the corrosion rate for without and with inhibitor. The corrosion rate increases as the immersion time increased. The average values were recorded to get the accurate results. For the exposure time 120 hours 1st 5 days), the average corrosion rate measured was 82.30 x 10^3 mm/yr in seawater solution. For 60 days, the average corrosion rate recorded was 3371.42 x 10^3 mm/yr. This shows that the corrosion rate is increasing with the immersion time.

For with inhibitor, the average corrosion rate is also increasing with the immersion time. For the first 5 days, the average corrosion rate was 77.86 x 10^3 mm/yr. The corrosion rate difference between with and without inhibitor is 4.44 x 10^3 mm/yr. This shows the solution contains inhibitor have lower corrosion rate compared to the solution without inhibitor. Using NaBz as inhibitor is slowdown the corrosion effect.

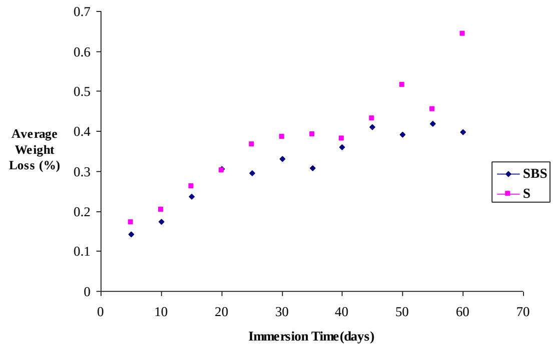

Figure 2 Weight loss of samples with and without inhibitor

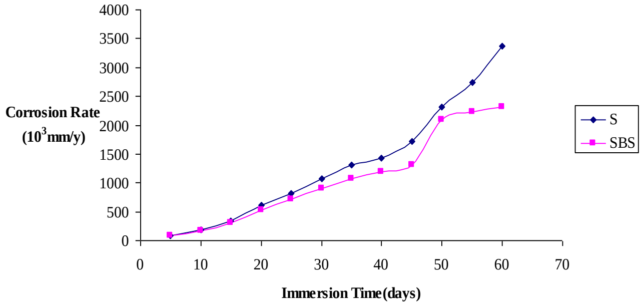

Figure 3 Corrosion rate for with and without inhibitor

One can clearly observe from the Figure 3 that corrosion rate for the aluminum alloy with inhibitor is lower than without inhibitor. This reveals that the sodium benzoate is suitable to react as corrosion inhibitor for aluminum alloy AA 7618 in seawater. Even though at the first 10 days, the rate of corrosion is almost similar but as the immersion period increase, sodium benzoate showed its inhibition characteristic efficiently. Benzoate compounds have good inhibitive action in minimize corrosion rate.

The Nyquist plot was obtained after the immersion of the aluminum alloy in the solutions. Figure 4 shows the plots for the aluminum alloy in seawater for immersion period of 60 days. By analyzing the shape of the Nyquist plots, it was found that the curves approximated by a single capacitive semicircles, which is showing that the corrosion process was mainly charge-transfer controlled. The general shape of the curves is very similar for all immersed periods where the shape was maintained throughout the whole test period. According to Rosliza *et al* [9], this indicates that almost no change in the corrosion mechanism occurred due to the immersion time. Smaller Nyquist plot mean the greater the corrosion rate. Therefore, from Figure 4, the immersion time increases the corrosion rate is higher for aluminum alloy.

Figure 5 shows the Nyquist plots for AA7618 with and without inhibitor. The plot for the test specimen contain seawater only has the smallest plot compared to the solution contains sodium benzoate. This reveals that the size of the curve increased with the addition of inhibitor. Moreover, corrosion rate becomes smaller for the test specimen with the presence of NaBz in the solution.

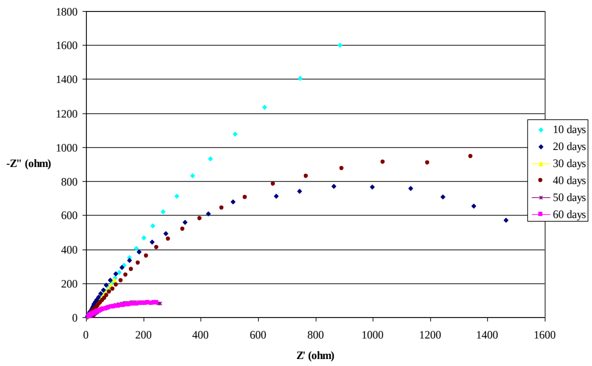

Figure 4 Nyquist plot for AA7618 in seawater

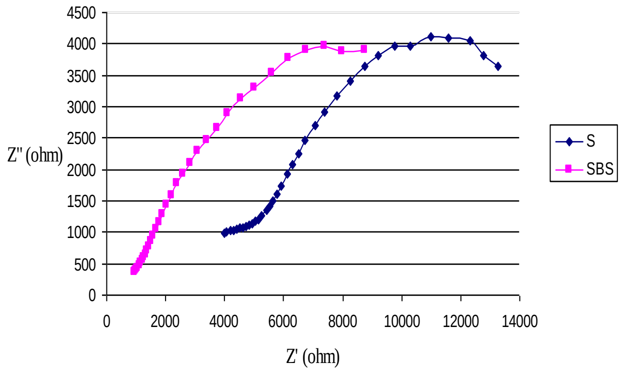

Figure 5 Nyquist plots for with and without inhibitor

From the EIS measurement, the impedance parameters such as polarization resistance (R_p) and capacitance (*CPE*) of the aluminum alloy in each solution were obtained. Table 2 shows impedance parameters of aluminum alloy in seawater solution and in solution contains seawater and sodium benzoatel. According to Rosliza *et al*. [9], the polarization resistance, R_p is usually decreases with immersion time. Moreover, a higher of R_p value indicates the lower corrosion rate.

From the Table 2, the R_p values for all test specimens were decreases with immersion time while the CPE values for all test specimens were increased with the immersion time. R_p is inversely proportional to CPE. By compared the seawater (S) to the solution that containing NaBz as inhibitor (SBS), it is found that R_p value was increases obviously with the addition of inhibitor. The results obtained shows that seawater have the lowest R_p value. This reveals that addition of NaBz induced the R_p value. Moreover, the NaBz proved can reduce the corrosion rate of the test specimens.

Table 2 The Impedance Parameters of Aluminum Alloy with and without Inhibitor

Solution	**Days**	**EIS**	
		Rp(Ω cm^2)	**CPE(mF cm^{-2})**
(S)	10	44.28	6.56
Seawater	20	35.60	7.45
	30	23.80	10.24
	40	10.05	13.87
	50	6.18	18.50
	60	4.05	20.22
(SBS)	10	80.08	1.76
Seawater	20	62.30	2.04
+	30	51.60	2.43

Sodium Benzoate	40	44.00	2.67
	50	23.80	4.89
	60	12.50	5.30

By using potentiodynamic polarization scan, the electrochemical parameters such as corrosion densitie (i_{corr}), corrosion potential (E_{corr}), anodic Tafel slope (b_a) and cathodic Tafel slope (b_c) of aluminum alloy in each solution were obtained. The corrosion densities and corrosion potential were evaluated form the intersection of the linear anodic and cathodic branches of the PC as Tafel plots.

From Table 3, the anodic Tafel slope (b_a) and the corrosion potential (E_{corr}) showed the different values with increased of immersion time for solutions with the presence and absence of NaBz. By comparing the solution without any inhibitor (seawater) with another solution which contains inhibitor, it was found that the cathodic Tafel slope (b_c) value of seawater is highest among the solutions. This reveals that the addition of sodium benzoate will induced the cathodic currents.

Table 3 The Electrochemical Parameters of Aluminum Alloy with and without Inhibitor

Solutions	**Days**	**Potentiodynamic polarization**			
		E_{corr} (mV)	**i_{corr} (10^{-6}Acm^{-2})**	**b_a (mVdec^{-1})**	**b_c (mV dec^{-1})**
(S) Seawater	10	-705	3.5474	306	302
	20	-696	3.8440	443	337
	30	-672	3.8780	271	491
	40	-643	4.3930	431	406
	50	-738	5.6260	309	295
	60	-749	7.1030	355	516
(SBS) Seawater + Sodium Benzoate	10	-753	0.2478	127	285
	20	-643	0.3863	176	280
	30	-69	0.5740	143	179
	40	-657	0.6299	291	176
	50	-752	0.7077	66	115
	60	-731	0.9651	167	179

The inhibition efficiencies of NaBz are listed in Table 4 using weight loss method, polarization scan, and EIS measurement. According to Table 4, for the first 10 days the inhibition efficiency was the lowest value that recorded in all the methods. But with increasing of immersion time, the inhibition efficiency also increased in all the 3 methods as stated. This reveals that the concentration of sodium benzoate used is suitable to use as inhibitor.

Table 4 Inhibition efficiency for NaBz obtained by various methods

Days	**Inhibition Efficiency (%)**		
	Weight loss	**Polarization**	**EIS**
10	55.20	50.82	60.92
20	85.09	78.59	83.38
30	86.40	79.36	85.53
40	92.73	80.16	92.81
50	96.27	83.86	93.36
60	96.65	84.65	95.42

4 CONCLUSION AND RECOMMENDATION

The result obtained lead to the conclusion that sodium benzoate is suitable to used as corrosion inhibitor of aluminum alloy in seawater. Sodium benzoate act as a barrier which slower the corrosion attack on aluminum alloy and thus the corrosion rate of aluminum alloy is reduced with the addition of sodium benzoate. However, the corrosion rate of aluminum alloy increases with the immersion time. The potentiodynamic polarization results suggested a cathodic character for the inhibition process in seawater. EIS measurements clarified that the corrosion process was mainly charge transfer controlled and no change in the corrosion mechanism occurred either due to the immersion time or to the inhibitor addition for seawater. It also indicates that the R_p values increase with addition of inhibitor while, the capacitance values decrease with the immersion time. It can be concluded that NaBz is an effective inhibitor for the aluminum alloy in seawater.

The following are some recommendations for future work that related to this study. Firstly, the research can be carried out in a broad range of temperatures, pH and concentration in order to observe the inhibition characterization of sodium benzoate on aluminum alloy (AA7618). Secondly, sodium benzoate may be tested in other corrosive media such as atmosphere, acid, high saline water and others as inhibitor. Other than that, the research also can be carried out with the comparison of other widely used metals such as copper, mild steel, stainless steel and others.

REFERENCES

[1]. Thretheway and Kennedy. 1995. Corrosion for science and engineering. England: Longman Scientific & Technical.

[2]. Eco Chemie. 2008. Corrosion:. Basic Concepts.

[3]. Rosliza, R., Nik, W. B. W. and Senin, H. B. 2008. The effect of inhibitor on the corrosion of aluminum alloys in acidic solutions. Journal of Materials Chemistry and Physics 107(2-3): 281-288.

[4]. Bockris, J. O'. M. and Reddy, A. K. N. 2000. Modern electrochemistry: electrodics in chemical engineering, biology, and environmental science. 2nd edition. New York: Plenum

[5]. Berkeley D. W., Sallamand, E. M. and Nayeb-Hashemi. 1998. The effect of ph on the mechanism of corrosion and stress corrosion and degradation of mechanical properties of AA6061 and nextel 440 fiber-reinforced AA6061 composite. Journal of Corrosion Science 40(2-3):141-153.

[6]. Blanc, C. and Mankowski, G. 1996. Susceptibility to pitting corrosion of AA6056 aluminium alloy. Journal of Corrosion Science 39(5): 949-959.

[7]. Fouda, A. S., Al-Sarawy, A. A., Ahmed, F. S. and El-Abbasy, H. M. 2009. Corrosion inhibition of aluminum 6063 using some pharmaceutical compounds. Journal of Corrosion Science 51(3): 485-492.

[8]. Li, X. H. and Mu, G. 2005. Tween-40 as corrosion inhibitor for cold rolled steel in sulphuric acid: Weight loss study, electrochemical characterization. Journal of Applied Surface Science 252(5):1254-1265.

[9]. Rosliza, R., Nik, W. B. W. and Senin, H. B. 2008. Electrochemical properties and corrosion inhibition of AA6061 in tropical seawater. Journal of Colloids and Surfaces A: Physicochemical and Engineering Aspects 312(2-3): 185-189.