STEM and EDS Profiling of Grain Boundary Characteristics of Three 6111-type Al Alloys and Alloys' IGC Susceptibility

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6XXX aluminum alloys are known to be susceptible to pitting and intergranualr corrosion, particularly so if the alloy contains copper additions or an excess amount of silicon. It has been postulated that the IGC attack on 6XXX Al alloys may operate through the same mechanism as the case of binary Al-Cu alloys except different second-phase particles other than $CuAl_2$ may exist. The direct or indirect observation of copper containing phases at the grain boundaries (GB) of Cu-containing 6XXX Al alloys has been reported by several authors.

In this study, we investigated the pitting and IGC susceptibilities of three 6111-type aluminum alloys with 0%, 0.68%, and 1.47%Cu, respectively. The electrochemical behavior of the alloys was evaluated using open circuit exposure, conventional polarization technique, and electrochemical noise techniques. Scanning electron microscopy (SEM) was used to characterize the corrosion morphologies of the alloys. Transmission electron microscopy was employed to characterize the alloys' microstructures. Scanning transmission electron microscopy (STEM) and EDS nano-profiling were used to study the grain boundary characteristics of the three alloys. 30~70 nm wide Mg and Si depleted regions and 10~100 nm wide Cu-depleted regions along the GBs have been detected in the non-copper containing alloy and copper containing alloys, respectively. A direct link between the grain boundary elemental profiles and the alloys' IGC susceptibility has been established for the first time on 6XXX aluminum alloys.

Figure 1 is a bright-field TEM image taken on a thin foil of the alloy with 1.47%Cu after 60 seconds immersion in dilute HCl solution (pH=2.7) showing extensive preferential dissolution at the GBs. The dilute HCl was used to simulate the aggressive environment inside an active pit or a propagating IGC front. Figure 2 is a HAADF STEM image of a high-angle grain boundary of the alloy with 1.47%Cu showing the Cu-Mg-Si rich phase at the GB and the accompanying EDS elemental profiles across the GB, also shown is the Cu-depleted region adjacent to the GB in the elemental profiles.

ACKNOWLEDGEMENTS
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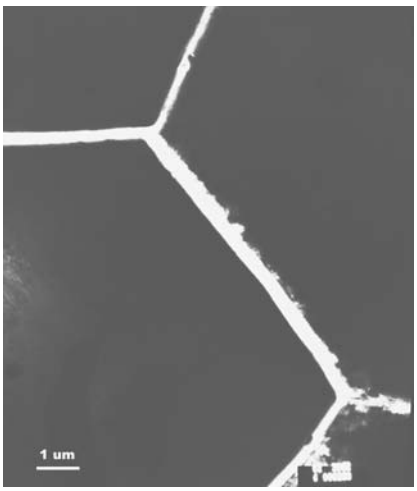
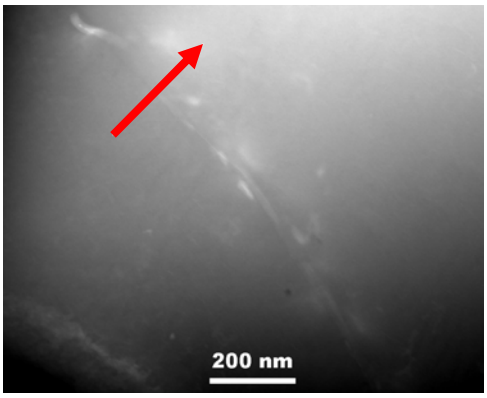
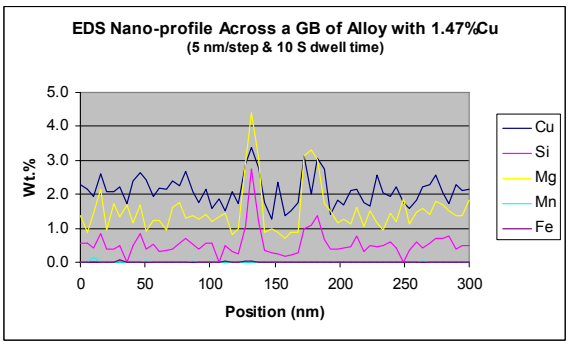


Figure 1 – Bright-field TEM image of foil of alloy with 1.47%Cu after 60 seconds immersion in dilute HCl (pH=2.7) showing extensive preferential attack along grain boundaries leaving narrow bands behind (0.4 μm in width).



(a)



(b)

Figure 2 - Alloy with 1.47%Cu: (a) HAADF STEM image showing a grain boundary, (b) EDS elemental profiles showing twin peaks of Cu, Mg and Si indicating the presence of Cu-Mg-Si rich phase and adjacent ~35nm Cu depleted region between the peaks. The Cu-Mg-Si rich phase appeared to be discontinuous along the GB. The balance is Al%.