Glasnik hemičara i tehnologa Bosne i Hercegovine

Bulletin of the Chemists and Technologists of Bosnia and Herzegovina

2019

52

23-32

Print ISSN: 0367-4444

Online ISSN: 2232-7266

UDC: ________________________

Original Scientific Article

Investigation of Inhibitory Effect of the *Aloe Vera* Extract on Corrosion of Aluminium Alloys

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Article info
Received: 17/042019
Accepted: 12/06/2019

Keywords:
Aluminium Alloys
Inhibitors
Aloe Vera
Cyclic Voltammetry

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Abstract: This paper considers the inhibition effect of Aloe Vera on the selected aluminium alloys in 10 % sulfuric acid and 3 % sodium chloride solutions at room temperature, using methods of potentiodynamic polarisation and cyclic voltammetry. The study involved as-cast and heat-treated 2xxx alloys, with the scanning speed of 1mV/s for linear polarisation and 50 mV/s for cyclic voltammetry. The various constant potential was applied for each tested alloy. Polarisation results indicate that the transpassivation occurs in an acid medium in case of each alloy. The obtained results indicate that Aloe vera extract acts as a cathodic inhibitor.

INTRODUCTION

Aluminium alloys, in the 2xxx series, based on copper and magnesium addition find application in the production of trucks, aircraft wheels, fuselage and wing skins, as well as various structural parts (Davis, 2001). Copper is added for increasing the strength, hardness, fatigue and creep resistance as well as for castability improvement of aluminium alloys (Al-Rawajfeh *et al.*, 2009). The optimal mechanical properties of 2xxx alloys similar or even better compared to low carbon steel could be achieved by heat treatment (Davis, 2001). Further improvement of strength during solution heat treatment and quenching may be caused by the addition of magnesium (Hatch, 1984). On the other hand, microstructural changes leading to better mechanical properties may result in a decrease in corrosion resistance of 2xxx alloys (Ghosh *et al.*, 2013). The oxide film formed while exposing the aluminium surfaces to different environmental conditions protects it from further oxidation (Davis, 1999). However, in highly acidic, or alkaline solutions, especially ones containing chloride ions, the oxide layer is unstable and it is destroyed (Xhanary *et al.*, 2017). The corrosion resistance of 2xxx alloys is often good but lower than most aluminium alloys (Hikmat *et al.*, 2014). Strong electrochemical effects on corrosion of 2xxx alloys may be caused by a more significant change in electrode potential with copper content in solid solution as well as non-uniformities in solid-solution concentration (Davis, 1999). In order to reduce corrosion progress of aluminium alloys in various environments inhibitors are commonly used (Ouchenane *et al.*, 2014, Hamdou *et al.*, 2017, Umoren *et al.*, 2009, Oguzie, 2007, Avwiri *et al.*, 2003, Lamaka *et al.*, 2007, Zheludkevich *et al.*, 2005, Al-Turkustani *et al.*, 2010).
The inhibitors retard or prevent the corrosion process by reducing the anodic or cathodic polarisation behaviour (decreasing the value of Tafel coefficients). Hence, the movement or diffusion of ions to the metallic surface is decreased and the electrical resistance of the metallic surface is increased. The inhibitors decrease the corrosion rate by adsorption of ions or molecules on the metal surface (Gerengi *et al.*, 2014). Various organic and inorganic compounds usually dissolved in aqueous environments may be used as inhibitors (Fayomi *et al.*,

2018). Although phosphates, chromates, dichromates, silicates, bromates and arsenates are popular inorganic inhibitors, their toxic effects on the environment are recognised (Khadraoui *et al.*, 2013). Therefore, the application of non-toxic organic inhibitors is encouraged (Hamdou *et al.*, 2017). The investigations focused on synthesising the environmental friendly chemical compound with low cost which could be used as inhibitors have shown that plant extracts from leaves, seeds, heartwood, bark, roots or fruits inhibit the corrosion of metals in acidic solutions (Khadraoui *et al.*, 2013). *Aloe Vera* leaves containing various active compounds may be used for the production of green inhibitor for corrosion of aluminium alloys (Xhanary *et al.*, 2017, Al-Turkustani *et al.*, 2010, Fayomi *et al.*, 2018).

In this work, the inhibition effect of *Aloe Vera* extract at the different concentration on corrosion behaviour of two 2xxx aluminium alloys in 10 % sulfuric acid and 3 % sodium chloride solutions has been studied using potentiodynamic polarisation and cyclic voltammetry technique.

EXPERIMENTAL

Two 2xxx alloys with the composition shown in Table 1 were prepared by melting commercially pure (99.4 %) aluminium, technically pure copper, magnesium, zinc and nickel as well as pre-alloy AlMn60 (Al-60 % Mn). The melting was carried out in a 5.5-kW electric resistance furnace using a graphite crucible. For the fluxing of the melts, a TAL – 2 was added in the amount of about 2 % of their quantities. Hexachloroethane tablets were used for the degassing the melts in the amount approximately equal to 0.25 % of each melt quantity. The pouring of the melts into the metal moulds was carried out at 740 ºC. As-cast specimens of alloys were solution treated at 505 ºC ± 5 ºC for 6 hours followed by quenching in water (at 80 ºC). The subsequent ageing treatment was performed at 200 ºC ± 5 ºC for 7 hours while specimens were finally cooled in ambient air.

Table 1. Chemical composition of 2xxx alloys

Alloy	Fe (%)	Si (%)	Cu (%)	Zn (%)	Mn (%)	Mg (%)
A	0.37	0.22	4.78	0.65	0.048	0.71
B	0.41	0.22	5.36	0.64	0.38	1.45

The samples for corrosion tests were cut from the as-cast and heat-treated specimens and then ground with silicon carbide abrasive papers and cleaning in acetone. The electrochemical tests were conducted at room temperature in 10 % sulfuric acid and 3 % sodium chloride solutions by performing a potentiodynamic polarisation test and cyclic voltammetry. In that sense, the potentiostat/galvanostat 263 A and 5210 Lock-in Amplifier supplied with Power CV software was used. The electrochemical measurements were performed in a cell containing a saturated Ag/AgCl electrode as a reference electrode and the platinum electrode as the counter electrode, while the specimens of 2xxx alloys were used as the working electrode. *Aloe vera* plant leaves from Kiseljak area in the amount of 0.5 kg were used for the preparation of inhibitor. The extract was obtained by the Soxhlet extraction method in the aqueous solution, with the initial concentration of 20 mg/ml. *Aloe Vera* inhibitor was added to 10 % sulfuric acid as well as 3 % sodium chloride solutions at concentrations of 0.0266 mg/ml, 0.0533 mg/ml and 0.08 mg/ml. Tafel extrapolation method was used for obtaining the potentiodynamic polarisation curves of the examined alloys over the range from -1.5 V to + 1 V related to open circuit potential (OCP) at a scan rate 1 mV/s. The corrosion kinetic parameters such as corrosion potential (E_{corr}), corrosion current density (j_{corr}), anodic Tafel slopes (β_a) as well as cathodic Tafel slopes (β_c) are determined using the software installed in the instrument.

The corrosion inhibition efficiency (in percentage) was calculated using the following equation:

$$\eta = \frac{j_{corr} - (j_{corr})_{inh}}{j_{corr}} \cdot 100 \qquad (1)$$

where j_{corr} and $(j_{corr})_{inh}$ represent corrosion current density values without and with inhibitor, respectively.

The cyclic voltammetry was used to examine the diffusion processes between the electrolytes and the layer on the surface of the electrode. All cyclic voltammetry tests were performed in 10% sulfuric acid solution over the potential range -0.5 V to 0.7 V, at a scan rate of 50 mV/s.

RESULTS AND DISCUSSION

The polarisation behaviour of as-cast and heat-treated specimens of 2xxx alloys in 10 % sulfuric acid and 3 % sodium chloride solutions in the absence and presence of *Aloe vera* extract is given in Figures 1 to 4. The Tafel extrapolations of the corrosion current density (j_{corr}), the corrosion potential (E_{corr}) as well as values of anodic Tafel slopes (β_a) and cathodic Tafel slopes (β_c) are shown in Tables 2 to 5. The inhibition efficiencies of various concentrations of *Aloe vera* extract for corrosion of 2xxx alloys in 10 % sulfuric acid solutions and 3 % sodiumchloride solutions are presented in Tables 6 and 7, respectively.

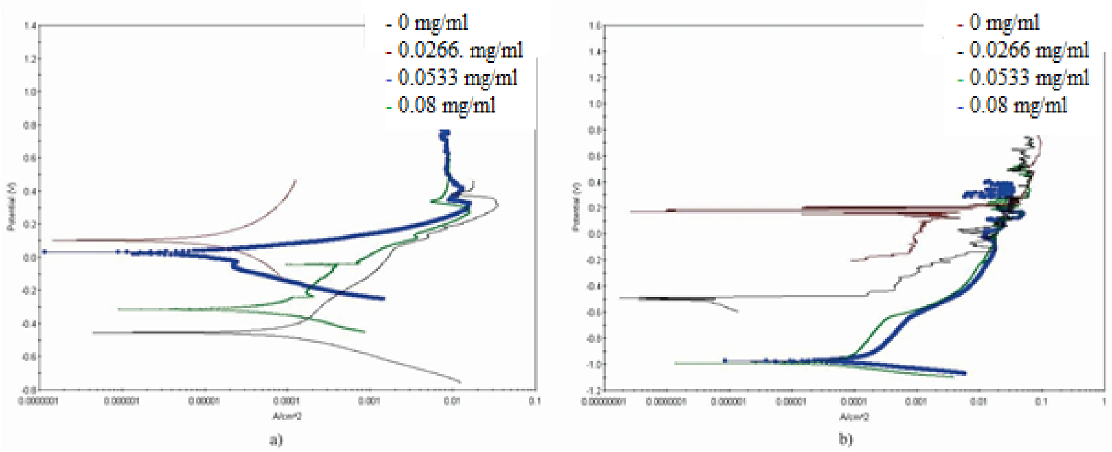

Figure 1. Potentiodynamic polarisation curves for as-cast alloy A in 10 % sulfuric acid solutions (a) and 3 % sodium chloride solutions (b) without and with various concentration of *Aloe vera* extract

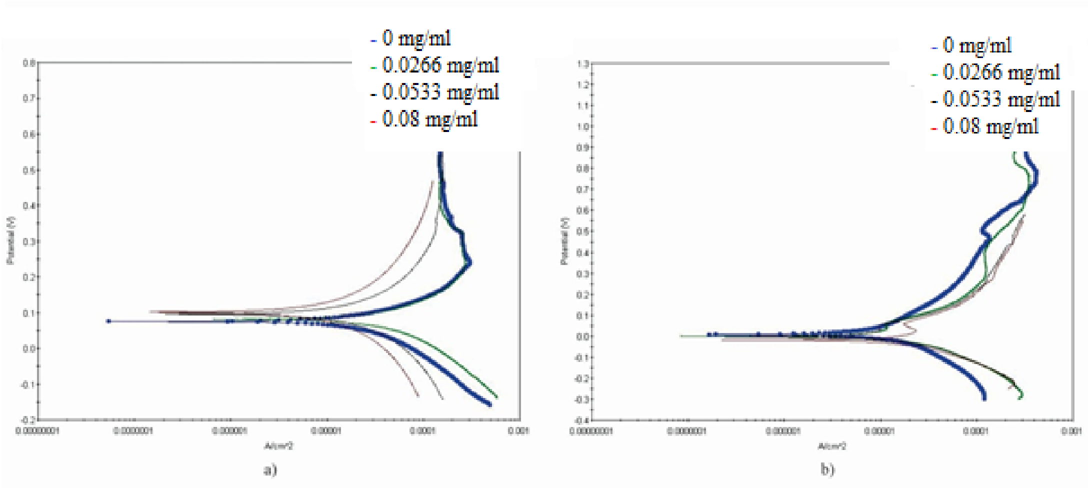

Figure 2. Potentiodynamic polarisation curves for heat-treated alloy A in 10 % sulfuric acid solutions (a) and 3 % sodium chloride solutions (b) without and with various concentration of *Aloe Vera* extract

Table 2. Potentiodynamic polarisation parameters for the corrosion of the as-cast and heat-treated specimens of alloy A in 10 % sulfuric acid solutions containing different concentrations of the *Aloe Vera* inhibitor

Alloy A	*Aloe Vera* extract (mg/ml)	E (mV)	I_{corr} (μAcm^{-2})	β_c (mVdec^{-1})	β_a (mVdec^{-1})
As-cast samples	Without inhibitor	12.851	7.348	142.481	54.283
	0.0266	- 327.336	9.609	117.880	358.659
	0.0533	- 460.290	6.951	134.933	387.645
	0.0800	- 482.789	1.591	142.929	383.931
Heat-treated samples	Without inhibitor	44.114	56.71	230.110	264.931
	0.0266	94.521	57.16	239.047	150.408
	0.0533	96.249	24.12	234.713	254.806
	0.0800	102.824	12.31	200.881	217.258

Table 3. Potentiodynamic polarisation parameters for the corrosion of the as-cast and heat-treated specimens of alloy A in 3 % sodium chloride solutions containing different concentrations of the *Aloe Vera* inhibitor

Alloy A	***Aloe Vera* extract (mg/ml)**	**E (mV)**	**I_{corr} (μAcm^{-2})**	**β_c (mVdec^{-1})**	**β_a (mVdec^{-1})**
As-cast samples	Without inhibitor	137.113	19.60	210.721	365.493
	0.0266	- 576.873	12.22	132.922	443.708
	0.0533	- 920.252	2.443	235.212	256.828
	0.0800	- 987.835	1.322	58.731	434.836
Heat-treated samples	Without inhibitor	14.690	18.11	237.467	551.970
	0.0266	13.177	9.484	116.624	234.630
	0.0533	11.309	8.640	104.450	181.084
	0.0800	9.364	1.277	123.885	229.973

The decrease in the corrosion current density with inhibitor addition to 10 % sulfuric acid solutions and 3 % sodium chloride solutions was detected for almost all as-cast and heat-treated specimens of alloy A with 4.78 % of copper and 0.71 % of magnesium (Figures 1 and 2, Tables 2 and 3). However, compared to corrosion examinations without inhibitor, the slight increase in the corrosion current density was detected for as-cast and heat-treated samples of alloy A studied in 10 % of sulfuric acid solution with an inhibitor concentration of 0.0266 mg/ml (Table 2). The values of corrosion potential of as-cast specimens of alloy A exposed to 10 % sulfuric acid and 3 % sodium chloride solutions were shifted to the more negative side with the addition of *Aloe vera* extract (Table 3). In the work of Al-Turkustani *et al.*, 2010 who examined the effect of *Aloe vera* extract on aluminium corrosion in hydrochloric acid solutions, the instantaneous and rapid attack of the oxide film by chloride ions was pointed out. The corrosion reaction was accelerated by chloride ions due to obstruction of the reparation of oxide protective film and forming the intermediate soluble complex (Al-Turkustani *et al.*, 2010). The dissolution of aluminium ions (atoms) from lattice to the solution was facilitated by formed complexes leading to the passive layer on the metal surface and pitting corrosion (Al-Turkustani *et al.*, 2010). The difference in the effect of the *Aloe Vera* extract on corrosion behaviour of carbon steel compared to aluminium alloys has been demonstrated in the work of Sribharathy et al., who indicated that the *Aloe Vera* controlled the anodic reaction predominantly by forming Fe^{2+} complex on the anodic sites of the metal surface in acid solution (Sribharathy *et al.*, 2013). In our work, we have a controlled formation of an aluminium complex on a metal surface.

Regarding heat-treated samples of alloy A, it could be seen that with the increasing concentration of *Aloe vera* extract, the corrosion potential was shifted toward positive values for samples examined in 10 % sulfuric acid solutions, while its shift towards negative direction was recorded for those studied in 3 % sodium chloride solutions. It may be seen that alloy A is more stable in its heat-treated condition and exhibits transpassivation, meaning the measurements are made in the region of the anode polarisation. Also, it can be observed that there is no significant inhibition of the anode process, due to the occurrence of the anodic passivity of the metal. Moreover, better inhibition effects of *Aloe vera* extract on corrosion of heat-treated specimens have been recorded compared to as-cast samples of alloy A. The anodic polarisation should be noted, while cathodic polarisation is observed only at a concentration of 0.08

mg/ml. What also can be pointed out with a view to the inhibitory effects on this type of alloy is that in case of any concentration, both passivation and transpassivation of metal occur.

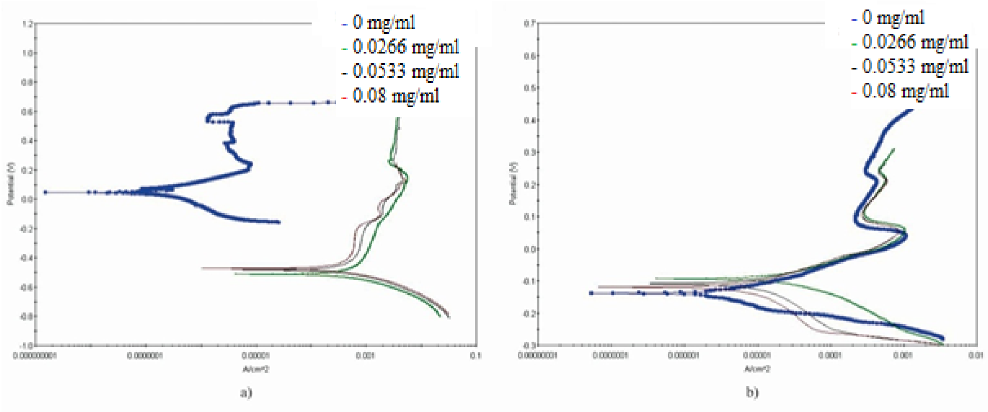

Figure 3. Potentiodynamic polarisation curves for as-cast alloy B in 10 % sulfuric acid solutions (a) and 3 % sodium chloride solutions (b) without and with various concentration of *Aloe vera* extract

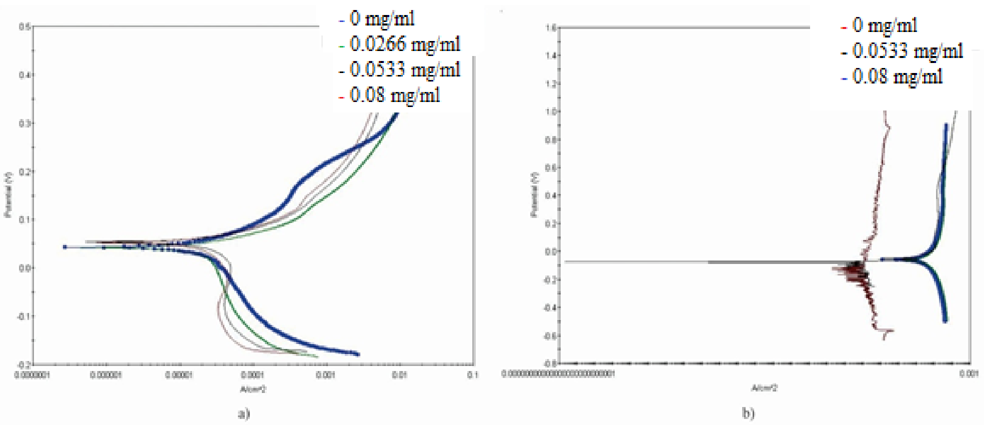

Figure 4. Potentiodynamic polarisation curves for heat-treated alloy B in 10 % sulfuric acid solutions (a) and 3 % sodium chloride solutions (b) without and with various concentration of *Aloe vera* extract

Table 4. Potentiodynamic polarisation parameters for the corrosion of the as-cast and heat-treated specimens of alloy B in 10 % sulfuric acid solutions containing different concentrations of the *Aloe Vera* inhibitor

Alloy B	***Aloe vera* extract (mg/ml)**	**E (mV)**	**I_{corr} (μAcm^{-2})**	**$β_c$ (mVdec^{-1})**	**$β_a$ (mVdec^{-1})**
As-cast samples	Without inhibitor	54.019	18.34	138.590	95.431
	0.0266	- 509.571	46.87	126.506	553.129
	0.0533	- 484.440	44.27	112.901	663.232
	0.08	-494.562	28.93	58.769	489.303
Heat-treated samples	Without inhibitor	4.748	29.52	170.337	135.670
	0.0266	21.846	26.03	300.848	67.512
	0.0533	50.008	33.80	317.795	60.550
	0.08	38.135	24.71	173.695	68.278

Table 5. Potentiodynamic polarisation parameters for the corrosion of the as-cast and heat-treated specimens of alloy B in 3 % sodium chloride solutions containing different concentrations of the *Aloe Vera* inhibitor

Alloy B	**[Inhibitor] mg/ml**	**E (mV)**	**I_{corr} (μAcm^{-2})**	**β_c (mVdec^{-1})**	**β_a (mVdec^{-1})**
As-cast samples	Without inhibitor	- 145.052	2.560	51.471	60.685
	0.0266	- 94.290	2.849	85.117	88.749
	0.0533	- 113.321	1.414	169.156	89.263
	0.08	- 118.871	0.9181	159.267	87.531
Heat-treated samples	Without inhibitor	- 132.597	13.7	720.816	608.799
	0.0533	- 60.643	4.670	223.668	220.135
	0.08	- 57.875	6.293	428.513	441.673

Compared to the corrosion testing of as-cast alloy B containing 5.36 % copper and 1.45 % of magnesium in 10 % sulfuric solution without inhibitor, higher values of current density was observed when the examination had included the addition of *Aloe vera* extract (Figure 3a, Table 4). The decrease in current density of as-cast samples of alloy B was recorded with the addition of inhibitor to 3 % sodium chloride solutions except for inhibitor concentration of 0.0266 mg/ml (Figure 3b, Table 5). The study of heat-treated samples of B alloy has shown that the addition of *Aloe vera* extract of 0.0266 mg/ml and 0.08 mg/ml to 10 % sulfuric acid solutions has caused the decrease in the current density (Figure 4a, Table 4). Regarding examination without using inhibitor, lower values of current density were obtained for heat-treated specimens of alloy B tested in 10 % sodium chloride solutions with 0.0533 mg/ml and 0.08 mg/ml of *Aloe vera* extract (Figure 4b, Table 5). The corrosion potential of as-cast specimens of alloy B studied in 10 % sulfuric acid solution was shifted significantly to a more negative value with the addition of 0.0266 mg/ml of inhibitor. Further increase in the amount of inhibitor in 10 % sulfuric acid solutions has caused the negative value of corrosion potential of as-cast samples of alloy B too. However, the values of corrosion potential of heat-treated specimens of alloy B exposed to 10 % sulfuric acid solutions containing a different concentration of inhibitor are shifted toward positive direction compared to the corrosion examinations without inhibitor usage. Moreover, for as-cast and heat-treated specimens of alloy B, the values of corrosion potential were shifted to a more positive side in the presence of *Aloe vera* extract in 3 % sodium chloride solutions.

The study of corrosion behaviour of the alloy B in an acid medium in the absence of the inhibitor indicates cathodic reaction of the metal, i.e. the abrupt slow-down of the cathode process in achieving the certain potential of passivation, because of formation of the phase passive films on the cathodic surface (Figure 3a). When comparing linear polarisation shown in Figure 1b and Figure 3b, it is evident that in case of as-cast specimens of both 2xxx alloys in 3 % sodium chloride solutions, the specimens of alloy B exhibited more distinguished passivation and transpassivation. Also, any inhibitor concentration causes cathodic polarisation, while the adsorption of inhibitors achieved the passivation potential onto the surface of the alloy. In the case of alloy B, the maximal inhibitory effect (65.91 %) was achieved for heat-treated specimens exposed to 3 % sodium chloride solutions. The potential value for the inhibitor concentration of 0.0266 mg/ml can be attributed to the dissolving of phase particles (Lopez-Garrity *et al.*, 2014).

By comparison of Figure 2a and Figure 4a, it is evident that despite the different composition of 2xxx alloys, the thermal treatment did not affect the passivation in acid medium. The distinguished occurrence of transpassivation process was not observed in examined alloys. Further on, the cathodic polarisation is recognised in both heat-treated alloys, while in the case of as-cast specimens of the alloy B, the adding of inhibitor resulted in anodic polarisation, meaning that the inhibitor reduced the corrosion rate of the tested alloy in the medium concerned, as shown in Figure 3a. The minor adsorption of the inhibitor on the surface of the anode and minor anodic passivation of heat-treated samples of alloy B in 3 % sodium chloride solutions were achieved (Figure 4b).

The obtained different values of the current density and corrosion potential with the variation of inhibitor concentration depend on molecules and substituents that form the structure of *Aloe vera*. The maximum value of inhibition efficiency of about 93.25 % was identified for alloy A exposed to 3 % sodium chloride solutions.

In the investigated system, the cathodic reaction is the evolution of hydrogen. Hence, if that reaction proceeds Tafel-Volmer mechanism, the value of the Tafel slope will be 118 mV/dec (Bockris *et al.*, 1974). The higher values of β_c obtained for the most examined specimens in 10 % sulfuric acid and 3 % sodium chloride solutions are consistent with the evolution of hydrogen at the electrode surface, which was covered by oxide film (Evans *et al.*, 1962) as well as the complex oxide-inhibitor. The Values of β_a are much higher than expected for uniform dissolution of aluminium giving the hydrated Al^{3+} ions (40 mV/dec). However, these values are comparable with the values of Tafel slope obtained for Al - electrode covered with oxide film (Hurlen *et al.*, 1984).

Table 6. Inhibition efficiency of various concentrations of *Aloe vera* extract for corrosion of 2xxx alloys in 10 % sulfuric acid solutions

Specimen	0.0266 *Aloe vera*	0.0533 *Aloe vera*	0.08 *Aloe vera*
As-cast samples of alloy A	-30.77%	5.40%	78.35%
Heat-treated samples of Alloy A	-0.79%	57.47%	78.29%
As-cast samples of alloy B	-60.87%	-54.52%	-36.60%
Heat-treated samples of Alloy B	11.82%	-14.50%	16.29%

Table 7. Inhibition efficiency of various concentrations of *Aloe vera* extract for corrosion of 2xxx alloys in 3 % sodium chloride solutions

Specimen	0.0266 *Aloe vera*	0.0533 *Aloe vera*	0.08 *Aloe vera*
As-cast samples of alloy A	37.65%	87.53%	93.25%
Heat-treated samples of Alloy A	47.63%	52.29%	92.95%
As-cast samples of alloy B	-11.30%	44.76%	64.13%
Heat-treated samples of Alloy B	/	65.91%	54.06%

As it can be seen from Tables 6 and 7, for some concentrations of *Aloe Vera* extract the inhibition effect was not recognised in 10 % sulfuric acid solutions. It could be the consequence of the occurrence of the reduction reactions and formation of the film on the electrode surface with molecules H_2O and SO_4^{2-} ions. The increase in corrosion current and dissolving of a passive film especially for as-cast specimens of alloy B are observed. Consequently, a uniform pitting corrosion occurs in the measured potential on the alloy surface.

On the contrary, *Aloe Vera* extract exhibited a strong inhibition effect in 3 % sodium chloride solutions meaning that it blocks corrosion spot on the alloy surface, which reduces the uniform corrosion and prevents forming of the pits. The significant inhibition influence is obvious for the alloys A and B in 10 % sulfuric acid and 3 % sodium chloride solutions containing *Aloe Vera* extract in a concentration of 0.0533 mg/ml and 0.0800 mg/ml. The reduced permeation currents in the presence of the inhibitors can be attributed to the slow discharge step followed by fast electrolytic desorption step:

$$M_{(e)} + H_3O^+ \xrightarrow{slow} MH_{ads} + H_2O \quad (2)$$

$$MH + H_3O^+ + M_{(e)} \xrightarrow{fast} 2M + H_2O + H_2 \quad (3)$$

The reduction of hydrogen uptake could be associated with the adsorption of the phytochemical constituents present in the plant extracts on the surface alloy, which prevented permeation of hydrogen into metal (Shyamala *et al.*, 2011).

The different values of the corrosion inhibition efficiency of *Aloe vera* extract in 10 % sulfuric acid solutions and 3 % sodium chloride solutions were evaluated depending on the chemical composition and condition of examined alloys (Tables 6 and 7). The higher inhibition efficiency of *Aloe Vera* extract was ensured in 3 % sodium chloride solutions compared to 10 % sulfuric acid solutions. It was found that the efficiency of *Aloe Vera* extract in a concentration of 0.0800 mg/ml in 10 % sulfuric acid solution was lower about 16 % than in 3 % sodium chloride solution.

The lowest corrosion inhibition efficiency (5.40 %) was observed for as-cast specimens of alloy A exposed to 10 % sulfuric acid solution containing 0.0533 mg/ml of inhibitor. At the same time, the highest efficiency (93.25 %) was ensured for as-cast specimens of alloy A in 3 % sodium chloride solution with a concentration of *Aloe vera* extract of 0.0800 mg/ml.

In addition to the Tafel's linear diagrams, cyclic voltammograms were recorded for each alloy in both media, which further confirmed separation between the anode and cathode peaks. Cyclic voltammetry (CV) represents an easy and fast technique used for characterisation of electrochemical properties of analytes that can be electrochemically oxidised or reduced. The cyclic voltammograms curves can also be used to study the surface coverage of inhibitor molecules. Visible oscillation of current density during a study on corrosion behaviour of 2xxx alloys in 10 % sulfuric acid solutions and 3 % sodium chloride solutions is not beneficial regarding corrosion inhibition. The pitting corrosion appeared due to the dissolution of the oxide film. The negative result of inhibitor addition is observed in an acid medium (0.5 HCl) by Al-Turkustani *et al.*, 2010. The increase in the corrosion rate in the maximal amount of 12.9 % is observed with the addition of a minimum concentration of inhibitor (Al-Turkustani *et al.*, 2010). In our study, the increase in the corrosion rate is recorded for specimens of alloy B exposed to 10 % sulfuric acid solution containing 0.0266 mg/ml of *Aloe Vera* extract. The common inhibitor effect is manifested by shift of the corrosion potential towards more positive side regarding the corrosion potential of medium without inhibitor used. The shift of corrosion potential towards the negative direction with the addition of inhibitor indicates that *Aloe Vera* extract acts as a cathodic inhibitor. Obtained results have shown that *Aloe Vera* extract acts as an activator in the presence of the lowest concentration which could be attributed to the presence of functional groups in the examined extract.

Figure 5 illustrated the cyclic voltammograms of as-cast and heat-treated specimens of alloy B in acid medium. The distinguished oxidation peaks resulted from different conditions of samples prepared from the alloy B. A smaller temperature-dependent corrosion potential can be observed for heat-treated specimens. With the scanning potential ranged from -0.5 V to 0.7 V, the current density of aluminium changed significantly from -0.007 to 0.018 Acm^{-2}. The cyclic voltammogram of the inhibitory reaction to the aluminium alloy in the acid solution of the author Wang et al., shows that the aluminium alloy electrodes in the presence of DAN inhibitor had relatively lower current densities which became lower gradually with the increasing of DAN concentration (Wang *et al.*, 2015). It might be attributed to the adsorption of DAN molecules on the aluminium alloy surface to form the protective layer (Wang *et al.*, 2015).

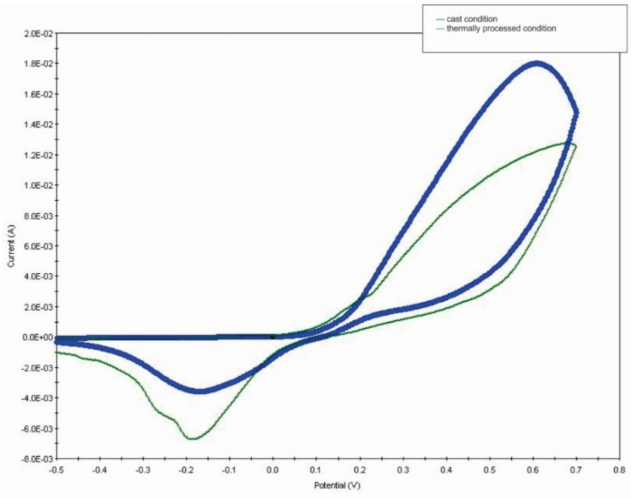

Figure 5. Cyclic voltammogram for as-cast (—) and heat-treated specimens of alloy B (—) in sulfuric acid 10%

CONCLUSION

The inhibitory effects of *Aloe Vera* extract on corrosion of two 2xxx alloys in 10 % sulfuric acid and 3 % sodium chloride solutions were studied. The dependence of the metal dissolving rate on the concentration of inhibitor added in an acid medium was confirmed. The protective film has contained Al^{2+}-*Aloe Vera* complex. Compared to basic solutions, the addition of *Aloe Vera* extract has caused the shift of corrosion potential towards the negative direction for most of the examined samples. Therefore, it has acted as a cathodic inhibitor. However, in the presence of the lowest concentration of *Aloe vera* extract in 10 % sulfuric acid solutions, it has acted as an activator.

Since the influence of *Aloe Vera* extract has changed with increasing concentration in a neutral medium (3 % sodium chloride), it could be used as a corrosion inhibitor with significant inhibition efficiency. The highest efficiency (93.25 %) was ensured for as-cast specimens of the alloy containing 4.78 % of copper and 0.71 % of magnesium in 3 % sodium chloride solution with a concentration of *Aloe vera* extract of 0.08 mg/ml.

REFERENCES

Al-Rawajfeh, A. E., Al Qawabah, S. A. (2009). Investigation of Copper Addition on the Mechanical Properties and Corrosion Resistance of Commercially Pure Aluminium. *Emirates Journal for Engineering Research*, *14(1)*, 47-52.

Al-Turkustani, A. M., Arab, S. T., Al-Dahiri, R. H. (2010). Aloe Plant Extract as Environmentally Friendly Inhibitor on the Corrosion of Aluminum in Hydrochloric Acid in Absence and Presence of Iodide Ions. *Modern Applied Science*, *4 (5)*, 105-124.

Avwiri, G.O., Igho, F.O. (2003). Inhibitive Action of Vernonia Amygdalina on the Corrosion of Aluminium Alloys in Acidic Media. *Materials Letters*, *57 (22-23)*, 3705-3711.

Bockris, J. O. M., Reddy, A.K. N. (1974). *Modern Electrochemistry 2*, Plenum Press, New York.

Davis, J. R. (1999). *Corrosion of aluminum and aluminum alloys*, ASM International, Materials Park, Ohio.

Davis, J. R. (2001). *Alloying: Understanding the Basics*. ASM International, Materials Park, Ohio.

Evans, S., Koehler, E. L. (1961). Use of Polarization Methods in the Determination of the Rate of Corrosion of Aluminum Alloys in Anaerobic Media. *Journal of the Electrochemical Society*, *108 (6)*, 509-514.

Fayomi, O. S. I., Anawe, P. A. L., Daniyan, A. (2018). The Impact of Drugs as Corrosion Inhibitors on Aluminum Alloy in Coastal-Acidified Medium. *IntechOpen*, 79-94, DOI: 10.5772/intechopen.72942.

Gerengi, H., Goksu, H., Slepski, P. (2014). The inhibition effect of mad honey on corrosion of 2007-type aluminium alloy in 3.5% NaCl solution. *Materials Research*, *17 (1)*, 255-264.

Ghosh, K. S., Hilal, Md., Bose S. (2013). Corrosion behavior of 2024 AlCuMg alloy of various tempers. *Transactions of Nonferrous Metals Society of China*, *23*, 3215-3227.

Hamdou, I., Essahl,i M., Lamiri, A. (2017). Inhibition of aluminum corrosion in 0.1 M Na_2CO_3 by Ricinus communis oil. *Mediterranean Journal of Chemistry*, *6 (4)*, 108-116.

Hatch, J. E. (1984). *Aluminum: Properties and Physical Metallurgy*. American Society for Metals, Metals Park, Ohio.

Hikmat, N. A., Farhan, A. M., Majed, R. A. (2014). Thermodynamic and kinetic parameters for corrosion inhibition of Al-Cu alloy by sodium acetate at pH 11. *Knowledge of Research*, *1 (1)*, 62-67.

Hurlen, T., Lian, H., Odegard, O. S., Valand, T. (1984) . Corrosion and passive behaviour of aluminium in weakly acid solution. *Electrochimica Acta*, *29 (5)*, 579-585.

Khadraoui A., Khelifa A., Touafri L., Hamitouche H., Mehdaoui R. (2013). Acid extract of Mentha pulegium as a potential inhibitor for corrosion of 2024 aluminum alloy in 1 M HCl solution. *Journal of Materials and Environmental Science*, *4 (5)*, 663-670.

Lamaka, S. V., Zheludkevich, M. L., Yasakau, K. A., Montemor, M. F., Ferreira, M. G. S. (2007). High effective organic corrosion inhibitors for 2024 aluminium alloy. *Electrochimica Acta, 52 (25)*, 7231-7247.

Lopez-Garrity, O., Frankel, G. S. (2014). Corrosion Inhibition of Aluminum Alloy 2024-T3 by Sodium Molybdate. *Journal of The Electrochemical Society*, *161 (3)*, C95-C106.

Oguzie, E. E. (2007). Corrosion inhibition of aluminium in acidic and alkaline media by Sansevieria trifasciata extract. *Corrosion science*, *49 (3)*, 1527-1539.

Ouchenane, S., Abderrahmane, S., Himour, A. (2014). Synergistic Effect of L-Methionine and KI on Copper Corrosion Inhibition in HNO_3 (1M). *Sensors & Transducers*, *27 (5)*, 299-304.

Shyamala, M., Kasthuri, P. K. (2011). A Comparative Study of the Inhibitory Effect of the Extracts of Ocimum sanctum, Aegle marmelos, and Solanum trilobatum on the Corrosion of Mild Steel in Hydrochloric Acid Medium. *International Journal of Corrosion*, *Volume 2011*, Article ID 129647, 11 pages, doi:10.1155/2011/129647.

Sribharathy, V., Rajendran, S., Rengan, P., Nagalakshmi R. (2013). Corrosion Inhibition By An Aqueous Extract Of Aleovera (L) Burm F.(Liliaceae). *European Chemical Bulletin*, *2 (7)*, 471-476.

Umoren, S. A., Obot, I. B., Ebenso, E. E., Obi-Egbedi, N. O. (2009). The Inhibition of aluminium corrosion in hydrochloric acid solution by exudate gum from Raphia hookeri. *Desalination*, *247 (1-3)*, 561-572.

Wang, F., Fan, R., Jia, M., Wang, J. (2015). Corrosion Inhibition of Triazinedithoil for Aluminum Alloy in Hydrochloric Acid Solution. *Journal of Material Sciences & Engineering*, 4:148.

Xhanari, K., Finšgar, M., Hrnčič, M. K., Maver, U., Knez, Ž., Seiti, B. (2017). Green corrosion inhibitors for aluminium and its alloys: A review. *RSC Advances*, *7*, 27299-27330.

Zheludkevich, M. L., Yasakau, K. A., Poznyak, S. K., Ferreira, M. G. S. (2005). Triazole and thiazole derivatives as corrosion inhibitors for AA2024 aluminium alloy. *Corrosion Science*, *47 (12)*, 3368-3383.

Summary/Sažetak

U ovom radu razmatran je inhibicioni efekat *Aloe vera* na odabrane legure aluminijuma u 10% sumpornoj kiselini i 3% rastvoru natrijum-hlorida na sobnoj temperaturi, korišćenjem metoda potenciodinamičke polarizacije i ciklične voltametrije. Istraživanje je obuhvatilo 2xxx legure kao livene i termički obrađene, sa brzinom skeniranja od 1mV/s za linearnu polarizaciju i 50 mV/s za cikličnu voltametriju. Za svaku ispitivanu leguru primijenjen je različit konstantni potencijal. Rezultati polarizacije ukazuju da se transpasivacija dešava u kiseloj sredini u slučaju svake legure. Dobijeni rezultati pokazuju da ekstrakt *Aloe vere* djeluje kao katodni inhibitor.