

Understanding the corrosion response of 6xxx series Al-alloys at near atomic to nanometer scale using advanced characterisation techniques.

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Age hardening 6xxx series Al-alloys are, medium strength alloys, based on the Al-Mg-Si-(Cu) system. These alloys are extensively being pursued in the automobile sector and also have potential to replace some of high strength 2xxx series Al-alloys, based on the Al-Cu-Mg system, for aircraft fuselage applications. These applications are realised by increasing the strength of 6xxx series Al-alloys by controlling composition, ageing temperature and time. Ageing introduces precipitates, which obstruct the motion of dislocations in the Al-matrix, resulting in an increase in the strength of the alloys. However, in general the corrosion behaviour deteriorates with the introduction of precipitates in the Al-matrix. The variation in the composition of precipitates compared with the surrounding Al-matrix generates a micro galvanic couple (in precise nano) between them. Based on the electrochemical behaviour, either precipitates or the Al-matrix dissolve. The corrosion process initiates at near atomic to nanometer length scale and extends to catastrophically fail components prior to their service span, resulting in loss of human life and money. A better understanding on the corrosion process at such length scale will aid in designing and developing high performance corrosion resistant alloys. This aim can be realised by applying advanced characterisation techniques, such as transmission electron microscopy (TEM) and 3D atom probe tomography (3D-APT), to understand the corrosion process at near atomic to nanometer scale.

In the present study, the corrosion behaviour of custom-made 6xxx alloy sheets varying in Si:Mg ratio, Cu content and ageing conditions was studied and correlated with the microstructure and hardness of the alloys. The corrosion morphology in 6xxx alloys was altered from pitting to intergranular corrosion (IGC), based on ASTM G110 standard test, with ageing at 185°C for 20 min, and the IGC persisted up to 24 h of ageing. Furthermore, the severity of IGC increased with an increase in Si:Mg ratio and Cu content, the latter being more significant. The origin of IGC in Cu-free alloys is due to the evolution of nanometer scale β -phase (Mg_2Si) and pure Si particles along grain boundaries (GBs), which are accompanied by precipitate-free zones on either side. In Cu-containing alloys, IGC is originated as a result of the segregation of Cu atoms along GBs, realised by TEM and 3D-APT for the first time. Furthermore, the evolution of nanometer scale precipitates, such as Q-phase ($Al_xCu_yMg_zSi_w$), S-phase (Al_2CuMg) and β -phase (based on Si:Mg ratio), also contributed to the development of IGC in Cu-containing alloys. The electrochemical behaviour of Q-phase was studied in 0.1M NaCl using a quasi in-situ TEM technique, an alternative to an expensive in-situ TEM technique. Dealloying of Q-phase was accompanied by the redeposition of pure nanocrystalline Cu containing nanometer scale twins. The present study unravelled the electrochemical behaviour of Q-phase for the first time. In addition, an optimum strength and corrosion resistant 6xxx series Al-alloy was developed and the mechanism was also proposed for the first time.