Evaluation of slow strain rate test to decide optimum corrosion protection potential of Al alloy

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1. Introduction

Fiber-reinforced plastic (FRP) ships, including small fishing boats, face many environmental and recycling challenges. Composite FRP materials are susceptible to fire and cannot be used in high-speed passenger ships and cargo boats with gross tonnages over 500 tons, such as those commonly used in coastal navigation. Like wooden vessels, FRP ships cannot be detected by larger craft since their composite materials are poor radar reflectors. According to data collected by the Ministry of Maritime Affairs and Fisheries, 72.4% of all marine accidents between 1998 and 2002 and approximately 58% of all collisions with fishing boats involved FRP vessels. For these reasons, aluminum (Al) is a much better material for ships than FRP. It is environmentally friendly, easy to recycle, and provides a high added value to fishing boats. Al craft also require less fuel. Developed nations have shown increasing interest in Al alloys since environmental restrictions on scrapping FRP ships have become more stringent.

In this study, we used electrochemical methods and slow strain rate tests to determine the optimum corrosion protection range of 5083-H112 Al alloy specimens in seawater to counter corrosion, stress corrosion cracking, and hydrogen embrittlement.

2. Materials and Experimental Method

The specimens used for the electrochemical tests were mounted on 5083-H112 with epoxy resin to give an exposed area of 100 mm^2, and then polished with #600 emery paper. The polarization system consisted of a Pt coil that acted as counter electrode, and a Ag/AgCl-saturated KCl reference electrode. The tests were carried out at a scan rate of 2 mV/s at room temperature. Anodic and cathodic polarizations were created using an open-circuit potential in the range +3.0 to -2.0 V with a Ag/AgCl electrode. In the potentiostatic experiment, the current densities were compared after 1200 s at various potentials in seawater solution. The 6-mm-thick test specimens were 235 × 4 mm. Notches 1 mm wide and 1 mm deep were made on both sides the specimens to cause a fracture. The specimens used for slow strain rate test (SSRT) were also exposed to natural seawater. The SSRT was carried out at a strain rate of 0.001 mm/min during which a constant potential was maintained using a potentiostat apparatus.

3. Results and Discussion

Fig. 1 shows the anodic and cathodic polarization curves for a 5083-H112 Al specimen in seawater. The first passivity stage in the anodic polarization curve occurred at a potential of -1.0 to -0.7 V. However, the current density increased remarkably above -0.7 V as the passivity film was destroyed. Thereafter, the current

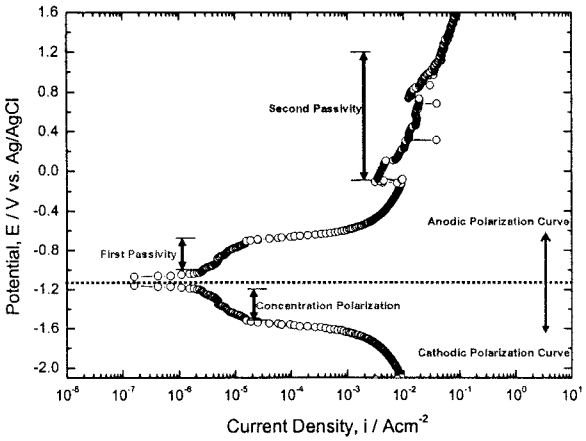

Fig. 1 Anodic and cathodic polarization curves

density decreased as the second passivity film formed at -0.1 V. After this, the current density slowly increased with time, and then decreased above +0.7 V. From the cathodic polarization curve, the potential that generated the concentration polarization, the corrosion protection potential, was approximately -1.55 V. The current density of the protection potential was between 2×10^{-6} and 2×10^{-5} A/cm^2. However, the potential for the first passivity phenomenon was -1.0 to -0.7 V, corresponding to a current density of 2.5×10^{-6} to 1.7×10^{-5} A/cm^2.

Fig. 2 compares the current densities after the 1200-s potentiostatic experiment on 5083-H112 specimens at various potentials in a natural seawater solution. For a potential in the range -1.45 to -0.7 V, current densities were very low and gave a good indication of the viable protection potential range. This range corresponds to the first passivation stage of anodic polarization (area 1 in Fig. 2) and the concentration polarization by the dissolved oxygen reduction reaction in the cathodic polarization curve (area 2 in Fig. 2). The current densities for potentials greater than -0.6 V on the anodic polarization curve were high. The curve for -0.4 V shows this very clearly. However, the current density for a potential of 0 V was lower than that of -0.4 V due to the first passivity phenomenon. After the first passivity, the current density increased as the potential increased. In addition, in the potentionstatic experiment, a potential of -1.45 V on the cathodic polarization curve is in the corrosion protection range. Moreover, the current density in the potentiostatic experiment was small. The current density for an applied potential of -1.5 V increased slightly due to the generation of atomic hydrogen. The potential at the transition point between corrosion protection by concentration polarization and activation polarization is affected by atomic hydrogen and molecular hydrogen. We concluded that the low current density is due mainly to the effect of atomic hydrogen (area 3 in Fig. 2). However, the current density suddenly increased as the potential increased in the negative direction toward the turning point. This was due to molecular hydrogen (area 4 in Fig. 2), as clearly seen from the cathodic polarization curve. Therefore, we concluded from the results of the potentiostatic experiment that the protection potential range was -0.7 to -1.45 V (area 5 in Fig. 2).

We next used SSRT to evaluate stress corrosion cracking and hydrogen embrittlement. Fig. 3 shows stress-elongation curves for -0.8 V, -0.7 V, and -0.6 V during SSRT in a seawater solution. The lowest tensile strength and elongation were observed at a potential of -0.6 V, after the first passivity on the anodic polarization curve. The deterioration of tensile strength and elongation at -0.6 V were due to the active dissolution reaction in parallel parts of the specimens. The strength and elongation at -0.6 V were less than what occurs in seawater with no protection. Potentials of -0.7 and -0.8 V corresponded to the first passivity stage. Under these conditions, the specimens were

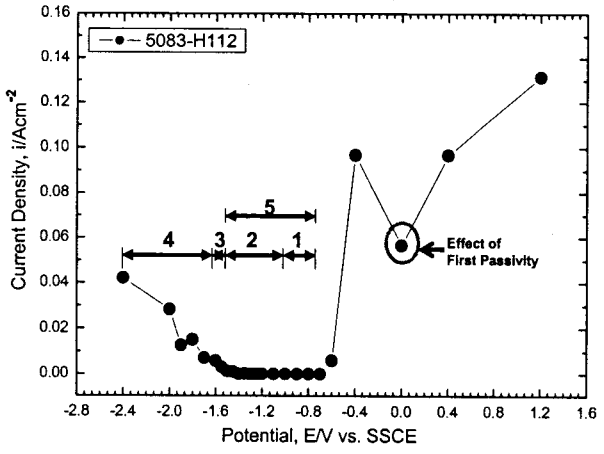

Fig. 2 Comparison of current density after potentiostatic experiment of 1200 s

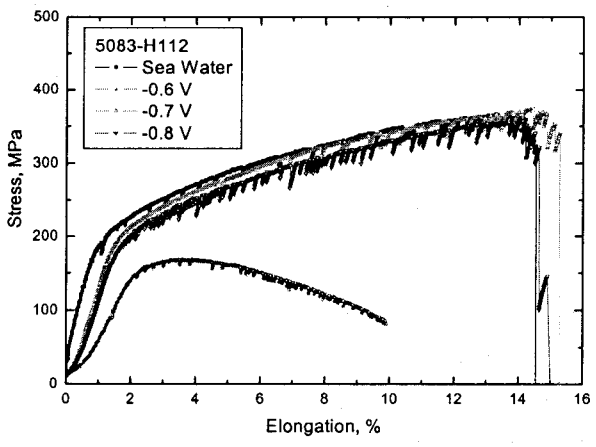

Fig. 3 Stress-elongation curves in sea water, -0.6 V, -0.7 V and -0.8 V

protected from corrosion due to the high strength and elongation.

Fig. 4 compares the effects of applied potential on maximum tensile strength after SSRT in a seawater solution. The maximum unprotected tensile strength was 358 MPa. In the case of an applied potential in the range -1.4 V to -0.7 V, the tensile strength was higher. This same potential range produced a low current density as shown in Fig. 2. The maximum tensile strengths dropped for a potential either above or below the protection range. The lowest tensile strength was measured for a potential of -0.6 V, which was when active dissolution occurred.

At the effect of the applied potential on elongation after SSRT in a seawater solution, the elongations were the greatest (14.53%) for an applied potential between -1.1 and -0.7 V compared to the unprotected condition. However, the elongation for a potential range of -1.4 V to -1.2 V was lower that what occurs under the unprotected condition, coinciding with the low current density for cathodic polarization and results of the potentiostatic experiment. In addition, potentials less than -1.6 V resulted in little elongation due to the influence of hydrogen. A potential of -0.6 V after the first passivity resulted in remarkably low elongation due to the effect of the active dissolution reaction. We therefore concluded that the protection potential range from the viewpoint of elongation was -1.1 to -0.7 V.

Table 1 presents the optimum corrosion protection potential obtained from various experiments. The lowest current densities in the potentiostatic experiment and galvanostatic experiment occurred for potentials between -1.45 and -0.7 V, and between -0.9 and -0.7 V, respectively. The common range from SSRT was -1.1 to -0.7 V. The galvanostatic experiment, however, indicated that the optimum range was -0.9 to -0.7 V based on observations of the corroded surfaces.

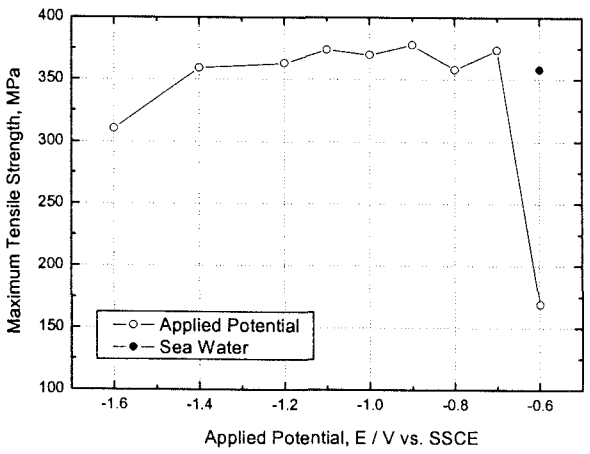

Fig. 4 Effects of applied potential for maximum tensile strength after SSRT in natural sea water.

Table 1 Optimum corrosion protection potential obtained from various experiments.

		Corrosion protection potential
Anodic Polarization Experiment		-1.0 V ~ -0.7 V
Cathodic Polarization Experiment		-1.55 V ~ -0.86 V
Galvanostatic Experiment		-0.9 V ~ -0.7 V
Potentiostatic Experiment		-1.45 V ~ -0.7 V
Slow Strain Rate Test	Maximum Tensile Strength (MPa)	-1.4 V ~ -0.7 V
	Yield Strength (MPa)	-1.6 V ~ -0.6 V
	Elongation (%)	-1.1 V ~ -0.7 V
	Time to Fracture (Hr)	-1.1 V ~ -0.7 V
	Fractography Analysis	-1.1 V ~ -0.7 V

Postscript

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