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ARTICLE

# Consistent Variation of Stress Corrosion Cracking Susceptibility and Passive Film-induced Stress for 7050 Aluminum Alloy with Polarization Potential

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**Abstract:** The film-induced stress and susceptibility to stress corrosion cracking (SCC) of 7050 aluminum alloy in the chloride solution at various potentials was investigated. The results show that large tensile stress is generated by the passive film during original corrosion. The passive film induced tensile stress increases obviously with an increase in potential under anodic potential; however, it decreases with an increase in potential when the potential $E \geq$-1100 $mV_{SCE}$ while it increased when $E <$-1100 $mV_{SCE}$ under cathodic potential. The variation of film-induced stress with potential is consistent with that of the susceptibility to SCC with potential.

**Key words:** 7050 aluminum alloy; stress corrosion cracking; passive film-induced stress; polarization potential

Aluminum alloys of 7000 series (Al- Zn-Mg-Cu) have been introduced since 1943 and used extensively as airframe structures due to their high specific strength [1]. In the numerous studies reported in the scientific literatures on this subject, two basic mechanisms have been proposed to model SCC (stress corrosion cracking): anodic dissolution and hydrogen embrittlement. However, there is currently no consensus on the precise mechanism [2,3]. Recently, many researchers have proposed a new mechanism to explain SCC that the corrosion process promotes localized plastic deformation and finally results in SCC. Chu Wuyang's [4-7] work shows that the corrosion process can facilitate dislocation emission and motion during SCC of brass, type 304 stainless steel, $\alpha$-Ti and $Ti_3Al$+Nb, and cracks of SCC will nucleate in a dislocation-free zone (DFZ) only when the corrosion-enhanced dislocation emission and motion develop to a critical condition. It has been mentioned that vacancies induced by anodic dissolution can facilitate the climb of edge dissolutions, which result in anodic polarization- enhanced ambient creep[8].

Many experiments show that metal foils with a protective layer formed on one side are concave or convex during anodic polarization using a potentiostat because of tensile or compressive stress, respectively, generated at or near the passive film interface[9]. For aluminum alloy there is a passive film formed during corrosion in a 3.5%NaCl solution impressed an anodic polarization potential; however, when impressed a cathodic polarization potential, there is still a passive film formed.

When the aluminum alloy is immersed in a chloride solution, the metallic ions cross the passive film into solution and dissolve constantly through exchanging with anions [10]; at

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the same time, great additional tension is generated at the interface of film and matrix which can facilitate dislocation emission and motion. When the dislocation emission and motion reaches to a critical value, the localized stress concentration will be equal to the atomic bonding force and then leads to breaking of atomic bonds, correspondingly, making the SCC micro-cracks nucleate[11,12]. So far, there have been few reports on the passive film and its relationship with susceptibility to SCC of 7050 aluminum alloy.

The aim of the present study is to determine the relationship between the passive film-induced stress and the susceptibility to SCC by a flowing stress difference method and slow strain rate testing (SSRT) in 3.5%NaCl solution impressed an anodic or cathodic polarization potential coupling electrochemical impedance spectroscopy (EIS) with energy dispersive spectroscope (EDS).

## 1 Experiment

The 7050 high strength aluminum alloy tested was supplied by Alcoa Co. in the form of smooth specimens machined from a 40 mm thick rolled plate. The chemical composition of the alloy is listed in Table 1. The specimens were 2 mm in thickness and 15 mm in gauge length with the tensile axis parallel to the short transverse direction which is known to be the most sensitive orientation to SCC [13]. They were heat-treated with over aging: solid solution at 470 °C for 2 h and then aging at 135 °C for 24 h after water quenching. All of the specimens were abraded with a sequence of emery papers from 500# to 1200#, rinsed in de-ionized water, degreased in acetone and dried prior to testing.

The susceptibility to SCC was evaluated in terms of the percent strength loss $I_\sigma$ measured through SSRT tests.

$$I_\sigma = (1-\sigma_{SCC}/\sigma_F)\times 100\% \quad (1)$$

where, $\sigma_F$ and $\sigma_{SCC}$ are the strength to fracture of tensile specimens during SSRT in air and in the 3.5%NaCl solution, respectively, at a strain rate of $1\times10^{-6}$ $s^{-1}$. The specimens were etched in a 2% NaOH solution for 1 min in order to remove the air-formed oxide. After cleaning in diluted $HNO_3$ solution, the specimens in the solution were kept at various constant potentials from −640 to −1300 $mV_{SCE}$ (including anodic and cathodic polarization). The stable open-circuit potential was −730 $mV_{SCE}$.

The specimens were strained in air to a plastic strain $\varepsilon_P \geq 1\%$ under a strain rate of $1\times10^{-6}$ $s^{-1}$. After unloading, the specimens were immersed in the 2% NaOH solution for 1 min to remove the oxide and cleaned in diluted $HNO_3$ solution, then put into the 3.5% NaCl solution and impressed various constant potentials for 24 h to form different passive films. After that, the specimens with passive film were again strained in air to yield. The yield stress of the specimen with passive film, $\sigma_{ys}$, was less than the flow stress of the specimen before unloading, $\sigma_f$. The difference between $\sigma_f$ and $\sigma_{ys}$ is the film-induced stress i.e., $\sigma_P = \sigma_f - \sigma_{ys}$.

**Table 1 Chemical composition of the 7050 aluminum alloy (wt%)**

| Element | Al | Zn | Mg | Cu | Zr | Fe | Si | Ti | Mn |
|---|---|---|---|---|---|---|---|---|---|
| Content | Bal. | 6.42 | 2.25 | 2.02 | 0.13 | 0.11 | 0.07 | 0.03 | 0.10 |

A potentiostat-galvanostat (PAR273A, Shanghai, China) and a frequency response analyzer were used together with a Faraday cage to avoid external interferences. The traditional EIS three electrode set-up was employed using Ag/AgCl, KCl (saturated) as the reference electrode, platinum gauze as the counter electrode and the 7050 aluminum alloy substrate as the working electrode. To control the exposed area of metal, a poly (methylmethacrylate) cylindrical tube was clamped to the metallic substrates. The area exposed to the electrolytes was 1 $cm^2$ and the volume of the electrolyte was 120 $cm^3$. The measurement of EIS was carried out in the frequency ranging from $10^{-2}$ Hz to $10^5$Hz and the amplitude deviation within 5 mV at OCP.

The film surface was studied with SEM (JEOL JSM6360-LA, Tokyo, Japan).

## 2 Results

### 2.1 Susceptibility to SCC of 7050 aluminum alloy in 3.5% NaCl solution

The maximum stress and time to fracture of the specimen during extending in air are $\sigma_F$ =500 MPa, and $t_F$ = 40.6 h, respectively. The stress and time to fracture of the specimen during SSRT at open circuit and various potentials are listed in Table 2. The susceptibility to SCC, $I_\sigma$ is also listed in Table 2. Table 2 indicates that polarization potential has a great influence on the susceptibility to SCC, especially under an anodic potential.

Fig.1 shows the fracture surface of 7050 aluminum alloy immersed in air, in 3.5% NaCl solution and impressed various potentials. The fracture surface of the alloy extending in air is dimple, and there has some inclusions inside. The open-circuit condition has a brittle dimple rupture surface and the fracto-graphy of SCC at a cathodic polarization of –1100 $mV_{SCE}$ is interpreted as mixed intergranular and quasicleavage trans-

**Table 2 Susceptibility to SCC of 7050 aluminum alloy at various potentials**

| $E$/$mV_{SCE}$ | $\sigma_{SCC}$/MPa | $I_\sigma$/% | $t_{SCC}$/h |
|---|---|---|---|
| −640 | 214 | 57.2 | 15 |
| −670 | 275 | 45 | 17.1 |
| −700 | 288 | 42.4 | 17.5 |
| −730* | 340 | 32 | 24 |
| −800 | 324 | 35.2 | 19 |
| −900 | 291 | 41.8 | 17.8 |
| −1100 | 260 | 48 | 16.4 |
| −1200 | 282 | 43.6 | 17.3 |
| −1300 | 300 | 40 | 18 |

* Open circuit potential