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Innovative Development of Al-Zn-Si Coated Sheet Steels for Automotive Applications

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Steels have excellent mechanical properties and weldability. They are also economically producible. Thus, they are widely applied in various industries. However, they have a disadvantage in that rust can occur after a certain period of time. To compensate for this, Zn, which has excellent sacrificial corrosion resistance, can be coated on steels. With global zinc consumption increasing at the current rate, depletion is expected in the near future. Recently, POSCO has developed innovative Al-Zn-Si alloy coated steel sheets with better corrosion resistance than Zn coating. In this study, corrosion resistance, weldability, friction characteristics, and so on were evaluated compared to GI steel sheets to evaluate their applicability to automotive steel sheets. It showed excellent corrosion resistance even at a lower coating weight compared to GI steel sheet. It was also excellent in terms of galling and welding LME. Its spot welding life, electrodeposition coating, and bendability were equally excellent. This is presumed to be related to the formation of the Al-Zn-Si alloy phase at the interface of the coating layer.

Keywords: *Al-Zn-Si coating, Corrosion resistance, Bendability, Spot welding, Galling*

1. Introduction

Zn coated steel sheets are widely applied in various industries such as automobiles, home appliances, and construction, and its usage is also continuously increasing. However, if the use of zinc around the world increases in the current trend, since complete depletion is expected in the near future, measures to improve corrosion resistance by adding other metals to the zinc coating layer are being sought. Recently, Zn-Al-Mg alloys, which are known to have significantly better corrosion resistance than Zn coating, are attracting attention as next-generation coating materials [1-6]. The method of manufacturing an alloy-coated steel sheet with excellent corrosion resistance by adding Mg and Al to molten zinc has been reported since the 1960s, a relatively early period [7].

However, when Mg and Al, which are elements with high chemical reactivity, are added, it is difficult to manage the Zn bath and secure the surface quality. Commercialization of high corrosion resistance alloy coating products has been achieved through ZAM (Zn-6%Al-3%Mg) [8] and Super Dyma (Zn-11%Al-3%Mg-0.2%Si) [9] of Japanese steelmakers since 2000). After the development, it started to be applied for high-end construction materials. Afterwards, Zn-Al-Mg-based alloys were mainly focused on European steel and automobile companies in the mid-2000s against the background of soaring Zn prices and the prospect of depletion of Zn resources in the future. As a result, European steelmakers have developed Zn-Al-Mg products with specifications suitable for interior/exterior parts for automobiles, such as surface quality and weldability, within the range of 1 to 2% Mg and 1 to 3% Al [1,2,10].

In Korea, POSCO developed PosMAC3.0 for building materials with 3% Mg added in 2012, and then newly developed PosMAC1.5 with 1-2% Mg for automobiles and home appliances [3-6]. Since then, most domestic and foreign steel makers have expanded the development and production of highly corrosion-resistant coating products. In terms of product standards, ASTM's high corrosion resistance alloy coating standards in the US have been expanded and revised to accommodate a wide

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range of coating components [11], and national standards have been established and revised in Korea, Europe, and Southeast Asia. This provided an opportunity for the application of highly corrosion-resistant alloy-coated steel sheets to be expanded throughout the industry, and global demand is expected to further increase in the future.

However, Zn-Al-Mg-based alloy coating requires more stringent quality control in order to satisfy the demand for automotive outer panels and home appliances, which place importance on aesthetic appearance, despite its excellent high corrosion resistance. In particular, compared to conventional GI coating, high corrosion-resistant alloy coating is more likely to generate dross defects in the zinc bath, and since various phases (Zn, $MgZn_2$, Al, etc.) with different solidification behavior are formed, surface quality control is tricky. In addition, since the melting point of the Zn-Al-Mg coated steel sheet is low, there is a disadvantage in that LME (Liquid Metal embrittlement) is likely to occur during coating of AHSS steel. Therefore, in this study, to solve these problems, the corrosion resistance, weldability, and friction characteristics of the 60 ~ 70%Al-Zn-Si coated steel sheet developed for the first time in the world were evaluated to evaluate the applicability of the steel sheet for automobiles.

2. Experimental Methods

To evaluate automotive application properties of 60-70%Al-Zn-Si steel, corrosion, spot welding, bending and surface friction were tested in various test conditions. In this study, experiment, Al-Zn-Si coated steel sheets with a material thickness of 1.2 mm and coating weight of 20 g/m^2, 30 g/m^2 and 60 g/m^2 produced by CGL were prepared (in this paper g/m^2 means g per one side of the strip). As a comparative material, a GI steel sheet having a coating weight of 60 g/m^2 was used.

Corrosion test is carried out in salt spray test (SST) by ISO 8227 and in cyclic corrosion test (CCT) test by ISO 14993. Surface dimension for corrosion test is 150 × 70 mm. Welding test is carried out by using spot welder. Weldability was evaluated by electrode life and weldable current range during spot welding. Electrode life is determined by the size of welding nugget and the number of welding points. The occurrence of LME was observed in the cross-sectional structure after spot welding of AHSS steel.

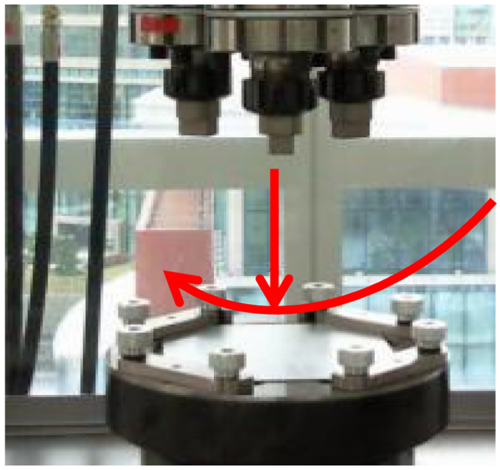

Fig. 1. Continuous friction tester

A repeated surface friction tests are carried out to evaluate friction coefficient of Al-Zn-Si coated steel in compare to conventional GI. The surface friction property is closely related with press forming quality (Galling) for complex shaped parts. The test procedure is as follow. As shown in Fig. 1, the test apparatus composed with 3 friction tips which located evenly in the circle of 200 mm diameter. Each tips surface dimension is 18 × 28 mm, and its surface is prepared by hard chromium coating and then finished by grinding. The surface hardness of the tip is 700 ~ 1,000 Hv. Friction tips contact on samples with 5 MPa compressive loads and then samples turned round repeatedly. The value of friction coefficient is continuously measured with the rotation of samples. The total rotation is 40 ~ 100 rounds. The samples surface roughness is 1.0 ~ 1.5 Ra, and test under the same oiled conditions on the surface.

In addition, comprehensive evaluation of bendability, phosphate treatment, and electrodeposition coating property were evaluated for applicability to automotive steel sheets.

3. Results

Fig. 2 shows the SEM observation of the cross-sectional structure of the Al-Zn-Si coating layer. The Al-Zn-Si alloy phase with a size of about 2.6 μm was observed at the interface between the base iron and the coating layer, and

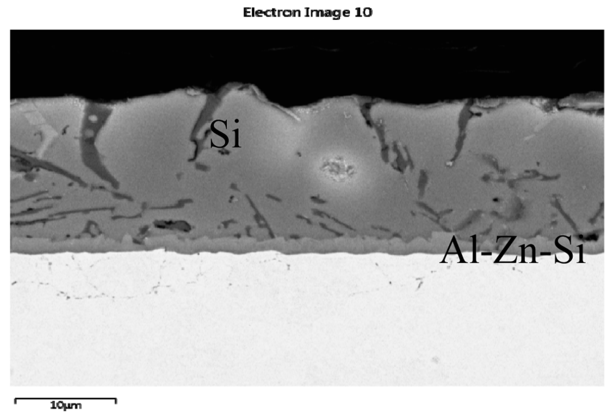

Fig. 2. Microstructure of Al-Zn-Si coating

it was found that Si was mainly distributed in a large amount where cracks were visible inside the coating layer.

Fig. 3 shows the surface appearance after 168 hours of salt spray test of Al-Zn-Si 60 g/m^2 compared to GI 60 g/m^2. In the Al-Zn-Si coating layer, only white rust occurred, but GI showed that red rust was severely formed, and the corrosion resistance of the Al-Zn-Si coating layer was more excellent at the same amount of coating weight.

Fig. 4 shows shows the surface appearance after 168 hours of cyclic corrosion test of Al-Zn-Si 30g/m^2 compared to GI 60 g/m^2. In the Al-Zn-Si coating layer, only white rust occurred, but GI showed that red rust was severely generated throughout the steel sheet, and the corrosion resistance of the Al-Zn-Si coating layer was more excellent at half the coating weight. According to the result of analyzing the corrosion product of Al-Zn-Si coating layer by XRD in Fig. 5, it was found that it was composed of ZnO, $Zn_2Al(OH)_6Cl_2{\cdot}H_2O$, Al_2O_3 and SiO_2. Therefore, it was assumed that dense $Zn_2Al(OH)_6Cl_2{\cdot}H_2O$, Al_2O_3 and SiO_2 improved the corrosion resistance compared to the porous GI.

Surface friction of the steel sheets is a very important for the press forming operation. The galling problem would have more occurred in press works when friction coefficient is higher. Higher friction resistance promotes surface deformation and dropping out of small particles

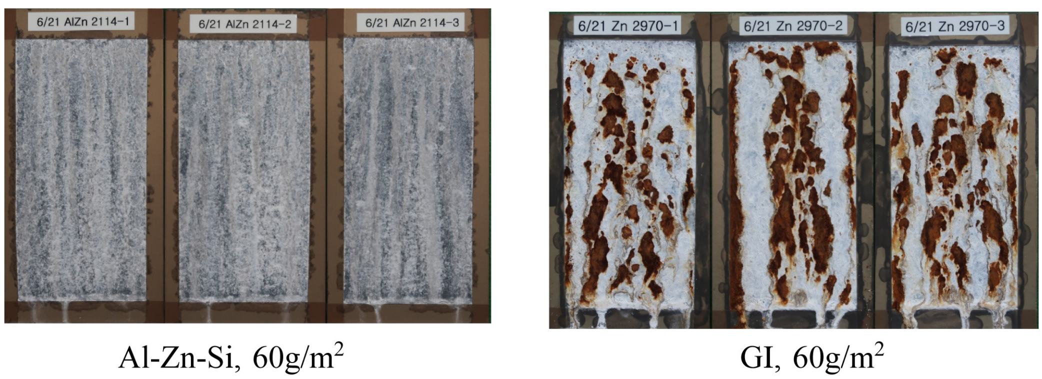

Fig. 3. Surface appearance after salt spray test

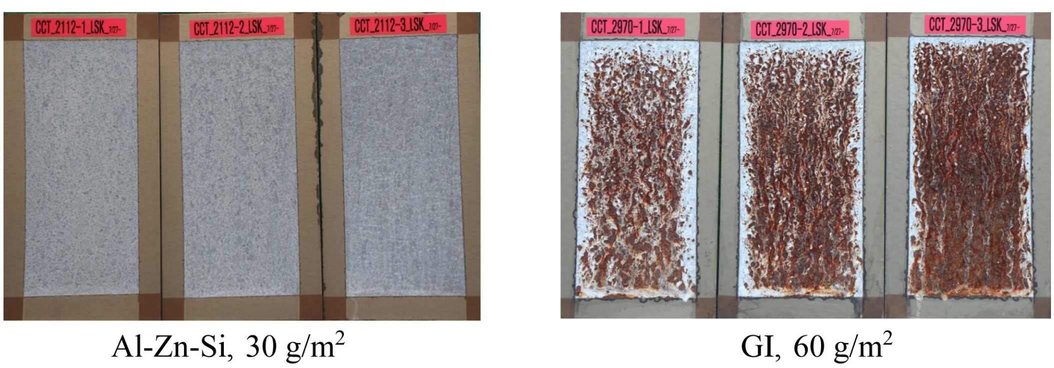

Fig. 4. Surface appearance after cyclic corrosion test

from the surfaces and then accumulate on the tool surface with repeated working, which would make galling defects during pressing operation. Conventional GI is apt to develop gallings due to their higher friction coefficient

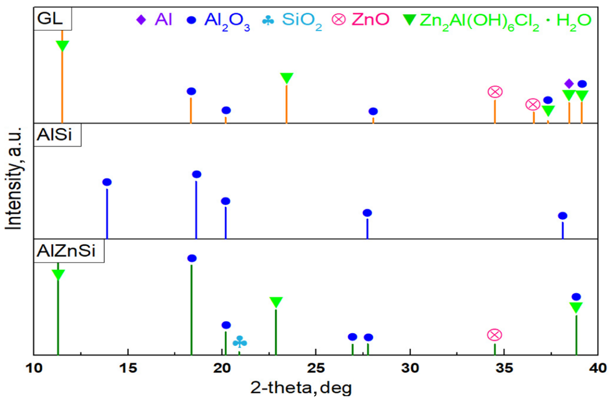

Fig. 5. XRD pattern of corrosion product after CCT

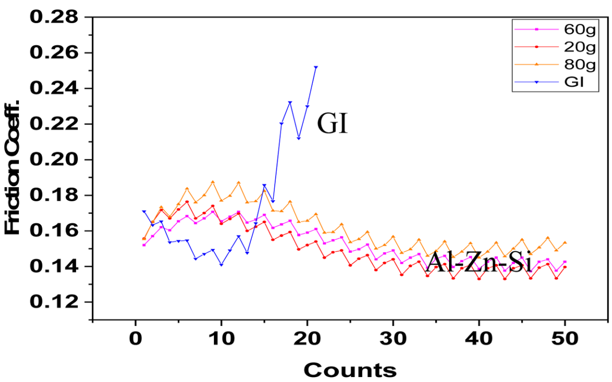

Fig. 6. Friction coefficient after repeated friction test

and the falling of particles from the coatings. A higher frequency of gallings would cause lower productivity because it needs interruption for press tool cleaning during production. Coating material with a lower friction coefficient and higher resistance of surface formation is a very desirable property for the pressing works.

Fig. 6 shows the friction coefficient after repeated friction tests of Al-Zn-Si coating layers with different coating weights compared to GI 60 g/m^2. The GI showed a significant increase in the friction coefficient when the friction test was repeated about 20 times, but the Al-Zn-Si coating showed a stable low value. This is assumed to be because the hardness of the GI coating layer is as low as 60, whereas the hardness of the Al-Zn-Si coating layer is as large as 130, which shows excellent galling properties.

Fig. 7 shows the electrode life during spot welding of Al-Zn-Si coated steel sheets with coating weight of 20 g/m^2 and 60 g/m^2. The electrode life of the GI coated steel sheet with the coating weight of 60 g/m^2 was approximately 500 to 1000, whereas the life span of the Al-Zn-Si coated steel sheet with the coating weight of 60 g/m^2 was high at 600 to 1700. This is presumably because the GI steel sheet has thin Fe_2Al_5 formed at the interface between the base iron and the coating layer, whereas the Al-Zn-Si coated steel sheet has a thick Al-Zn-Si alloy layer with high Fe content.

Fig. 8 shows the welding current available during spot welding of Al-Zn-Si coated steel sheets with coating weight of 20 g/m^2 and 60 g/m^2. The weldable current range of the Al-Zn-Si coated steel sheet with the coating

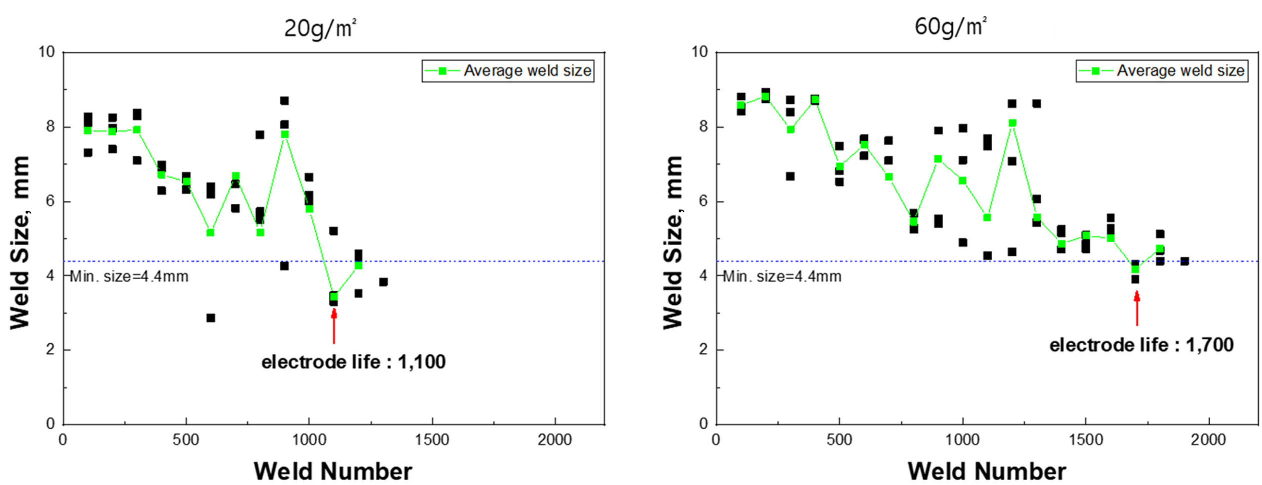

Fig. 7. Electrode life after spot welding test

Table 1. Evaluation of automotive properties of Al-Zn-Si coated steel sheet

Specimen	LME	Electrode Life	SST	CCT	Bending	Galling	Phosphating	Electrodeposition
Al-Zn-Si	○	600~1700	600h	>1000h	○	○	○	○
GI	△	500~1000	100h	<100h	○	△	○	○

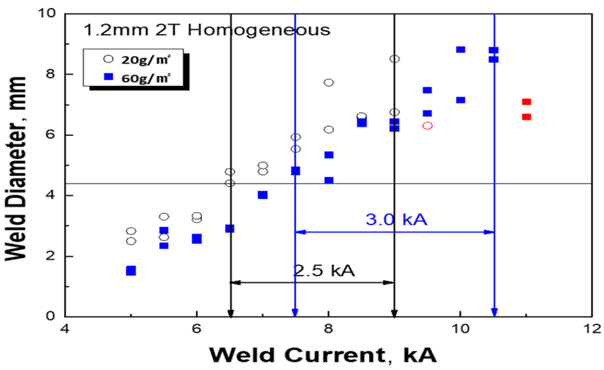

Fig. 8. Available welding current during spot welding test

weight of 60 g/m^2 was 3.0 kA, and the Al-Zn-Si coated steel sheet with the coating weight of 20 g/m^2 was 2.5 kA. Therefore, it is judged that the spot weldability of the Al-Zn-Si coated steel sheet is excellent.

Table 1 shows the results of the comprehensive evaluation of automotive properties of the Al-Zn-Si coated steel sheet and GI having a coating weight of 60 g/m^2. It was found that Al-Zn-Si coated steel sheet was excellent in terms of corrosion resistance, galling, and welding LME compared to GI and its welding life, electrodeposition coating, bendability, and phosphate treatment were equal or better. In addition, there is no spangle in the surface appearance, and it shows a very good appearance, and it has excellent coating wettability, so it has the advantage of being able to manufacture AHSS steels including TRIP with good coating adhesion.

4. Conclusions

POSCO recently developed an innovative 60 ~ 70%Al-Zn-Si coated steel sheet with good surface appearance. It showed excellent corrosion resistance even at a lower coating weight compared to GI steel sheet, and was also excellent in terms of galling and welding LME. In addition, spot welding life, electrodeposition coating and bendability were equally excellent. This is presumed to be related to the formation of the Al-Zn-Si alloy phase at the interface of the coating layer. It is expected to be used as automotive steel sheets through joint evaluation with automobile companies in the future

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