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Accelerated and Outdoor Exposure Tests of Aluminum Coated Steel Sheets

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Hot dip metallic coated steels like as galvanized (GI), zinc-aluminium (GL) and aluminium coated steels are mostly used where corrosion resistance is needed. There are two kinds (type 1 and type 2) of aluminium coated steel being commercially used among them. Type 1 aluminium coated steel is coated with an Al-5~11 wt%Si alloy and Type 2 aluminium coated steel consists of commercially pure aluminium. Type 1 Al coated steel is generally used in automotive components and electrical appliances while type 2 aluminium coated steel is mainly used in construction applications such as building cladding panels, air conditioning and ventilation system. In this study, Type 1 aluminium coated steels have tested by accelerated conditions (salt spray or corrosive gas) and outdoor exposure condition in order to understand their corrosion behaviour. Due to the distinct corrosion mechanism of Al which exposes to the severe chloric condition, Salt Spray Test cannot predict the ordinary atmospheric corrosion of Al based coated materials. In addition, the test results and their corrosion feature of Al coated steel sheets will be discussed comparing with other metallic coated steel sheets of GI and GL.

Keywords *: corrosion resistance, corrosion behavior, metallic coated steel sheets, salt spray test, outdoor exposure test, electrochemical measurement*

1. Introduction

The coating of steel with aluminum is an economical means of combining the corrosion resistance of aluminum with the strength of steel. The coating operation can be performed by a variety of processes, but continuous hot dipping of wide strip remains the most economical for the mass production of aluminum coated steel sheet. The first production of aluminized steel sheet was commercialized at the U.S. Armco in 1939 when a continuous coating method, developed for galvanizing, was successfully modified to permit aluminizing of steel coils.[1),2)]

There are generally two kinds of commercial hot dipping aluminum coated steel sheet (aluminized steel sheet). Type 1 aluminized steel sheet is typically produced in the Al melts with 5~11 wt% Si. This coated steel is used in a variety of applications where resistance to both corrosion and elevated temperature oxidation are required. Typical examples include automobile exhaust systems and domestic heating appliances such as cookers, dryers, and heating boilers, etc. Type 2 aluminized steel is produced by hot dipping in a bath of pure aluminum. This material generally only finds applications where resistance to ambient temperature corrosion is required, usually in conjunction with a demand for a high reflectivity surface. The main market of Type 2 is construction industries, for instance, building cladding panels and air conditioning and ventilation systems. Without silicon in the bath to control alloy layer growth, the coating formed on type 2 aluminized steel sheets contains a thicker iron-aluminum alloy layer which is less formable than type 1. Typical minimum coating mass for type 2 is 195 g/m^2.[3),4)]

Zn and Al coated on steel trigger different corrosion protection mechanisms. Zinc and zinc alloy coatings afford sacrificial (i.e. cathodic) corrosion protection of the steel base. In these materials, the greater negative electrode potential of zinc compared with iron, coupled with the porous nature of the corrosion products, ensures the constant preferential corrosion of the zinc coating. Thus, the coating is maintained at a potential anodic to the cathodic iron substrate. Advantageously, such protection usually extends to uncoated pores, cut edges, and the microfissures resulting from cold working of the material. With aluminum, primary corrosion protection of the steel base is afforded by formation of an impervious oxide barrier. The barrier

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property arises from the aluminum's quick ability of generating a very thin(typically 5~25 nm thick) and tenacious alumina surface film which is practically impermeable and insoluble in most common oxidizing media. Thus, though more anodic than either iron or zinc, aluminum has only a very limited ability to protect steel cathodically since in most environments its preferential corrosion is essentially self-limiting.[5)]

Since 1990s, aluminized steel specifications and applications have become somewhat indistinct. In the UK, for example the only indigenous producer of aluminized steel exclusively manufactures the type 1 grade for both heat resistance and ambient temperature applications. The latter product is designated type 1 'building quality' and has a minimum 45 ㎛ coating thickness.[4)] Analogous products in Japan have led to the development of specifications which differentiate aluminized steels on the basis of coating thicknesses rather than coating composition.[1)]

In this paper, galvanized, zinc-aluminium and aluminium coated steels have been tested by accelerated conditions (salt spray or corrosive gas), outdoor exposure condition and electrochemical measurement in order to understand its corrosion behaviour. The test results and its corrosion feature of aluminized steel sheet will be discussed comparing with other metallic coated steel sheets, GI and GL.

2. Experimental procedures

2.1 Specimens

Commercial products of hot-dip coated steel sheets were obtained for this study. Three kinds of typical products of hot-dip coated steel sheets; galvanized steel sheet(GI), zinc-55% aluminum alloy coated steel sheet(GL) and aluminized steel sheet (AL) without a chromate post-treatment, were used in this study. Low-carbon steels (CQ grade) with a thickness of 0.5~1.2 mm were used as a substrate for each coating. The coating thickness at the test side of all specimens were 13 ㎛ and 20 ㎛ approximately.

2.2 Accelerated corrosion tests

Two kinds of accelerated corrosion tests were applied to investigate the effect of a test environment. One is a salt spray test (hereinafter referred to as SST) as specified by KS D 9052 (ASTM B117). The other is cyclic corrosion test with artificial acid rain (hereinafter referred to as CCT) as specified by KS D 8334 (similar to ASTM G 85). Details of the accelerated corrosion tests conditions are described in Table 1. In the case of SST, experiments were conducted for two kinds of test specimens. One was sealed at edges with adhesive tapes and the other was not sealed, scribed on the surface and bended by 90 degree. In the case of CCT, test specimens were sealed at edges with adhesive tapes. The dimension of test specimens for SST and CCT was 1.2^t x 70^W x 150^L mm. Corrosion resistance for SST and CCT was evaluated by the time when the first sign of 5% red rust occurred.

2.3 Outdoor exposure test

Test specimens were exposed at three atmospheric corrosion test locations, representing rural, urban and coastal

Table 1. Condition of corrosion tests

Corrosion test	Standard	Condition
Salt spray test	KS D 9502 (ASTM B117)	5% NaCl spray 35℃
Cyclic corrosion test	KS D 8334 (similar to ASTM G 85)	SST (5%NaCl + HNO_3 + H_2SO_4, pH 3.5, 35℃, 2 hrs) → Dry (60℃, 20~30% R/H, 4hrs) → Wet (50℃, 95% R/H, 2hrs)

Table 2. Description of atmospheric corrosion

Atmospheric Corrosion test site	Environment	Location	The yearly mean			
			Temperature (℃)	Relative humidity (%)	Rainfall (mm)	SO_2 / NO_2 (ppm)
Dangjin	Coastal	300m from the coastline	11.7	75.4	1232	0.004 /0.017
Eumseong	Rural	Surrounded by the green zones	11.2	72.4	1187	0.005 /0.017
Pohang	Urban	Surrounded by heavy industrial area	13.8	64.8	1220	0.029 /0.048

environments, as described in table 2. Dangjin test site is situated in a coastal environment that is located 300 m away from the coastline with strong influence of sea-salt particles. Eumseong test site is situated in a rural environment surrounded by green zones, 55 km or more away from coastline. Pohang test site is situated in a heavy industrial area where much SO_2 and NO_2 existed in the atmosphere. Two kinds of test specimens were used like SST. One type was sealed at edges with adhesive tape and the other type was not sealed at edges, scribed on the surface and bended by 90 degree. They will have been exposed for 7 years at 45 degrees from the horizontal with skyward surface facing south. Every year, the corrosion loss of test specimens will be measured.

2.4 Electrochemical measurement

The polarization of the coated steel sheets was measured using a potentiostat. The specimens were immersed in a 3% NaCl and 1 N H_2SO_4 solutions using a Pt electrode as a counter electrode and a saturated calomel electrode as a reference electrode, and then, anode and cathode polarization was conducted at a potential scanning rate of 1 mV/s.

3. Result and discussion

3.1 Salt spray test

Fig. 1 and Fig. 2 show the plating surface after red rusts appeared in SST. Fig. 1 is in the case of the specimens of which cut edges were sealed. Fig 2 is in the case of specimens of which cut edges were not sealed. As shown in Fig. 1 and Fig 2, depending on cut edges being sealed or not, the results of three coating materials are very different. When cut edges being sealed, after the test time exceeded 390 hrs, red rust appeared on GI but no red rust appeared on GL and AL. Red rust appeared in AL and GL after 800 hrs and 1220 hrs, respectively. Thus, in SST, when cut edges being sealed, the order of corrosion resistance of three kinds of specimens was as follows;

(good) GL > AL > GI (poor)

When cut edges not being sealed, after the same test time, 530 hrs, went past, red rust appeared on GI and

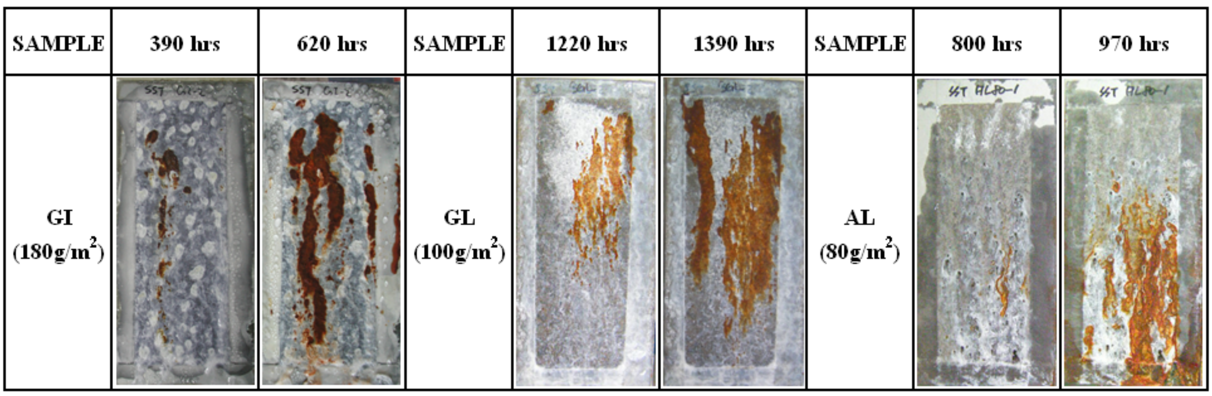


Fig. 1. Appearance of coating steel sheets of which cut edges being sealed with SST.

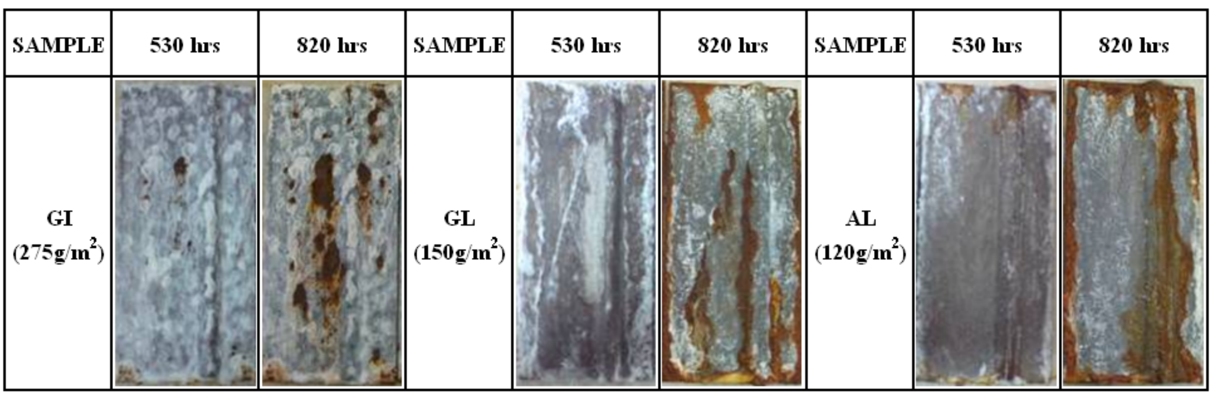


Fig. 2. Appearance of coating steel sheets of which cut edges being not sealed with SST.

AL while no red rust appeared on GL. But after 820 hrs, it is similar to degree of red rust on surfaces of three kinds of specimens. There is a unique point that red rust came out from the part of center in GI but red rust showed up from the part of edges in AL and GL. So, in the case of GI, corrosion resistance increased with coating weight regardless of whether cut edges being sealed or not. However, in the case of GL and AL (Fig.2), though coating weight is larger than that of sealed cut edges, red rust appeared early. It can be confirmed from these results that GL and AL are better than GI in corrosion resistance in surface while GI is superior to GL and AL in corrosion resistance in edge.

Accordingly, in SST, when cut edges not being sealed, the order of corrosion resistance of three kinds of specimens was as follows;

(good) GL $\geq$ AL ≒ GI (poor)

3.2 Cyclic corrosion test

Fig. 3 shows the appearance of plating surface after red rusts appeared in CCT. As can be seen in Fig. 3, the results from CCT are very different from that of SST. After the test time exceeded 1000 hrs, red rust appeared on GI but no red rust appeared on GL and AL. In GL, Red rust came out after 2240 hrs while no red rust showed up in AL. Thus, in CCT, the order of corrosion resistance of three kinds of specimens was as follows;

(good) AL > GL >> GI (poor)

This result indicates that aluminum is stronger than zinc in acidic environment as known. But the method of CCT does not completely imitate real atmosphere environment.[6] It seems to differ from the result of outdoor exposure test as discussed in the next section.

3.3 Outdoor exposure test

Fig. 4 shows the appearance of plating surfaces and cut edges in test specimen which was not sealed at edges, scribed on the surface and bended by 90 degree after about 7 months in outdoor exposure test. Because the test time did not go sufficiently, until now there is no major difference by region. As can be seen in Fig. 4, test specimens in Eumseong were likely to be a little less corroded compared with those in the other areas. Depending on the type of coatings, red rust did not appeared in plating surfaces of GI and GL except for AL. In the case of AL, red rust started to show up around scribes and edges. At cut edges, AL was most corroded and no red rust appeared in GI. Thus, in outdoor exposure test, the order of corrosion resistance at cut edge of three kinds of specimens was as follows;

(good) GI > GL >> AL (poor)

This result is considered to be a reason that zinc operates as a sacrifice against steel but aluminum does not operate as a sacrifice against steel because when aluminum is exposed to the atmosphere, an impervious layer of aluminum oxide (Al_2O_3) rapidly forms on its surface.[7]

3.4 Electrochemical measurement

Fig. 5 shows polarization curves of three kinds of specimens in (a) 1 N H_2SO_4 and (b) 3% NaCl solutions respectively. Regardless of the type of solution, GI and GL showed a similar behavior but depending on kinds of solution AL exhibited a different behavior. Corrosion currents of AL in 1 N H_2SO_4 and 3% NaCl solutions were similar to each other. But in 1 N H_2SO_4 solution corrosion potential of AL was -0.454 V and in 3% NaCl solution corrosion

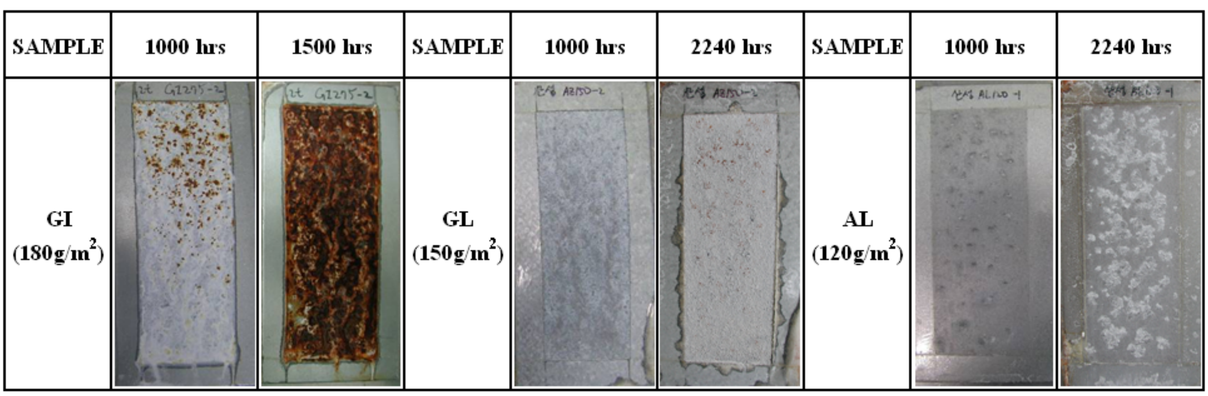
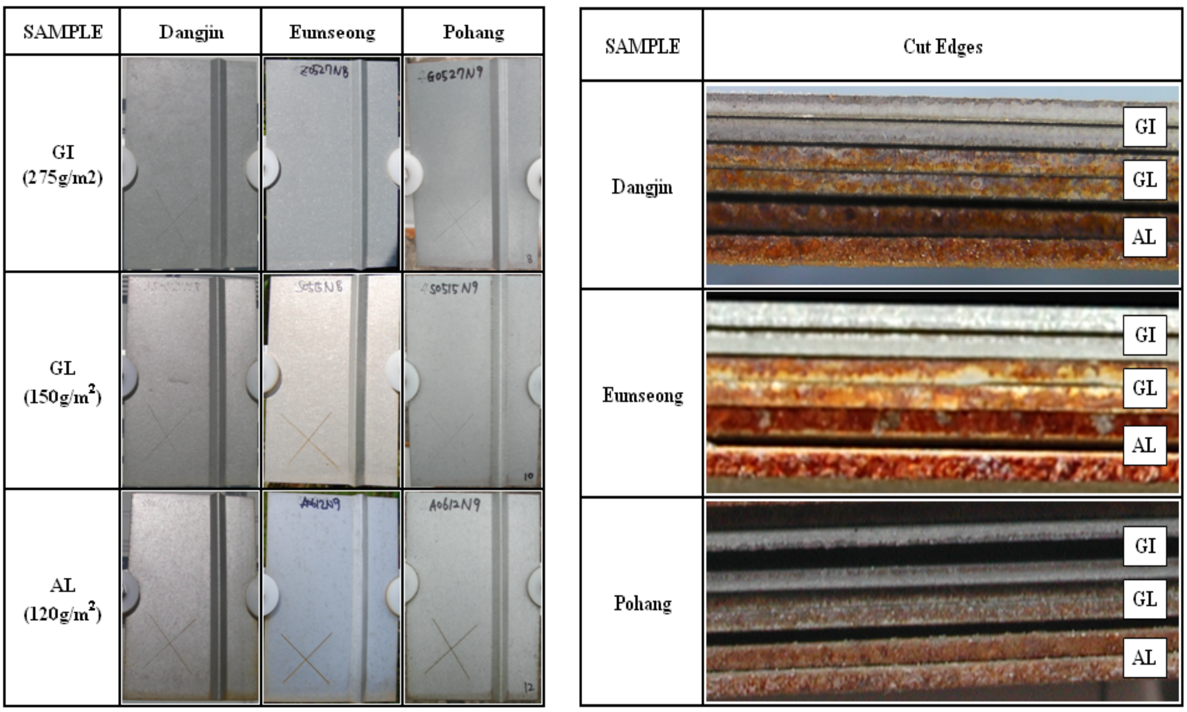


Fig. 3. Appearance of coating steel sheets with CCT.

potential of that was -0.877 V which was close to those of GI and GL. This means that aluminum can operate as sacrifice like zinc. This fact can explain that the result of SST was different from that of outdoor exposure test. In atmosphere environment in where is little chloride ion, aluminum deforms the oxide film on its surface so that aluminum does not operate as a sacrifice against steel. But In the case of SST which includes much chloride ions, the oxide film can be disrupted and the aluminum coating may provide some galvanic protection at pores and cut edges.[3),6),8)] In 1 N H_2SO_4 solution log of corrosion currents of AL, GL and GI were -6.76, -6.45 and -4.3 respectively. This means that corrosion rate of GI is the largest of them and this fact can account for the result of CCT.

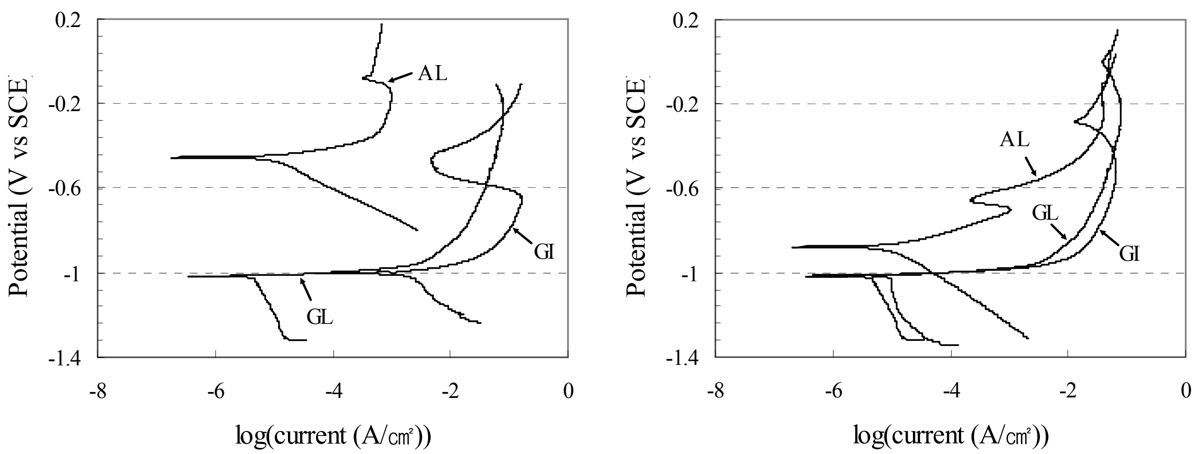
5. Conclusions

The corrosion resistance and corrosion behavior of GI,



(a) Plating surface (b) Cut edge

Fig. 4. Appearance of coating steel sheets with outdoor exposure test, (a) plating surface, (b) cut edge.



(a) 1N H_2SO_4 (b) 3% NaCl

Fig. 5. Polarization curves of coating steel sheets in (a) 1N H_2SO_4, (b) 3% NaCl.

GL and AL in several methods which are SST, CCT, outdoor exposure test and electrochemical measurement have been studied. The following main points were obtained

1) In SST, depending on cut edges being sealed or not, the corrosion resistances of three kinds of coated steel sheet were different. When cut edges being sealed, AL was better than GI and worse than GL. But when cut edges being not sealed, they were similar to each other.

2) In CCT, in the case of cut edges being sealed, AL exhibited the best corrosion resistance all of them. This means that it can be more efficient to use AL in acidic environment.

3) In outdoor exposure test, after 7 months, there is no major difference in corrosion resistance by region. Test specimens in a rural area, eumseong were likely to be a little less corroded compared with those in a coastal and urban areas. Depending on the type of coatings, AL is worse than GI and GL. At cut edge, AL and GL were much corroded and no red rust appeared in GI. From now on, every year, the corrosion loss of test specimens will be measured

4) In electrochemical measurement, depending of solutions, AL showed a different result but GI and GL exhibited similar behaviors. Due to the severe marine environments where is much chloride ion, the oxide film of aluminum can be disrupted and consequently the aluminum coating may provide some galvanic protection at pores and cut edges. This unexpected galvanic cell may be responsible for the different results in SST and outdoor exposure test.

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