Corrosion Behavior of Al-alloy in NaCl Contains Some Inhibitors

Khalid Ahmed Eldwaib

***Abstract*—**In this study, Al-Mg alloy 5052 was used as the testing material. Corrosion resistance behavior was studied for the alloy in 3.5% NaCl (pH=1, 3, 5, 7, 9, and 11), and 3.5% NaCl (pH=1) with inhibitors. Corrosion rates were determined by measuring the weight loss of the tested samples. The immersion period was 5 days. The compound inhibitors were composed mainly of phosphate (PO_4^{-3}), adding a certain proportion of other nontoxic inhibitors so as to select alternatives to environmentally hazardous chromate. The inhibitors were Na_3PO_4, Na_2MoO_4, and $Na_3C_6H_5O_7$.

In the weight loss measurements by immersion in 3.5% NaCl solutions, the maximum corrosion rate was at pH 11, and the minimum corrosion rate was at pH 5 and pH 7. The corrosion rates in the presence of inhibitors with 3.5% NaCl were improved by different percentages. The surface morphology of the specimens had been characterized through optical microscope.

***Keywords*—** Al-Mg alloy 5052, Corrosion, inhibitors.

I. Introduction

ALUMINUM and its alloys represent an important category of materials due to their high technological value and wide range of industrial applications, especially in aerospace and household industries. The use of 5052AA in aircraft fuel and oil lines, fuel tanks, miscellaneous marine and applications were good workability, very good resistance to corrosion, high fatigue strength, and weldability, are desired [1]. The use of inhibitors is one of the most practical methods for protection against corrosion, especially in acidic solutions. A corrosion inhibitor is a substance which, when added in small amount to an environment normally corrosive to a metal or alloy in contact with it, effectively reduces the corrosion rate. Inhibitors are widely used in neutral aqueous solutions and are particularly useful in recirculating systems, such as heating, hydraulic, and refrigerating systems [2].

II. Experimental Work

Testing material was AA 5052 (Al-Mg) wrought alloy in O-temper (without thermal treatment) state. Weight loss during immersion was conducted on the investigated alloy in various environments. The test material, 5052 aluminum alloy whose chemical composition is shown in Table I was used in all experiments in this study.

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TABLE I
Chemical Composition of 5052 Al alloy (wt. %).

Element	Si	Fe	Cu	Mn
Wt. %	0.1.	0.26	0.029	0.081
Mg	Cr	Zn	Ti	Al
2.51	0.192	0.025	0.028	Bal.

Specimens of all tests were prepared by polishing with 280-, 400-, and finally to 1200-grit papers in succession, cleaned, degreased and dried in air. Corrosion resistance of material is measured by immersion tests in different environments. Rectangular specimens of dimensions (30 x 30 x 3.80) mm were used in immersion technique to determine the weight loss. The samples were cleaned, degreased, and weighted on an analytical balance (measuring accuracy ±0.0001 g) before and after the tests. Tests were lasted 5 days. The corrosion products on the samples surfaces were removed by standard procedures, after the tests samples weighted.

The corrosion resistance of AA 5052 was determined by the oxide film of the surface and the intermetallic phases containing Al and Mg and it exhibited the characteristic of localized corrosion in chloride media. Therefore, the chosen inhibitors should have been able to prevent (Cl^-) from destroying the oxide film, enhance its stability, and inhibit the corrosion induced by intermetallic phases [3]. The chosen inhibitors in this study are sodium phosphate Na_3PO_4, sodium molybdate Na_2MoO_4, and sodium citrate $Na_3C_6H_5O_7$. Phosphate has been used to suppress the corrosion of an aluminum alloy in practice, so it was combined with other chosen inhibitors to get different kinds of the compound inhibitors. Full immersion tests were performed in 3.5% NaCl aqueous solutions at pH = 1, 3, 5, 7, 9, and 11. Exposure time was 5 days. Full immersion tests were performed in 3.5% NaCl aqueous solutions at pH = 1 with the presence of previous inhibitors. The total amount of inhibiting pigments was at different concentrations (250,500,750, and 1000) ppm in the solutions. The immersion period was 5 days. Corrosion rates were determined by measuring the weight loss of the tested samples. For this purpose, corrosion products were removed.

III. Results and Discussion

After immersion for 120 h, the corrosion rates of AA5052 in the presence or absence of inhibitors at different concentrations were determined. As a general rule, the protective film is stable in aqueous solutions of the pH range

4.5-8.5 whereas it is soluble in strong acids or alkalis leading to rapid attack of aluminum [4]. Corrosion rates in various environments are presented in figures below:

Fig. 1 shows the effect of pH on the corrosion rate of the investigated alloy. The highest corrosion rate is shown at pH 11 (26.88 mpy) followed by pH 1 (20.02 mpy) while there is a high protection of surface due to high passivation in the pH range of 4.0 to 8.5. The highest corrosion rate at pH 11 is due to presence of sodium hydroxide in the solution because the surface oxide film is soluble in it, thus aluminum dissolves uniformly at a steady rate (uniform surface attack).

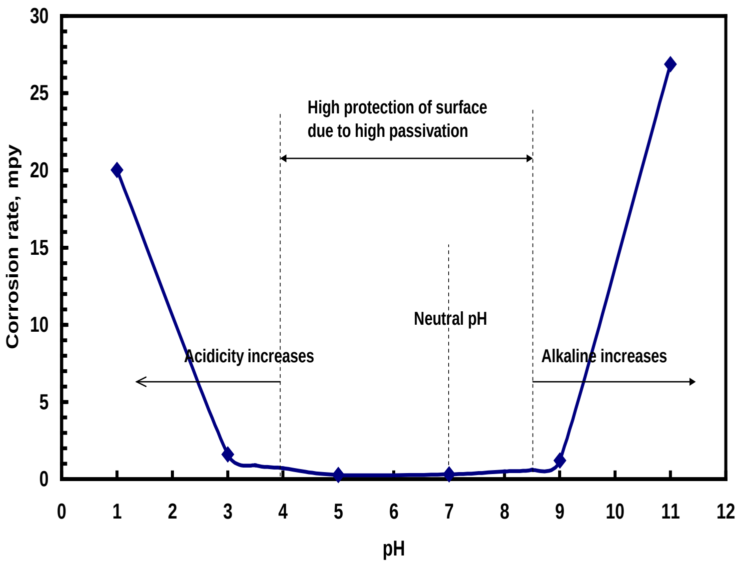


Fig.1 The relationship between of pH solution (3.5%NaCl) and corrosion rate of 5052 alloy.

The morphology of the tested specimens is shown in Fig. 2 These photos show that the specimen was tested at pH 11 suffers from severe uniform corrosion attack on its surface. Specimen of pH 1 suffers from severe pitting corrosion. On the other hand specimens of pH 3 and pH 9 do not show a noticeable corrosion.

Phosphate was combined with other inhibitors such as molybdate and citrate. Previous study in immersion test of the compound inhibitors showed that this was a practical way to mix phosphate with other nontoxic inhibitors in a certain proportion to satisfy the demands of anti-corrosion for both an aluminum alloy and environmental protection [3].

It is observed from the Fig. 3&5 that the corrosion rate decreased as the concentration of the inhibitors increased; 4.12 mpy at concentration 1000 ppm of (Na3PO4 & Na2MoO4) ratio (4:1) and 1.62 mpy at concentration 1000 ppm of (Na3PO4 & Na2MoO4 & Na3C6H5O7) ratio (8:1:1), i.e. the corrosion inhibition strengthened with the increase of the inhibitor concentration. This trend may result from the fact that adsorption and surface coverage increases with the increase in concentration. Thus the surface is efficiently separated from the medium [5].

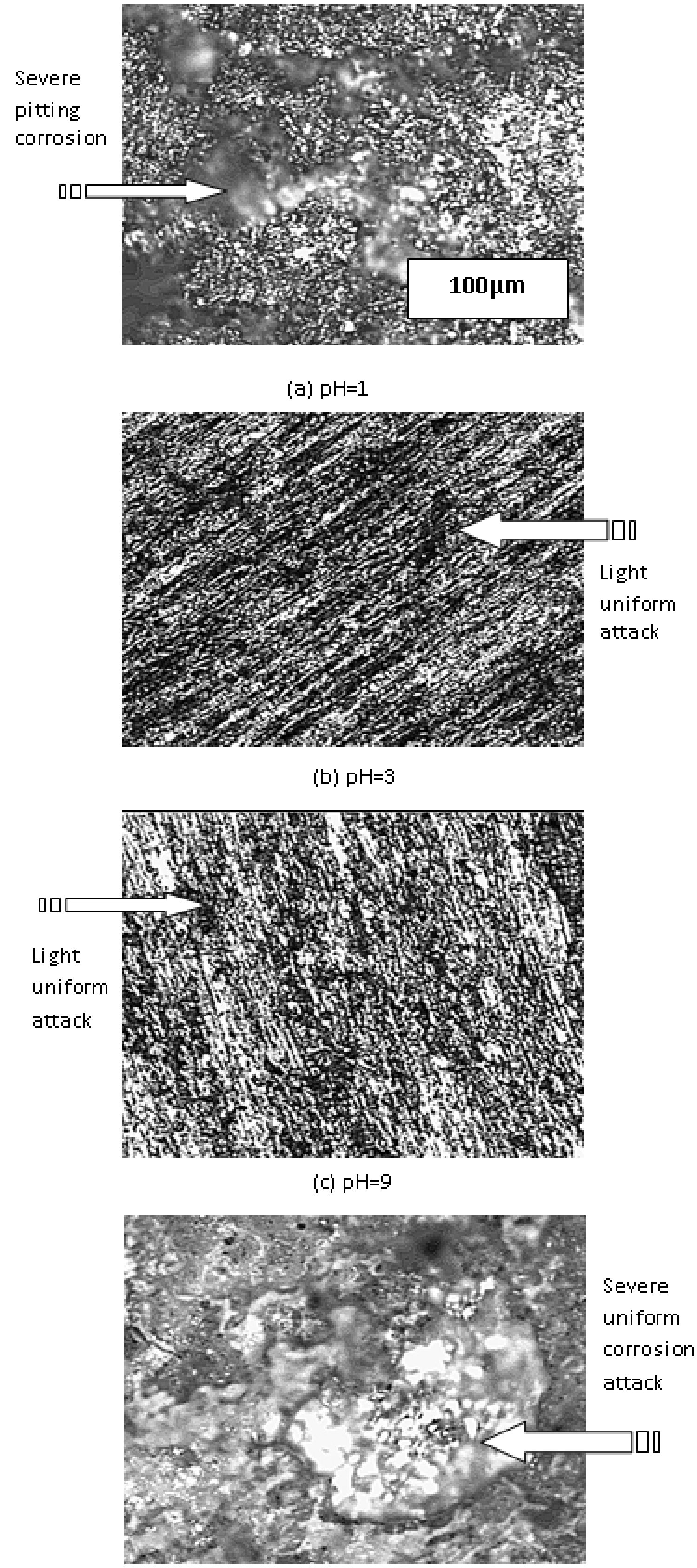


Fig.2 The optical microscopic of the samples after immersion in 3.5% NaCl.

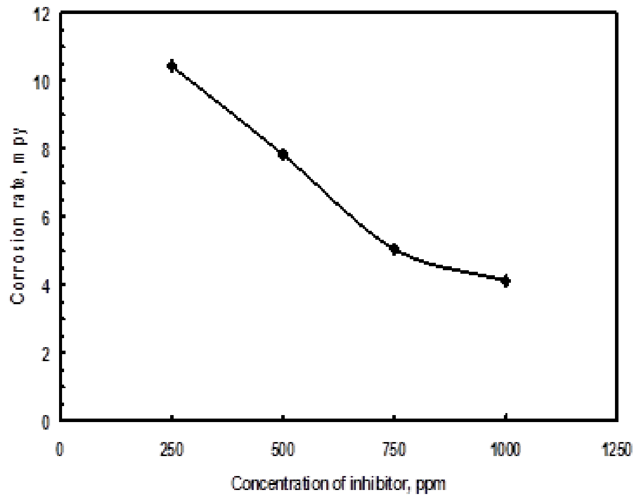
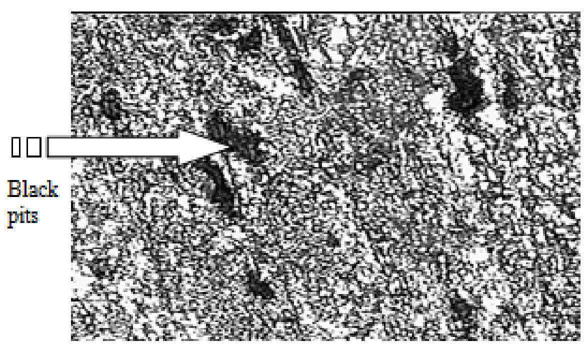
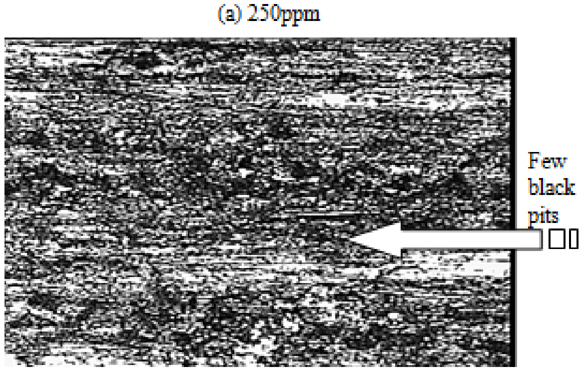


Fig.3 Effect of inhibitor addition (Na_3PO_4 & Na_2MoO_4) ratio (4:1) on corrosion rate.

The surface morphology of the corroded samples after addition of (Na_3PO_4 & Na_2MoO_4) to 3.5% NaCl is shown in Fig. 4. The photos show black pits at (a) where the corrosion rate is 10.44 mpy. On the other hand there is light attack and a few black pits on the surface of the specimen (b). The optical micrographs of the tested specimens in the presence of (Na_3PO_4 & Na_2MoO_4 & $Na_3C_6H_5O_7$) as inhibitor are shown in Fig. 6. There are corrosion pits on the surface of the specimen (a), while the sound surface appears on the sample in (b).



(a) 250ppm



(b) 1000ppm

Fig.4 The samples morphology after addition of (Na_3PO_4 & Na_2MoO_4) ratio (4:1) to 3.5% NaCl.

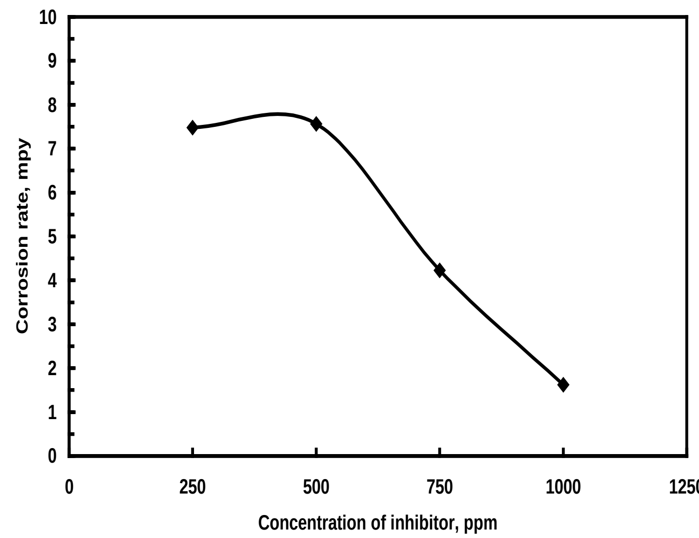
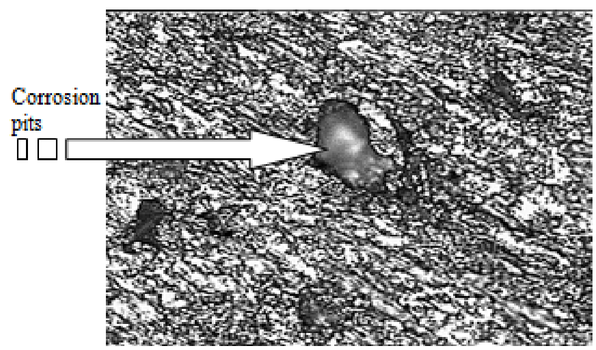
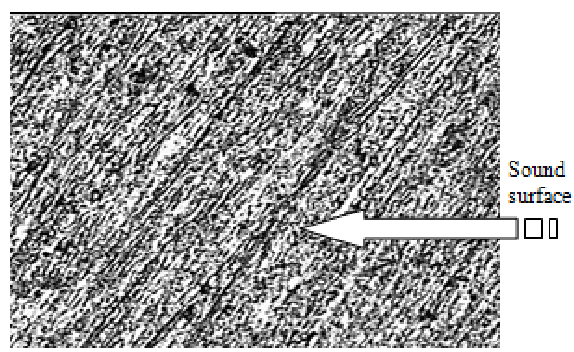


Fig.5 Effect of inhibitor addition (Na_3PO_4 & Na_2MoO_4& $Na_3C_6H_5O_7$), ratio (8:1:1) on corrosion rate.



(a) 250ppm



(b) 1000ppm

Fig.6 The samples after addition of (Na_3PO_4 & Na_2MoO_4& $Na_3C_6H_5O_7$), to 3.5% NaCl.

Inhibiting efficiency of the immersion test (IE) is calculated by equation:

$$IE(\%) = \frac{C.R_{without} - C.R_{with}}{C.R_{without}} \times 100$$

Where
$C.R_{without}$: Corrosion rate without inhibitor
$C.R_{with}$: Corrosion rate with inhibitor

Inhibiting efficiencies are listed in the table II.

Corrosion of AA5052 in 3.5%NaCl solution was induced mainly by Cl^- ions and the potential difference between the matrix and intermetallic phases. If the inhibitors in the solution could retard these reaction processes, they would be able to inhibit the corrosion of the aluminum alloy [3].

The main protection of **phosphate** is to react with corrosion products that deposit on the surface of metal and form a protective film.

TABLE II
PERCENTAGE INHIBITION EFFICIENCY OF INHIBITORS AT VARIOUS CONCENTRATIONS IN 3.5% NACL (PH=1).

Solution	Concentration of inhibitor	Inhibiting Efficiency (IE), %
A	250 ppm	47.9
A	500 ppm	60.9
A	750 ppm	74.7
A	1000 ppm	79.4
B	250 ppm	62.6
B	500 ppm	62.2
B	750 ppm	78.9
B	1000 ppm	91.9

A: 3.5% NaCl (pH=1) + (Na_3PO_4 & Na_2MoO_4) ratio (4:1).
B: 3.5% NaCl (pH=1) + (Na_3PO_4 & Na_2MoO_4 & $Na_3C_6H_5O_7$) ratio (8:1:1).

For the aluminum alloy in 3.5% NaCl solution with phosphate, phosphate could react with Al^{3+} and Mg^{2+}, which can result from the hydrolysis of the oxide layer and localized corrosion induced by the intermetallic phases and form the deposition film on the surface to further inhibit propagation of the hydrolysis and galvanic couple corrosion. However, the processes occurred only after metal cations appeared in the solution; therefore, the inhibition of phosphate cannot occur in a short time [3]. **Molybdate** has the capability to act as an oxidizing inhibitor and reinforce the surface passivating film of the aluminum alloy, so it is difficult for the ingress of chlorides into the aluminum surface layer. As a result, a small amount of pitting and localized corrosion occurs [3]. In 3.5% NaCl solution containing phosphate/molybdate, a few black spots still appeared as shown in Fig.4. **Carboxylates** in general provide the combined action of an easily-reduced cation and a strongly-adsorbed anion that forms a chemical bond between the carboxyl ion and the metal substrate. **Citrate** has three carboxyls, which has been used as an inhibitor for pitting corrosion of aluminum alloys. It combines with phosphate to inhibit corrosion of the aluminum alloy. They adsorb on the surface of the aluminum alloy instead of the chloride ion with competitive adsorption so as to reduce the rupture probability of the oxide film [3]. In 3.5% NaCl solution containing phosphate/molybdate/citrate, there are corrosion pits and sound surface as shown in Fig.6.

IV. CONCLUSION

From the study of the effects of corrosion inhibiting pigments on corrosion resistance behavior of 5052 aluminum alloy in 3.5%NaCl solution, the following conclusions were drawn:

- In the weight loss measurements by immersion in 3.5% NaCl solutions, the maximum corrosion rate of 5052 was at pH 11, and the minimum corrosion rate was at pH 5 and pH 7.

- Immersion tests show that the inhibitors can improve the corrosion resistance of AA5052 in corrosive medium such as 3.5% NaCl (pH=1) solution.

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REFERENCES

[1] ASM Metal Handbook, Volume 2: Properties and Selection: Nonferrous Alloys and Pure Metals, 1979.
[2] Anti-Corrosion, Manual published by Corrosion Prevention and Control (1964) p. 288.
[3] X.F.Liu, S.J. Huang, and H.C. Gu, "Corrosion protection of an aluminum alloy with nontoxic compound inhibitors in chloride media", CORROSION 58 (2002) 826-834.
[4] I. J. Polmear, "Metallurgy of the Light Metals", Monash University, Melbourne, (1989) p. 31.
[5] G.Y. Elewady and I.A.El-Said A.S.Fouda, "Anion Surfactants as Corrosion Inhibitors for Aluminum Dissolution in HCl Solutions", Int. J. Electrochem. Sci., 3 (2008) 177-190.