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Investigation on optimum corrosion protection potential of Al alloy in marine environment[*]

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The Al alloy is environmental friendly, easy to recycle, and provides a high added value to fishing boats. We report a number of electrochemical experiments undertaken to determine the optimum conditions for protecting 5083 Al alloy in seawater. The current density in the cathodic polarization increased with the potential shifts to a more negative value. Current densities in –1.8 V to –2.4 V increased abruptly with any shift toward the active direction. On shifting in more anodic and cathodic directions outside the range from –1.4 V to –0.7 V, the current density increased suddenly. It was concluded that this potential range offered optimal protection potential.

Key words: *Al alloy; fishing boat; electrochemical experiments; optimum protection potential*

1. Introduction

Fibre-reinforced polymer (FRP) ships used with small boats for fishing pose numerous problems from both the environmental and recycling perspectives. In particular, no methods exist to dispose of these ships at the end of their service. Al alloy is environmental friendly, easy to recycle, and provides a high added value to fishing boats. Aluminum craft require less fuel. Developed nations have shown an increasing interest in utilizing Al alloys in ships since environmental restrictions on scrapping FRP ships have become stronger. The specific strength of Al ships is higher than that of steel ships [1]. Ships constructed with 5000-series Al alloy suffer little or no corrosion in the marine environment.

In this paper, we report a number of electrochemical experiments undertaken to determine the optimum conditions for protecting 5083F (Al–Mg alloy) in seawater.

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2. Experimental

For the electrochemical experiments, the 5083F specimen (Al-Mg alloy, Si 0.090%, Fe 0.289%, Cu 0.018%, Mn 0.589%, Mg 4.449%, Cr 0.076%, Zn 0.005%, Ti 0.009%, Al balance, tensile strength 319.2 MPA, yield strength 154.8 MPa, elongation 23.7%) was mounted in an epoxy resin so as to leave an exposed area of 100 mm^2 that was polished with #600 emery paper. Each specimen was carefully degreased with acetone and distilled water. The electrochemical apparatus consisted of a Pt coil as the counter electrode and an Ag/AgCl reference electrode. Anodic polarization experiments were executed from an open circuit potential to the range of –0.5–3.0 V in seawater. Cathodic polarization experiments were undertaken from open circuit potential to –2.0 V. In potentiostatic experiments, a variety of polarization potentials in seawater were applied for 1200 s and evaluated in terms of the variations of current density remaining after 1200 s at a given applied potential.

3. Results and discussion

The anodic polarization curve for 5083F specimen in seawater is shown in Fig. 1. The 5083 Al alloy is most widely used because it is both strong and resistant to corrosion in the seawater environment. The current densities from open circuit potential to –0.5V for 5083F alloy were abruptly increased. The current density at the potential range above –0.5 V shows a very high value. The passivity phenomenon of 5083F Al alloy was not observed by a continuous increase in current density.

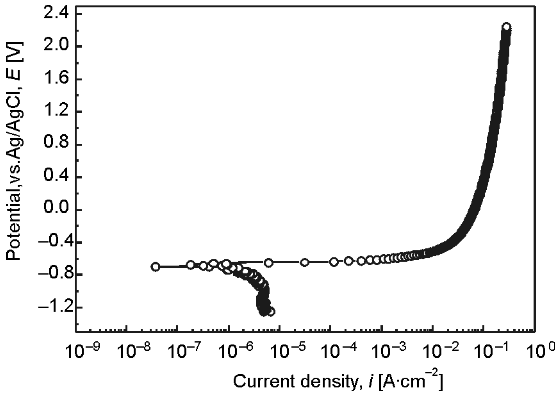

Fig. 1. Anodic polarization curve of 5083F in sea water

Figure 2 presents time dependences of current densities obtained from the potentiostatic experiment at anodic applied potentials of 5083F alloy in seawater. A variation in the current density was observed over the entire 1200 s of the experiment in the range from –0.80 V to ca. –0.60 V, but the values remained low. The current densities at –0.80, –0.70, and –0.60 V after 1200 s were 1.2×10^{-6}, 8.5×10^{-6}, and 7.0×10^{-3} A/cm^2, respectively. The current densities at applied potential from –0.50 V to ca.

–0.20 V remained constant from the earliest stages of the experimental run. The current densities for potentials of –0.20 and –0.50 V behaved in a similar manner to that during anodic polarization, gradually increasing over the initial stages. As the potential increased from 0 to 0.8 V and then to 1.6 V, the current density after 1200 s increased.

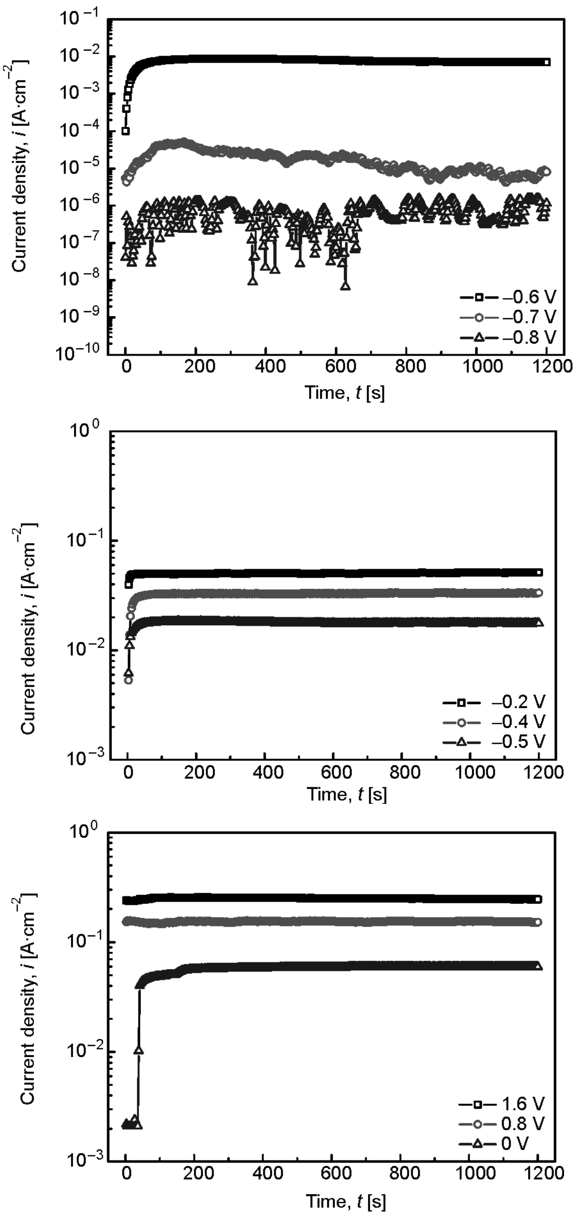

Fig. 2. Time-current density curves during 1200 s at anodic potential for 5083F in sea water

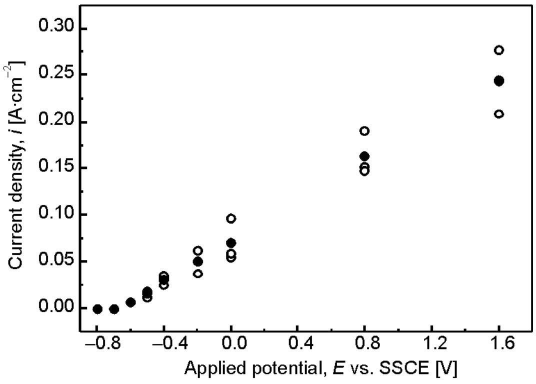

Fig. 3. Current densities after potentiostatic experiment during 1200 s for 5083F

Figure 3 compares the current densities obtained in the potentiostatic experiments after 1200 s for all 5083F specimens analyzed at various anodic potentials in seawater. Each potentiostatic experimental run was executed several times, with the black circles representing the mean values under various conditions. The current densities in the range from –0.8 V to –0.7 V show very low values in all experimental runs. At –0.6 V, the current density increased slightly. Above –0.6 V, the current densities increased in a straight line with increasing potential. Corrosion can similarly occur when hydrogen is generated at appropriate potentials in both acidic and alkaline solutions as shown in the *E*–pH diagram for Al [2]. The behaviour of Al in seawater (approximately pH 8.0) differs from that of Al in neutral solutions.

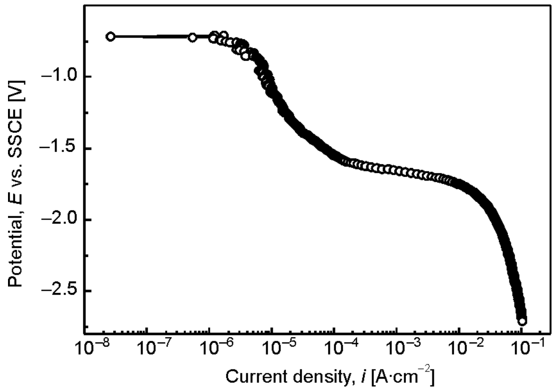

Fig. 4. Cathodic polarization curves in sea water

Figure 4 presents the result of cathodic polarization experiment for 5083F specimen in seawater. The polarization for 5083F Al alloys shows the effects of concentration polarization ($O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$) and activation polarization ($2H_2O + 2e \rightarrow H_2 + 2OH^-$). The turning point between the concentration polarization due to oxygen reduction and the activation polarization due to hydrogen gas generation is the limit potential which determines the corrosion protection potential. The current density in anodic polarization is higher than that of dissolved oxygen reduction during cathodic polarization. This implies that from the economical point of view cathodic protection is more beneficial than the anodic one. The current density at the corrosion protection potential of metal, which has a potential range corresponding to the concen-

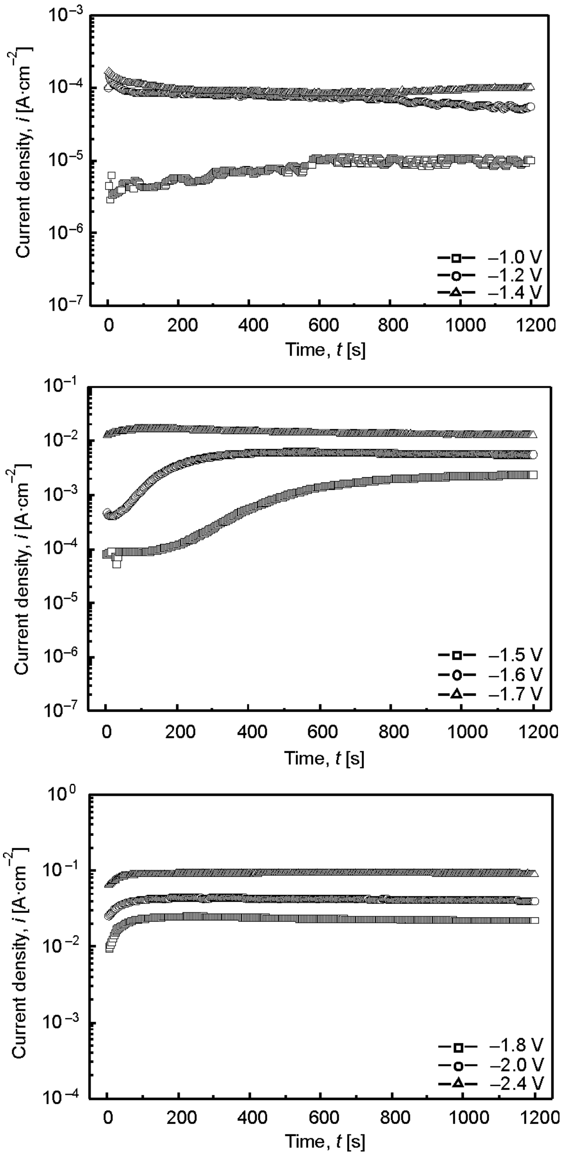

Fig. 5. Time–current density curves during 1200 s at cathodic potential for 5083F in sea water

tration polarization of the cathodic polarization curve, is very important. The limit protection potential (hydrogen embrittlement generation potential) at cathodic polarization of this Al alloy is –1.64 V.

In Figure 5, time dependences of current densities obtained from the potentiostatic experiment at cathodic potentials applied to 5083F alloy in seawater. The results were obtained at applied potentials of –1.4 V to –1.0 V, a potential range that includes that of dissolved oxygen reduction, i.e., that within the protection potential range. Current densities in the range from –1.4 V to –1.0 V showed stable values at early stages. All current densities tended to be low. In the range from –1.7 V to –1.5 V, spanning the changeover from concentration polarization to activation polarization, the current density increased with the potential shifts to a more negative value. This potential range corresponded to the generation of atomic hydrogen ($H^+ + e \rightarrow H$) or the production of molecular hydrogen from atomic hydrogen ($H^+ + e + H \rightarrow H_2$, $H^+ + H \rightarrow H_2$). The upshot was acceleration of activation polarization and an increase in current density. We concluded that atomic hydrogen affected the potential at which the changeover occurred. In the range from –2.4 V to –1.8 V, the current density increased with an increase in negative potential and the increase in current density was linear, with activation polarization intensifying the generation of hydrogen due to cathodic polarization that could be seen by the unaided eye. The effect of atomic hydrogen was smaller than that of molecular hydrogen. In investigations on hydrogen embrittlement in high-strength steel [3, 4], the point at which the changeover takes place from concentration polarization to activation polarization is at approximately –1.0 V (SCE). The current density for the potential at which hydrogen is generated during cathodic polarization increased abruptly. The potential of –0.9 V (SCE) in high-strength steel can also be included in the range at which concentration polarization occurs because the reaction involves the reduction of dissolved oxygen. However, hydrogen embrittlement can also occur at –0.9 V when atomic hydrogen is present. The changeover point for 5083F Al alloy appears at approximately –1.64 V. A comparison of the current densities measured for 5083F alloy in seawater at the conclusion of 1200 s is shown in Fig. 6 at various cathodic potentials.

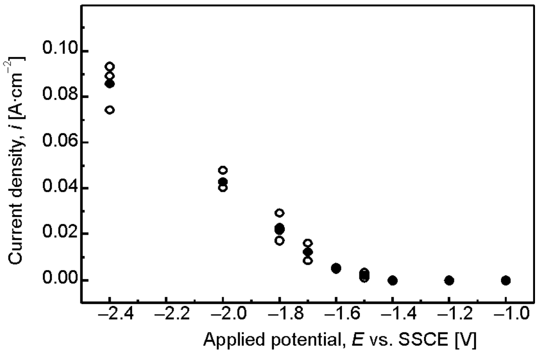

Fig. 6. Comparison of current density

The potential range between –1.4 V and –1.0 V during cathodic polarization showed a low current density applicable to protection. At –1.5 V, the effects of atomic hydrogen are seen in a slightly elevated current density. The potential range from –1.7 V to – 1.5 V corresponded to the changeover, and was affected by the presence of both atomic hydrogen and molecular hydrogen. We concluded, however, that effects on the current density from atomic hydrogen were small. Current densities in the range from –2.4 V to –1.8 V increased abruptly with any shift toward the negative direction and it seems likely that their high current densities reflected the presence of molecular hydrogen. This was the same trend observed in cathodic polarization. In the potential range from –0.7 V to –1.4 V, current densities were low and gave an estimate of the viable protection potential range. The current density increased suddenly when the applied potential shifted beyond the protection potential range in either the anodic or cathodic directions. The optimum protection potential in the potential range from –1.4 V to –0.7 V for 5083F alloy was obtained, when current densities were very low. According to the criteria for cathodic protection given by England (CP 1021) [5], the protection potential of Al is from –0.85 V to –1.1 V(SSCE), with pitting not occurring at a cathodic polarized potential of about 0.15 V compared to the open circuit potential. The current densities in all experiments undertaken to ascertain electrochemical properties returned very low values in the potential range in that effects on the current density from atomic which concentration polarization by dissolved oxygen reduction occurs.

4. Conclusions

Cathodic polarization results in concentration polarization by dissolved oxygen reduction and activation polarization as a result of hydrogen generation. The changeover occurs at –1.64 V (SSCE) in 5083F Al alloy. Current densities increase suddenly in both anodic and cathodic directions beyond the potential range of –1.4 V to –0.7 V. Consequently, optimum protection occurs in the potential range of –1.4 V V to –0.7 V.

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