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Animal glue as green inhibitor for corrosion of aluminum and aluminum-silicon alloys in sodium hydroxide solutions

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ABSTRACT

The inhibition effect of animal glue toward the corrosion of aluminum and two aluminum-silicon alloys in 0.1 M NaOH solution was investigated using potentiostatic polarization, electrochemical impedance spectroscopy (EIS), cyclic voltammetry and potentiodynamic anodic polarization techniques. The percentage inhibition efficiency increases with increasing concentration of animal glue and decreases with increasing temperature as well as Si content. The inhibiting effect of animal glue is due to the adsorption on the Al and two Al—Si alloys surface. The adsorption process follows Langmuir isotherm. Polarization curves revealed that the studied inhibitor acts as a mixed type inhibitor mainly cathodic. The effect of rising temperature on the inhibition efficiency was studied and the values of activation thermodynamic parameters were computed and explained. It was found that the animal glue provides a good protection to Al and Al—Si alloys against pitting corrosion by shifting the pitting potential to more noble direction. Results obtained from all electrochemical techniques were consistent with each other.

1. Introduction

Aluminum (Al) and aluminum-silicon (Al—Si) alloys are widely used in many industrial applications such as automotive and aircraft industries due to their cheap, light weight, low density, good appearance, high thermal and electrical conductivity. The high corrosion resistance of Al and its alloys arises from the formation of a compact, adherent passive oxide film. This film is amphoteric and dissolves substantially when the metal is exposed to acids or alkaline solutions [1]. The corrosion of Al and its alloys in aqueous solutions causes considerable costs [2]. It is necessary to add inhibitors to protect the metal from corrosion. Various organic compounds are used as inhibitors for corrosion of Al and its alloys in acidic and alkaline solutions [3–12]. The inhibitory action of these compounds depends on the chemical structure of the inhibitor, the surface charge of the metal, and the type of interaction between the inhibitor molecules and the metal surface [13].

Most organic compounds used are extremely expensive and hazardous in nature. Trials were made to find very low cost, non-toxic, natural and eco-friendly inhibitors for protection of metals and alloys against corrosion in aqueous solutions [14–20]. In our previous work [21,22], methyl cellulose and gelatin were used as a corrosion inhibitor for Al and Al—Si alloys in 0.1 M NaOH solution. Animal glue is an adhesive that is created by prolonged boiling of animal connective tissue. It has a cheap price and readily soluble in water. For our best knowledge, there is no study of using animal glue as a corrosion inhibitor for aluminum alloys. The aim of the present work is to study the inhibiting action of animal glue on the corrosion of Al and Al—Si in 0.1 M NaOH solution using different electrochemical techniques e.g., potentiostat polarization, electrochemical impedance spectroscopy (EIS), cyclic voltammetry and potentiodynamic anodic polarization techniques.

2. Experimental procedures

The chemical composition of Al and two Al—Si alloys is given in Table (1). For potentiostatic, potentiodynamic anodic polarization and electrochemical impedance spectroscopy (EIS) techniques, a cylindrical rod embedded in Araldite with an exposed surface area of 0.487 cm^2 for Al, 0.453 cm^2 for alloy I and 0.347 cm^2 for alloy II was used. The electrodes were abraded with different grades of emery paper, degreased with acetone and rinsed with bidistilled water. The experiments were carried out at 30 ± 1 °C using air thermostat. Complete wetting of the surface was taken as an indication of its cleanliness. All chemicals used were of A.R. quality. A three compartment cell with saturated calomel reference electrode (SCE) and a Pt foil was used as an auxiliary electrode. Potentiostatic polarization and potentiodynamic anodic polarization experiments were carried out using a PS remote potentiostat with PS6 software, while cyclic voltammetry and Impedance were controlled by SP-150 potentiostat/galvanostate with 092-06/2 Potentio.Galvano board with EIS option at 30 ± 1 °C. The impedance measurements were carried out with frequency range

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Table 1
The chemical composition of Al and Al—Si alloys (%).

Sample	Si	Fe	Cu	Mn	Mg	Ni	Ti	Zn	Na
Al	–	–	–	–	–	–	–	–	–
Alloy 1 (6063)	0.42	0.17	0.001	0.009	0.42	0.001	0.010	0.001	0.0012
Alloy II (20,556)	7.01	0.11	0.000	0.000	0.318	0.001	0.091	0.001	0.0012

from 200 kHz to 50 Hz. All solutions were freshly prepared using distilled water.

The amino acid analyzer curve for gelatin is represented in Fig. (1). The main components of animal glue are given in Table (2). The structure of glycine, alanine and glutamic acid as an example of the high percentage of amino acids is represented in Fig. (2).

3. Results and discussion

3.1. Potentiodynamic polarization

Fig. 3 shows the effect of increasing concentration of animal glue on the potentiostat polarization curves of Al in 0.1 M NaOH solution at a scan rate of 10 mV/s. Similar curves were obtained for alloy I and alloy II (not shown). The calculated corrosion parameters from these figures, e.g. anodic and cathodic Tafel slopes (β_a and β_c), corrosion potential (E_{corr}) corrosion current density (I_{corr}), the degree of surface coverage (θ) and the percentage of inhibition efficiency (%IE) are given in Table (3).

The percentage inhibition efficiency (%IE) and a parameter (θ) which represents the part of the metal surface covered by the inhibitor molecules were calculated using the following equations [21,22]

$$IE = \left[1 - \frac{I_{add}}{I_{free}}\right] 100 \quad (1)$$

$$\theta = \left[1 \frac{I_{add}}{I_{free}}\right] \quad (2)$$

where, I_{free} and I_{add} are the corrosion current densities in free and inhibited solution, respectively.

Inspection of Table 3, it is obvious that, as the concentration of animal glue increases,

i) The values of the anodic and cathodic Tafel slopes (β_a and β_c), and corrosion potential (E_{corr}) is nearly constant indicating that the inhibiting effect of the animal glue on the surface of Al and Al—Si alloys due to blocking adsorption mechanism [23]. This compound acted as a mixed-type inhibitor mainly cathodic, but the cathode is less polarized when an external current density was applied ($\beta_c < \beta_a$). This means that the animal glue molecule adsorb on both anodic and cathodic sites on aluminum surface, making a barrier between the metal and the corrosion medium.

ii) The values of corrosion current density (I_{corr}) decreases and the inhibition efficiency (%IE) increases, indicating the inhibiting effect of the animal glue toward the corrosion of Al and Al—Si alloys in 0.1 M NaOH solution.

iii) In free NaOH solution the values of I_{corr}, decreases in the following order alloy II > alloy I > Al indicating that the corrosion resistance of Al in 0.1 M NaOH solution increases with alloying it with Si. The presence of silicon as an alloying element increases the corrosion resistance of aluminum alloys due to the incorporation Si atom in Al_2O_3 film [24]. This incorporation repairs the film defects and precludes significant dissolution of the oxide film.

iv) The percentage inhibition efficiency (%IE) decreases with increasing silicon content in the following order:

Aluminum>alloy I>alloy II.

This order may be explained due to the high affinity of the animal glue to adsorb on the Al surface faster than Si surface Therefore, increasing of Si content reduces the strength of adherence of the adsorbed inhibitor molecules leading to decreased values of inhibition efficiency.

Table 2
The data obtained from the amino acid analyzer of animal glue.

Peak no.	Time, min	Area	%	Peak name
1	23.06	7.9769	4.51	Asp
2	24.56	1.2971	0.73	Thr
3	25.14	2.8607	1.62	Ser
4	27.16	13.2621	7.50	Glu
5	29.81	0.7568	0.43	Pro
6	34.01	86.0458	48.68	Gly
7	35.51	24.9727	14.13	Ala
8	42.67	4.9540	2.80	Val
9	45.32	1.3335	0.75	Met
10	47.91	2.4060	1.36	Ile
11	49.27	6.5128	3.68	Leu
12	54.87	1.1339	0.64	Tyr
13	56.71	2.7437	1.55	Phe
14	60.81	2.3379	1.32	His
15	64.27	6.5230	3.69	Lys
16	67.56	5.6873	3.22	Amm
17	73.91	5.9622	3.37	Arg

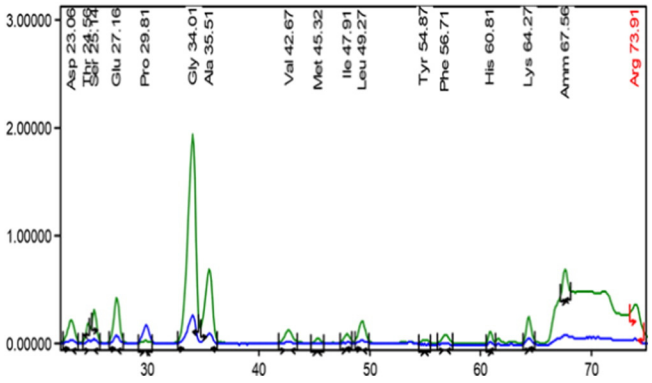

Fig. 1. The amino acid analyzer curve for animal glue.

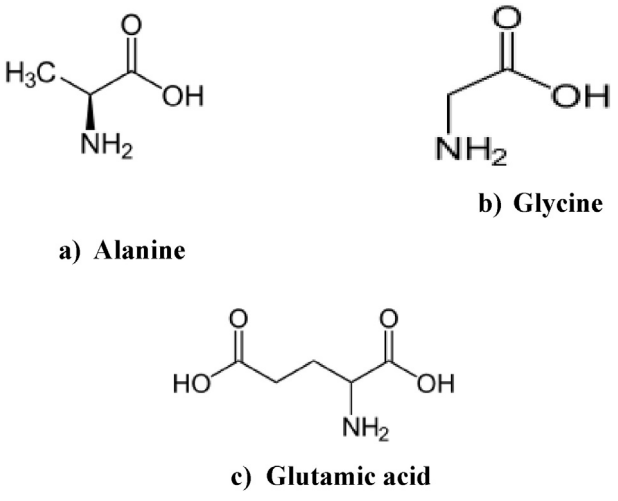

Fig. 2. Glycine, alanine and glutamic acid structures.