Initial localized corrosion and long-term atmospheric corrosion induced by multiscale precipitates in the high-strength Al-Zn-Mg-Cu alloy

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Abstract: This work focuses on the distribution characteristics of harmful micron-scale precipitates and high-density nanoscale precipitates in the new generation high-strength Al-Zn-Mg-Cu alloy, as well as the electrochemical mechanism of initial localized corrosion. The results demonstrate that the micron-scale harmful precipitates are mainly irregular shaped Al_7Cu_2Fe phase with ~ 0.5 vol%. Main strengthening phase is rod-like and cube-shaped Mg (Zn, Al, Cu)$_2$ nano-precipitates, which range in size from a few tens to several hundred nanometers. Opposite to the traditional view of considering Mg-rich phase as micro-anodes, experimental and calculation results both suggest that Mg (Zn, Al, Cu)$_2$ precipitates exhibit higher Volta potential than the matrix due to the doping of Cu atoms. In aggressive conditions, the surrounding matrix is preferentially corroded while the Mg (Zn, Al, Cu)$_2$ particles undergo localized breakdowns by forming nano-pits ascribed to the Mg atoms dissolution. Compared with Mg (Zn, Al, Cu)$_2$ phases, a greater potential difference (approximately 600 mV) between Al_7Cu_2Fe micro-cathodes and matrix drives the earlier initiation of galvanic corrosion. In addition, the work functions of different precipitates are calculated by DFT. The work function values: Al_7Cu_2Fe > $Mg_4Zn_4Cu_3Al$ > Al > $MgZn_2$, and the theoretical calculation results are highly consistent with the experimental results.

Moreover, the influence of impurity content on the corrosion behavior of Al-Zn-Mg-Cu alloys in a tropical marine atmospheric environment has also been systematically investigated. Combined with experimental measurements and theoretical calculations, it has been elaborated that the Volta potential difference is the main reason for the localized corrosion. The composition-property correlation has been established between the impurity contents, the type, size, and quantity of precipitates, and the corrosion behavior. The effects of impurity contents on the volume fraction of precipitates and corrosion parameters such as corrosion rate and average pit depth have been quantified, offering quantitative guidance to develop novel Al-Zn-Mg-Cu alloys. The results demonstrate that pitting corrosion, IGC, and intragranular corrosion are the main corrosion forms for the three alloys. As the reduction of impurity content, the number and depth of pits decrease, and severe intragranular corrosion transforms into IGC. Compared with the 7050 alloy (3.34 g·m-2·a-1), the corrosion rates of HPA and UPA alloys have decreased to 2.92 g·m-2·a-1 and 2.84 g·m-2·a-1 respectively, which is attributed to the reduction of impurity content in the alloys. The corrosion rate of UPA alloy is merely reduced by 3% compared to HPA, thereby indicating that further reduction of impurity content has a negligible improvement on the atmospheric corrosion resistance of the Al-Zn-Mg-Cu alloys.

Keywords: High-strength Al-Zn-Mg-Cu alloy; Precipitates; Impurity contents; Localized corrosion; Atmospheric corrosion