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ORIGINAL PAPER

Inhibitive Behaviour of Zinc Gluconate on Aluminium Alloy in 3.5 % Nacl Solution

O. Sanni · C. A. Loto · A. P. I. Popoola

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Abstract The present work investigates corrosion behaviour of aluminium alloy in 3.5 % sodium chloride medium at 28 °C in the absence and presence of 0.5, 1.0, 1.5 and 2.0 % g/v concentrations of zinc gluconate using gravimetric and electrochemical techniques. The aluminium alloy was cut to corrosion coupons, and immersed into 3.5 % sodium chloride solution containing different inhibitor concentrations (0.5, 1.0, 1.5 and 2.0 % g/v) within a period of twenty-eight days. The surface morphology of the metal was examined by high resolution scanning electron microscopy equipped with energy dispersive spectroscopy (HR-SEM/EDS). From the results, it was found that the adsorption of zinc gluconate reduced aluminium alloy corrosion in the sodium chloride medium. Experimental results also showed that inhibition efficiency increased with an increase in zinc gluconate concentration. Furthermore, potentiodynamic polarization results revealed decrease in corrosion rates (CR), corrosion current densities (Icorr), and increasing corrosion resistance (Rp) in the presence of zinc gluconate in 3.5 % NaCl solution. Tafel polarization analyses indicated that zinc gluconate is a mixed type inhibitor. The adsorption of zinc gluconate on the aluminium alloy surface followed Langmuir adsorption isotherm.

Keywords Corrosion · Zinc gluconate · Aluminium alloy · Adsorption isotherm · 3.5 % NaCl solution · SEM/EDS

1 Introduction

Aluminium and its alloys have proved to be an essential material, and are widely use in many industries. They are used in the aerospace industries, aviation, household utensils, automotive, building and military hardware [1–3]. Their usefulness is derived from their good qualities such as good corrosion resistance, excellent workability, high strength-to-weight ratio, high thermal/electrical conductivity [4–9]. Despite these good properties, when exposed to an aggressive environment, they are prone to corrosion and degradation. However, the ability of aluminium and its alloy to resist corrosion attack in an aggressive environment have been reported to be inadequate [10]. Several methods such as coating [11], cathodic protection [12, 13], anodic protection [14], alloying [15], thermal treatment [16, 17] have been used to tackle these limitations. Also, corrosion resistance of aluminium and its alloys using inhibitors have been investigated in various environments [18–24]. Corrosion inhibitors are substances which when added in small concentrations to corrosive environments decrease or prevent the reaction of the metal with the media. Different zinc salt had been successfully used on mild steel in saline medium [25]. In view of this, the inhibiting effect of zinc gluconate on aluminium alloy in 3.5 % sodium chloride medium was investigated. The purpose of this research is to establish the effectiveness of zinc gluconate as corrosion inhibitor (Fig. 1).

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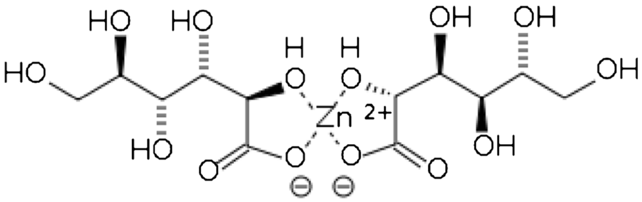

Fig. 1 Structure of zinc gluconate

2 Material and Methods

Preparation of Zinc Gluconate Powdered zinc gluconate was diluted with appropriate quantity of distilled water to obtain inhibitor test media of 0.5, 1.0, 1.5 and 2.0 % g/v concentrations [26].

Specimen Preparation Aluminium specimens of the composition presented in Table 1 of rectangular dimension 12 × 12 × 2 mm with 3 mm diameter hole at the centre were used to determine the corrosion rate in a beaker containing the aggressive medium of sodium chloride.

These coupons used were mechanical polished, degreased in ethanol, dried in acetone and stored in moisture-free desiccators before use.

Weight Loss Measurement Aluminium alloy specimens of size 12 × 12 × 2 mm were immersed in 200 ml of 3.5 % sodium chloride in the absence and presence of different ZG concentrations at 28 °C for 28 days exposure time. The aluminium alloy specimens were weighed, and suspended in the beaker with a hook and thread. After 48 h, each sample was taken from the chloride solution, washed in double distilled water, dried and re-weighed [27]. The corrosion rate, degree of surface coverage and percentage inhibition efficiency (%IE) of the inhibitor, were calculated using the equations below.

Table 1 Chemical composition of aluminium alloy

Element	Compositions (%wt)
Si	0.157
Fe	0.282
Cu	0.0025
Mn	0.024
Mg	0.51
Cr	0.023
Ti	0.006
Ca	0.0011
Zr	0.002
V	0.0035
Al	Balance

$$Corrosion\ rate \left(\frac{87.6W}{DAT}\right) \tag{1}$$

Where:

W *weight loss (mg)*
D *specimen density* (g/cm^3)
A *specimen area* (cm^2)
T *exposure time (h)*

Degree of surface coverage (θ)

$$\theta = \frac{CR_o - CR}{CR_o} \tag{2}$$

Where CR and CR_O are corrosion rates of the material in the presence and absence of inhibitors respectively in 3.5 % NaCl at 28 °C.

The percentage inhibition efficiency (*%IE*):

$$IE(\%) = \frac{CR_o - CR}{CR_o} \times \frac{100}{1} \tag{3}$$

Electrochemical Test Samples for electrochemical studies were cut similar to the samples for weight loss studies. The samples were prepared by connecting an insulated copper wire to one side of the sample using an aluminum conducting tape, and cold mounted in methyl methacrylate resin. Emery papers of different grades were used to polish the samples and washed thoroughly with distilled water. The potentiodynamic polarization tests were carried out with a typical three electrode cell at 28 °C. The working electrode used was aluminium alloy samples with 1 cm^2 surface area exposed and the rest being covered by the resin. Saturated Ag/AgCl was used as reference electrode and a graphite rod as counter electrode. The polarization studies were conducted in 200 ml of 3.5 % NaCl solution using AUTOLAB Potentiostat (model Reference-668), which was connected to an acquisition system to control the experiments, and NOVA software packaged with version 1.8 was used in analyzing the data. The linear region of anodic and cathodic curves was extrapolated with 0.0016 V/sec scan rate. From the Tafel analysis; linear polarization resistance, corrosion potential, corrosion current density and corrosion rate were obtained in a static solution.

SEM/EDS Analysis The surface morphology of the aluminium alloy samples in the absence and presence of zinc gluconate for 28 days at 28 °C was investigated after weight loss test using Jeol JSM – 7600F scanning electron microscope.

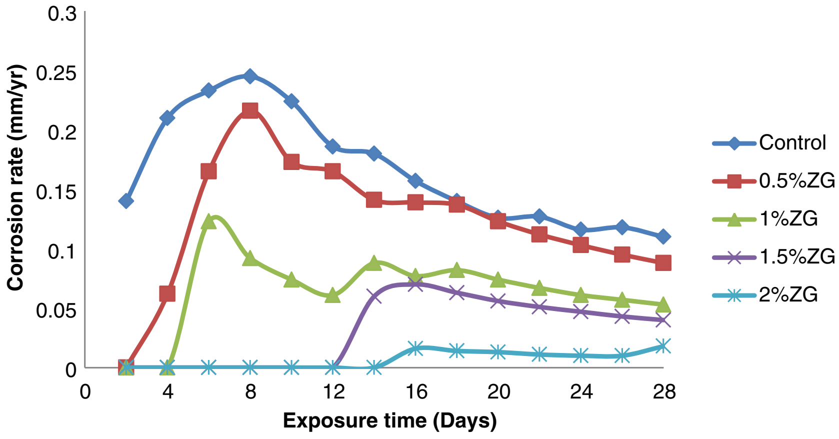

Fig. 2 Corrosion rate versus exposure time for aluminium alloy immersed in 3.5 % NaCl solution with varied zinc gluconate addition

3 Results and Discussion

Weight Loss Tests The obtained values of corrosion rate (*C*R) and percentage inhibition efficiency (% IE) from weight loss tests in the absence and presence of different concentrations of zinc gluconate in 3.5 % NaCl medium at 28 °C is shown in Figs. 2 and 3. The variation of corrosion rate for aluminium alloy specimens with exposure time immersed in 3.5 % NaCl environment in the absence and presence of different ZG concentrations are shown in Fig. 2. The Figure shows that in the absence of ZG, the corrosion rate value of aluminium alloy increased from 0.140 to 0.245 mm/yr at the end of 8 days of exposure time to the corrosive environment, after exposure for 8 days, corrosion rate value decreased with further exposure to the corrosive medium. The final corrosion rate value was 0.110 mm/yr at the end of the 28 days of exposure time. There was a severe decrease in the corrosion rate value in the presence of all the concentrations of ZG studied. The corrosion rate values reduced with an increase in the ZG concentration from 0.5 to 2.0 % g/v with an interval of 0.5. The percentage reduction in corrosion rates value with relative to the control experiment at the end of 28 days of exposure time are 20 % for 0.5 % g/v, 52 % for 1.0 % g/v, 64 % for 1.5 % g/v and 84 % for 2.0 % g/v concentration of zinc gluconate respectively. This implies that ZG inhibits the aluminium alloy corrosion in 3.5 % sodium chloride medium, and adsorption of ZG on aluminium alloy reduces the surface area available for chloride ions attack in the solution.

Shown in Fig. 3 is the variation of inhibition efficiency (IE) with different ZG concentrations. There was reduction in IE of ZG depending on the concentration of ZG added to the corrosive environment. The inhibition efficiency increased with an increase in the ZG, this behaviour could be ascribed to the adsorption of the inhibitor on the aluminium alloy sample surface resulting in inhibition corrosion phenomenon. The IE of 0.5 % g/v concentration of ZG reduced to 20 %, 1.0 % g/v reduced to 52 %, 1.5 % g/v reduced to 64 %, and 2.0 % g/v reduced to 84 % after 28 days of exposure time. The optimum inhibition efficiency was observed at 1.5 % g/v concentration of ZG in 3.5 % NaCl solution at 28 °C.

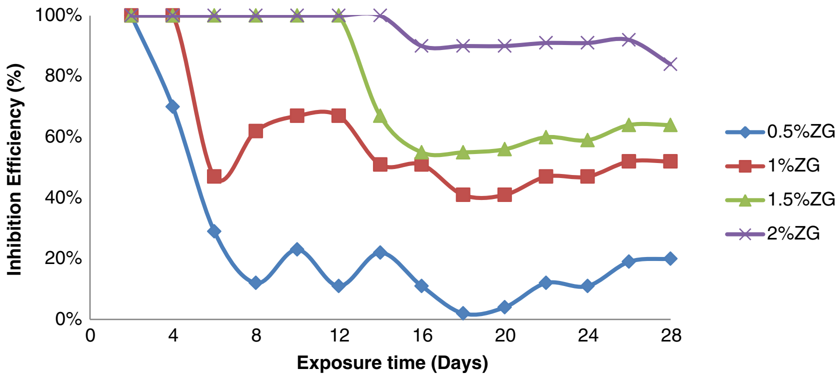

Fig. 3 Inhibition efficiency versus exposure time for aluminium alloy immersed in 3.5 % NaCl solution with varied zinc gluconate addition

Table 2 Polarization data for ZG inhibited aluminium alloy in 3.5 % NaCl solution

S/N	C (%g/v)	Icorr (A/cm^2)	bc (V/dec)	ba (V/dec)	LPR Rp (Ωcm^2)	-Ecorr (V)	CR (mm/yr)
1	0.0	8.59E-06	0.050867	0.080038	1572.300	0.75893	0.277870
2	0.5	2.70E-09	1.159700	0.272330	3.54E + 07	0.84633	8.84E-05
3	1.0	3.21E-10	0.276120	1.038800	2.95E + 08	0.84633	1.05E-05
4	1.5	2.79E-10	0.524900	0.574110	4.27E + 08	0.84633	9.12E-06
5	2.0	8.60E-11	0.142750	0.194700	4.16E + 08	0.84633	2.81E-06

Electrochemical Studies Shown in Table 2 and Fig. 4 is the experimental and calculated values obtained from the polarization corrosion test.

The results recorded are for the linear polarization resistance (Rp), corrosion current density (Icorr), corrosion potential (Ecorr), corrosion rate (CR), anodic and cathodic Tafel slopes (βa and βc) in the absence and presence of different concentrations of ZG. The potentiodynamic polarization curves for aluminium alloy dissolution in 3.5 % sodium chloride solution in the absence and presence of different concentrations of ZG at 28 °C. The result revealed that, there was a decrease in the corrosion current density (Icorr) and corrosion rate (CR) in the presence of all the concentrations of ZG studied. The polarization resistance (Rp) and corrosion potential (Ecorr) also increased in the presence of the inhibitor and the changes in anodic and cathodic region suggest a mixed type inhibition for aluminium alloy in 3.5 % NaCl solution at 28 °C. This also correlates with the observed order of corrosion inhibition obtained from the weight loss method.

Adsorption Isotherm The corrosion inhibition mechanism may be explained based on the adsorption behaviour [28].

Basic information on the surface of aluminium alloy and interaction between the inhibitor can be provided by the adsorption isotherm. In view of this, the surface coverage values (θ) at different zinc gluconate concentrations in sodium chloride medium at 28 °C from weight loss method was use to describe the best isotherm for the adsorption process. Adsorption of an inhibitor molecule occurs when interaction energy between molecule and metal surface is higher than that between H_2O molecule and the metal surface [29]. In this study, Langmuir adsorption isotherm was found to best describe the adsorption behaviour of ZG on the aluminium alloy surface in 3.5 % sodium chloride solution. Figure 5 shows the surface fraction covered (C/θ) as a function of ZG concentration (C). The plot obtained for the inhibitor is linear with a correlation coefficient of 1.

SEM/EDS Surface Analysis Aluminium alloy specimen surface morphological studies in the absence and presence of ZG in sodium chloride solution were carried out by SEM after immersion for 28 days at 28 °C. Figure 6 shows the SEM/EDS images of the surface of aluminium alloy after 28 days immersion in the absence of ZG in 3.5 % sodium chloride solution (Fig. 6a, and in the presence of ZG (Fig. 6b. A surface severely corroded was observed after immersion in the absence of ZG as a result of corrosive

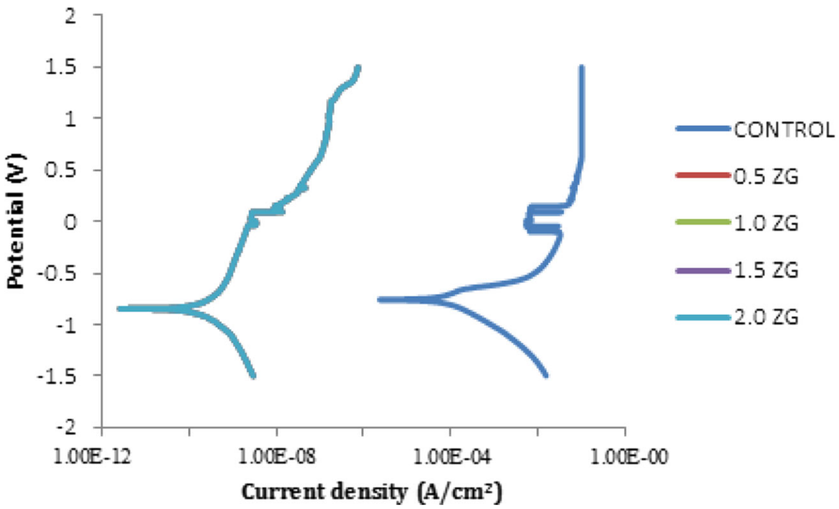

Fig. 4 Linear polarization curves for aluminium alloy in 3.5 % NaCl solution in the absence and presence of different concentrations of ZG at 28 °C

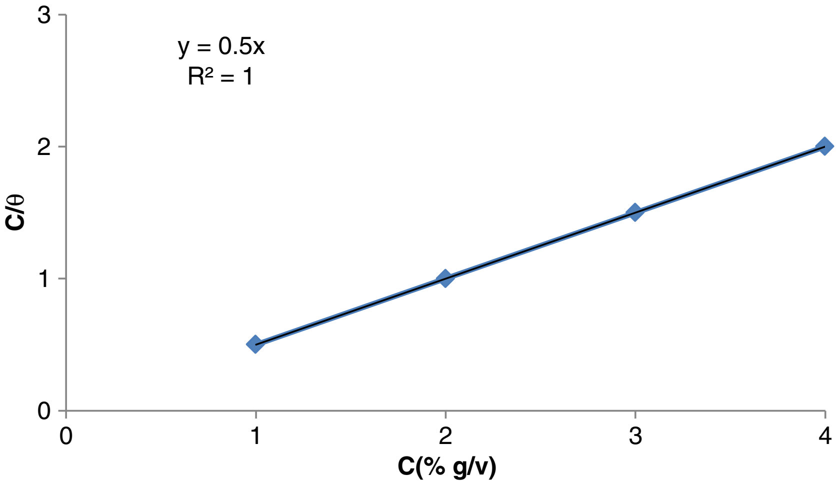

Fig. 5 Langmuir isotherm for the adsorption of ZG in 3.5 % NaCl at 28 °C

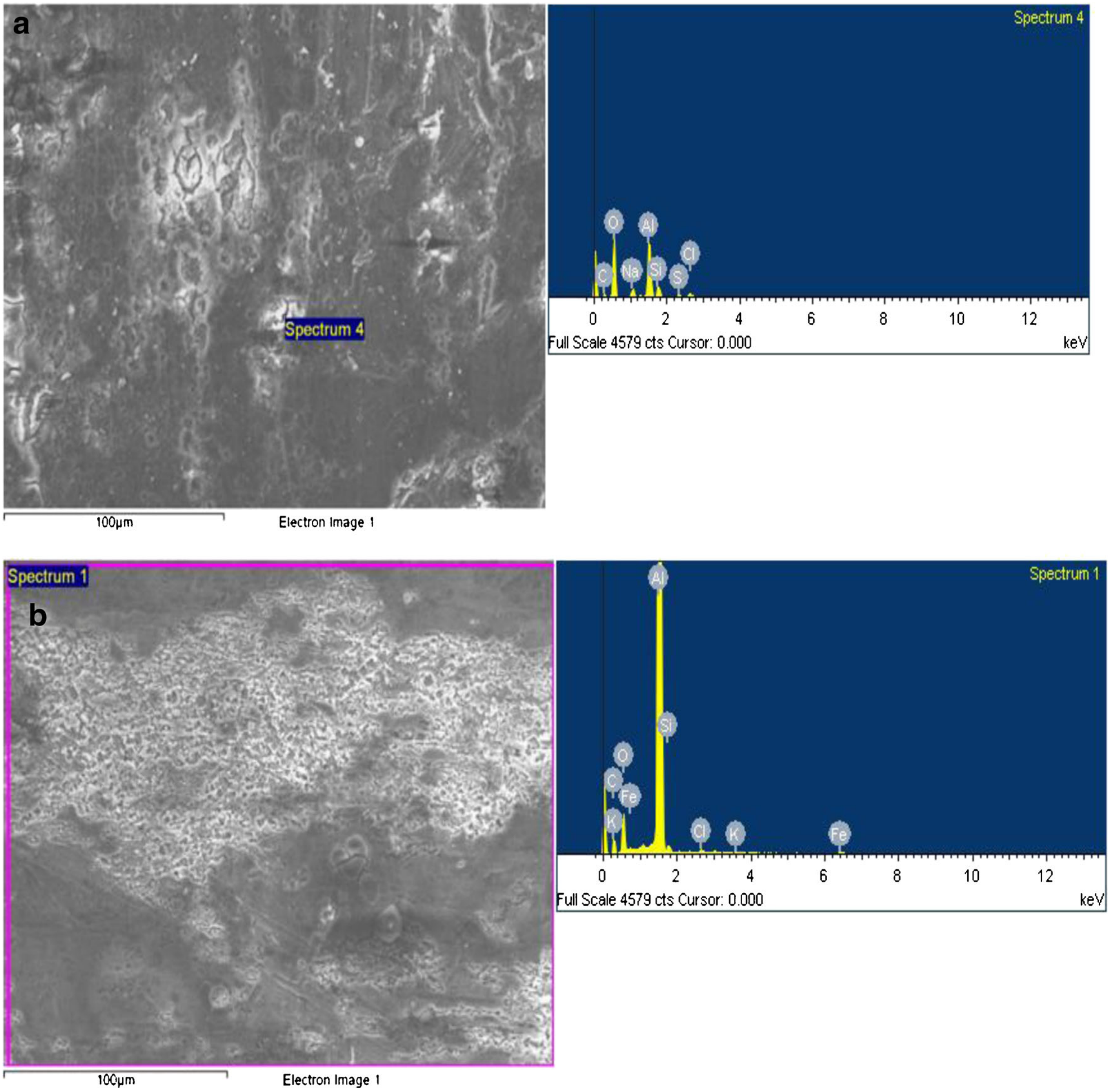

Fig. 6 SEM/EDS images of aluminium alloy surface after 28 days immersion at 28 °C in 3.5 % NaCl in the: **a** absence of ZG and **b** presence of ZG

attack of the chloride solution (Fig. 6a. The corrosion product layer on the surface of aluminium alloy in the absence of inhibitor (Fig. 6a was clearly porous and thus offers no corrosion protection. In the presence of ZG (Fig. 6b, the corrosion damage was clearly reduced, and there was an evidence of the presence of ZG on the surface of the metal.

Mechanism of Inhibition Aluminium alloy corrosion inhibition in 3.5 % sodium chloride solution by zinc gluconate can be explained based on molecular adsorption. The zinc gluconate inhibits corrosion by controlling both the cathodic and anodic reactions. From the data showed in Table 2, it is clear that zinc gluconate inhibits corrosion of aluminium alloy simply by blocking both cathodic and anodic site. Chloride content has a prevailing effect on the mechanism of zinc gluconate inhibitive action. Inhibition efficiency depends on quite a lot of factors such as; adsorption sites number and their charge density, heat of hydrogenation, molecule size, mode of interaction with the surface of metal and formation of metallic complexes [30].

4 Conclusion

From the investigation of ZG as corrosion inhibitor for aluminium alloy in 3.5 % NaCl medium the following deductions were made:

1) ZG functioned as an efficient inhibitor for aluminium alloy corrosion in 3.5 % NaCl solution and the inhibition efficiency of ZG increased with an increase in concentration of the inhibitor.
2) Potentiodynamic polarization curves showed that the ZG acts as mixed type in 3.5 % NaCl solution.
3) The adsorption of ZG molecules on the aluminium alloy surface in 3.5 % sodium chloride solution was consistent with Langmuir adsorption isotherm.

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