Corrosion behavior of Zn-Mg-Al Alloy Coated Steel Sheets Depending on the Alloy Coating Microstructure

Jae-Won Lee¹, Je Ha Shon¹, Min-Suk Oh², Sang-Heon Kim²

¹POMIA (Pohang Institute of Metal Industry Advancement), jwlcyh@pomia.or.kr
²POSCO Technical Research Laboratories

The effects of Mg and Al content on the microstructure and corrosion resistance of hot-dip Zn-Mg-Al alloy coated steels were investigated. Pure Zn and Zn-based alloy coatings containing 0 to 5 wt.% of Mg and 0.2 to 15 wt.% of Al compositions were produced by a hot-dip galvanizing. The coating consists of complex microstructures including Zn phase, MgZn₂ rich phases (MgZn₂ intermetallic compounds, Zn/MgZn₂ binary eutectic and Zn/MgZn₂/Al ternary eutectic) and Zn-Al intermetallic compounds. MgZn₂ rich phases played the most important role in increasing surface corrosion resistance. The volume fraction of MgZn₂ rich phases (Zn/MgZn₂ binary + Zn/Al/MgZn₂ ternary + MgZn₂ intermetallic compound) rather than total Mg contents in alloy coating is important to determine surface corrosion resistance of Zn-Mg-Al alloy coated steel. Zn-3%Mg-2.5%Al coated steel showed the best cut edge corrosion resistance induced by large volume of MgZn₂ rich phase especially Zn/MgZn₂ binary eutectic phase.

Keywords: Zn–Mg-Al alloy coated steel, microstructure, volume fraction, corrosion resistance, cut-edge corrosion

Introduction

Hot-dip zinc-coated steel sheets have been widely used in various industrial markets from construction to automotive parts due to their excellent corrosion resistance. As global warming has accelerated, clean and energy-efficient technologies have emerged as the most important agenda in scientific research and development. In the galvanizing industry, in order to not only conserve natural Zn resources but also reduce production costs, great attention has been paid to further improvement of the corrosion resistance of Zn or Zn alloy-coated steel products to extend the coating lifetime with less material. Recently, it has been reported that the addition of Mg and Al to the zinc coating provides rich opportunities for enhancing the corrosion resistance of the coatings [1-4].

Experimental procedure

Zn-Mg-Al alloy-coated steel sheets containing various compositions of Mg and Al were fabricated by using a hot-dip galvanizing simulator (RHESCA HDPS-250A). 1 mm-thick cold-rolled low carbon steels were cut into 105 × 200 mm² pieces and ultrasonically degreased in acetone prior to being loaded into the load lock chamber. All of the samples were annealed at 750 °C for 40 s in a reducing ambient, and then dipped in the molten bath
with different Mg and Al compositions. All of the samples were coated under the same coating conditions, except for the pot temperature, which was adjusted from 440 to 600 °C. Surface and cross-sectional microstructure of the coatings were observed by using field-emission scanning electron microscope (FE-SEM, SUPRA-55VP, ZEISS) and field-emission transmission electron microscopy (FE-TEM, JEM-2100F, JEOL). Image analysis using soft imaging system (analySIS) was performed in order to calculate volume fraction of each intermetallic compound.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pot temp. (°C)</th>
<th>Chemical composition (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Al</td>
</tr>
<tr>
<td>A0.2</td>
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<tr>
<td>A55</td>
<td>600</td>
<td>54.4</td>
</tr>
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</table>

**Results and Discussion**

Fig. 1 shows the surface morphology of Zn-Mg-Al coatings which contain different Al and Mg composition. Zn, Zn/MgZn$_2$ binary eutectic and Zn/Al/MgZn$_2$ ternary eutectic phases are shown on the surface of Zn-Mg-Al alloy coating on A2M1 and A2.5M3. FE-TEM was employed to fulfill the detailed examination on the microstructure of intermetallic compounds.

![Fig. 1. Cross-sectional images of Zn-Mg-Al coatings with different Mg and Al content: (a) A0.2 (b) A2M1, (c) A2.5M3, (d) A2M5, (e) A5M3, (f) A15M3, (g) A23M3, and (h) A55.](image)
By addition of Mg and Al, various intermetallic compounds were formed in the Zn-Mg-Al coating layer and the volume fraction of those Zn, Mg and Al-related compounds was changed in accordance with Mg and Al composition. Fig. 2 shows the cross-sectional images of Zn-Mg-Al coatings with different Al and Mg compositions.

Corrosion resistance of the flat surface was evaluated by measuring the time to red rust occurrence on the surface through the salt spray test (SST) of conducted an international standard ASTM B117. Edges of all the samples were taped and sealed by adhesive tape to prevent the cut-edge corrosion. Fig. 3 shows the initiation time of red rust formation on the surface as a function of coating weight for each coating layer. Compare to galvanized steel of pure Zn, Zn-Mg-Al alloy coated steel sheets exhibited 4~10 times higher corrosion resistance in terms of time to red rust formation. The evaluation also indicates that corrosion resistance of the alloy coated steel product was proportionally increased as increase of Mg composition from 0 to 5 wt.%. Even though Al contents was changed from 2.5 to 5 wt.%, however, coating layers containing 3 wt.% of Mg exhibited almost equivalent time for red rust formation. On the other hands, when Al contents is higher than 15 wt.%, A15M3 with 3 wt.% of Mg has lower corrosion resistance compare to A2.5M3 and A5M3. In case of the flat surface corrosion, the corrosion resistance is related with the amount of released Mg$^{2+}$ dissolved from the alloy coating [3,4]. Therefore, the alloy coating having similar Mg contents shows almost same surface corrosion resistance.

Fig. 2. Volume fraction comparison of each microstructure in the cross section of coating layers, which have different Al and Mg compositions.
Fig. 3. The volume fraction of intermetallic structures in Zn-Mg-Al coating layers, and red rust formation time for each coating layer with the same coating weight of 30 g/m²

Summary

Effect of Mg and Al content on microstructure and corrosion resistance of Zn-Mg-Al alloy coated steel sheets was investigated. Volume fraction of the intermetallic compound within the microstructure was varied according to Mg and Al composition. The volume fraction of MgZn₂ rich phases (Zn/MgZn₂ binary + Zn/Al/MgZn₂ ternary + MgZn₂ intermetallic compound) rather than total Mg contents in alloy coating is important to determine surface corrosion resistance of Zn-Mg-Al alloy coated steel.

Reference