

Control of Galvanic Corrosion Between A516Gr.55 Steel and AA7075T6 Depending on NaCl Concentration and Solution Temperature

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Chloride ion is one of the most important corrosive agents in atmospheric corrosion, especially in marine environments. It has high adsorption rate and increases the conductivity of electrolytes. Since chloride ions affect the protective properties and the surface composition of the corrosion product, they increase the corrosion rate. A low level of chloride ions leads to uniform corrosion, whereas a high level of chloride ions may induce localized corrosion. However, higher solution temperatures tend to increase the corrosion rate by enhancing the migration of oxygen in the solution. This work focused on the effect of NaCl concentration and temperature on galvanic corrosion between A516Gr.55 carbon steel and AA7075T6 aluminum alloys. When AA7075T6 aluminum alloy was galvanically coupled to A516Gr.55 carbon steel, AA7075T6 was severely corroded regardless of NaCl concentration and solution temperature, unlike the corrosion properties of single specimen. The combined effect of surface treatment involving carbon steel and aluminum alloy on corrosion behavior was also discussed.

Keywords: Carbon steel, AA7075T6, Galvanic corrosion, NaCl concentration, Solution temperature

1. Introduction

Metallic materials have been used in various environments including atmospheric, soil, and sea water. The variety of environmental factors known as pH, dissolved oxygen, aggressive ions, and temperature can generate and facilitate any kinds of corrosion [1-3].

In an atmospheric corrosion, chloride ion is one of very important corrosive agent, especially in marine environments, and its properties show high adsorption rate and increase the conductivity of electrolytes. Since chloride ions have influenced the protective properties and composition of corrosion product formed on the surface, they increased the corrosion rate; low level of chloride ion can form an uniform corrosion but high level of chloride ion may induce a localized corrosion [4-8]. On the other hand, higher solution's temperature, corrosion rate tends to be increased, because the migration of oxygen in the solution was active by increasing the temperature [9,10].

Recently, we reported the effects of NaCl concentration

(0.01 ~ 1% NaCl) and solution temperature (30 ~ 75 °C) on the galvanic corrosion between CFRP (Carbon Fiber Reinforced Plastic) and A516Gr.55 carbon steel [11]; Since CFRP showed the water absorption and the high open circuit potential, most of metallic materials may be galvanically corroded if the materials contact with CFRP. Average corrosion rate of single carbon steel increased 0.63% when NaCl concentration increased from 0.01% to 1%, but its rate of the steel coupled with CFRP increased 46.9%. However, when the temperature increases by 10 °C, corrosion rates of single specimen or coupled specimen with CFRP revealed a similar effect, even though the rate of coupled specimen was higher than that of single specimen.

Aluminum and its alloys can form the passive film on the surface in exposed corrosive environments. However, in the presence of chloride ion, they have influenced the stability of the passive film and eventually generate the pitting corrosion [12-17]. On the other hand, pitting potential in high temperature can be lowered than that in low temperature of solution, because the diffusivity of aggressive ion in high temperature was increased than that in low temperature. But in some cases, the passive film formed in high temperature can be more protective than

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that of low temperature [18-20].

As reported elsewhere [21], the effect of NaCl concentration of (0.01, 0.1, and 1)% NaCl and solution temperature of (30, 50, and 75 °C) on the corrosion between CFRP and AA7075 aluminum alloy was discussed; On increasing the NaCl concentration or solution temperature, the galvanic corrosion rate of AA7075T6 by CFRP was increased several hundred times over that of the single specimens, and the effects of NaCl concentration or solution temperature on the increasing of the corrosion rate in the galvanic coupled specimen were higher than that in the single specimen.

This work focused on the effect of the concentration of NaCl and temperature on the galvanic corrosion between A516Gr.55 carbon steel and AA7075T6 aluminum alloy and the combination effect of surface treatment for carbon steel and aluminum alloy on corrosion behavior was discussed.

2. Experimental methods

2.1 Materials

Commercial aluminum alloy (AA7075T6) and carbon steel (A516Gr.55) were used in this work. The chemical composition of AA7075 used in the experiments was Al-0.095Si-0.137Fe-1.540Cu-0.008Mn-2.590Mg-0.209Cr-5.590Zn-0.020Ti and A516Gr.55 was Fe-0.26C-0.90Mn-0.27Si. In order to investigate the galvanic effect, Zn-55%Al coated carbon steel (Galvalume) was also used.

2.2 Polarization test

Specimens were cut to a size of 1.5 mm × 1.5 mm and the surface was ground using #600 SiC paper and was the specimen was electrically connected with a rubber coated Cu wire, and the surface of the specimen was coated with epoxy resin, except for an area of 1 cm². Polarization tests were performed using a potentiostat (Gamry co. Interface 1000, DC105). The reference electrode was a saturated calomel electrode (SCE), and the counter electrode was high-density graphite rods. The test solution was deaerated using nitrogen gas at the rate of 200 ml/min for 30 min and the scanning rate was 0.33 mV/s. NaCl concentration was controlled as 0.01, 0.1, and 1% NaCl and solution temperature was maintained as 30, 50, and 75 °C.

2.3 Immersion corrosion test

Specimen was cut to a size of 15 mm × 20 mm × 1.5 mm and each surface was ground using #120 SiC paper. Every specimen was weighed and immersion test was performed during 10 days. Test solution was no-deaerated

and after the test, corrosion rate was calculated and the surface appearance was observed using an optical microscope (OM, Axiotech 100HD, Carl Zeiss, Germany).

2.4 Galvanic corrosion test

Specimens were cut to a size of 1.5 mm × 1.5 mm and the surface was ground using #600 SiC paper and the specimen was electrically connected with a rubber coated Cu wire, and the surface of the specimen was coated with epoxy resin, except for an area of 1 cm². Galvanic corrosion current and potential were measured during 5 hours using a potentiostat (Gamry co. Interface 1000, DC105). The reference electrode was a saturated calomel electrode (SCE), and the working electrode was AA7075 and the counter electrode was A516Gr.55. Test solutions were no-deaerated 0.1% NaCl at 30 °C, 50 °C, and 75 °C, and 0.01% NaCl, 0.1% NaCl, 1% NaCl at 50 °C. The corrosion rate was calculated by obtaining the average current density value from the current-time graph and putting it in the equation of $k \cdot ai/ZD$ (k = Conversion factors of corrosion rate, a = Atomic weight (g/mol), i = Current density ($\mu\text{A}/\text{cm}^2$), Z = valence, D = density (g/cm^3)).

2.5 Surface treatment

Anodizing of AA7075; The specimen of AA7075T6 was cut into a size of 50 mm × 20 mm, the surface was polished using #1200 SiC paper, the specimen was electrically connected with a rubber coated Cu wire, and the connection part was coated with an epoxy resin. The specimen was degreased with 10 wt% NaOH for 1 minute at 55 °C and then was acid cleaned for 2 minutes with 20 vol.% HNO₃ at room temperature. Anodizing solution was 5.5 vol.% H₂SO₄ at 5 °C using a cooling bath and pumping and Pb was used as a cathode. During the anodizing, the endothermic heat on the surface by anodizing was diminished through N₂ gas purging and AA7075T6 was anodized for 20 minutes in 90 mA/cm².

Ni-plating of A516Gr.55; The specimen of A516Gr.55 was cut into a size of 50 mm × 20 mm, the surface was polished using #2000 SiC paper, the specimen was electrically connected with a rubber coated Cu wire, and the connection part was coated with an epoxy resin. The specimen was ultrasonically cleaned for 1 minute in ethyl alcohol and was also activated for 10 minutes in 7 vol.% H₂SO₄. Ni-plating was performed at 100 mA/cm² for 30 minutes in Watts solution at 60 °C.

3. Results and Discussion

Fig. 1 depicts the effect of NaCl concentration on the corrosion rate of AA7075T6 by galvanic coupled

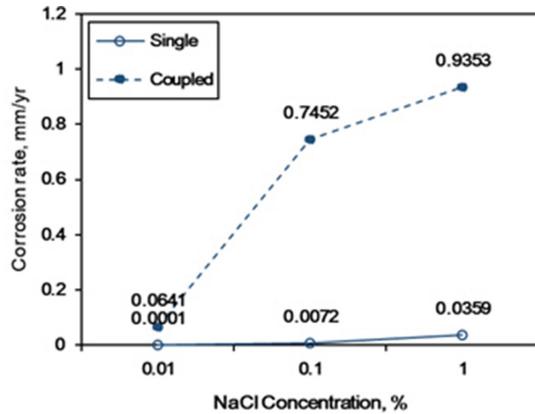


Fig. 1 Effect of galvanic coupling with A516Gr.55 on the corrosion rate of AA7075T6 by different concentration of NaCl (Solution temperature: 50 °C, x% NaCl solution).

A516Gr.55. Solution temperature was 50 °C and x% NaCl solutions were used. In the single AA7075T6 specimen, the corrosion rate increased slightly with increasing NaCl concentration. However, when AA7075T6 was galvanically coupled with A516Gr.55, the corrosion rate of AA7075T6 was drastically increased; At 0.01% NaCl solution, 64,100% of corrosion rate was increased by the galvanic effect with A516Gr.55. At 0.1% and 1% NaCl solutions, 10,350% and 2,605% of corrosion rates were increased

respectively, and thus average galvanic corrosion rate of AA7075T6 by A516Gr.55 increased several hundred times than the single specimens.

Fig. 2 shows the effect of NaCl concentration on the surface appearance of AA7075T6 after the corrosion tests. Solution temperature was 50 °C. Fig. 2a is for the single AA7075T6 specimen (OM, ×100) and as the concentration increases the shape of pits was almost spherical [11]. Fig. 2b is for the galvanic coupled AA7075T6 specimen with A516Gr.55 (OM, ×100) and the shape of pits was similar to the single specimen. Even though A516Gr.55 carbon steel was the cathode, color change by red rust was observed on the surface of the steel.

Fig. 3 reveals the combined curves between polarization curves of A516Gr.55 and polarization curves of AA7075T6. Solution temperature was 50 °C. Cathodic polarization curves of A516Gr.55 met the anodic polarization curves of AA7075T6 regardless of NaCl concentration. According to the mixed potential theory, corrosion cell can be divided into anode and cathode, and the summation of cathodic current is same to that of anodic current. Therefore, if two materials forms the galvanic cell, A516Gr.55 will be the cathode and AA7075T6 will be the anode, and AA7075T6 will corrode at very low rate because AA7075T6 was passive. However, as shown in Fig. 1, AA7075T6 was severely corroded than that of

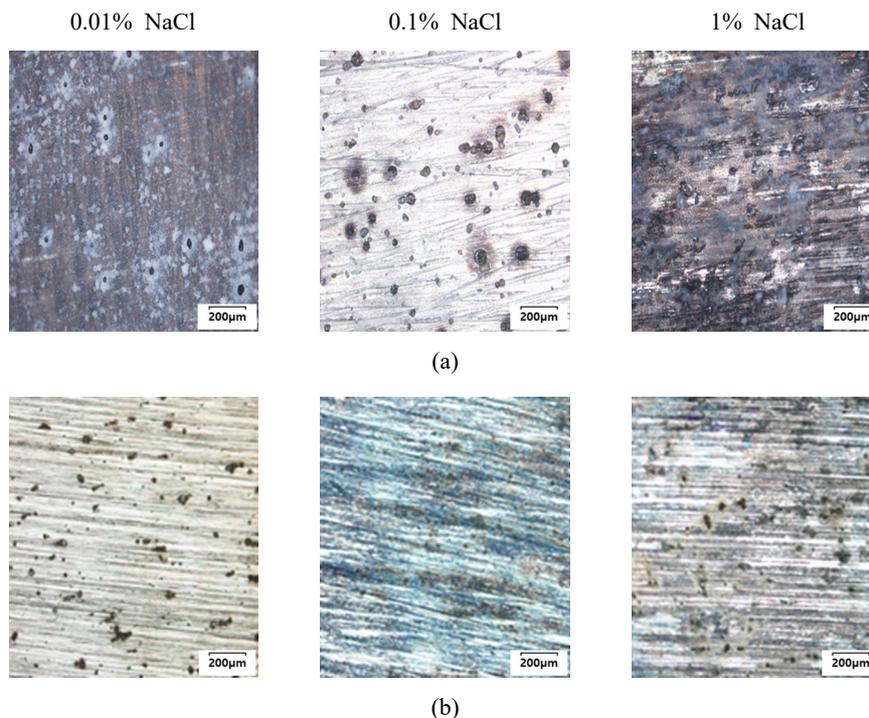


Fig. 2 Effect of NaCl concentration on the surface appearance of AA7075T6 after the corrosion tests (Solution temperature; 50 °C); (a) single specimen (OM, ×100) [21] and (b) galvanic coupled specimen with A516Gr.55 (OM, ×100).

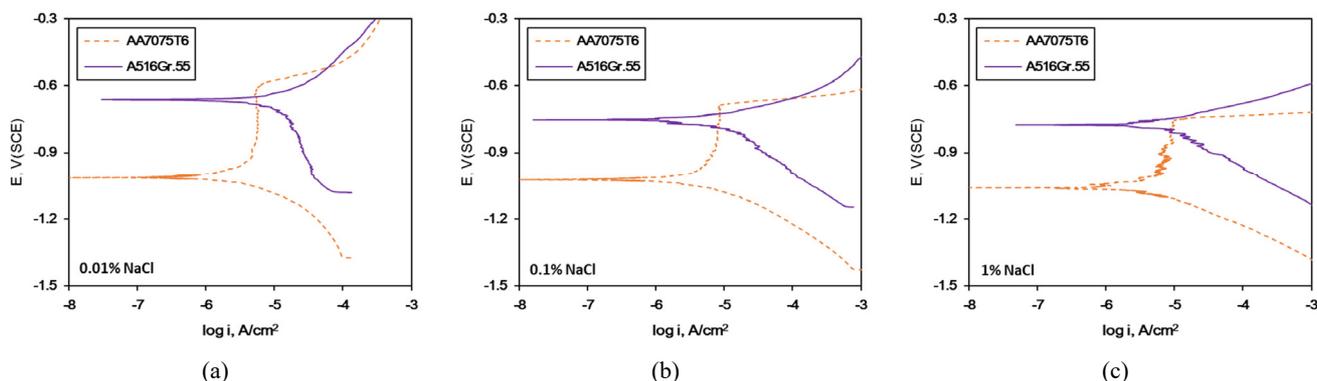


Fig. 3 Overlapped polarization curves of A516Gr.55 and AA7075T6 obtained in deaerated x% NaCl at 50 °C; (a) 0.01% NaCl, (b) 0.1% NaCl, (c) 1% NaCl.

single specimen.

Fig. 4 depicts the effect of solution temperature on the corrosion rate of AA7075T6 by galvanic coupled A516Gr.55. NaCl concentration was 0.1%. In the single AA7075T6 specimen, the corrosion rate increased slightly with increasing solution temperature. However, when AA7075T6 was galvanically coupled with A516Gr.55, the corrosion rate of AA7075T6 was drastically increased; At 30 °C, 413,900% of corrosion rate was increased by the galvanic effect with A516Gr.55. At 50 °C and 75 °C, 10,350% and 1,594 % of corrosion rates were increased respectively, and thus average galvanic corrosion rate of AA7075T6 by A516Gr.55 increased several hundred times than the single specimens.

Fig. 5 shows the effect of solution temperature on the surface appearance of AA7075T6 after the corrosion tests. NaCl concentration was 0.1%. Fig. 5a is for the single AA7075T6 specimen (OM, $\times 100$) and as the temperature increases the shape of pits was almost spherical. Fig. 5b

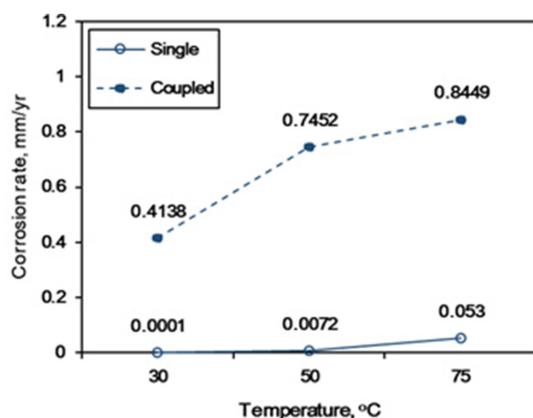


Fig. 4 Effect of galvanic coupling with A516Gr.55 on the corrosion rate of AA7075T6 by different solution temperature in deaerated 0.1% NaCl solution.

is for the galvanic coupled AA7075T6 specimen with A516Gr.55 (OM, $\times 100$) and the shape of pits was similar to the single specimen. Even though A516Gr.55 carbon steel was the cathode, color change by red rust was observed on the surface of the steel.

Fig. 6 shows the combined curves between polarization curves of A516Gr.55 and polarization curves of AA7075T6. NaCl concentration was 0.1%. Cathodic polarization curves of A516Gr.55 met the anodic polarization curves of AA7075T6 regardless of solution temperature. On the basis of the mixed potential theory, corrosion cell can be divided into anode and cathode. Therefore, if two materials form the galvanic cell, A516Gr.55 will be the cathode and AA7075T6 will be the anode, but AA7075T6 will corrode at very low rate because AA7075T6 was in a passive state.

However, as shown in Fig. 1 and Fig. 4, AA7075T6 was greatly corroded as the anode, regardless of NaCl concentration and solution temperature. Why did the difference happen? Fig. 7 reveals the variation of open circuit potential and galvanic potential of A516Gr.55 with time in non-deaerated 0.1% NaCl at 50 °C. That is, when carbon steel was exposed in corrosive environments, its open circuit potential increased to noble direction. Also, the average galvanic corrosion potential of AA7075T6 coupled with carbon steel is about -649mV(SCE), which is higher than that of AA7075T6's pitting potential. Therefore, as confirmed in Fig. 3 and Fig. 6, A516Gr.55 will be a cathode and AA7075T6 will be an anode over the pitting potential, and thus when AA7075T6 was galvanically coupled with A516Gr.55, AA7075T6 revealed very high galvanic corrosion rate, not as like a single specimen.

In order to protect the corrosion of AA7075T5 coupled with A516Gr.55 in chloride solution, AA7075T6 was anodized in sulfuric acid. When the anodized AA7075T6

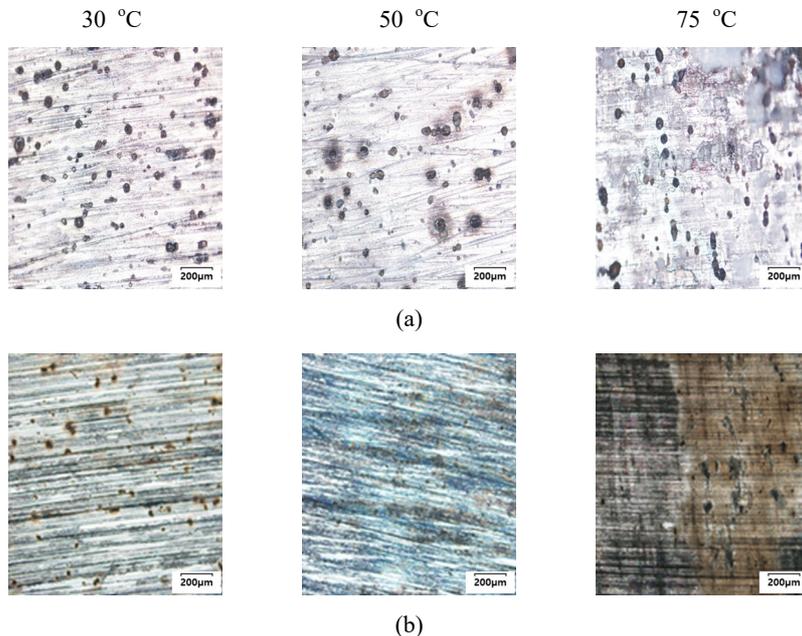


Fig. 5 Effect of solution temperature in 0.1% NaCl on the surface appearance of AA7075T6 after the corrosion tests in 0.1% NaCl solution; (a) single specimen (OM, $\times 100$) [21] and (b) galvanic coupled specimen with A516Gr.55 (OM, $\times 100$).

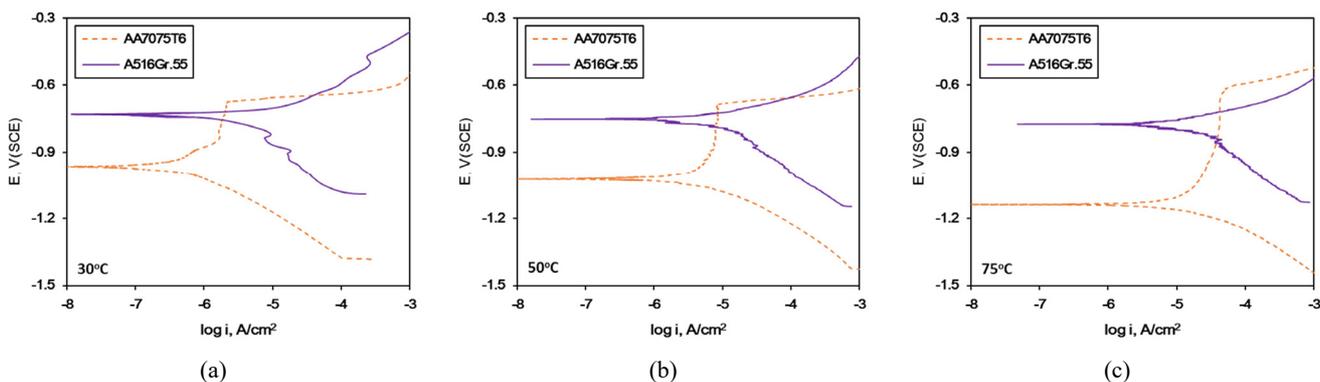


Fig. 6 Combination between cathodic polarization curve of A516Gr.55 and anodic polarization curve of AA7075T6 in deaerated 0.1% NaCl solution; (a) 30 °C, (b) 50 °C, (c) 75 °C.

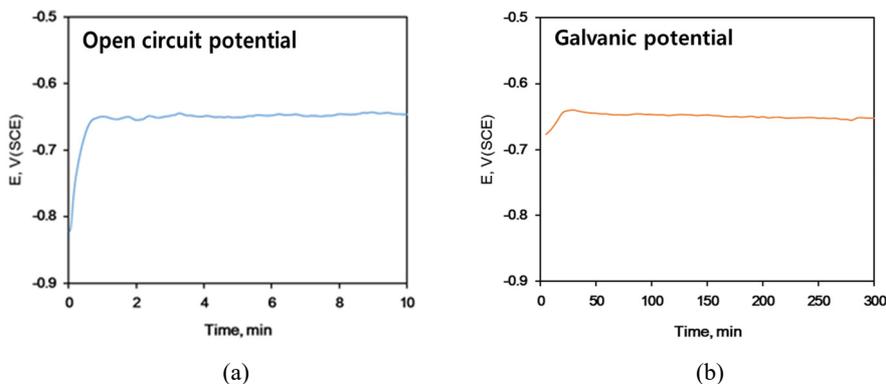


Fig. 7 Variation of open circuit potential and galvanic potential of A516Gr.55 with time in non-deaerated 0.1% NaCl at 50 °C; (a) open circuit potential, (b) galvanic potential.

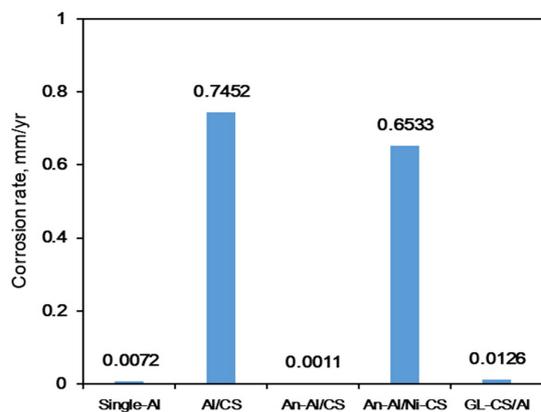


Fig. 8 Effect of surface treatment on the corrosion rate of AA7075T6 by galvanic coupled A516Gr.55 in non-deaerated 0.1% NaCl solution at 50 °C.

(An-Al) was galvanic coupled with A516Gr.55, the corrosion of anodized AA7075T6 was very suppressed at 0.0011 mm/yr (Fig. 8).

Actually, galvanic coupling between A516Gr.55 and AA7075T6 in chloride solution is the combination of two corroding metals. Therefore, even though AA7075T6 may protect the corrosion of A516Gr.55 via sacrificial anode, it would be not perfect and the red rust can be observed. Therefore, Ni-plating was applied to A516Gr.55. However, when the anodized AA7075T6 was galvanic coupled with Ni-plated A516Gr.55(Ni-CS), the anodized AA7075T6(An-Al) was severely corroded as shown in Fig. 8. This was not an optimum answer to solve the galvanic corrosion between AA7075T6 and A516Gr.55 in chloride solution. Therefore, we applied the galvanized steel to solve the galvanic corrosion. When Zn-55Al Galvalume was coupled to AA7075T6, the galvanized steel was the anode and its corrosion rate was 0.0126 mm/yr but this corrosion will give the sacrificial anode protection of AA7075T6 and the steel.

The variation of corrosion behavior can be explained through Fig. 9. Fig. 9 reveals the polarization curves in deaerated 0.1% NaCl solution at 50 °C of surface treated AA7075T6 and A516Gr.55. As shown in Fig. 9, anodizing treatment increased the corrosion potential of AA7075T6 and then the anodizing induced the corrosion of A516Gr.55, but Ni-plating corroded the anodized AA7075T6 because of very high potential of Ni-plated steel. However, Zn-55%Al Galvalume coating (GL-CS) revealed a similar corrosion potential to that of AA7075T6 and acted as the sacrificial anode as confirmed in Fig. 8. Therefore, it can be summarized that among the various surface treatment, Zn-55%Al coating was appropriate to protect the galvanic corrosion between A516Gr.55 carbon steel and AA7075T6

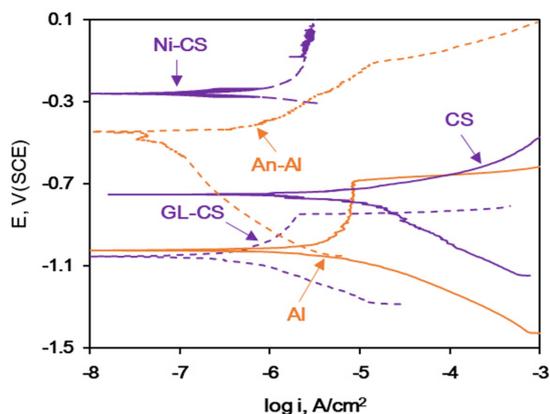


Fig. 9 Polarization curves in deaerated 0.1% NaCl solution at 50 °C of surface treated AA7075T6 and A516Gr.55.

aluminum alloy in a chloride solution and this was attributed to the similar corrosion potential and sacrificial anode property.

4. Conclusions

This work focused on the effect of NaCl concentration and solution temperature on the corrosion between A516Gr.55 carbon steel and AA7075T6 aluminum alloy and the effect of surface treatment on galvanic corrosion. The following can be concluded.

1. When AA7075T6 aluminum alloy was galvanically coupled with A516Gr.55 carbon steel, AA7075T6 was severely corroded regardless of NaCl concentration and solution temperature, not as like the corrosion properties of single specimen. This can be arisen because corrosion potential of carbon steel was increased as the immersion time and thus the increased potential induced the pitting corrosion of aluminum alloy.
2. Among the various surface treatment, a potential increasing treatment was not effective to prevent the galvanic corrosion of the combination of aluminum alloy and carbon steel, but the galvanizing was very effective to suppress the galvanic corrosion of two alloys because they had a similar corrosion potential and the galvanizing performed a sacrificial cathodic protection.

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