

DESCRIPTION

Title of Invention

HOT-DIP ZINC-ALUMINUM ALLOY COATED STEEL SHEET HAVING HIGH
CORROSION RESISTANCE AND FORMABILITY AND METHOD FOR
PRODUCING THE SAME

Technical Field

The present invention relates to a hot-dip Zn-Al alloy coated steel sheet suitable for use in construction, civil engineering, household electric appliances, etc., and a method for producing the sheet. In particular, it relates to improvements in formability and corrosion resistance of formed portions.

Background Art

In the fields of building materials, household electric appliances, automobiles, etc., hot-dip galvanized steel sheets have been widely used. Hot-dip Zn coated steel sheets applied to such usages are mainly required to exhibit high corrosion resistance. However, for example, in the field of construction, hot-dip galvanized steel sheets are formed into particular shapes and used as parts of roofs, walls, structures, etc., and thus hot-dip galvanized steel sheets for such usages are required to exhibit not only high corrosion resistance but also high formability and,

furthermore, high corrosion resistance in formed portions. In the fields of building materials and household electric appliances, for example, the sheets are frequently used unpainted and are thus required to excel also in uniformity of appearance and blackening resistance.

To meet such requirements, for example, Patent Literature 1 proposes a hot-dip Zn-Al alloy coated steel sheet that has good coating appearance with metallic luster and high blackening resistance. In the technique described in Patent Literature 1, a steel sheet is immersed into a hot-dip Zn-Al alloy coating bath, withdrawn from the coating bath, and cooled at a cooling rate of 1 to 15°C/s to 250°C so as to form a hot-dip Zn-Al alloy coating layer composed of Al: 1.0 to 10%, Mg: 0.2 to 1.0%, Ni: 0.005 to 0.1%, and the balance being Zn and unavoidable impurities on surfaces of the steel sheet, thereby producing a hot-dip Zn-Al alloy coated steel sheet having good coating appearance with metallic luster and high blackening resistance. In the technique described in Patent Literature 1, the cooling rate after coating is controlled to be within the aforementioned particular range to accelerate condensation of Ni in the outermost surface portion of the coating due to a synergetic effect of Mg and Ni.

Patent Literature 2 describes a technique related to a hot-dip galvanized steel sheet having high corrosion

resistance. A coated steel sheet described in Patent Literature 2 has, on surfaces of a steel sheet, a hot-dip Zn-Al alloy coating layer composed of, in terms of mass%, Al: 1.0 to 10%, Mg: 0.2 to 1.0%, Ni: 0.005 to 0.2%, and the balance being Zn and unavoidable impurities, and a Ni-rich layer at the interface between the coating layer and the base steel sheet. According to this technique, the coating layer exhibits high formability, cracking in formed portions is suppressed, and thus corrosion of the base steel sheet is suppressed, thereby producing a coated steel sheet having high corrosion resistance in formed portions.

Citation List

Patent Literature

PTL 1: Japanese Unexamined Patent Application
Publication No. 2008-138285

PTL 2: Japanese Unexamined Patent Application
Publication No. 2010-255084

Summary of Invention

Technical Problem

In the technique described in Patent Literature 1, a Zn-Al-Mg coating layer containing Ni is used to mainly improve the blackening resistance. However, Patent Literature 1 makes no mention as to the amount of Fe in the coating layer. For example, when Fe contained in the coating bath is excessively incorporated into the coating

layer and a thick alloy phase is formed between the coating layer and the substrate, the coating layer becomes susceptible to cracks on forming such as bending. The coating layer becomes thin in cracked portions and exposure of the base steel sheet may sometimes result. Accordingly, a coated steel sheet produced by the technique described in Patent Literature 1 has suffered from low formability and low corrosion resistance in formed portions as a natural consequence.

In the technique described in Patent Literature 2, a coated steel sheet having high formability and high corrosion resistance in formed portions is obtained. However, Patent Literature 2 makes no mention as to the amount of Fe in the coating layer. Accordingly, as with the coated steel sheet produced by the technique described in Patent Literature 1, there has been a problem in that when Fe in the coating bath is excessively incorporated into the coating layer and the steel sheet is subjected to forming such as bending, cracks readily occur in the coating layer, resulting in low formability and low corrosion resistance in formed portions.

Patent Literature 2 merely describes that the sheet immersing temperature of the steel sheet upon immersing into the coating bath is appropriately controlled to be within the range of 450°C to 600°C and the coating bath temperature

is appropriately controlled to be within the range of 400°C to 550°C both on the basis of the sheet thickness and the line speed, and makes no mention of a clear and specific production process. Moreover, in Patent Literature 2, no confirmation is made on effects achieved by the production method.

An object of the present invention is to provide a hot-dip Zn-Al alloy coated steel sheet having both high corrosion resistance and high formability and a method for producing the sheet.

Solution to Problem

The inventors of the invention of the subject application have carried out extensive studies on various factors that affect the corrosion resistance and formability of a hot-dip Zn-Al alloy coated steel sheet to achieve the object described above. As a result, the inventors have found that in order to improve coating adherence, corrosion resistance, and corrosion resistance after forming, it is preferable to use a coating bath having a Zn-Al-Mg alloy coating composition containing an adequate amount of Ni, adjust the bath temperature of the coating bath to a temperature within an adequate range, and adjust the temperature of a steel sheet (sheet temperature), which serves as a substrate, upon immersing into the coating bath to be within an adequate range but not less than the bath

temperature of the coating bath. The inventors have found that, in this manner, a Ni-rich layer having an adequate thickness can be formed at the interface between the coating layer and the substrate, i.e., the steel sheet (base steel sheet).

The inventors have also found that in order to stably improve the formability of the coating layer, the Fe content in the coating layer must be adjusted to 2.0 g/m^2 or less per unit area of the coating layer. The inventors have found that Fe contained in the coating layer is incorporated therein by solidification of Fe in the coating bath and that in order to adjust the Fe content in the coating layer to a desired value or less, the Fe concentration in the coating bath may be adjusted to an adequate level, in particular, 0.05% or less in terms of mass%.

The present invention has been made based on these findings and further studies. The present invention is summarized as follows.

(1) A method for producing a hot-dip Zn-Al alloy coated steel sheet having high corrosion resistance and high formability, the method including introducing a steel sheet serving as a substrate into a hot-dip Zn-Al alloy coating bath having a composition of Al: 3 to 6%, Mg: 0.2 to 1.0%, Ni: 0.01 to 0.10%, and the balance being Zn and unavoidable impurities in terms of percent by mass, withdrawing the

steel sheet therefrom, and cooling the steel sheet to form a hot-dip Zn-Al alloy coating layer on a surface of the steel sheet. The hot-dip Zn-Al alloy coating bath has an Fe content adjusted to 0.10% or less, a temperature of the hot-dip Zn-Al alloy coating bath is adjusted to be within a range of 420°C to 520°C, and a temperature of the steel sheet upon immersing into the hot-dip Zn-Al alloy coating bath is adjusted to be within a range of 420°C to 600°C but not less than the temperature of the hot-dip Zn-Al alloy coating bath.

(2) A hot-dip Zn-Al alloy coated steel sheet having high corrosion resistance and high formability, including a steel sheet serving as a substrate and a hot-dip Zn-Al alloy coating layer having a composition of Al: 3 to 6%, Mg: 0.2 to 1.0%, Ni: 0.01 to 0.10%, and the balance being Zn and unavoidable impurities in terms of percent by mass, the hot-dip Zn-Al alloy coating layer being formed on at least one surface of the steel sheet. The hot-dip Zn-Al alloy coating layer has an Fe content adjusted to 2.0 g/m² or less and a Ni-rich layer having a thickness of 0.05 to 1.0 μm lies at the interface between the hot-dip Zn-Al alloy coating layer and the steel sheet.

Advantageous Effects of Invention

According to the present invention, formability as well as corrosion resistance is improved and thus the present

invention has an advantageous effect that a hot-dip Zn-Al alloy coated steel sheet having both high corrosion resistance and high formability can be easily produced at low cost. Another advantageous effect of the present invention is that the adherence of the coating layer is improved.

Description of Embodiments

First, a method for producing a hot-dip Zn-Al alloy coated steel sheet of the present invention (hereinafter may be referred to as "coated steel sheet of the invention") is described.

A steel sheet used as a substrate is, for example, immersed into a hot-dip Zn-Al alloy coating bath by using a continuous galvanizing line, withdrawn therefrom, and cooled to form a hot-dip Zn-Al alloy coating layer on surfaces of the steel sheet.

The type and composition of the steel sheet used as the substrate need not be limited and may be appropriately selected from known hot-rolled steel sheets and cold-rolled steel sheets according to the intended use.

The steel sheet serving as the substrate is, for example, first heated to a desired heating temperature by using a continuous galvanizing line. The heating temperature may be appropriately determined according to the steel sheet used and is not particularly limited. However,

in the present invention, at the time the steel sheet is immersed into the coating bath, the steel sheet temperature (sheet temperature) must be adjusted to a particular desired temperature. In this regard, the heating temperature must at least be a temperature with which a desired steel sheet temperature (sheet temperature) can be achieved upon immersing of the steel sheet into the coating bath.

The steel sheet heated to a particular temperature is immersed into a hot-dip Zn-Al alloy coating bath having a particular composition maintained at a particular bath temperature to form a hot-dip Zn-Al alloy coating layer on surfaces of the steel sheet.

The composition of the hot-dip Zn-Al alloy coating bath into which the steel sheet is immersed contains, in terms of mass%, Al: 3 to 6%, Mg: 0.2 to 1.0%, Ni: 0.01 to 0.10%, and the balance being Zn and unavoidable impurities. In the present invention, the coating bath has an Fe content adjusted to 0.10% or less.

The reasons for the limitations on the composition of the coating bath are as follows. Note that % used in describing the composition denotes mass%.

Al: 3 to 6%

When the Al content in the coating bath is less than 3%, a thick Fe-Al alloy layer is likely to be formed at the interface between the coating layer to be formed and the

base steel sheet (substrate), resulting in degradation of formability of the coating layer. At an Al content exceeding 6%, the sacrificial protection effect of Zn on the coating layer is reduced and the corrosion resistance of the coated steel sheet end surface portions and the like is degraded. When the Al content in the coating bath exceeds 6%, top dress mainly composed of Al tends to occur and the appearance of the resulting coating layer is degraded. Furthermore, the blackening resistance of the resulting coating layer is degraded, formation of the Zn-Al-Mg ternary eutectic is enhanced, and the formability of the coating layer is degraded. Thus, the Al content in the coating bath is limited to a range of 3 to 6%.

Mg: 0.2 to 1.0%

In order to improve the corrosion resistance, in particular, the blackening resistance, of the coating layer to be formed, Mg is added to the coating bath. When the Mg content in the coating bath is less than 0.2%, the effect of improving the corrosion resistance of the coating layer to be formed is small. In contrast, at an Mg content exceeding 1.0%, an excessively large amount of Zn-Al-Mg ternary eutectic is formed in the resulting coating layer and the formability of the coating layer is degraded. Thus, the Mg content in the coating bath is limited to a range of 0.2 to 1.0%.

Ni: 0.01 to 0.10%

Nickel is added to the coating bath in order to improve the corrosion resistance of the coating layer to be formed. At a Ni content less than 0.01%, the effect of improving the corrosion resistance is small. In contrast, at a Ni content exceeding 0.10%, the surface of the coating layer to be obtained will be excessively activated and become susceptible to corrosion, leading to formation of white rust at an early stage. Thus, the Ni content in the coating bath is limited to a range of 0.01 to 0.10%.

The balance is composed of Zn and unavoidable impurities.

The coating bath used in the present invention has an Fe content adjusted to 0.10% or less in terms of mass%. Iron is not intentionally added to the coating bath. However, during the coating treatment, Fe is dissolved from the steel sheet immersed into the coating bath and stays in the coating bath. Iron in the coating bath becomes incorporated into the coating layer as the coating solution adhering to the surfaces of the steel sheet solidifies and forms a coating layer. When a large amount of Fe is incorporated into the coating layer, a thick alloy phase is formed and thus the formability of the coating layer is degraded. According to studies carried out by the inventors, the Fe content in the coating layer needs to be adjusted to

a particular value (2.0 g/m^2) or less in order to suppress degradation of the formability of the coating layer. In order to control the Fe content in the coating layer to a particular value or less, it is important that the Fe concentration in the coating bath be appropriately controlled to 0.10% or less. Note that since the Fe content in the coating layer is dependent on the coating layer thickness, the Fe content herein is expressed as content per unit area (g/m^2).

In the present invention, the temperature of the coating bath adjusted to produce the above-described composition is adjusted to be within a range of 420°C to 520°C . If the temperature of the coating bath is less than 420°C , the viscosity of the coating bath increases due to the excessively low bath temperature and the desired coating treatment cannot be carried out. In contrast, when the temperature exceeds 520°C , the coating bath is excessively oxidized and extensive dross formation occurs. Thus, the temperature of the coating bath is limited to a range of 420°C to 520°C .

A steel sheet serving as a substrate is immersed into a coating bath adjusted to have such a composition and a bath temperature.

In the present invention, the temperature of the steel sheet (sheet temperature) upon immersing into the coating

bath is adjusted to be within a range of 420°C to 600°C but not lower than the bath temperature of the coating bath. If the sheet temperature of the steel sheet upon immersing is lower than the temperature of the coating bath, the temperature of the coating bath will decrease gradually, thereby causing the viscosity of the coating bath to increase and obstructing the operation. In contrast, at a temperature exceeding 600°C, the temperature of the coating bath will gradually increase. Thus the temperature of the steel sheet (sheet temperature) upon immersing into the coating bath is limited to a range of 420°C to 600°C but not lower than the temperature of the coating bath.

In the present invention, the coating bath having the aforementioned composition is adjusted to a temperature within the range described above and the temperature of the steel sheet (sheet temperature) upon immersing into the coating bath is adjusted to be within a range of 420°C to 600°C but not lower than the temperature of the coating bath. As a result, alloying elements diffuse at the interface between the coating bath and the steel sheet surface and formation of an adequate Ni-rich layer is accelerated at the interface between the coating layer and the steel sheet (substrate). Since the Ni-rich layer is formed, the corrosion resistance can be improved even when damage reaching the substrate occurs in the coating layer or cracks

occur in the coating layer due to forming. The thickness of the Ni-rich layer can be controlled to be within an adequate range of 0.05 to 1 μm by adjusting the coating bath composition, the bath temperature, and the sheet temperature of the steel sheet upon immersing to be within the aforementioned ranges.

The steel sheet having been immersed into the coating bath is then withdrawn from the coating bath and cooled.

A coated steel sheet of the invention produced by the process described above is a hot-dip Zn-Al alloy coated steel sheet having a hot-dip Zn-Al alloy coating layer constituting at least one surface thereof, the layer containing, in terms of mass%, Al: 3.0 to 6.0%, Mg: 0.2 to 1.0%, Ni: 0.01 to 0.10%, 2.0 g/m² or less of Fe, and the balance being Zn and unavoidable impurities; and a Ni-rich layer having a thickness of 0.05 to 1 μm at the interface between the coating layer and a steel sheet.

The reasons for the limitations on the composition of the hot-dip Zn-Al alloy coating layer are the same as the reasons for the limitations on the coating bath described above and description thereof is omitted. The coating weight of the hot-dip Zn-Al alloy coating layer may be set according to the intended use as usual and no limitation is imposed thereon. However, the coating weight of the hot-dip Zn-Al alloy coating layer is preferably about 30 to 300 g/m²

per side. When the coating weight is less than 30 g/m^2 , the thickness of the coating layer is insufficient and the desired corrosion resistance cannot be maintained. When the coating weight exceeds 300 g/m^2 , the thickness of the coating layer increases excessively and peeling off of the coating layer easily occurs.

The coated steel sheet of the invention includes a Ni-rich layer at the interface between the coating layer and the base steel sheet (substrate). As a result, the corrosion resistance of the coating layer can be maintained even when damage reaching the base steel sheet (substrate) occurs in the coating layer or cracks occur in the coating layer due to forming. The thickness of the Ni-rich layer is to be within a range of 0.05 to $1.0 \text{ }\mu\text{m}$. When the thickness of the Ni-rich layer is less than $0.05 \text{ }\mu\text{m}$, the reaction between the coating layer and the base steel sheet (substrate) is insufficient and thus the coating adherence is insufficient. In contrast, when the thickness exceeds $1.0 \text{ }\mu\text{m}$, the formability of the coating layer is degraded. Accordingly, the thickness of the Ni-rich layer formed at the interface between the coating layer and the base steel sheet (substrate) is limited to be within a range of 0.05 to $1.0 \text{ }\mu\text{m}$.

The Ni-rich layer is formed by an alloying reaction between Ni in the coating bath and Fe on a steel sheet

surface. The thickness of the Ni-rich layer can be adjusted to be within a particular range by appropriately controlling the coating bath temperature, the steel sheet, and the sheet immersing temperature as described above.

[EXAMPLES]

A cold-rolled steel sheet (sheet thickness: 0.5 mm, unannealed) was used as the substrate. The substrate was heated so that the substrate would have a sheet immersing temperature (sheet temperature) shown in Table 1 upon immersing into the coating bath, immersed into a hot-dip Zn-Al alloy coating bath having various compositions and bath temperatures shown in Table 1, withdrawn therefrom, and cooled to form a hot-dip Zn-Al alloy coating layer having a coating weight shown in Table 2.

The coating layer of the resulting hot-dip Zn-Al alloy coated steel sheet was melted and the composition of the coating layer was analyzed by a common method. Using the resulting hot-dip Zn-Al alloy coated steel sheet, observation of the microstructure in a cross-section of the coating layer, a formability test, and a corrosion test of bended portions were conducted. The test methods were as follows.

(1) Observation of microstructure in cross-section of coating layer

A test specimen for microstructural observation was

taken from the resulting hot-dip Zn-Al alloy coated steel sheet. A section taken in the sheet thickness direction was polished and the microstructure of the section of the coating layer was observed in 10 or more observation areas using a scanning electron microscope (2000x magnification) to analyze Ni. Whether the Ni-rich layer was present and the thicknesses of the Ni-rich layer were determined and the average thicknesses were calculated. Note that the term "Ni-rich layer" refers to a region where a peak attributable to Ni is detected with an energy-dispersive X-ray spectrometer of a scanning electron microscope.

(2) Formability test

A JIS No. 5 tensile test specimen was taken from the resulting hot-dip Zn-Al alloy coated steel sheet and subjected to a tensile test. During the test, the surface of the coating layer was observed with the naked eye, the amount of strain at which cracks are identifiable in the coating layer surface (crack-generating strain amount) was determined, and the formability of the coated steel sheet was evaluated. The evaluation standard was as follows.

Rating AA: The crack-generating strain amount was 20% or more.

Rating A: The crack-generating strain amount was 10% or more and less than 20%.

Rating B: The crack-generating strain amount was 5% or more

and less than 10%.

Rating C: The crack-generating strain amount was less than 5%.

(3) Corrosion resistance test on bended portions

The resulting hot-dip Zn-Al alloy coated steel sheet was subjected to 1R-180° bending and a salt spray test was carried out in accordance with JIS Z 2371. Salt spray conditions were as follows: spray solution: 5% NaCl solution, temperature: 35°C, testing hours: 1000 h. After the test, the surface of the specimen was observed with the naked eye and the red rust generation ratio (area fraction) was determined to evaluate the corrosion resistance of the bended portions. The standard of the evaluation was as follows.

Rating A: No red rust

Rating B: Red rust generation ratio of 1 to 50%

Rating C: Red rust generation ratio of 51% or more

The results are shown in Table 2.

[Table 1]

Steel sheet No.	Sheet temperature (upon immersing into coating bath) (°C)	Coating bath						(Sheet temperature) - (bath temperature) (°C)	Remarks
		Bath temperature (°C)	Composition (mass%)						
			Al	Mg	Ni	Fe	Zn		
1	420	430	4.5	0.5	0.05	0.02	Balance	-10	Comparative Example
2	460	430	4.5	0.5	0.05	0.02	Balance	30	Invention Example
3	470	450	4.5	0.5	0.05	0.02	Balance	20	Invention Example
4	480	460	4.5	0.5	0.05	0.02	Balance	20	Invention Example
5	500	480	4.5	0.5	0.05	0.02	Balance	20	Invention Example
6	530	500	4.5	0.5	0.05	0.02	Balance	30	Invention Example
7	540	510	4.5	0.5	0.05	0.02	Balance	30	Invention Example
8	570	510	4.5	0.5	0.05	0.02	Balance	60	Invention Example
9	560	530	4.5	0.5	0.05	0.02	Balance	30	Comparative Example
10	540	500	4.5	0.5	0.05	0.41	Balance	40	Comparative Example
11	480	460	2.5	0.5	0.05	0.02	Balance	20	Comparative Example
12	480	460	6.5	0.5	0.05	0.02	Balance	20	Comparative Example
13	480	460	4.5	0.1	0.05	0.02	Balance	20	Comparative Example
14	480	460	4.5	1.2	0.05	0.02	Balance	20	Comparative Example
15	480	460	4.5	0.5	-	0.02	Balance	20	Comparative Example
16	480	460	4.5	0.5	0.12	0.02	Balance	20	Comparative Example

[Table 2]

Steel sheet No.	Coating layer						Microstructure in cross-section of coating layer	Formability	Corrosion resistance of bended portions	Remarks
	Composition (mass%)				(g/m ²)	Coating weight (g/m ²)	Thickness of Ni-rich layer (μm)	Rating	Rating	
	Al	Mg	Ni	Zn	Fe					
1	4.5	0.5	0.05	Balance	0.05	90	0.03	B	A	Comparative Example
2	4.5	0.5	0.05	Balance	0.15	90	0.10	AA	A	Invention Example
3	4.5	0.5	0.05	Balance	0.27	90	0.15	AA	A	Invention Example
4	4.5	0.5	0.05	Balance	0.32	90	0.20	AA	A	Invention Example
5	4.5	0.5	0.05	Balance	0.51	90	0.30	AA	A	Invention Example
6	4.5	0.5	0.05	Balance	0.78	90	0.40	AA	A	Invention Example
7	4.5	0.5	0.05	Balance	0.89	90	0.60	A	A	Invention Example
8	4.5	0.5	0.05	Balance	1.43	90	0.70	A	A	Invention Example
9	4.5	0.5	0.05	Balance	2.12	90	1.10	C	B	Comparative Example
10	4.5	0.5	0.05	Balance	2.25	90	0.45	C	C	Comparative Example
11	2.9	0.5	0.05	Balance	2.45	90	1.25	C	C	Comparative Example
12	6.5	0.5	0.05	Balance	0.55	90	0.35	B	B	Comparative Example
13	4.5	0.1	0.05	Balance	0.43	90	0.25	A	B	Comparative Example
14	4.5	1.2	0.05	Balance	0.39	90	0.25	C	A	Comparative Example
15	4.5	0.5	-	Balance	0.34	90	-	A	B	Comparative Example
16	4.5	0.5	0.12	Balance	0.29	90	0.35	A	C	Comparative Example

In all of the invention examples, hot-dip Zn-Al alloy coated steel sheets having high formability and corrosion resistance at formed portions were obtained. In contrast, Comparative Examples outside the range of the present invention exhibited low formability or low corrosion resistance in formed portions or both.

CLAIMS

[Claim 1]

A method for producing a hot-dip Zn-Al alloy coated steel sheet having high corrosion resistance and high formability, the method comprising introducing a steel sheet serving as a substrate into a hot-dip Zn-Al alloy coating bath having a composition of Al: 3 to 6%, Mg: 0.2 to 1.0%, Ni: 0.01 to 0.10%, and the balance being Zn and unavoidable impurities in terms of percent by mass, withdrawing the steel sheet therefrom, and cooling the steel sheet to form a hot-dip Zn-Al alloy coating layer on a surface of the steel sheet,

wherein the hot-dip Zn-Al alloy coating bath has an Fe content adjusted to 0.1% or less, a temperature of the hot-dip Zn-Al alloy coating bath is adjusted to be within a range of 420°C to 520°C, and a temperature of the steel sheet upon immersing into the hot-dip Zn-Al alloy coating bath is adjusted to be within a range of 420°C to 600°C but not less than the temperature of the hot-dip Zn-Al alloy coating bath.

[Claim 2]

A hot-dip Zn-Al alloy coated steel sheet having high corrosion resistance and high formability, comprising a steel sheet serving as a substrate and a hot-dip Zn-Al alloy coating layer having a composition of Al: 3 to 6%, Mg: 0.2

to 1.0%, Ni: 0.01 to 0.10%, and the balance being Zn and unavoidable impurities in terms of percent by mass, the hot-dip Zn-Al alloy coating layer being formed on at least one surface of the steel sheet,

wherein the hot-dip Zn-Al alloy coating layer has an Fe content adjusted to 2.0 g/m^2 or less and a Ni-rich layer having a thickness of 0.05 to $1.0 \text{ }\mu\text{m}$ lies at the interface between the hot-dip Zn-Al alloy coating layer and the steel sheet.