Effect of Magnesium on Corrosion Resistance of Galvalume Coating

Z L Ding1,2, J Zhang1*, S M Jiang1 and Q F Zhang1

1 National Engineering Laboratory of Advanced Coating Technology for Metals, China Iron & Steel Research Institute Group, Beijing 100081, China
2 Baosteel Research Institute, Baoshan Iron and Steel Co. Ltd., Shanghai 201900, China
Email: zhangj0212@163.com

Abstract. In order to improve the performance of Galvalume coating, the expected microstructure and the better property could be obtained by adding 1~3% Magnesium into Galvalume coating (55%Al-Zn). In this paper, effect of magnesium on the corrosion resistance of 55%Al-Zn coating was studied. The morphology and microstructure of coatings, polarization curve and surface corrosion of two different kinds of samples were analysed by SEM, EDS, electrochemistry workstation and salt spray test. The results show that the numbers of surface spangles by adding 2% magnesium are not changed obviously; the corrosion resistance of 55% Al-Zn-2%Mg coating becomes much better.

Keywords. 55%Al-Zn coating; Magnesium; Microstructure; Corrosion Resistance.

1. Introduction
Hot-dip Galvalume steel plate has good corrosion resistance and heat resistance because of aluminum, and also has good cathodic protection and incision protection because of zinc. In addition, it has excellent heat radiation and reflection resistance. Due to its excellent performance, hot-dip Galvalume steel has been widely used in the construction and home appliance industries [1, 2].

In order to further improve the general properties of the coating, high-performance coating structure can be obtained by adding 1-3% magnesium into the coating [1-4]. In 1990s, Japanese companies found that the corrosion resistance was improved significantly and service life was extended greatly by adding proper amount of Al and Mg into the pure zinc coating. Zn-Al-Mg is called the new generation coating of high corrosion resistant after Galvalume and Galfan. In order to improve the plane and incision corrosion resistance of Galvalume coating [5], BlueScope in Australian added 2% Mg into the GL coating in 2013. Japanese companies have also done relevant research and development.

In this paper, effect of magnesium on corrosion resistance of Galvalume coating was studied by using 55%Al-Zn and 55%Al-Zn-2%Mg coating produced in the production line. It can provide technical support for application of high aluminum Zn-Al-Mg.

2. Materials and Test Methods

2.1. Materials
The coated steel plates used in the experiment are 55%Al-Zn and 55%Al-Zn-2%Mg coated steel produced in the hot-dip production line. The plate thickness is 0.5mm and 0.6mm. The weight of
single-sided coating is 52g/m², 75g/m² and 90g/m².

2.2. Test Method and Characterization
The surface and section morphology of the coating were observed by FE-SEM. The element distribution in the coating was analyzed by EDS.

Corrosion test of coating: Electrochemical impedance spectroscopy and potentiodynamic polarization were carried out in 3.5wt% NaCl solution at (25±1) °C.

Effect of outdoor environment on the corrosion behavior of coating was simulated by SST which is according to GB/T 10125-1997. The concentration of NaCl was 50 g/L, the size of steel plate is 150×75mm and there were three parallel samples in each group. Occurrence time of red rust on the plate surface and incision was observed by the neutral salt spray test.

3. Results and Discussion

3.1. Surface Morphology of Coatings
During the solidification process of hot-dip 55%Al-Zn coating, spangles on coating surface is related to the solidification temperature. It shows that the outline of spangles is formed at about 520 °C in theory (the size of spangles is basically fixed) [6].

Q Y Liu [7] proposed that the effect of spangles on the appearance is significant when added the element Mg to the coating. The dendrite spacing and the size of spangles decreased significantly, and the size of spangles decreased from 0.86 mm/piece to 0.42 mm/piece.

The surface morphology of 55%Al-Zn and 55%Al-Zn-2%Mg coating of a thickness of 0.5mm and a coating weight of 52 g/m² (figure 1). The size of spangles on the surface of 55%Al-Zn and 55%Al-Zn-2%Mg are both about 2 mm, which indicates that the addition of Mg does not reduce the size of spangle on the surface of coated steel. These are different with the results of Q Y. Liu's study.

It is found that the secondary dendrite spacing (DAS) of 55%Al-Zn coating is about 12 μm, and which of 55%Al-Zn-2%Mg coating is about 13.5 μm (figure 2), indicating that it has no significant effect on the secondary dendrite spacing of the addition of Mg.

![Figure 1](image1.png)

**Figure 1.** The surface morphology of 55%Al-Zn and 55%Al-Zn-2%Mg coating.
3.2. Cross-section Morphology and Microstructure of Coatings

Figure 3 shows the cross-section morphology of 55%Al-Zn and 55%Al-Zn-2%Mg coating.

The microstructure of 55%Al-Zn coating is composed of aluminum rich dendrites (α-Al), followed by Al-Zn eutectoid phase filled in the dendrite gap and Si rich phase. The microstructure of 55%Al-Zn-Mg coating is composed of aluminum rich dendrites (α-Al). Due to the addition of Mg, Mg and Zn form MgZn$_2$ compounds, which are mainly distributed in the Al-Zn eutectoid phase, the Al-Zn-MgZn$_2$ phase is formed, and there are a small amount of Si rich phases in the coating.

3.3. Electrochemical Corrosion Resistance of Coatings

According to the polarization curve shown in figure 4, the corrosion potential ($E_{cor}$) of 55%Al-Zn and 55%Al-Zn-2%Mg coating are -1.02 and -1.03v respectively. The polarization curves of the two coatings are fitted by Tafel (table 1). The corrosion current of 55%Al-Zn coating in 3.5% NaCl aqueous solution is 0.74 μA·cm$^{-2}$, while that of 55% Al-Zn-2%Mg coating is 0.27 μA·cm$^{-2}$. Therefore, the increase of Mg content can reduce the corrosion current and improve the corrosion resistance.
Figure 4. The polarization curves of 55%Al-Zn and 55%Al-Zn-2%Mg coating.

Table 1. The fitting result of polarization curves of 55%Al-Zn and 55%Al-Zn-2%Mg coating.

|                          | 55%Al-Zn coating | 55%Al-Zn-2%Mg coating |
|--------------------------|------------------|-----------------------|
| Self corrosion potential | -1.02 mV         | -1.03 mV              |
|                          | 0.74 (μA·cm⁻²)   | 0.27                  |

Figure 5 shows the AC impedance spectrum of 55%Al-Zn and 55%Al-Zn-2%Mg coated steel plates. It can be seen from figure 5(a) that the electrochemical impedance spectrum of 55%Al-Zn coating and 55%Al-Zn-2%Mg coating steel plate shows a short oblique line in the low frequency area, showing Warburg impedance characteristics, which indicates that the corrosion process is changed from the control of electrochemical reaction to the control of material diffusion and electrochemical reaction.

It can be seen from figure 5(b) that the impedance of 55%Al-Zn and 55%Al-Zn-2%Mg coating steel plate is significantly different before and after the change at the low frequency area: The impedance of 55%Al-Zn-2%Mg coating is about 1/3 higher than that of 55% Al-Zn coating. The results show that the corrosion resistance of 55% Al-Zn-2%Mg coating is higher than that of 55% Al-Zn coating.

Figure 5. AC impedance spectrum of 55%Al-Zn and 55%Al-Zn-Mg coating steel plate.
3.4. Corrosion Resistance on Steel Plate Surface
Table 2 shows the results of surface red rust produced by different weight coating plate which sides are sealed by salt fog test. The surface red rust time of 55%Al-Zn-2%Mg is longer than that of 55%Al-Zn from the surface red rust time of different coating weight. After adding magnesium, the time of red rust of 52/52 g/m², 75/75 g/m² and 90/90 g/m² coating weight is increased by about 56-66%.

The results show that Corrosion resistance on surface coating of 55%Al-Zn steel plate is obviously enhanced in neutral salt spray conditions by adding magnesium. The result of surface red rust of 90/90 g/m² coating weight in different time is showed in table 3.

Table 2. The salt fog performance result of different coating of 55%Al-Zn and 55%Al-Zn-2%Mg.

| The coating weight(g/m²) | The coating type       | The time of red rust(h) |
|-------------------------|------------------------|-------------------------|
| 52/52                   | 55%Al-Zn               | 1900                    |
|                         | 55%Al-Zn-2%Mg          | 3000                    |
| 75/75                   | 55%Al-Zn               | 2830                    |
|                         | 55%Al-Zn-2%Mg          | 4700                    |
| 90/90                   | 55%Al-Zn               | 3200                    |
|                         | 55%Al-Zn-2%Mg          | 5000                    |

Table 3. The result of surface red rust of 90/90 g/m² coating in different test time.

| The coating type | 40h | 680h | 2830h | 3200h | 5000h |
|------------------|-----|------|-------|-------|-------|
| 55%Al-Zn         |     |      |       |       |       |
| 55%Al-Zn-2%Mg    |     |      |       |       |       |

3.5. Corrosion Resistance on Steel Plate Incision
The occurrence time of red rust on the incision by salt spray test with different coating weight is showed in figure 6. The occurrence time of red rust on the incision of 55%Al-Zn-2%Mg is longer than that of 55%Al-Zn coating of different coating weight. After adding magnesium, the occurrence time of red rust on the incision is increased by about 20-40%. The results show that the protection on incision of 55%Al-Zn steel plate is obviously enhanced by adding magnesium, and the protection on incision becomes stronger with the increase of coating weight.
4. Conclusion

There was no significant change in the size of spangles and the secondary dendrite spacing after adding 2% Mg into 55%Al-Zn coating.

After Mg is added into 55%Al-Zn coating, the microstructure changes from Al rich dendrite (α-Al), Al-Zn eutectic phase, Si rich phase to Al rich dendrite (α-Al), Al-Zn-MgZn$_2$ phase and Si rich phase.

The corrosion resistance and protection of 55%Al-Zn coating increased significantly after addition of Mg.

Reference

[1] Zhang Q F, Liu B J and Huang J Z 2007 *Continuous Hot Galvanizing of Modern Steel Strip* (Beijing: Beijing Metallurgical Industry Press) pp 609-610

[2] Ding Z L, Zhang J and Jiang S M 2017 *J. Material Protection* **50** 39-41

[3] Hideloshi S and Kazumi N 1999 *Nippon Steel Technical Report* p63-67

[4] Takao T, Atsushi K and Atsushi A 2001 *Proc. Int. Conf. on Zinc and Zinc Alloy Coated Steel Sheet* p 145-152

[5] Xie Y X, Jin X Y and Wang L 2017 *J. Iron and Steel Research* **29** 167-169

[6] Guo T X, Liu C S, Liu C F 2016 *J. Material Protection* **49** 50-54

[7] Liu Q Y, Williams J, Nolan D, Shedden B, Smith R and Neufeld A 2015 *Proc. Int. Conf. on Zinc and Zinc Alloy Coated Steel Sheet* p 208-215