Assessment of the Zn/Al Metal Spraying Technology without Blast Treatment

Keiji SONOYA


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Recently, in the view of maintenance-free type corrosion prevention of steel bridges, thermal spraying with good durability and long life is desired. Zn/Al metal spraying is spotlighted due to its low life cycle cost (LCC). Zn/Al metal spraying without blast treatment, one of corrosion prevention methods, has better efficiency and environmental property, such as less fume, than the conventional method based on JIS H 8305. In this paper a comparison was made on the properties of the Zn/Al sprayed coating without blast treatment and the coating of the conventional method. In the results, it was shown that the coating of Zn/Al metal spraying without blast treatment had the same properties as conventional method based on JIS H 8305.

KEY WORDS: Zn/Al metal spraying; corrosion prevention; blast treatment.

1. Introduction

Paintwork has been a general procedure for protecting steel structures from corrosion. However, the recent trend is to apply corrosion protection methods that are highly durable and have extended life from the viewpoint of maintenance-free operations of steel structures as shown in Table 1. The environmental consideration requires thermal spraying type corrosion protection methods of lower life-cycle cost than that of paintwork to be applied.

The thermal spraying with aluminum and zinc, which is specified in the JIS H 8305, is applied on steel surfaces after the surfaces are pre-treated by blasting operations. A recently developed thermal spraying method deposits a pseudo alloy of Zn/Al on steel surfaces after the surfaces are painted by a rough-surface forming agent instead of applying the blasting treatment as applied to the conventional method based on JIS H 8305. The developed process is convenient to be applied at construction sites because of the absence of the blasting pretreatment. The developed thermal spraying will be denoted as the metal spray (MS) method in this paper. The conventional method based on JIS H 8305 will be denoted as the CP (Corrosion Prevention) spraying method in this paper. The application of the CP spraying method for protecting steel beams from corrosion of a bridge of the Route No. 5 of Fukuoka Expressway that is 18 km between Nishi-tukisumi and Fukushige of the Highway Authority of Fukuoka and Kita-Kyushu.

The MS method is highly efficient because a simplified surface pre-treatment is only needed, and thus, it is believed to be environmentally friendly, such as less fume, than the CP spraying method that is applied after steel surfaces are treated by a blasting operation. The present article compares the performances of coatings prepared by the CP spraying method that consists of a blasting operation followed by the flame spraying of an alloy of Zn and Al on steel surfaces, and the developed MS method with respect to the adhesion strength, corrosion resistance, and microstructure for verifying the effectiveness of the MS method.

2. Experimental Methods

2.1. Outlines of the Thermal Spraying Methods

Thermal spraying is conducted through the following steps, namely, the spray materials are heated either by com-

<table>
<thead>
<tr>
<th>Coating method environments</th>
<th>Galvanizing (as galvanized)</th>
<th>Zinc-aluminum alloy (spraying and sealing)</th>
<th>Polyurethane resin type painting</th>
<th>Fluoresin type painting</th>
</tr>
</thead>
<tbody>
<tr>
<td>General environments (mountain areas)</td>
<td>100</td>
<td>100</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Relatively harsh environments (urban areas)</td>
<td>60</td>
<td>70</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Harsh enivironment (coastal areas)</td>
<td>25</td>
<td>60</td>
<td>20</td>
<td>30</td>
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</table>

2. Numerical numbers in years
bustion energy or electric energy, and molten or partly molten pulverized spray materials thus formed are impinged on substrates to form deposits of the spray materials. As defined by JIS H 8300, various thermal sprayings exist according to the heat sources employed, and the typical thermal sprayings for protecting steel parts from corrosion are shown in Fig. 1 for the MS method as shown in Fig. 1(a), and for the CP spraying method with spray wires in Fig. 1(b).5)

2.2. Thermal Spraying Procedures

2.2.1. MS Method

Mild steel substrate specimens of the size of 200×200×10 mm are treated on the surfaces for cleaning of the order of ISO-St36 by depositing a surface roughening agent containing ceramic particles, called by the trade name of Blasnon #21 by Dainippon Toryo Co., of the suitable thickness of about 30 μm. Separate wires of zinc and aluminum of the diameters of 1.3 mm are fed simultaneously to the arc type spray gun to deposit the alloy sprayed coating with the composition of Zn : Al = 3 : 1 in weight ratio to form the deposit of about 100 μm thick as shown in Fig. 2(a).

2.2.2. CP Spraying Method

Mild steel substrate specimens of the size of 200×200×10 mm are blasted to clean the steel surfaces of the cleanliness better than ISO-Sa2.5,6) and the surface roughness larger than Ra 8 μm. The thermal spraying is conducted with an alloy wire of the diameter of 4.6 mm with the composition of Zn : Al = 3 : 1 in weight ratio to form the deposit of about 100 μm thick as shown in Fig. 2(b).

2.3. Test Items

The following items are tested to compare the performances of the deposits formed by the MS method and the CP spraying method.

2.3.1. External Appearance Observation

The surfaces of the deposits by the MS method and that by the CP spraying method are visually compared. Here, sealers are applied on the surfaces of the deposits before the observation is made. The surfaces obtained by the MS method are applied with a butyl alcohol resin, called by the trade name of MS sealer by Dainippon Toryo Co., and the surfaces by the CP spraying method are applied with an inorganic type paint, called by the trade name of Ceratect GS Seal by Kansai Paint Co.

2.3.2. Microstructural Observation

The cross sections of the deposits prepared by the MS method and by the CP spraying method without sealing treatment are observed under a optical microscope by Rize in the magnification of 100 to compare the characteristics.

2.3.3. Hardness Measurements

Microhardness measurements are conducted on the cross sections of deposit surfaces obtained by the MS method and the CP spraying method with the test load of 0.98 N. Five measurements on the cross sections are averaged to obtain average hardness value. Here, sealers are not applied on the surfaces of the deposits before the measurement is made.

2.3.4. Adhesion Strength Tests

The adhesion strength of the deposits to the substrates is measured according the tensile test method specified in JIS.
H 8661, [Test methods of spray formed deposits of zinc, aluminum and the alloys of zinc and aluminum]. Five measurement values obtained by an adhesion tester by Elco Meter Co. are averaged to obtain a representative value of the adhesion strength. Here, sealers are not applied on the surfaces of the deposits before the measurement is made.

2.3.5. Measurements of Coefficients of Friction

The coefficients of friction of the deposits obtained by the MS method and the CP spraying method without sealing treatment are measured according to the test method specified by the Society of Japan Construction.4)

2.3.6. Corrosion Tests

Corrosion tests of the deposits formed by the MS method and the CP spraying method are conducted with an aqueous solution of 5% NaCl at 25°C according the salt spray test method specified by JIS H 8661, [Test methods of spray formed deposits of zinc, aluminum, and related alloys]. Although the JIS specifies the corrosion test time for 72 h, the present tests are conducted for up to 500 h to investigate the corrosion behavior of the deposits in the accelerated corrosion condition. Here, sealers are not applied on the surfaces of the deposits before the measurement is made.

3. Test Results

3.1. External Appearance Observation

Figure 3 shows the exterior appearance of the deposits prepared by the MS method and the CP spraying method. The surfaces treated by the sealers are smooth, and no difference is detected except of a little difference of color for both surfaces.

3.2. Microstructure Observation Results

Figure 4 shows the typical microstructure of the deposits prepared by the MS method and the CP spraying method. The deposits formed by the MS method contains a layer of the surface roughening agent with ceramic particles to exist near the substrate surface. The deposit formed by the MS method is a layered structure of the pseudo alloy of Zn–Al. On the other hand, the deposit formed by the CP spraying method is a mixed structure of layers of Zn and Al.

3.3. Hardness Measurement Results

Table 2 shows the micro Vickers hardness values of the deposits prepared by the MS method and the CP spraying method. The results show that the average hardness for both types of the deposits is HV39. There was some scatters in hardness values because the deposit formed by CP spraying method was a mixed structure of layers of Zn and Al.

<table>
<thead>
<tr>
<th>Spray method</th>
<th>Measured values*</th>
<th>Average values</th>
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<tbody>
<tr>
<td>MS method</td>
<td>39.2 39.9 35.8 40.5 39.1</td>
<td>38.9</td>
</tr>
<tr>
<td>CP spraying method</td>
<td>36.8 40.1 47.9 33.1 40.0</td>
<td>39.6</td>
</tr>
</tbody>
</table>

Remarks: *measured by the load of 0.98N
3.4. Adhesion Strength Test Results

Table 3 shows the adhesion strength test results of the deposits prepared by the MS method and CP spraying method. The adhesion strength of the MS method is 2.4 MPa on average. From Microstructure observation results, the fracture location was the boundary between the surface roughening agent and sprayed coating. The value satisfies the standard strength to be above 2.3 MPa according to the room temperature metal sprayed design and fabrication manual for steel bridges set by the civil structure room temperature spraying method study group,7) and the specifications for the Fukuoka Expressway No.5 steel bridge corrosion protection works done in 20018) as to be above 2.3 MPa. Some values are low because of lack of the surface roughening agent. Thus, much carefulness for the roughened surface preparation before the MS method is applied is necessary.

The average value of the adhesion strength of the deposits prepared by the CP spraying method is 4.1 MPa on average, which is higher than the value obtained by the MS method. The value well satisfies the standard values cited above, and the adhesion strength for the CP spraying method is not mattered.

3.5. Measurement Results of Coefficients of Friction

The measured coefficients of friction for the deposits prepared by the MS method without sealing treatment is 0.55–0.7, and that by the CP spraying method is 0.68. These values are well above the specified value to be larger than 0.4 set by the steel road bridge corrosion protection handbook.4) The measured coefficients of friction for the deposits prepared by the CP spraying method is 0.68. These values are well above the specified value to be larger than 0.4 set by the steel road bridge corrosion protection handbook.4)

3.6. Corrosion Test Results

3.6.1. External Appearance

Figure 5 shows the external appearance of the corrosion test pieces after various test periods up to 500 h of the salt spray test are done for the deposits prepared by the MS method and the CP spraying method. The specimen surfaces of the MS deposits remain unchanged during the test without forming rust of white and red color.

The deposit surfaces prepared by the JIS thermal spray method start to grow longitudinal dents after the test time of 200 h with some dissolution of the surface of the deposits. The dent gradually increases the depth with increasing the test time with the selective dissolution of electro-chemically inferior Zn in the deposited alloy.9)

3.6.2. Microstructure after the Corrosion Tests

Figure 6 shows the cross-sectional microstructure of the corrosion test pieces after the test time of 200, 300 and 500 h for the deposits prepared by the MS method and the CP spraying method. The cross-sectional microstructure of the deposits prepared by the MS method shows no change of the thickness after the test of 200 h. The total thickness of the deposit and the roughening agent prepared by the MS method shows no change after the test of 300 h. The deposits prepared by the CP spraying method show thickness to decrease during the corrosion tests with the minimum thickness to reach 60 μm. The thickness of the deposit decreases as well with the minimum thickness of about 50 μm at the test time of 300 h for the deposit by the MS method. The corrosion of the deposit by the CP spraying method is much severe to reach the minimum thickness of 20 μm.

The test results outlined above indicate that the longer the test time, the larger the corrosion losses for the deposits prepared by the MS method and the CP spraying method than that for the MS method. The reason is thought that the deposit by the MS method consists a pseudo alloy of Zn/Al and Al becomes the barrier against the corrosion of Zn.7)

3.7. Deposition Capacity of the Thermal Spraying Methods

The deposition rate of the CP spraying method is computed to be 720 m²/d, whereas that of the MS method is 360 m²/d. The lower capacity of the MS method is because of the lower heat input allowable to the method not to melt the surface roughening agent of epoxy resin during the deposition.

3.8. Cost Comparison for the Spray Methods

The fabrication costs such as preceding treatment, spraying and sealing treatment for preparing the deposits by these methods are computed for comparison, and the neces-
sary expense for the MS method is estimated to be about 1.06 times of that for the CP spraying method mainly because of the lower deposition rate of the MS method.

3.9. Comprehensive Evaluation

Table 4 shows the comprehensive evaluation results of the deposits that are prepared by the MS method and the CP spraying method. The adhesion strength of the deposits prepared by the MS method is lower than that of the CP spraying method. However, the strength satisfies the requirement set by the room temperature metal spray design and fabrication manual of the civil structure room temperature spray study group, namely, above 2.3 MPa. Although the fabrication capacity of the MS method is about one half of the CP spraying method, the long-range corrosion resistance of the MS deposit is superior to that of the CP spraying method. The necessary expenditure for the MS method is almost the same to that for the CP spraying method. Thus, the comprehensive evaluation result is that the MS method can be applied to bridges as a corrosion prevention method similar to the CP spraying method that is employed frequently.

4. Applications of the MS Method to Bridges

The present investigation has demonstrated the superior characteristics in deposits that are prepared by the MS method. We have employed the MS method in addition to painting methods as a corrosion prevention method utilizing the opportunity of the order granted for the construction of a bridge.

4.1. Spray Fabrication on Steel Bed Frames and Main Girders

The shop construction of the steel bed frames and the main girders was initiated, and the MS fabrication started in parallel to it. The steel bed frames were treated by the MS method except for the upper surfaces where inorganic zinc-rich paint was applied. Small parts like numerous angles and parts of small areas were sprayed under suitable conditions with sufficient cares. The coating fabrication of the steel bed frames and main girders was completed.

4.2. Site Fabrication

The fabricated steel bed frames and main girders are constructed to blocks at the work, and shipped to the construction site for completion. The site joints were sprayed after completing the welding works. The bridge of the total length of 214 m was completed 2 years after the initiation of construction for the bridge.

5. Conclusion

The present article compares the performances of coatings prepared by the CP spraying method, conventional method based on JIS H 8305, and the MS method with re-

<table>
<thead>
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<th>Spray method</th>
<th>External appearance</th>
<th>Hardness</th>
<th>Adhesion strength</th>
<th>Coefficient of friction</th>
<th>Corrosion resistance</th>
<th>Fabrication shop capacity</th>
<th>Cost</th>
<th>Comprehensive evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS method</td>
<td>○ (1)</td>
<td>○ (1)</td>
<td>○ (0.6)</td>
<td>○ (1)</td>
<td>○ (2.5)</td>
<td>○ (1)</td>
<td>○ (1)</td>
<td>○ (1)</td>
</tr>
<tr>
<td>CP spraying method</td>
<td>○ (1)</td>
<td>○ (1)</td>
<td>○ (1)</td>
<td>○ (1)</td>
<td>○ (1)</td>
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</table>
spect to the adhesion strength, corrosion resistance, and microstructure for verifying the effectiveness of the MS method. The results are as follows.

(1) The adhesion strength of the deposits prepared by the MS method is lower than that of the CP spraying method. However, the strength satisfies the requirement set by the room temperature metal spray design and fabrication manual of the civil structure room temperature spray study group, namely, above 2.3 MPa.

(2) Although the fabrication capacity of the MS method is about one half of the CP spraying method, the long-range corrosion resistance of the MS deposit is superior to that of the CP spraying method. The necessary expenditure for the MS method is almost the same to that for the CP spraying method.

(3) The comprehensive evaluation result is that the MS method can be applied to bridges as a corrosion prevention method similar to the CP spraying method that is employed frequently.

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