



Corrosion pathways in aluminium alloys



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Abstract: The corrosion pathways in AA2024-T3, AA5083-O and AA6082-T6 alloys have been investigated. The objective of the investigation is to further the understanding of the complex localised corrosion mechanism in aluminium alloys. The investigation was carried out by examining the corroded surfaces of the alloys after potentiodynamic polarization tests in a 3.5% NaCl solution with the aid of a scanning electron microscope, and by analysing the flow of anolyte solution using the scanning vibrating electrode technique. The results revealed that the overall corrosion pathways in the alloys are distinctively different and are influenced by the flow of anolyte solution. Also revealed, was the fact that corrosion propagates in two ways (particularly in the AA5083-O and AA6082-T6 alloys): an overall pathway in the corrosion front (filiform-like pathway in the AA5083 alloy and organized linear pathways in AA6082 alloy); and the crystallographic channelling along the $\langle 100 \rangle$ directions. These are dependent on the grain distinct features of the AA5083-O and AA6082-T6 alloys and are not influenced by the presence of coarse second phase particles in these alloys, compared with the AA2024-T3 alloy, where the corrosion pathways are more dependent on the presence of second phase particles and grain boundary character.

Key words: corrosion front pathway; crystallographic channelling; anolyte flow; aluminium alloy

1 Introduction

The localized corrosion behaviour of aluminium alloys has been widely studied, particularly in the last two decades, using various characterization tools and techniques. Electrochemical techniques do not give a true representation of the localized corrosion kinetics and morphology. ZHANG and FRANKEL [1] argued this in the past, where they stated that there are problems associated with the use of electrochemical techniques for the study of localized corrosion in high strength aluminium alloys because 1) it is difficult to measure the active area during localized corrosion, 2) some of the anodic currents are used for H₂ evolution and, thus, the measured current will not be a true representation of the corrosion kinetics, and 3) the use of electrochemical techniques in the study of localized corrosion under open circuit conditions is impossible. Thus, other techniques have been used to give more information on the morphology and kinetics of localized corrosion in addition to electrochemical techniques. Such techniques

and tools include foil penetrant technique [1], confocal laser scanning microscopy [2], 3-D tomography and reconstruction [3–5], Auger electron spectroscopy and Rutherford backscattering [6], scanning Kelvin probe force microscopy and atomic force microscopy [7–9], and scanning electron and transmission electron microscopies [3,5,10–13].

Reports about the influence of second phase particles on the localized corrosion behaviour of aluminium alloys abound in the literature [10,12–21]. Second phase particles like the Al₂CuMg, Al₃Mg₂, Mg₂Si, and MgZn₂ are anodic to the Al matrix and corrode preferentially with respect to the surrounding Al matrix. The behaviour of the S-phase (Al₂CuMg) is a bit more complicated: firstly, the Mg and Al components are leached out to leave behind a spongy Cu remnant which makes it eventually cathodic to the Al matrix and causes the dissolution of the adjacent Al matrix. On the other hand, there are second phase particles such as Al₂Cu (θ), AlFeMnSi, AlCuFeMn, AlCuFeSi, and (Al,Cu)_x(Fe,Mn)_ySi particles which are mostly cathodic to the Al matrix and cause peripheral trenches of the

surrounding Al matrix adjacent to these second phase particles.

The morphological characterization of the localized corrosion behaviour of Al alloys has been mostly linked to the behaviours or nature of these second phase particles [10,12,13,15–21]. However, few authors have considered other factors. LUO et al [22] considered the influence of grain stored energy on the intergranular corrosion pathway in an AA2024T3 alloy and revealed that the intergranular dissolution was more on the grain with higher stored energy at the grain boundary between the two grains. Still on grain boundary character, KIM et al [23] investigated the effect of grain boundary character distribution on the intergranular corrosion susceptibility of pure Al alloy in different concentrations of HCl solution. It was reported that low angle grain boundaries were more resistant to intergranular corrosion compared with twin boundaries and random boundaries in all the concentrations of HCl used in the study, and this was particularly noted at lower concentrations of HCl solution. At HCl concentrations of 16% and 8%, twin boundaries were observed to be more resistant to intergranular corrosion compared with random boundaries. In addition, TAN and ALLEN [24] reported that grain angle boundaries less than 20° tend to be more resistant to corrosion. MINODA and YOSHIDA [25] also made similar findings while investigating the intergranular corrosion behaviour of an extruded AA6061 aluminium alloy in accordance with the ISO 11846 method. It was observed that the surface of the extruded AA6082 alloy, which has recrystallized grains with random high angle boundaries, was more susceptible to intergranular corrosion compared with the centre plane of the extruded alloy. The susceptibility to intergranular corrosion was attributed to the formation of precipitate free zones, and the formation of the precipitate free zones was related to the presence of high angle boundaries. This was confirmed by cold rolling and recrystallizing the grains of the centre plane; and random high angle grain boundaries and heavy intergranular corrosion were observed afterward. However, more recent findings have shown that finer grained regions of aluminium alloys are more resistant to corrosion in near neutral pH media and are more prone to corrosion in low pH (acidic) media [10,26,27] such as the medium MINODA and YOSHIDA used in conducting their investigation. Higher kinetics of passive film formation and “cleaner” grain boundaries were attributed to the better corrosion resistance of finer grained regions in near neutral environment [26,27].

In spite of all this work on the influence of grain boundary character, grain stored energy, and second phase particles on the localized corrosion behaviour of aluminium alloys, the localized corrosion behaviour of

aluminium alloys is far from being fully understood and arguments still exist. This is in addition to the fact that information on the effect of grain distinct crystallographic details of the alloys and flow of anolyte solution on the localized corrosion behaviour of aluminium alloys is rare to find in literature. Therefore, the focus of this work is to investigate the corrosion pathways, particularly within the grains of AA2024-T3, AA5083-O and AA6082-T6 alloys after polarization tests. The investigation is based on the observed corrosion morphologies in the grains of the alloys (using scanning electron microscopy, after potentiodynamic polarization tests) and the observation of anolyte solution flow during a galvanic corrosion test between AA2024-T3 and mild steel alloys using the scanning vibrating electrode technique (SVET).

2 Experimental

Three different aluminium alloys, namely AA2024-T3, AA5083-O and AA6082-T6 aluminium alloys were used in this study. The compositions of the alloys are presented in Table 1. The AA2024-T3 alloy was obtained from Airbus whilst the AA5083-O and AA6082-T6 alloys were obtained from the Welding Institute, UK.

Table 1 Compositional analysis of major alloying elements in AA2024-T3, AA5083-O, and AA6082-T6 aluminium alloys used in this study (mass fraction, %)

Alloy	Mg	Si	Mn	Fe	Zn	Cu	Ti	Cr
AA2024-T3	1.2–1.8	0.5	0.3–0.9	0.5	0.24	3.8–4.9	0.15	0.1
AA5083-O	3.92	0.03	0.44	0.23	0.01	–	–	–
AA6082-T6	0.74	0.44	0.40	0.33	0.05	–	–	–

Samples from the alloys were sequentially polished up to 1 µm surface finish using SiC papers and a 1 µm diamond paste with an alcohol based lubricant. The polished samples were then degreased in an ultrasonic bath for 15 min and rinsed in deionized water before drying in a cool air stream. The dried samples were then coated with Lacquer 45 whilst exposing a 1 cm² surface area prior to potentiodynamic polarization tests.

Potentiodynamic polarization tests were conducted in a naturally aerated 3.5% NaCl solution using a Modulab potentiostat. A 3-electrode cell comprising the workpiece, a saturated calomel electrode (as the reference electrode) and a platinum electrode (as the counter electrode) was used for the polarization tests. Polarized samples were immediately rinsed in deionized

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