

Corrosion rate of AA 7050 in 3.5% NaCl environment with sodium chromate (Na_2CrO_4) inhibitor variation

Pramesti A D Wulandari¹, and M Noer Ilman^{1*}

¹Universitas Gadjah Mada, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Yogyakarta, Indonesia

Abstract. Aluminium alloy 7050 is widely used for aerospace applications due to its excellent mechanical properties. However, when the airplane is operated and exposed by the corrosive environment, alumina layer of aluminium is not thick enough to provide protection. Therefore, corrosion protection method in the airplane needs to be improved. In the recent experiments, corrosion process in the airplane could be inhibited by corrosion inhibitors that are mixed with a protective coating. In this current study, the effect of sodium chromate inhibitor on the corrosion rate of aluminium alloy AA 7050 has been investigated. The 7050 aluminium alloys in this experiment were machined into specimens for the tensile test, hardness test, corrosion test and metallographic examination. The corrosion test was performed in 3.5% NaCl solution containing 0.1%, 0.3%, 0.5%, 0.7% sodium chromate inhibitor and the results have been compared with the corrosion rate in 3.5% NaCl solution as reference. The tensile test results showed that the ultimate and yield strength were 527.36 MPa and 481.42 MPa. Hardness test results were 175.36 VHN on the short transverse plane, 164.43 VHN on the long transverse plane, and 164.23 VHN on the longitudinal plane. This experimental study can be concluded that the corrosion rate of material decreases with increasing of Na_2CrO_4 concentration in the solution.

1 Introduction

Airplane components such as fuselage skin, fuselage bulkhead, and lower wing skins use aluminium alloy 7050 as a structural material due to the excellent combination of high strength to weight ratio, high strength and fracture toughness, low density, and good corrosion resistance [1,2]. The aluminium oxide layer developed naturally on aluminium alloy surface is able to provide good corrosion resistance characteristics. However, when the airplane is operated and exposed in a corrosive environment, the natural oxide layer of aluminium alloy is not thick enough to ensure corrosion protection [3,4]. Therefore, researchers have to concern to improving the level of corrosion protection for aerospace components and structures [5].

Several ways to reduce the risk of corrosion process on the military and civil airplane can be done through design, the selection of materials that are resistant to corrosion, the application of protective treatment to the individual component, and modifying properties of the medium by inhibitors such as sodium chromate [5,6]. The aerospace application generally uses sodium chromate inhibitor to protect aluminium alloys from the aggressive environment [1]. However, sodium chromate inhibitor can be hazardous due to its carcinogenic effect, so that the use of chromate has been limited since 1982. The most dangerous effect of chromate on human body is lung cancer due to direct contact by inhalation, ingestion, and

skin contact [7]. Recently, numerous researcher have made efforts in the search to find a promising replacement inhibitor for chromate. Unfortunately, there is no corrosion inhibitor as good as sodium chromate. Sodium chromate inhibitor contains chloride ions which make it the most efficient inhibitor for aluminium alloy [5]. The objective of this study is to investigate the effect of sodium chromate inhibitor variation to corrosion rate AA 7050 in 3.5% NaCl environment.

2 Experimental procedures

2.1. Materials

Material used in this study is a commercial 7050 aluminium alloy as investigated materials. The main alloying elements in the alloys are Al-Mg-Zn-Cu whereas the mechanical properties of AA 7050 can be improved by heat treatment. The chemical composition of this material is given in Tables 1.

2.2 Microstructure examination

In this study, the specimens for microstructure analysis were prepared according to standard metallographic (ASTM E3) method including cutting specimen from three principal directions, mechanical polishing of material, and etching process using Keller's Reagent.

* Corresponding author: ilman_noer@ugm.ac.id

Three principal directions of material are short transverse (ST), long transverse (LT), and longitudinal (L). The samples of microstructure analysis were examined using optical microscope.

Table 1. Chemical composition of AA 7050.

Element	Weight (%)	Element	Weight (%)
Al	87.55	Si	0.0663
Fe	0.0991	Cu	1.9275
Mn	0.0071	Mg	2.0012
Cr	0.0050	Ni	0.0093
Zn	8.2914	Ti	0.0276
Ca	0.0040	P	0.0011
Pb	0.0003	Sb	0.0013
Sn	0.0006		

2.3 Tensile test

Tensile tests use ASTM E 8M standard as reference. The geometry of specimen is given in Fig. 1. Tensile test specimens were taken along longitudinal section and parallel to rolling direction. The result of tensile test will show the ultimate and yield stresses of the material.

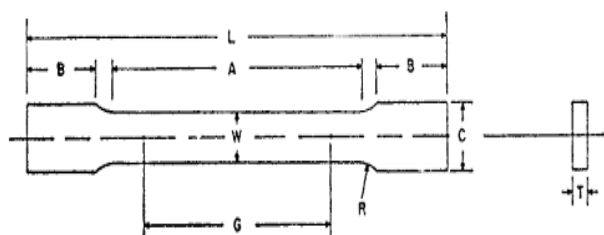


Fig. 1. Tensile test specimen (ASTM E8).

The dimension of tensile test specimen are:

- G = Gage length = 50 mm
- W = Width = 12.5 mm
- T = Thickness = 4 mm
- R = Radius of fillet = 12.5 mm
- L = Overall length = 200 mm
- A = Length of reduce = 57 mm
- B = Length of grip = 50 mm
- C = Width of grip = 20 mm

2.4 Hardness test

Hardness test was conducted to determine the ability of material to resist indentation, scratch, and penetration. Like microstructure examination, hardness test was carried out on three principal directions of material by means of Buehler microhardness tester with Vickers microhardness method.

2.5 Electrochemical polarisation test

The result of electrochemical polarisation test is corrosion rate of material in miles per year. The test was performed in 3.5% sodium chloride environment mixed with chromate inhibitor variation and then compared with

3.5% sodium chloride environment as a reference. The concentrations of chromate inhibitor were varied, i.e. 0.1%, 0.3%, 0.5%, and 0.7%. The corrosion test was conducted using a three-electrode cell with saturated calomel electrode (SCE) as the reference electrode and platinum wire as the auxiliary electrode.

3 Results and discussion

3.1 Microstructure analysis

The microstructure of three principal directions of the materials are shown in Fig. 2. It can be seen that short transverse and long transverse sections have an elongated grains structure because both planes are parallel with rolling direction. In the longitudinal plane, the microstructure has a large equiaxed grains structure because the rolling direction is not parallel to the longitudinal section. Another microstructural feature shown in Fig.1 is the presence of the secondary phase due to aging process. The secondary phase consists of Mg_2Zn precipitates which spread throughout the grain structure and increase the mechanical properties due to dislocation movement prevention.

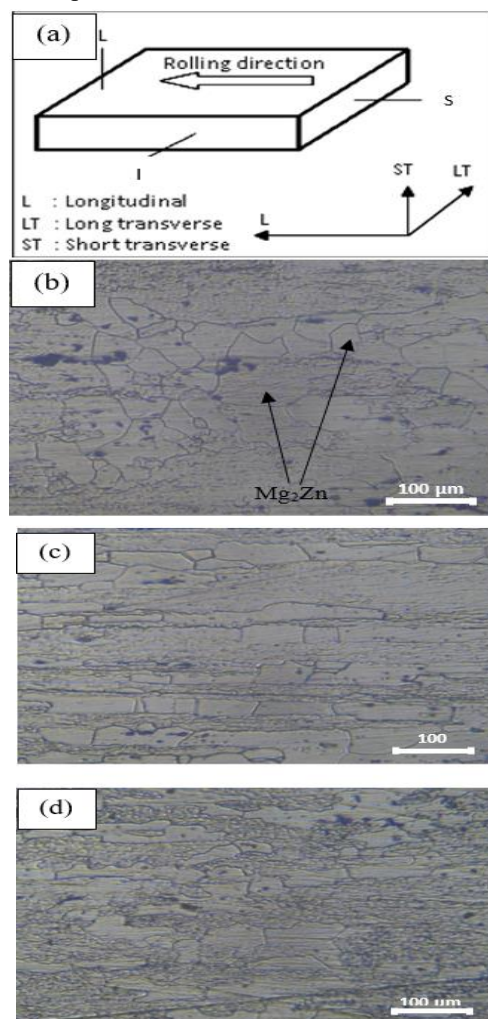


Fig. 2. (a) Three principal direction in wrought AA 7050 with the corresponding microstructure: (b) longitudinal, (c) long transverse, (d) short transverse.

3.2 Tensile test results

The average tensile test results of the three tested samples are presented in Fig 3. The tensile test showed the ultimate and yield strengths were 527.36 MPa and 481.42 MPa respectively.

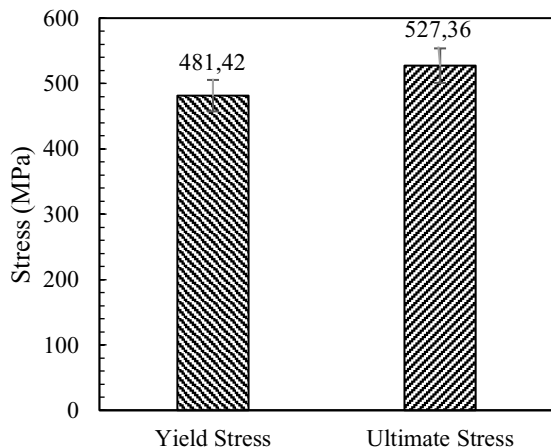


Fig. 3. Tensile test result.

3.3 Hardness test results

Fig. 4 shows the hardness test results in three principal directions. The highest Vickers micro hardness value is achieved by short transverse section whereas the lowest hardness value occurs in the longitudinal section. The rolling process in material causes increasing dislocation density and resulting strain hardening.

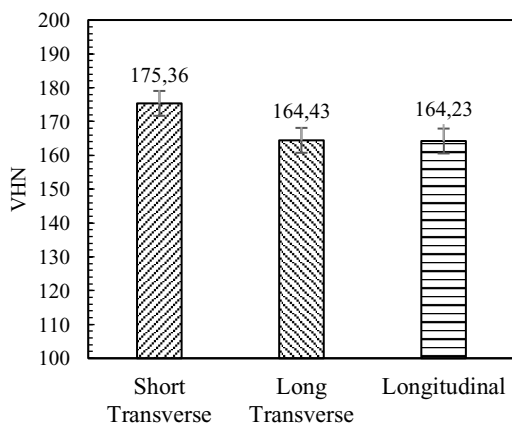


Fig. 4. Hardness test result.

3.4 Corrosion rate results

Based on anodic polarisation curve in Fig. 5, i_{corr} values can be determined where i_{corr} represents corrosion rates. In this study, the effect of increasing chromate inhibitor concentration will decrease i_{corr} values as shown in Table 2. The corrosion rates are not only given in current density (i_{corr}) value but also in (mpy) and (mm/year). Referring to Table 2 the corrosion rate of AA7050 material decrease with sodium chromate addition.

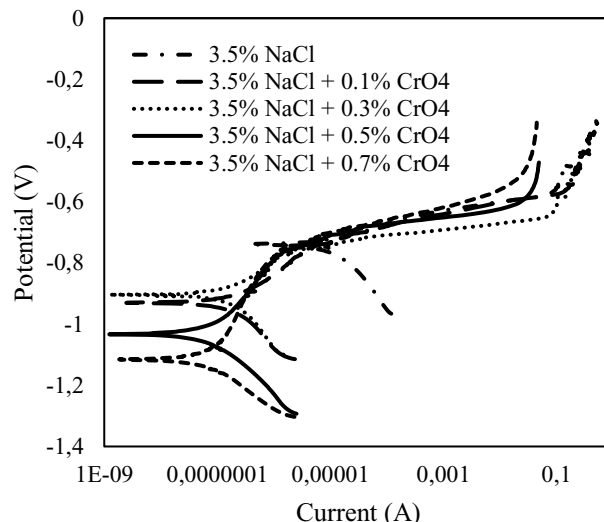


Fig. 5. Anodic polarisation curves of AA 7050 in 3.5% NaCl with inhibitor variation content.

Table 2. Corrosion rate of AA 7050.

Environment	i_{corr} ($\mu A/cm^2$)	Corrosion rate (mpy)	Corrosion rate (mm/year)
3.5% NaCl	5.021	2.01	0.051
3.5% NaCl + 0.1% Na_2CrO_4	0.122392	0.045	0.001
3.5% NaCl + 0.3% Na_2CrO_4	0.086086	1.658	0.042
3.5% NaCl + 0.5% Na_2CrO_4	0.050245	2.115	0.053
3.5% NaCl + 0.7% Na_2CrO_4	0.049145	2.343	0.059

Based on Table 2 the effectiveness of inhibitor can be determined by inhibitor efficiency (IE) equation [4]:

$$IE (\%) = \frac{i_o - i}{i_o} \times 100 \quad (1)$$

Where i and i_o in Eq. (1) are corrosion rate of material with and without inhibitor corrosion. Figure 6 shows that increasing inhibitor efficiency is affected by increasing corrosion inhibitor concentration.

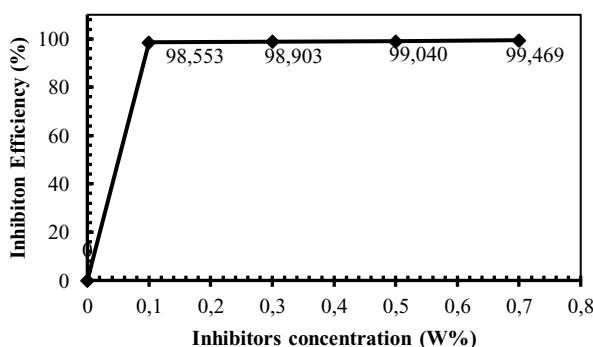


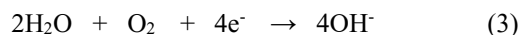
Fig. 6. Inhibitor efficiency curves.

The corrosion behaviours of AA7050 in 3.5% NaCl environment with chromate additions are marked by the presence of plateau region which are associated with thin and oxidized layer. These oxide layers provide corrosion protection to the surface. However, as time passes, the

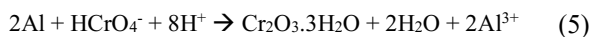
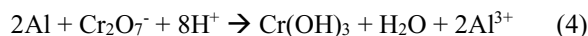
thin layer will be damaged due to the combination of oxidation and reduction reaction between the material and its environment. Electrochemical reaction that occurred in the corrosion process caused the transferred of electron between the anode and cathode. The oxidation reaction occurred in 3.5% NaCl environment is [7],



The electrons released by oxidation reactions are received by reduction reactions and dissolved in basic condition. The reduction reactions in this condition is [7],



Chromate can be occurred in two form, i.e. HCrO_4^- or $\text{Cr}_2\text{O}_7^{2-}$, the both of ions have characteristic as strong an oxidizing agent. In low pH, chromate can be reacted to the following equation [8],



The $\text{Cr}(\text{OH})_3$ and $\text{Cr}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ compounds from Eq (4) and (5) have an insoluble characteristic which can form a thin passive layer. The passive layer provided protection to anodic site from aggressive environment, therefore the corrosion rate of material will decrease.

4 Conclusions

The addition of corrosion inhibitor concentration in the 3.5% NaCl environment can reduce the corrosion rate of materials indicated by decreasing I_{corr} value due to increasing passivity of AA 7050.

References

1. M. N. Ilman, Chromate inhibition of environmentally assisted fatigue crack propagation of aluminium alloy AA 2024-T3 in 3.5% NaCl solution *Int. J. of Fatigue* **62** 228–235, (2014)
2. P. Jia, Y. Cao, Y. Geng, L. He, N. Xiao, J. Cui, Studies on the microstructures and properties in phase transformation of homogenized 7050 alloy, *Materials Science & Engineering* **A612** 335–342, (2014)
3. M. Chaussuimier, C. Mabru, M. Shahzad, R. Chieragatti, R. Farhad, A predictive fatigue life model for anodized 7050 aluminium alloy, *Int. J. of Fatigue* **48** 205–213, (2013)
4. Q. B. Zhang, Y. X. Hua, Corrosion inhibition of mild steel by alkyimidazolium ionic liquids in hydrochloric acid, *Electrochim Acta* **54**:1881–7, (2009)
5. C. J. E. Smith, M.S. Higgs and K. R. Baldwin, 1999, *Advances in Protective Coatings and their Application to Ageing Aircraft, RTO meeting proceeding 25* (1999)
6. C. Vargel, *Corrosion of Aluminium*, (Elsevier Ltd, 2004)
7. Trethewey KR, Chamberlain J. *Corrosion for science and engineering*. 2nd ed. (Longman, Essex, 1995)
8. Zhao J, Xia L, Sehgal A, Lu D, McCreery RL, Frankel GS. Effects of chromate and chromate conversion coatings on corrosion of aluminum alloy 2024-T3. *Surf Coat Technol* 140:51–7, (2001)