Development of Zn-Mg-alloy-coated Anti-corrosion Steel Plate for Oil Storage Tank

Kenji KATOH*1 Kazumi NISHIMURA*1 Hidetoshi SHINDO*1 Hiroyasu ISHIMOTO*2 Takashi YASHIKI*3

Abstract

New corrosion resistant Zn-Mg alloy coated (thermal sprayed or hot dip galvanized) steel, which is used for bottom plate or roof plate of oil storage tanks, was developed. Coated Zn-Mg alloy inhibits formation of Zn-Fe alloy layer and Zn oxide in melting, and it also enables reduction of coating thickness. Because of these superior properties, developed Zn-Mg alloy coated steel reserves good workability in welding providing superior corrosion resistance.

1. Introduction

Anti-corrosion measures of oil storage tanks are focused on localized corrosion of bottom plates by sand, sea salt corrosion of the outer surface of roof plates and inner surface corrosion caused by stored oil.

While the localized corrosion behavior of the bottom plates, which are faced to the ground, was not altogether clear, it was found that there were sometimes gaps between the bottom plates and tank foundations, and that localized condensation corrosion took place in the gaps with grains of sand and the like on the plate surface. They also found that a similar situation took place in the case of an asphalt bed in nearly the same severity as the case of a sand bed. The authors used for the bottom plates thermal sprayed Zn-coated steel plates, which are cathodic protection plates having a sacrifice metal coating a base metal and are effective even in the cases of the gaps and condensation therein, and as a result, confirmed their excellent corrosion protection performance. Welding heat input limitations are imposed on thermal spray-coated plates with simple Zn coating for avoiding deterioration of corrosion resistance at welded joints. For the purpose of relaxing the limitation and reducing the time (or the coating thickness) of the thermal spray work, the suitability of thermal sprayed Zn-Mg-coated steel plates for the oil storage tanks, based on experiences of the above and similar cases was studied.

Hot-rolled steel sheets have been used for tank roofs, in most cases with paint coating on the outer surface and without it on the inner surface. In the past, the authors had used hot dip Zn galvanized steel sheets for the roof plates for the purpose of extending the service life on the inner surface and eliminating initial painting on the outer surface side, and based on this, studied measures for extending the service life. Increase in coating weight is effective for extending service life. However, since roof plates have to be welded together, there is a problem that the coating layers are greatly damaged at heat affected zones on the inner surface side when the coating weight is 225 g/m² or more per side. In view of this, the possibility of applying hot-dip Zn-Mg-coated steel plates to the roofs as a material having excellent corrosion resistance with a smaller coating weight was studied.

2. Methods of Tests and Investigations

2.1 Bottom Plates

A 2,000 kl ambient temperature oil storage tank was constructed on an asphalt bed using thermal sprayed Zn-coated steel plates (9 mm in initial thickness, 0 negative tolerance, 400 µm in coating thickness) for the bottom, and their thickness was measured 10 years thereafter. During construction, the plates were welded by overlap fillet welding and the welding heat input was limited to 0.6 kJ/mm for preventing damage to the thermal sprayed Zn layers.

Another corrosion test was carried out in a laboratory wherein test pieces of JIS SS400 steel plates with thermally sprayed Zn coat-

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were used as test pieces. The coating weight was 150 g/m² per

2.2 Roof Plates

a solution shown in layers at heat affected zones and a spray corrosion test at 30°C. Then, the test coating, 60 to 400 µm in thickness, were subjected to an EPMA line analysis of the thermal sprayed lap fillet welding with a heat input of 1.2 kJ/mm. Then, the test pieces were subjected to an EPMA line analysis of the thermal sprayed layers at heat affected zones and a spray corrosion test at 30°C using a solution shown in Table 1.

In addition, test pieces 9 mm in thickness, some having thermal sprayed Zn coating and others having thermal sprayed Zn-0.5%Mg coating, 60 to 400 µm in coating thickness, were subjected to overlapped fillet welding with a heat input of 1.2 kJ/mm. Then, the test pieces were subjected to an EPMA line analysis of the thermal sprayed Zn coating (rusting observed) Zn-Mg coating (no rusting)

Fig. 2 shows the result of the EPMA line analysis of the heat affected zones of Zn-coated and Zn-Mg-coated plates having a coating thickness of 150 µm. Whereas, in the conventional Zn-coated plates, an Fe-Zn alloy layer about 50 µm in thickness was formed at the interface with the base metal, and an oxide layer of zinc about 50 µm in thickness on the outer surface, such layers were little seen in the newly developed Zn-Mg-coated plates, evidencing excellent corrosion resistance of the Zn-Mg-coated plates at heat affected zones.

Based on the test results and detail examination thereof⁶, Fig. 3 shows service life estimation of steel plates having thermally sprayed Zn-Mg coating layers 400 µm in thickness when applied to the bottom plates of oil storage tanks, under the assumption of a severe corrosion condition expected of only one tank among a hundred. The figure, which is drawn assuming a safety factor of 2, shows that the newly developed Zn-Mg coating has a corrosion resistance 6 times as good as that of the conventional Zn coating or better. Even under

### Table 1 Spray corrosion test condition

<table>
<thead>
<tr>
<th>Test condition</th>
<th>Cl⁻ (ppm)</th>
<th>SO₄²⁻ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum concentration in real environment</td>
<td>1,000</td>
<td>300</td>
</tr>
<tr>
<td>1,200</td>
<td>487</td>
<td>287</td>
</tr>
</tbody>
</table>

### Fig. 1

**Measured thickness value (mm)**
- Measured at 2,000-kl oil tank with thermally sprayed Zn-coated plates (design thickness of bottom plates: 9 mm)
- Used since April 14, 1988
- Measured on May 28, 1998
- Minimum plate thickness at production

**Time before rusting of thermally sprayed plates with 100-µm coating thickness**
- Zn coating: 3 months, Zn-Mg coating: 18 months or more

Fig. 1 Thickness measurement of thermally sprayed steel plates for bottom of 2,000-kl oil tank after 10 years of use

Photo 1 Evaluation of corrosion resistance of thermally sprayed coated surfaces including heat affected zones

thickness were buried into the foundations at the time of construction, and after 10 years, their Zn coating layers were found to have disappeared locally. As a conclusion of a close examination³, the service life of the thermally sprayed Zn coating layer 400 µm in thickness was judged to be about 10 years.

**Photo 1** shows appearances of some of the thermal-spray-coated plates after the spray corrosion test. The test pieces include the heat affected zones of overlap fillet welding. Whereas rusting resulting from base metal corrosion is seen with the Zn-coated plates, no such rusting is seen with the Zn-Mg-coated plates. While Zn-coated plates having layers 100 µm in thickness began to corrode after 3 months of the spray test, Zn-Mg-coated plates having the same coating thickness withstood 18 months or more of testing without corrosion; the corrosion resistance of the Zn-Mg-coated plates is at least 6 times that of the Zn-coated plates.

**Fig. 2** shows the result of the EPMA line analysis of the heat affected zones of Zn-coated and Zn-Mg-coated plates having a coating thickness of 150 µm. Whereas, in the conventional Zn-coated plates, an Fe-Zn alloy layer about 50 µm in thickness was formed at the interface with the base metal, and an oxide layer of zinc about 50 µm in thickness on the outer surface, such layers were little seen in the newly developed Zn-Mg-coated plates, evidencing excellent corrosion resistance of the Zn-Mg-coated plates at heat affected zones.

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the severest condition, a service life about 5 times that of conventionally used materials can be realized with steel plates having the thermal sprayed Zn-Mg coating.

### 3.2 Roof Plates

**Table 2** shows the result of the exposure test at Aichi Refinery of Idemitsu Kousan Co., Ltd. The Zn-coated plates (B) tested in a waste water treatment plant environment, where salt damage is considered to be the severest, lost as much as 137 g/m² of their coating layers in 6 months, and rusting was seen on the surfaces. In contrast, the Zn-Mg-coated plates (A) lost only 36 g/m² of their coating layers in the same environment in the same period, and no rusting was seen (see **Fig. 4**). As for the test pieces exposed inside a tank, only very slight corrosion occurred after 12 months and, as a consequence, it is understood that what is mostly responsible for the service life of roof plates is the corrosion on the outer surface.

**Fig. 2** Sectional EPMA line analysis of heat affected zones (welding heat input: 1.2 kJ/mm)

**Fig. 3** Estimation of corrosion service life of tank bottom plates with and without thermal spray Zn-Mg coating

**Fig. 4** Exposure test of Zn-Mg-coated roof material (waste water treatment plant environment)

<p>| Table 2  Environmental condition and result of exposure test of oil tank roof plates |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Environmental condition</th>
<th>Exposure location</th>
<th>(1) Waste water treatment plant</th>
<th>(2) Tank roof</th>
<th>(3) Inside tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt concentration in rainwater</td>
<td>5,000 ppm</td>
<td>200 ppm</td>
<td>Dilute sulfuric acid gas</td>
<td></td>
</tr>
<tr>
<td>Concentration of suspended salt particles from sea</td>
<td>2,000 mg / h·m³</td>
<td>200 ppm / h·m³</td>
<td>200 ppm / h·m³</td>
<td></td>
</tr>
<tr>
<td>Test period</td>
<td>3 months</td>
<td>6 months</td>
<td>12 months</td>
<td>3 months</td>
</tr>
<tr>
<td>A</td>
<td>Zn-0.5%Mg</td>
<td>36.5</td>
<td>36.4</td>
<td>193.3</td>
</tr>
<tr>
<td>B</td>
<td>Zn</td>
<td>65.0</td>
<td>137.8</td>
<td>585.6</td>
</tr>
<tr>
<td>Appearance</td>
<td>White rust, clear difference between A and B</td>
<td>Red rust in B</td>
<td>Red rust in A and B</td>
<td>Early stage rust, clear difference between A and B</td>
</tr>
</tbody>
</table>

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4. Closing

Past studies have made it clear that when there is a gap between bottom plates and the foundations of an oil tank and humidity is high in the gap, an unexpected extent of corrosion may occur to the bottom plates, even when countermeasures such as use of asphalt bed and cathodic protection are provided. A thermally sprayed Zn-Mg-coated steel plate is a cathodic protection steel plate having a sacrifice metal coating the steel substrate and capable of achieving a sufficient corrosion protection effect even in the above mentioned severe conditions. The newly developed Zn-Mg-coated steel plate demonstrates excellent corrosion resistance and sacrifice protection capacity, and at the same time, has good welding workability. The plate was applied to the bottom of a 30,000-kl oil storage tank in 2001 already.

Based on the excellent corrosion protection performance of the Zn-Mg coating explained above, hot-dip Zn-Mg-coated steel sheets have also already been used for the roof of about 60 oil storage tanks, exhibiting excellent corrosion resistance on both outer and inner surfaces.

Reference
3) High Pressure Institute of Japan: HPIS-G-105-1989, 1989