

DESCRIPTION

TITLE OF INVENTION: HOT-DIP PLATED STEEL MATERIAL

TECHNICAL FIELD

5 [0001]

The present invention relates to a hot-dip plated steel material.

Priority is claimed on Japanese Patent Application No. 2023-067061, filed April 17, 2023, the content of which is incorporated herein by reference.

BACKGROUND ART

10 [0002]

In a case where a steel material is used for a long period of time, it is preferable to apply some kind of antirust treatment to resist corrosion of the steel material. A hot-dip Zn plating method is used in various fields where antirust for steel materials is required, such as the fields of civil engineering, construction, and automobiles, as a means for inexpensive antirust of steel materials.

[0003]

An important issue from the viewpoint of corrosion resistance of a plated layer includes minimization of the amount of white rust formed. When a Zn-based plated layer is corroded, the Zn-based plated layer reacts with oxygen in the atmosphere to form a corrosion product. It is preferable to prevent generation of white rust in the plated layer as much as possible because white rust is likely to deteriorate the external appearance. In addition, once corrosion has occurred, the surface area of corrosion increases, and the corroded area then acts as a starting point for further corrosion, leading to greater progression of corrosion thereafter. In general, since the Zn-based plated layer has a sacrificial corrosion protection action, no significant problems occur in terms

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of material performance even though defects reaching the base metal and the like or corrosion of the plated layer occurs to some extent; however, a problem of deterioration of external appearance due to white rust has been confirmed as described above.

[0004]

5 On the other hand, with respect to such a Zn-based plated layer, a plated layer containing an element such as Sn, Ni, or Cr, which has a higher ionization tendency than Fe, is called a barrier-type coating, and does not have a sacrificial corrosion protection action on Fe, easily leading to fatal material defects when defects or the like occur. However, in such a barrier-type coating, metallic gloss can be maintained for a long
10 period of time in terms of external appearance, and this metallic gloss is maintained even for a certain period of time after manufacture, so that a high-quality external appearance with minimal signs of use can be maintained. Therefore, it is considered that it is possible to reduce the amount of white rust formed and improve the external corrosion appearance by adjusting the ionization tendency to approach the potential of Fe even in a
15 Zn-based plated layer.

[0005]

For example, Patent Documents 1 and 2 describe Zn-Al-Mg-based plated layers used as highly corrosion-resistant plating in recent years. A technique is disclosed in which these Zn-Al-Mg-based plated layers improve designability and corrosion
20 resistance by microstructural control, and further improve corrosion resistance by adding an element to the plated layer or actively forming a corrosion product.

Citation List

Patent Documents

[0006]

25 Patent Document 1: PCT International Publication No. WO 2019/230894

SUMMARY OF INVENTION

Technical Problem

[0007]

5 However, in the Zn-Al-Mg-based plated layers in the related art as described in Patent Documents 1 and 2, the method for adding an element to the plated layer finally manufactured and the way of controlling the ionization tendency thereof have not been sufficiently studied, and are insufficient from the viewpoint of improving the external appearance and suppressing the corrosion initiation by minimizing white rust generated
10 at the initial stage of corrosion.

[0008]

 An object of an embodiment of the present invention is to provide a hot-dip plated steel material capable of minimizing white rust generated at the initial stage of corrosion.

15 Solution to Problem

[0009]

 In order to solve the above-described problem, aspects of the present invention adopt the following configurations.

 [1] A hot-dip plated steel material according to one aspect of the present
20 invention is a hot-dip plated steel material including: a steel material; and a plated layer disposed on a surface of the steel material, in which

 the plated layer has a chemical composition including, in terms of mass%,

 more than 10.0% and less than 45.0% of Al,

 4.0% or more and 15.0% or less of Mg,

25 0.01% or more and 2.0% or less of Si, and

at least one of 0.03% or more and 5.0% or less of Cu, or 0.03% or more and

6.0% or less of Ag, and

further including

0% or more and 0.7% or less of Sn,

5 0% or more and 0.3% or less of Bi,

0% or more and 0.3% or less of In,

0% or more and 0.6% or less of Ca,

0% or more and 0.3% or less of Y,

0% or more and 0.3% or less of La,

10 0% or more and 0.3% or less of Ce,

0% or more and 0.3% or less of Sr,

0% or more and 0.3% or less of Li,

0% or more and 1.0% or less of Ni,

0% or more and 0.5% or less of Cr,

15 0% or more and 0.3% or less of Mo,

0% or more and 0.25% or less of Sb,

0% or more and 0.25% or less of Pb,

0% or more and 0.5% or less of B,

0% or more and 0.5% or less of P,

20 0% or more and 0.25% or less of Ti,

0% or more and 0.25% or less of Co,

0% or more and 0.25% or less of V,

0% or more and 0.25% or less of Nb,

0% or more and 0.25% or less of Mn,

25 0% or more and 0.25% or less of Zr,

0% or more and 0.25% or less of W,

0% or more and 5.0% or less of Fe, and

a remainder of Zn and impurities, and

a total amount of Cu and Ag satisfying 0.03% or more and 6.0% or less, and

5 in a case where, in an elemental distribution profile obtained by quantitative analysis using a glow discharge optical emission spectrometry in a direction from a surface of the plated layer toward the steel material, a thickness of the plated layer is denoted by t , and a ratio of the total amount of Cu and Ag to a concentration of Zn in an internal region between a $1/3t$ position and a $2/3t$ position from the surface of the plated layer is denoted by CAZ, an absolute maximum value $CAZ_{\max}$ of the CAZ and an
10 absolute minimum value $CAZ_{\min}$ of the CAZ satisfy Expressions (1) to (3),

$$CAZ_{\max}/CAZ_{\min} \leq 1.20 \dots (1)$$

$$0.0005 \leq CAZ_{\min} \dots (2)$$

$$CAZ_{\max} \leq 0.1000 \dots (3).$$

15 [2] In the hot-dip plated steel material according to [1], an area fraction of a β phase may be 3% or more in a cross section along a thickness direction of the plated layer, and concentrations of Al, Zn, Cu, and Ag in the β phase may satisfy Expression (4),

$$0.85 \leq [Al]/([Zn] + [Cu] + [Ag]) \leq 1.15 \dots (4)$$

where, each of [Al], [Zn], [Cu], and [Ag] in Expression (4) is a quantitative
20 analysis value (at%) obtained by energy dispersive X-ray spectrometry in the β phase.

[3] In the hot-dip plated steel material according to [1] or [2], 10 or more (Zn + Al) - (Cu + Ag) compounds having an average grain size of 1 μm or more may be contained as intermetallic compound particles within a range of 10000 μm^2 in a cross section along the thickness direction of the plated layer.

25 Advantageous Effects of Invention

[0010]

According to the embodiment of the present invention, it is possible to provide the hot-dip plated steel material capable of minimizing white rust generated at the initial stage of corrosion.

5 BRIEF DESCRIPTION OF DRAWING

[0011]

[FIG. 1] A diagram representing a result of GDS analysis performed on a plated layer of a hot-dip plated steel material according to an embodiment of the present invention, and a graph illustrating an example of an elemental distribution profile.

10 DESCRIPTION OF EMBODIMENTS

[0012]

Hereinafter, a hot-dip plated steel material according to one embodiment of the present invention will be described.

Note that, in the present specification, the “%” indication of the amount of each
15 element in a chemical composition of a plated layer means “mass%” unless otherwise specified.

In addition, a numerical range represented by “to” means a range including the numerical values described before and after “to” as the lower limit and the upper limit. Note that a numerical range in which “more than” or “less than” is attached to the
20 numerical values described before and after “to” means a range not including these numerical values as the lower limit or the upper limit.

[0013]

The “corrosion resistance” described in the present specification indicates a property that the plated layer itself is hardly corroded. A Zn-based plated layer has a
25 sacrificial corrosion protection action on a steel material. Therefore, during the

corrosion process of a plated steel sheet, the plated layer corrodes and turns into white rust before the steel material corrodes, and after the plated layer turns into white rust and disappears, the steel material corrodes, resulting in the formation of red rust.

The “sacrificial corrosion resistance” described in the present specification
5 indicates a property of inhibiting corrosion of the steel material at a portion where the steel material is exposed (for example, a cut end surface portion of the plated steel material and a portion where the steel material is exposed due to cracking of the hot-dip plating layer during processing).

[0014]

10 First, the results of studies on means for minimizing the formation of white rust by the present inventors will be described. Specifically, the present inventors have intensively studied the means for minimizing the formation of white rust at the initial stage of corrosion in a Zn-Al-Mg-based plated steel material.

[0015]

15 First, the corrosion morphology of the Zn-Al-Mg-based plated layer was investigated. As a result, it was found that corrosion of the Zn-Al-Mg-based plated layer proceeded from the Zn-Al (β) phase. Furthermore, the present inventors have found that this is because the Zn-Al (β) phase exhibits the electrochemically lowest corrosion potential (-1.3 V vs. Ag/AgCl in 1M NaCl aqueous solution) in the plated
20 layer.

[0016]

Furthermore, it was observed that, in the Zn-Al-Mg-based plated layer, after corrosion proceeds from the Zn-Al (β) phase, the MgZn_2 phase is subsequently corroded. The corrosion potential of the MgZn_2 phase was (-1.1 V vs. Ag/AgCl in 1M NaCl
25 aqueous solution). The β phase is distributed throughout the plated layer, and it is

effective to increase the potential of the Zn-Al (β) phase, which is a corrosion-prone portion, for improving the external appearance and corrosion resistance.

[0017]

In order to increase the potential of the β phase, it is preferable that an
5 electrochemically noble element is contained in the Zn-Al (β) phase. Examples of an element effective for increasing the potential of the β phase include Cu and Ag. This is because Cu and Ag have atomic radii similar to those of Al and Zn, respectively, form substitutional solid solutions, and are easily mixed with each other.

[0018]

10 Examples of a suitable method for containing Cu or Ag in the Zn-Al (β) phase within the plated layer include the following two-stage plating method.

[0019]

A plating original sheet is first electro-plated with Zn, and then electro-plated with Cu or Ag. Cu or Ag may be an alloy thereof. Subsequently, a plated substrate is
15 prepared by heating the plating original sheet on which Zn and Cu or Ag have been plated to allow diffusion of Cu and/or Ag into the Zn-plated layer. Thereafter, the plated substrate is immersed in a Zn-Al-Mg-based hot-dip plating bath (in which Cu and Ag may be contained) to form a hot-dip plating layer. In the present specification, as described above, a method for forming a predetermined pre-plated layer in advance on
20 the plating original sheet and then sequentially performing Zn-Al-Mg-based hot-dip plating is referred to as a “two-stage plating method”.

[0020]

During plating solidification, the Zn-Al (β) phase is formed and grows in a specific temperature region. Therefore, in such a temperature region, by reducing the
25 cooling rate, the Zn-Al (β) phase can be sufficiently formed, and the Zn-Cu phase formed

on the surface of the plated substrate can be dissolved and contained in the Zn-Al (β) phase.

[0021]

As described above, in the plated layer containing Cu and Ag thus formed, the atomic positions of Zn are substantially identical to those of Cu and Ag, while the distribution of these atoms differs from the component distribution of Al within the plated layer.

[0022]

In the plated layer according to the present embodiment, Cu and Ag that exhibit noble potentials are efficiently contained in the Zn-Al (β) phase, which is the most corrosion-prone portion, resulting in an increase in the corrosion potential of the β phase. Therefore, the potential distribution of the entire plated layer is substantially uniform with that of the $MgZn_2$ phase. As a result, since the potential difference at a specific portion decreases, the amount of white rust formed at the initial stage of corrosion in the plated steel material decreases. In addition, even though white rust is generated, the white rust is uniformly generated, so that it is possible to make the white rust generation itself inconspicuous.

[0023]

[Hot-Dip Plated Steel Material]

Hereinafter, a hot-dip plated steel material according to the present embodiment will be described.

The hot-dip plated steel material according to the present embodiment is a hot-dip plated steel material including a steel material and a plated layer disposed on a surface of the steel material. The average chemical composition of the plated layer includes, in terms of mass%,

more than 10.0% and less than 45.0% of Al,

4.0% or more and 15.0% or less of Mg,

0.01% or more and 2.0% or less of Si, and

at least one of 0.03% or more and 5.0% or less of Cu, or 0.03% or more and

5 6.0% or less of Ag, and

further includes

0% or more and 0.7% or less of Sn,

0% or more and 0.3% or less of Bi,

0% or more and 0.3% or less of In,

10 0% or more and 0.6% or less of Ca,

0% or more and 0.3% or less of Y,

0% or more and 0.3% or less of La,

0% or more and 0.3% or less of Ce,

0% or more and 0.3% or less of Sr,

15 0% or more and 0.3% or less of Li,

0% or more and 1.0% or less of Ni,

0% or more and 0.5% or less of Cr,

0% or more and 0.3% or less of Mo,

0% or more and 0.25% or less of Sb,

20 0% or more and 0.25% or less of Pb,

0% or more and 0.5% or less of B,

0% or more and 0.5% or less of P,

0% or more and 0.25% or less of Ti,

0% or more and 0.25% or less of Co,

25 0% or more and 0.25% or less of V,

0% or more and 0.25% or less of Nb,

0% or more and 0.25% or less of Mn,

0% or more and 0.25% or less of Zr,

0% or more and 0.25% or less of W,

5 0% or more and 5.0% or less of Fe, and

a remainder of Zn and impurities, and

the total amount of Cu and Ag satisfies 0.03% or more and 6.0% or less.

[0024]

(Steel Material)

10 First, a steel material (original sheet) to be plated will be described.

The steel material is, for example, mainly a steel sheet, but its size is not particularly limited. The steel sheet may be a steel sheet applicable to a general hot-dip galvanizing step. In particular, steel sheets applicable in a step of solidification by immersion in molten metal, such as a continuous hot-dip galvanizing line (CGL), apply to this. As the size of the steel sheet, for example, a steel sheet having a sheet thickness of 10 mm or less and a sheet width of 2000 mm or less can be applied, but the size of the steel sheet is not limited thereto.

[0025]

The material of the steel material is not particularly limited. As the steel material, for example, various steel sheets such as a general steel, a pre-plated steel in which various metals are thinly plated, an Al killed steel, an ultra low carbon steel, a high carbon steel, various high tensile strength steels, some high alloy steels (a steel containing a corrosion resistance reinforcing element such as Ni or Cr), steels for bolts, steel wire rods for bridge cables are applicable. More specifically, as the steel material, for example, a hot-rolled steel sheet defined in JIS G 3131 (2018) and a cold-rolled steel

sheet defined in JIS G 3141 (2017), a steel material included in a general structural rolled steel material corresponding to a so-called SS material, a so-called general steel included in a hot-rolled steel sheet defined in JIS G 3193 (2019), pre-plated steels in which various metals are thinly plated described in JIS H 8641 (2021), JIS G 3302 (2019), JIS G 3303 (2017), JIS G 3313 (2017), JIS G 3314 (2019), JIS G 3315 (2017), JIS G 3317 (2019), JIS G 3321 (2019), and the like, a rolled steel material for structural use in buildings described in JIS G 3136 (2012), Al killed steel described in JIS G 3126 (2015), ultra low carbon steel, high carbon steel, various high tensile strength steels described in JIS G 3113 (2018), JIS G 3134 (2018), and JIS G 3135 (2018), and some of high alloy steels (for example, steels containing corrosion resistance-enhancing elements such as Ni and Cr) are applicable.

[0026]

Examples of a step of manufacturing the steel material include general steps such as an iron making and steelmaking step by a blast furnace or an electric furnace, a hot rolling step, a pickling step, a cold rolling step, and a heat treatment step.

[0027]

(Plated Layer)

Next, the plated layer provided on the steel material will be described.

The plated layer according to the present embodiment includes a Zn-Al-Mg-based alloy layer. In a case where an alloying element such as Al or Mg is contained in the Zn phase, corrosion resistance is improved. Therefore, such a plated layer containing the Zn phase can exhibit corrosion resistance equivalent to that of a conventional Zn-plated layer even though the plated layer is formed as a thin film (for example, a thickness of about a half of the conventional Zn-plated layer). Similarly, even in a case where the plated layer of the present embodiment is formed as a thin film,

corrosion resistance equal to or higher than that of the conventional Zn-plated layer is ensured.

[0028]

The Zn-Al-Mg-based alloy layer is made of a Zn-Al-Mg-based alloy. The Zn-Al-Mg-based alloy means a ternary alloy containing Zn, Al, and Mg.

[0029]

The plated layer may include an Al-Fe-based interfacial alloy layer (with a thickness of less than 5 μm). The Al-Fe-based interfacial alloy layer is an interfacial alloy layer between the steel material and the Zn-Al-Mg-based alloy layer, and is in contact with a surface of the steel material. That is, the plated layer according to the present embodiment may have a single-layer structure formed of the Zn-Al-Mg-based alloy layer or a stacked layer structure including the Zn-Al-Mg-based alloy layer and the Al-Fe-based interfacial alloy layer. For the stacked layer structure, the Zn-Al-Mg-based alloy layer is preferably a layer constituting a surface of the plated layer.

[0030]

The Al-Fe-based interfacial alloy layer does not have a large influence on corrosion resistance, but has an influence on adhesion and workability (presence or absence of cracks) of the plated layer during processing of the hot-dip plated steel material. In particular, the Al-Fe-based interfacial alloy layer may affect powdering resistance indicating the degree of peeling of the plated layer during processing.

Usually, an Al-Fe-based interfacial alloy layer having a thin thickness can reduce the number of crack initiation sites in the plated layer during processing, thereby further improving powdering resistance. Therefore, it is preferable that the thickness of the Al-Fe-based interfacial alloy layer is as thin as possible in a hot-dip plated steel material that may be subjected to high processing when used as a member or the like. Specifically,

the thickness of an intermetallic compound constituting the Al-Fe-based interfacial alloy layer is less than 5 μm . The thickness is preferably 2 μm or less, more preferably 1 μm or less, and still more preferably 0.5 μm or less. The thickness may be 0.3 μm or less.

As a result, the occurrence of cracks during processing can be minimized, and the

5 powdering resistance can be further improved. Furthermore, a ratio of the thickness of the Al-Fe-based interfacial alloy layer to the thickness of the plated layer is less than 10% on average, more preferably less than 5%.

[0031]

The Al-Fe-based interfacial alloy layer is formed on a surface of the steel

10 material, specifically, between the steel material and the Zn-Al-Mg-based alloy layer.

The Al-Fe-based interfacial alloy layer is a layer in which an Al_5Fe_2 phase is the main phase as the microstructure. The Al-Fe-based interfacial alloy layer is formed by

mutual atomic diffusion between the base metal (steel sheet) and the plating bath. In a case where a continuous hot-dip plating method is used as a procedure, the Al-Fe-based

15 interfacial alloy layer is easily formed in the plated layer containing an Al element. In the present embodiment, since a certain concentration or more of Al is contained in the plating bath, the Al_5Fe_2 phase is the predominant phase formed in the Al-Fe-based interfacial alloy layer. However, since it takes time to diffuse atoms, the Fe

concentration in the Al-Fe-based interfacial alloy layer is not uniform, and the Fe

20 concentration may be high in a portion close to the base metal. Therefore, a small

amount of an AlFe phase, an Al_3Fe phase, an Al_5Fe_2 phase, or the like may be partially contained in the Al-Fe-based interfacial alloy layer. Since a certain concentration of Zn

is also contained in the plating bath, a small amount of Zn may also be contained in the

Al-Fe-based interfacial alloy layer. A small amount of Si that is likely to accumulate at

25 the interface may also be contained in the Al-Fe-based interfacial alloy layer.

[0032]

In the present embodiment, the plated layer contains Si. Si is partially incorporated into the Al-Fe-based interfacial alloy layer to form an Al-Fe-Si intermetallic compound phase. One of the identified intermetallic compound phases is an AlFeSi phase. Examples of the isomer of the AlFeSi phase include an α phase, a β phase, a q1 phase, and a q2 phase. Therefore, these AlFeSi phases and the like may be detected in the Al-Fe-based interfacial alloy layer. The Al-Fe-based interfacial alloy layer containing these AlFeSi phases and the like is also referred to as an Al-Fe-Si alloy layer.

[0033]

The upper limit and the lower limit of the thickness of the entire plated layer are not particularly limited. The thickness is also affected by the drawing speed of the steel material from the plating bath and the wiping conditions. That is, the thickness of the entire plated layer is affected by the viscosity and specific gravity of the plating bath in the case of the continuous hot-dip plating method. The absolute maximum value of the thickness of the plated layer formed by the continuous hot-dip plating method is often 100 μm or less. Therefore, the plating thickness of the hot-dip plated steel material of the present embodiment may be, for example, 100 μm or less.

[0034]

Next, the average chemical composition of the plated layer will be described.

In a case where the plated layer has a single-layer structure of the Zn-Al-Mg-based alloy layer, the average chemical composition of the entire plated layer is the average chemical composition of the Zn-Al-Mg-based alloy layer. In a case where the plated layer has a stacked layer structure including the Al-Fe-based interfacial alloy layer and the Zn-Al-Mg-based alloy layer, the average chemical composition of the entire plated layer is the total average chemical composition of the Al-Fe-based interfacial alloy layer and the Zn-

Al-Mg-based alloy layer.

[0035]

In the plated layer of the present embodiment, the thickness of the Al-Fe-based interfacial alloy layer is preferably 10% or less with respect to the thickness of the entire plated layer. In a case where the thickness of the Al-Fe-based interfacial alloy layer is sufficiently small with respect to the entire plated layer as described above, the Fe concentration of the plated layer is often 5% or less. Therefore, the average chemical composition of the plated layer is approximately the same as the components of the Zn-Al-Mg-based alloy layer. Furthermore, traces of a plating raw material are less likely to remain as chemical components of the plated layer. Therefore, the average chemical composition of the plated layer is substantially equal to the components of the plating bath used for manufacture.

[0036]

Al: More Than 10.0% and Less Than 45.0%

Al is an element mainly constituting the plated layer. In a case where the Al content is 10% or less, a sufficient amount of a Zn-Al phase may not be ensured. Therefore, the Al content is more than 10%. On the other hand, in a case where the Al content is 45.0% or more, the Al-Zn (α) phase is mainly formed in the plated layer, and the Al-Zn (β) phase is not formed. Therefore, the upper limit of the Al content is less than 45%.

[0037]

Mg: 4.0% Or More and 15.0% Or Less

Similarly to Zn, Mg is an element mainly constituting the plated layer. Mg is an important element for improving sacrificial corrosion resistance in the plated steel sheet according to the present embodiment. In a case where the Mg content in the

plated layer is less than 4.0%, the improvement effect of sacrificial corrosion resistance is not clearly observed as compared with the case where Mg is not contained. Therefore, the Mg content is 4.0% or more. In contrast, in a case where Mg is excessively added in the Zn-Al-Mg-based plating bath, a rapid oxidation reaction occurs on a bath surface of the plating bath, and plating cannot be stably performed. Therefore, in order to stably perform plating and ensure good manufacturability, the Mg content in the plated layer is 15% or less.

[0038]

Si: 0.01% Or More and 2.0% Or Less

Si suppresses an Al-Fe reaction, thereby inhibiting the formation of an Al-Fe-based interfacial alloy layer. In addition, Si is incorporated into part of the Al-Fe-based interfacial alloy layer to form an Al-Fe-Si compound. In a case where Si is not contained, the Al-Fe reaction becomes active, the thickness of the Al-Fe alloy layer increases, powdering occurs during processing, and corrosion resistance is significantly impaired. On the other hand, in a case where the Si content is 0.01% or more, the growth rate of the thickness of the interfacial alloy layer is reduced. However, in a case where the Si content is 2.0% or more, an intermetallic compound having a composition in which Mg reacts with Si to form Mg_2Si is formed in a large amount, resulting in the extremely high viscosity of the plating bath. Therefore, the adhesion amount of molten metal to the steel material is reduced when the steel material is pulled up from the plating bath, and the thickness of the plated layer is extremely thin. In addition, the plating appearance is significantly deteriorated. Therefore, the upper limit of the Si content is 2.0% or less. The preferable range is 0.10% to 0.40%, and more preferably 0.20% to 0.30%. In a case where the Si content is 2.0% or less, Mg_2Si is less likely to be formed.

[0039]

Since Cu and Ag have atomic radii similar to those of Zn and Al, Cu and Ag are easily mixed by being substituted with these elements in the plated layer. Since Cu and Ag are contained in the plated layer, the potential of the Zn-Al (β) phase increases, and corrosion resistance is improved. Cu and Ag have almost the same action. In order to change the potential and change the initial white rust formation behavior, it is effective that the plated layer contains at least one of Cu or Ag in an amount of 0.03% or more. Preferably, the total concentration of Cu and Ag in the plated layer is 0.4% or more. In contrast, in a case where the contents of Cu and Ag are excessive, an electrically noble portion may be formed by Cu and Ag that cannot be contained in the β phase, thereby promoting corrosion. Therefore, the upper limit of the Cu content is 5.0% or less, and the upper limit of the Ag content is 6.0% or less. In a case where Cu and Ag are both contained, the upper limit of the total amount of Cu and Ag is 6%. This is because in a case where the total amount of Cu and Ag is 6.0%, an electrically noble portion is formed by Cu and Ag that cannot be contained in the β phase, thereby promoting corrosion.

[0040]

Sn: 0% or more and 0.7% or less

Bi: 0% or more and 0.3% or less

In: 0% or more and 0.3% or less

Each of Sn, Bi, and In is an element that promotes softening of the plated layer when contained in the plated layer. Since Sn, Bi, and In are elements that can be optionally contained, each content is 0% or more. When Sn is contained, Mg_9Sn_5 tends to be formed in the plated layer. Bi forms Mg_3Bi_2 , and In forms Mg_3In , for example. These elements are softer than the MgZn_2 phase and have good workability, so that containment of these elements in the plated layer clearly improves workability. These elements also exhibit very low electrochemical nobility, and thus provide a high

sacrificial anticorrosion effect. By containing at least one of Sn, Bi, and In, the effect of improving worked portion corrosion resistance can be obtained.

[0041]

Ca: 0% or more and 0.6% or less

5 Y: 0% or more and 0.3% or less

La: 0% or more and 0.3% or less

Ce: 0% or more and 0.3% or less

Sr: 0% or more and 0.3% or less

Li: 0% or more and 0.3% or less

10 Ni: 0% or more and 1.0% or less

Cr: 0% or more and 0.5% or less

Mo: 0% or more and 0.3% or less

Sb: 0% or more and 0.25% or less

Pb: 0% or more and 0.25% or less

15 B: 0% or more and 0.5% or less

P: 0% or more and 0.5% or less

Ti: 0% or more and 0.25% or less

Co: 0% or more and 0.25% or less

V: 0% or more and 0.25% or less

20 Nb: 0% or more and 0.25% or less

Mn: 0% or more and 0.25% or less

Zr: 0% or more and 0.25% or less

W: 0% or more and 0.25% or less

Ca, Y, La, Ce, Sr, Li, Ni, Cr, Mo, Sb, Pb, B, P, Ti, Co, V, Nb, Mn, Zr, and W all

25 form an intermetallic compound with Si, Zn, Al, or the like. However, in a case where

the contents of these elements are within the above-described range, the elements do not affect the initial corrosion of the plated layer. In contrast, in a case where these elements are excessively contained, a potential difference may be generated in the plated layer, and a large amount of initial white rust may be formed. Therefore, in the case
5 where these elements are contained, the contents thereof may be within the above-described range.

[0042]

Fe: 0% Or More and 5.0% Or Less

Since the hot-dip plated steel material of the present embodiment is
10 manufactured by a continuous hot-dip plating method, Fe may be diffused into the plated layer from the plating raw material during manufacturing. As described above, in the present embodiment, the Al concentration of the plated layer is high, and the Al-Fe-based interfacial alloy layer may be formed, but the thickness thereof is thin. As a result, Fe may be contained in the plated layer up to 5.0%, but Fe does not affect the frequency of
15 occurrence of cracks and the like in the plated layer as long as the Fe concentration is limited to 5.0% or less. Therefore, the Fe content is 0 to 5.0%. The Fe content may be more than 0%.

[0043]

Remainder: Zn and Impurities

20 The remainder preferably contains Zn. Since the hot-dip plated steel material of the present embodiment is a highly versatile Zn-based plated steel material, the element constituting the main phase of the plated layer is Zn.

[0044]

The impurity refers to a component that is contained in the raw material or
25 mixed in the manufacturing step and not intentionally contained. For example, in the

plated layer, a small amount of component other than Fe may be mixed as the impurity due to mutual atomic diffusion between the steel material (base metal) and the plating bath. In addition, since a metal having a purity of 3 N is usually used for manufacturing a plating alloy, the concentration of impurities may be approximately 0.03% or less in total.

[0045]

In order to identify the average chemical composition of the plated layer, an acid solution is obtained in which the plated layer is peeled off and dissolved with an acid containing an inhibitor that inhibits corrosion of the base metal (steel material). Next, the obtained acid solution is measured by ICP emission spectrometry or an ICP-MS method to obtain the chemical composition. The type of the acid is not particularly limited as long as the acid can dissolve the plated layer. In a case where the area and weight before and after peeling are measured, a plating adhesion amount (g/m^2) can also be obtained at the same time.

[0046]

Next, the distribution of the components of the plated layer in the depth direction will be described.

For grasping the component distribution in the depth direction of the plated layer, glow discharge optical emission spectrometry (GDS) is used. On the other hand, GDS is effective for grasping components in a relatively wide range of ϕ of several mm or more, and the interface position also varies depending on the sputtering rate or the like as well as on the definition. In the present embodiment, the surface of the plated layer is defined as a start point (zero point), and the interface position of the plated layer is defined as a position at which the Fe concentration reaches a quantitative analysis value of 5 mass% based on the Fe concentration distribution. Details of the GDS analysis

conditions and the like will be described later.

[0047]

Although a FeAl-based compound may be generated in the interfacial alloy layer, the interface position in this case is on the interfacial alloy layer. According to the above-described definition, it is possible to grasp the components focused only on the plated layer of the Zn-Al-Mg-based alloy layer excluding the interfacial alloy layer. In a case where the thickness of the plated layer is denoted by t , the central part of the plated layer can be regarded as $1/3 t$ to $2/3 t$ with respect to the thickness t of the plated layer. That is, a range of $1/3 t$ to $2/3 t$ is a main portion of the plated layer. The outline is illustrated in FIG. 1.

[0048]

In the plated layer of the present embodiment, Cu and Ag elements are mostly bonded to or substituted with Zn in the depth direction, and thus have a similar distribution. On the other hand, for example, for a plated layer formed by adding Cu and Ag elements to a plating bath, Cu and Ag elements have distributions close to that of Al, and there is a case where there is no correlation with Zn.

[0049]

The incorporation of electrochemically noble Cu or Ag into the electrochemically less noble Zn site leads to an increase in the corrosion potential of the plated layer. That is, the present inventors have found as follows: the fact that Cu or Ag occupies the same site as Zn suggests that Cu or Ag is either contained in the Zn-Al (β) phase or substitutes for Zn in the Zn-Al (β) phase, which means that as the fraction (degree) of such containment or substitution is uniform, the overall potential of the plated layer increases.

[0050]

The degree of substitution (CAZ) of Zn with Cu and/or Ag can be expressed by the following Expression (5) in component analysis of GDS.

[0051]

$$\text{CAZ} = [\text{Cu} + \text{Ag}]/[\text{Zn}] \dots (5)$$

5 In Expression (5), [Cu], [Ag], and [Zn] are quantitative component analysis values (mass%) in the depth direction in the GDS.

[0052]

“CAZ” is a ratio of the total concentration of the Cu concentration and the Ag concentration to the Zn concentration in the internal region between the 1/3 t position and
10 the 2/3 t position with respect to the surface of the plated layer. The larger the CAZ value is, the more substitution proceeds.

[0053]

In addition, in the plated layer, in a case where the absolute maximum value CAZ_{max} of CAZ and the absolute minimum value CAZ_{min} of CAZ satisfy the following
15 Expression (1), an increase in corrosion potential in the plated layer occurs in the entire plated layer, and the amount of white rust formed tends to decrease in the plated steel sheet. This is because Cu and/or Ag are uniformly distributed in the plated layer. $\text{CAZ}_{\text{max}}/\text{CAZ}_{\text{min}}$ is preferably 1.1 or less.

[0054]

20 $\text{CAZ}_{\text{max}}/\text{CAZ}_{\text{min}} \leq 1.20 \dots (1)$

[0055]

In order to sufficiently increase the potential, it is necessary to satisfy the following Expression (2). On the other hand, an excessive increase in corrosion potential promotes corrosion. Therefore, CAZ_{max} needs to satisfy the following
25 Expression (3). $0.01 \leq \text{CAZ}_{\text{min}}$ and $\text{CAZ}_{\text{max}} \leq 0.08$ are more preferable. As a result,

the corrosion potential can be set to a potential almost equal to that of the MgZn_2 phase present in a large amount in the plated layer, and the formation of white rust due to corrosion is minimized, so that the external appearance is further improved.

[0056]

$$5 \quad 0.0005 \leq \text{CAZ}_{\min} \dots \quad (2)$$

$$\text{CAZ}_{\max} \leq 0.1000 \dots \quad (3)$$

[0057]

It is effective to increase the potential of the Zn-Al phase (β phase) for deterioration of the external appearance due to the formation of white rust of the plated layer. In addition, in a case where the potential is increased to reduce the potential difference with the surrounding intermetallic compounds and the metal phases, and furthermore, the electrical resistance of the β phase itself is increased, corrosion progression can be reduced and corrosion resistance can be improved. This tendency can be evaluated by the corrosion current density, and can be achieved by making the substitution of Al and Zn in the β phase constant. Since the β phase has a size of about 5 μm or more in the plated layer, the presence of the β phase can be easily observed by SEM. In addition, quantitative analysis values of the site can be obtained by EDS, EPMA, or the like.

[0058]

20 The ratio of Zn to Al (Zn : Al) in the β phase is about 1 : 1, and the β phase having excellent corrosion resistance can be present in this range. In addition, it is preferable to satisfy the following Expression (4) at any point or in any region in the β phase. By satisfying the following Expression (4), the electrical resistance of the β phase is increased, and corrosion resistance can be further improved.

25 [0059]

$$0.85 \leq [\text{Al}]/([\text{Zn}] + [\text{Cu}] + [\text{Ag}]) \leq 1.15 \dots \quad (4)$$

Here, each of [Al], [Zn], [Cu], and [Ag] in Expression (4) is a quantitative analysis value (at%) obtained by energy dispersive X-ray spectrometry in the β phase.

[0060]

5 Furthermore, the corrosion current density depends on the area fraction of the β phase. Therefore, in any portion at the SEM cross section of the plated layer, the area fraction of the β phase may be 3% or more. The area fraction of the β phase in the plated layer can be controlled by a manufacturing method. The area fraction of the β phase is more preferably 5% or more, and still more preferably, the Cu + Ag
10 concentration in the plated layer is 0.4% or more, and the area fraction of the β phase is 10% or more.

Here, the term “ β phase” as described herein can also be said to be an intermetallic compound region containing at least one or more of an Al-Zn-Cu compound, an Al-Zn-Ag compound, and an Al-Zn-Cu-Ag compound.

15 [0061]

In order to appropriately supply Cu and/or Ag to the β phase in the plated layer, it is preferable to provide Cu and/or Ag from a pre-plated layer formed on the plating original sheet by a method described later. Zn, Cu, and Ag in the pre-plated layer are thermally diffused during pre-annealing to form a Cu-Ag-Zn-based diffusion plated layer
20 (aggregate of Cu, Ag-Zn intermetallic compounds). However, the Cu-Ag-Zn-based diffusion plated layer disappears during hot-dip plating. However, in a case where a small amount of a (Zn + Al) - (Cu + Ag) compound is finally present in the plated layer, the potential of the plated layer can be increased.

[0062]

25 The (Zn + Al) - (Cu + Ag) compound is a compound in which Cu, Ag, and Al

are slightly dissolved in Zn, and has a potential of -1.2 V(vs. Ag/AgCl in 1M NaCl). Since the (Zn + Al) - (Cu + Ag) compound is thus allowed to remain in the final plated layer, the potential of the plated layer can be further increased. The (Zn + Al) - (Cu + Ag) compound can be observed in the plated layer through SEM, and a quantitative analysis value by point analysis can be determined in the same manner as described above.

[0063]

In order to obtain the (Zn + Al) - (Cu + Ag) compound exhibiting an appropriate potential, the component ratio is preferably Zn + Al : Cu + Ag = 4 : 1 to 9 : 1. In addition, the (Zn + Al) - (Cu + Ag) compound has an equivalent circle diameter of 1 μm or more in any cross section among cross sections along the thickness direction of the plated layer, and the number thereof is preferably 10 or more, more preferably 20 or more per 10000 μm^2 . The number of (Zn + Al) - (Cu + Ag) compounds tends to depend on the adhesion amount of Cu, Ag, and Zn on the original sheet, that is, depend on the adhesion amount of the pre-plated layer.

[0064]

Next, an example of an analysis method for the plated layer will be described.

[0065]

As the analysis method for components in the plated layer in the depth direction, a glow discharge optical emission spectrometer (GDS) may be used. The present inventors use LECO Japan 850A as the glow discharge optical emission spectrometer, but the measurement apparatus is not limited thereto. In a case of performing analysis in the depth direction, it is preferable to perform the analysis while performing Ar sputtering, the analysis conditions include an argon pressure of 0.27 MPa, an output power of 30 W, an output voltage of 1000 V, and a discharge region in a circular region

having a diameter of 4 mm. The measurement is performed from the surface of the plated layer toward the depth direction until the Fe concentration reaches 100% (reaches the base metal). Therefore, the analysis range of the depth direction analysis carried out by GDS is a range reaching from the plated surface to the Zn-Al-Mg plated layer, the interfacial alloy layer (Al-Fe alloy layer), and part of the steel material. After the GDS analysis, the sputtering depth of the cross section is measured using surfcom130A manufactured by Tokyo Seimitsu Co. Ltd. The elemental distribution profile of the plated layer in the depth direction is obtained by the GDS analysis. In the elemental distribution profile, in a case where the total amount of the detected elements is 100%, the distribution of the amount of each element in the depth direction is illustrated.

[0066]

The cross-section observation through SEM may be performed by the following procedure.

First, a sample for observation having a size of about 20 × 20 mm square is cut out from a plated steel sheet such that a cross section of a plated layer is exposed, and this sample is embedded in a resin. Next, the observed section is mirror-polished to observe the cross section of the plated layer. The cross-section observation may be performed after Au deposition on the cross-section of the plated layer. For the selection of the field of view of the plated layer, in order to eliminate bias, at least three observation samples are collected from one plated steel sheet, at least 30 randomly selected fields of view are observed at magnifications of about 500 to 2000 times, and identification and measurement of an area fraction of each phase are performed.

[0067]

In a case where the area fraction of the β phase is determined, the field of view is specified, followed by specifying the field of view so that the component range of the

β phase includes a region close to $0.85 \leq [\text{Al}]/([\text{Zn}] + [\text{Cu}] + [\text{Ag}]) \leq 1.15$ by point analysis using EDS. In a case where the β phase has been found, a quantitative analysis element mapping image of the entire plated layer is imaged. The same component range is specified from Zn and Al of the imaged mapping image by using image analysis software “ImageJ”, and binarization or the like is executed. The area fraction of the β phase in the plated layer is measured from the obtained binarized area.

[0068]

In the same manner, Zn, Cu, and the equivalent circle diameter are measured for the Zn-Cu compound. The distribution of the number of $(\text{Zn} + \text{Al}) - (\text{Cu} + \text{Ag})$ compounds can be determined by a function included in known image analysis software such as ImageJ. After observing each field of view, the number distribution is observed for each sample until the total area (corresponding to the number of pixels) of the plated layer reaches $10000 \mu\text{m}^2$. The number of $(\text{Zn} + \text{Al}) - (\text{Cu} + \text{Ag})$ compounds is preferably observed from at least three samples.

15 [0069]

[Method for Manufacturing Hot-Dip Plated Steel Material]

Next, a preferred method for manufacturing the hot-dip plated steel material according to the present embodiment will be described. In the manufacturing method according to the present embodiment, Cu and Ag exhibit substantially the same behavior, and thus Cu will be described as a representative without distinguishing between Cu and Ag. That is, the description regarding Cu described below may be read as “Ag”, or may be read as “Cu and Ag”.

[0070]

As a method for forming the plated layer as described above, it is conceivable to perform plating by directly adding Cu to a Zn-Al-Mg-based plating bath. However, in

this method, the formation of an intermetallic compound such as CuAl_2 or a reaction between base metal as a substrate and Cu occurs, so that there is a concern that Cu is not efficiently contained in the β phase. Therefore, as an example of a suitable procedure for manufacturing the hot-dip plated steel material of the present embodiment, a method for supplying Cu from a pre-plated layer provided on a plating original sheet to a plated layer will be described below as an example.

[0071]

First, Zn is plated in advance on a plating original sheet such as a cold-rolled steel sheet or a hot-rolled steel sheet by electro plating to form a pre-Zn-plated layer (hereinafter, also simply referred to as a Zn-plated layer or a Zn layer). The adhesion amount of the Zn-plated layer is preferably equal to or more than the amount of Cu in the finally obtained plated layer. The plating means may be electro plating, substitution plating, vapor deposition, or the like.

[0072]

Zn plating on Fe is not particularly limited as long as it is performed under conventional zinc plating formation conditions, such as those using cyanide baths, zincate baths, zinc chloride baths, or zinc sulfate baths.

[0073]

Thereafter, Cu is further plated on the Zn layer to form a pre-Cu plated layer. In the present embodiment, it is effective to form a pre-Cu plated layer on the pre-Zn-plated layer after forming the pre-Zn-plated layer. In a case where the pre-Cu plated layer and the pre-Zn-plated layer are formed in this order, Cu in the pre-Cu plated layer may diffuse to the original sheet side, and a desired plated layer may not be obtained. Therefore, it is preferable to form the pre-Zn-plated layer and the pre-Cu plated layer in this order. Copper sulfate, copper cyanide, copper pyrophosphate, an alkanol bath, and

the like can be applied to the Cu plating, and the plating bath is not particularly limited. Silver cyanide can be used for Ag plating, and furthermore, Cu can be electroless plated. [0074]

In order to increase the number of (Zn + Al) - (Cu + Ag) compounds, it is
5 preferable that the adhesion amount of the pre-Cu plated layer is more than 1/1000 of the final plating adhesion amount. [0075]

Then, the plating original sheet is heated to 450°C to 600°C. The heating may also serve as annealing of the original sheet (hereinafter, the heating may be referred to as
10 pre-annealing). By the heating, Zn is dissolved and reacts with Cu to form an alloy, so that a Zn-Cu diffusion-plated layer can be formed. In a case where the heating temperature is lower than 450°C, Cu may not be efficiently diffused into the plated layer. On the other hand, in a case where a heating temperature is higher than 600°C, evaporation of the pre-Zn-plated layer and the formation of a reaction layer between Fe
15 and Zn may occur, which is not preferable. The temperature range of the pre-annealing is preferably 450°C to 600°C. [0076]

Next, the original sheet on which the Zn-Cu diffusion-plated layer is formed is immersed in a Zn-Al-Mg-based plating bath, and then pulled up. At this time, the bath
20 temperature of the Zn-Al-Mg-based plating bath is preferably 450°C to 600°C. In a case where the original sheet on which the Zn-Cu diffusion-plated layer is formed is immersed in a Zn-Al-Mg-based plating bath and pulled up, the Zn-Cu-plated layer is more likely to be dissolved, and Cu is more likely to be finely dispersed in the plated layer as the bath temperature is higher. Therefore, the bath temperature is preferably
25 450°C or higher. The temperature is more preferably 470°C or higher, still more

preferably 500°C or higher, and even still more preferably 550°C or higher. On the other hand, in a case where the bath temperature is excessively high, Zn in the plating bath is evaporated, and the bath balance is easily lost. Therefore, the bath temperature is preferably 600°C or lower. The bath temperature is more preferably 580°C or lower.

5 In the present embodiment, temperature control is preferably performed when the plating original sheet is pulled up. That is, by performing appropriate temperature control and cooling control after immersion, Cu is finely dispersed in the plating bath, and Cu is contained in the Zn-Al (β) phase in the solidification process of the plated layer.

10 [0077]

The Zn-Al (β) phase is a phase formed after the Al (α) phase is precipitated and grown from the plating molten state. After the Al (α) phase is sufficiently grown, Zn-Al (β phase) precipitates and grows so as to surround the Al (α) phase. Since the Zn-Cu fine compounds incorporated from the plating original sheet are not dissolved in the solid

15 Al (α) phase, a large amount of Zn-Cu fine compounds can remain.

[0078]

The temperature range of 550°C to 450°C is a temperature range in which only the α phase is formed and the β phase is not formed. In a case where the average cooling rate in this temperature range is higher than 10°C, the growth of the α phase may

20 be inhibited. In a case where the α phase is not sufficiently grown in the temperature range of 550°C to 450°C, the subsequent formation of the β phase may be insufficient. In addition, in a case where the average cooling rate in the temperature range of 550°C to 450°C is too high, the amount of the β phase cannot be sufficiently secured. Therefore, Zn-Cu cannot be sufficiently incorporated into the β phase, and as a result,

25 $CAZ_{\max}/CAZ_{\min}$ may increase. Therefore, the average cooling rate in the temperature

range of 550°C to 450°C is set to 10°C/sec or lower.

[0079]

The average cooling rate in the temperature range of 450°C to 350°C is not particularly limited. However, in a case where the average cooling rate between 450°C
5 and 350°C is low, the β phase amount can be increased. Therefore, the average cooling rate between 450°C and 350°C is preferably 8°C/sec or lower.

[0080]

The average cooling rate in the temperature range of lower than 350°C does not affect the formation of the β phase. The cooling condition in the temperature range of
10 lower than 350°C is not particularly limited because it does not affect the potential, the corrosion current density, and the like.

[0081]

Next, a method for evaluating performance of the hot-dip plated steel material will be described.

15 [0082]

(Corrosion Potential)

The corrosion potential and the like of the plated layer can be measured by a general device configuration using a device such as an electrochemical cell, a reference electrode, a salt bridge, or a potentiostat (constant potential electric field device).

20 Examples of the evaluation method include a method in which an Ag/AgCl-type reference electrode is used and 1 M NaCl aqueous solution is employed as a measurement solution, the method being carried out under conditions such as degassing and constant room temperature. In a case where the plated steel sheet surface is sufficiently washed and the steel sheet is then immersed in the measurement solution, the
25 corrosion potential immediately after immersion shifts markedly to the negative side, but

in a case where the steel sheet is immersed in the solution for about 1800 seconds, the potential is stabilized. This potential is the corrosion potential of the surface of the plated layer.

[0083]

- 5 In a case where the corrosion potential approaches -1.1 V, the variation in potential of the plated layer is reduced, which is preferable, and the amount of white rust formed at the initial stage of corrosion can be minimized. The initial stage of corrosion refers to a tendency of a white rust area fraction after 24 hours of a salt spray test (SST) as specified in JIS Z 2371 (2015).

10 [0084]

<Evaluation Criteria>

E: The corrosion potential is -1.3 V or less, and the white rust area fraction on the evaluation surface of the corrosion test is “25% or more”.

- 15 D: The corrosion potential was -1.3 to -1.25 V, and the white rust area fraction on the evaluation surface of the corrosion test was “20% to 25% or more”.

C: The corrosion potential was -1.25 to -1.2V, and the white rust area fraction on the evaluation surface of the corrosion test was “15% to 20% or more”.

B: The corrosion potential was -1.25 to -1.2V, and the white rust area fraction on the evaluation surface of the corrosion test was “10% to 15% or more”.

- 20 A: The corrosion potential was -1.2 to -1.1V, and the white rust area fraction on the evaluation surface of the corrosion test was “less than 10%”.

[0085]

(Corrosion Current Density)

- 25 The potential is varied in both the positive and negative directions to obtain a polarization curve, and the corrosion potential is determined by the Tafel extrapolation

method. The corrosion current density depends on the corrosion rate. This can also be inferred from the corrosion weight loss in the salt spray test. That is, since only the β phase corrodes at the initial stage, the corrosion weight loss after 120 hours of the SST is measured. In the method for measuring the corrosion weight loss, the corrosion amount
 5 of the β phase can be estimated by immersing the steel sheet before and after the corrosion test in 30% chromic acid for 5 minutes.

[0086]

<Evaluation Criteria>

E: A case where the measured value of the corrosion current density $\log i_l$
 10 (A/cm^2) is -4 or more and the corrosion weight loss is $25g/m^2$ or more.

D: A case where the measured value of the corrosion current density $\log i_l$
 (A/cm^2) is -4.5 to -4 and the corrosion weight loss is $20g/m^2$ or more.

C: The value obtained when the corrosion current density $\log i_l$ (A/cm^2) is -5 to
 -4.5, and the corrosion weight loss is $15 g/m^2$ or more.

15 B: A case where the measured value of the corrosion current density $\log i_l$
 (A/cm^2) is -5.5 to -5 and the corrosion weight loss is $10g/m^2$ or more.

A: A case where the measured value of the corrosion current density $\log i_l$
 (A/cm^2) is -6 to -5.5 and the corrosion weight loss is $5g/m^2$ or more.

S: A case where the measured value of the corrosion current density $\log i_l$
 20 (A/cm^2) is less than -6 and the corrosion weight loss is less than $5g/m^2$.

[0087]

After the plated layer is formed, various chemical conversion treatments and coating treatments may be performed.

[0088]

25 In the hot-dip plated steel material of the present embodiment, a film may be

formed on the plated layer. A film having a single layer or two or more layers may be formed. Examples of the type of the film immediately above the plated layer include a chromate film, a phosphate film, and a chromate-free film. A chromate treatment, a phosphating treatment, and a chromate-free treatment for forming these films can be performed by known methods.

[0089]

The chromate treatment includes an electrolytic chromate treatment in which a chromate film is formed by electrolysis, a reaction type chromate treatment in which a film is formed by utilizing a reaction with the material and then the excess treatment liquid is washed away, and an application type chromate treatment in which a film is formed by applying a treatment liquid to an object to be coated and drying the treatment liquid without washing with water. Any treatment may be adopted.

[0090]

Examples of the electrolytic chromate treatment include an electrolytic chromate treatment using chromic acid, a silica sol, a resin (phosphoric acid, an acrylic resin, a vinyl ester resin, a vinyl acetate acrylic emulsion, a carboxylated styrene-butadiene latex, a diisopropanolamine-modified epoxy resin, and the like), and hard silica.

[0091]

Examples of the phosphating treatment include a zinc phosphate treatment, a zinc calcium phosphate treatment, and a manganese phosphate treatment.

[0092]

The chromate-free treatment which does not impose a burden on the environment is particularly suitable. The chromate-free treatment includes an electrolytic chromate-free treatment in which a chromate-free film is formed by electrolysis, a reaction type chromate-free treatment in which a film is formed by

utilizing a reaction with the material and then the excess treatment liquid is washed away, and an application type chromate-free treatment in which a film is formed by applying a treatment liquid to an object to be coated and drying the treatment liquid without washing with water. Any treatment may be adopted.

5 [0093]

Further, an organic resin film made of a single layer or two or more layers may be formed on the film immediately above the plated layer. The organic resin is not limited to a specific type, and examples thereof include polyester resins, polyurethane resins, epoxy resins, acrylic resins, polyolefin resins, and modified products of these
10 resins. Here, the modified product refers to a resin obtained by causing a reactive functional group included in the structures of these resins to react with another compound (a monomer, a crosslinking agent, or the like) having a functional group capable of reacting with the functional group in the structure thereof.

[0094]

15 As such an organic resin, one or more types of organic resins (unmodified organic resins) may be mixed and used, or one or more types of organic resins obtained by modifying, in the presence of at least one type of organic resin, at least one type of other organic resin may be mixed and used. The organic resin film may contain any coloring pigment or antirust pigment. Also, water-based organic resins which are
20 dissolved or dispersed in water may be used.

Examples

[0095]

Next, Examples of the present invention will be described, but conditions in Examples are examples of conditions adopted to confirm feasibility and an effect of the
25 present invention, and the present invention is not limited to these examples of

conditions. The present invention may adopt various conditions as long as an object of the present invention is achieved without departing from the gist of the present invention.

[0096]

First, a cold-rolled steel sheet (corresponding to SPCC specified in JIS G 3141
5 (2017)) having a size of 100 mm × 200 mm and a sheet thickness of 0.8 mm was prepared as a plating original sheet. For this cold-rolled steel sheet, first, a Zn-plated layer was formed by depositing a predetermined amount of Zn onto the sheet surface using a zinc plating bath described below.

[0097]

10 Zinc plating conditions: a zinc chloride of 50 g/L, an ammonium chloride of 200 g/L, pH = 5.5, a bath temperature of 30°C, a current density of 2 A/dm².

[0098]

Next, a Cu-plated layer or Ag-plated layer, or a plated layer containing Cu and Ag was formed on the plating original sheet on which the Zn-plated layer was formed,
15 using the following copper plating bath and the following silver plating bath. In a case of forming the plated layer containing Cu and Ag, the plating original sheet was immersed in a copper plating bath and a silver plating bath in this order. The following copper plating bath was subjected to air stirring. In addition, the pH of the following silver plating bath was adjusted by H₄P₂O₇ and KOH.

20 [0099]

Copper plating conditions: copper pyrophosphate of 80 g/L, potassium pyrophosphate of 290 g/L, ammonia water of 3 mg/L, potassium nitrate of 10 g/L, an anode made of oxygen-free high-purity copper, a current density of 3 A/dm².

[0100]

25 Silver plating conditions: KAg (CN) 2 of 40 g/L (in terms of Ag), K₄P₂O₇ of 150

g/L, EDTA (4 potassium salt) of 5 g/L, a smooth material HS II (* Selenium and mercapto compounds) of 0.5 mL/L, pH=8 to 9, a current density of 40 A/dm², a bath temperature of 40°C, an anode of Pt/Ti electrode.

[0101]

5 After the Cu-plated layer or Ag-plated layer, or the plated layer containing Cu and Ag was formed on the plating original sheet, the plating original sheet was heated at the pre-annealing temperature illustrated in Tables 1A to 1C for 0.5 to 3 minutes to form a diffusion-plated layer, thereby obtaining a plated substrate. The composition of the diffusion-plated layer is illustrated in Tables 1A to 1C.

10 [0102]

The resulting plated substrate was hot-dip plated in a hot-dip plating simulator.

First, alloys having plating bath components illustrated in Tables 1A to 1C were prepared by a vacuum dissolution method, and a plating bath was formed in a completely oxygen-free and nitrogen-substituted atmosphere (O₂ concentration: less than 5 ppm).

15 Next, one point (the center rear surface of the evaluation surface) of the plating original sheet was bonded to a K thermocouple by spot welding, and the temperature history until the completion of plating solidification was grasped. The plated steel sheet is heated to a predetermined temperature in a H₂ (25%) -N₂ atmosphere. The plating bath temperature was set to 550°C to 600°C, the plated substrate was immersed at an
20 immersion rate of 600 mm/sec, stopped in the bath for 3 seconds, and the plated substrate was then pulled up at 600 mm/sec.

Immediately after the pulling up, the adhesion amount was adjusted to 135 to 140 g/m² with N₂ wiping gas, and N₂ gas whose flow rate was controlled in an oxygen-free and nitrogen-replaced atmosphere was then blown and air-cooled at the average
25 cooling rate illustrated in Tables 1A to 1C.

A plated steel sheet was obtained by the above-described steps.

[0103]

Next, samples for evaluation were cut out from the various plated steel sheets.

Each sample for GDS analysis and SEM observation was cut out at a 30 mm square

5 position on the opposite side to the thermocouple position. As the sample for corrosion, 100 × 50 mm was taken from the center portion of the plated steel sheet.

[0104]

As the evaluation of the various samples that have been cut, an electrochemical test and a corrosion test SST were performed. Among the compositions of the plated

10 layer, the composition of Fe was not described in the tables, but was in a range of 0% to 5%.

Tables 2A to 2C show the evaluation results, the compositions of the plated layer, the GDS analysis results, and each configuration in the β phase region. Note that the underline in each table indicates that the numerical value is out of the range of the present invention or out of the preferable manufacturing conditions, or the characteristic value is not preferable. In addition, (*) in Tables 2A to 2C indicates the number of (Zn + Al) - (Cu + Ag) compounds having an equivalent circle diameter of 1 μm or more per 10000 μm^2 in any cross section along the thickness direction of the plated layer.

[0105]

[Table 1A]

No.	Type	Pre-annealing temperature (°C)	Manufacturing method															
			Average cooling rate (°C/sec)		Diffusion-plated layer (mass%)				Bath temperature (°C)	Plating bath component (mass%)								
					Zn	Cu	Ag	Σ		Zn	Al	Mg	Ca	Si	Cu	Ag	Cu + Ag	Others
			550-450°C	450-350°C														
1	Comparative Example	600	5	5	0.8	0.27	0.270	0.54	550	85.6	10.0	4.0	0.2	0.2	0	0	0	
2	Example	500	10	6	0.8	0.27	0.270	0.54	550	83.6	11.0	5.0	0.2	0.2	0	0	0	
3	Example	500	10	6	0.8	0	0.300	0.30	550	83.6	11.0	5.0	0.2	0.2	0	0	0	
4	Example	550	10	8	0.8	0.27	0.000	0.27	550	82.99	12.0	5.0	0	0.01	0	0	0	Ce = 0.1
5	Example	580	10	8	0.8	0.27	0.000	0.27	550	82.99	12.0	5.0	0	0.01	0	0	0	La = 0.1
6	Comparative Example	590	12	10	0.8	0.27	0.000	0.27	550	83	12.0	5.0	0	0	0	0	0	
7	Comparative Example	550	12	4	0.8	0.27	0.000	0.27	550	83	12.0	5.0	0	0	0	0	0	
8	Example	550	3	11	0.8	0.27	0.000	0.27	550	82.99	12.0	5.0	0	0.01	0	0	0	La = 0.1
9	Example	480	10	8	1.2	0.405	0.100	0.51	550	81.7	12.0	6.0	0	0.3	0	0	0	La = 0.1 Ce = 0.1
10	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Bi = 0.1
11	Example	450	8	2	2.0	0.675	0.670	1.35	550	80.3	12.0	7.0	0.2	0.5	0	0	0	
12	Example	460	1	11	2.0	0.675	0.670	1.35	550	80.3	12.0	7.0	0.2	0.5	0	0	0	
13	Example	550	10	2	0.4	0.135	0.135	0.27	550	79.99	15.0	5.0	0	0.01	0	0	0	Sn = 0.1
14	Example	550	10	8	1.6	0.54	0.000	0.54	550	77.8	15.0	7.0	0.1	0.1	0	0	0	
15	Example	550	8	10	0.4	0.135	0.000	0.14	550	75.9	19.0	5.0	0	0.1	0	0	0	V = 0.1
16	Example	550	10	4	0.8	0.27	0.130	0.40	550	74.8	19.0	6.0	0	0.2	0	0	0	Y = 0.1
17	Example	500	10	4	0.8	0.27	0.000	0.27	550	74.8	19.0	6.0	0	0.2	0	0	0	Cr = 0.5%
18	Comparative Example	550	50	50	0.8	0.27	0.130	0.40	550	83	12.0	5.0	0	0	0	0	0	
19	Comparative Example	550	15	5	0.8	0.27	0.000	0.27	550	83	12.0	5.0	0	0	0	0	0	
20	Example	550	10	10	0.8	0.27	0.000	0.27	550	82.99	12.0	5.0	0	0.01	0	0	0	

[0106]

[Table 1B]

			Manufacturing method																
No.	Type	Pre-annealing temperature (°C)	Average cooling rate (°C/sec)		Diffusion-plated layer (mass%)				Bath temperature (°C)	Plating bath component (mass%)									
			550-450°C	450-350°C	Zn	Cu	Ag	Σ		Zn	Al	Mg	Ca	Si	Cu	Ag	Cu+Ag	Others	
			21	Example	550	9	9	1.2	0.405	0.000	0.41	550	72.4	19.0	8.0	0.3	0.3	0	0
22	Example	550	5	5	3.2	1.08	0.300	1.38	550	70.5	19.0	10.0	10.0	0.4	0.1	0	0	0	B = 0.1
23	Example	550	5	5	3.2	1.08	0.300	1.38	550	70.5	19.0	10.0	10.0	0.4	0.1	0	0	0	B = 0.1
24	Example	550	10	8	4.1	1.35	0.000	1.35	550	70.7	19.0	10.0	10.0	0.2	0.1	0	0	0	
25	Example	550	10	8	4.1	1.35	0.000	1.35	550	70.7	19.0	10.0	10.0	0.2	0.1	0	0	0	Mo = 0.1
26	Comparative Example	550	12	12	4.1	1.35	0.000	1.35	550	70.7	19.0	10.0	10.0	0.2	0.1	0	0	0	
27	Comparative Example	550	12	8	4.1	1.35	0.000	1.35	550	70.7	19.0	10.0	10.0	0.2	0.1	0	0	0	
28	Example	550	9	9	0.1	0.0405	0.000	0.04	550	74.8	20.0	5.0	5.0	0	0.2	0	0	0	
29	Example	550	10	10	6.1	2.025	0.000	2.03	550	73.9	20.0	6.0	6.0	0	0.1	0	0	0	Co = 0.1
30	Example	550	5	7	8.1	2.7	0.000	2.70	550	64.4	25.0	10.0	10.0	0.3	0.3	0	0	0	
31	Example	550	7	9	12.2	4.05	0.000	4.05	550	62.2	30.0	7.0	7.0	0.6	0.2	0	0	0	
32	Example	550	9	9	15.0	0	5.000	5.00	550	62.2	30.0	7.0	7.0	0.6	0.2	0	0	0	
33	Example	550	2	4	14.2	4.725	0.000	4.73	550	60	30.0	9.0	9.0	0.3	0.7	0	0	0	
34	Example	550	2	14	14.2	4.725	0.000	4.73	550	60	30.0	9.0	9.0	0.3	0.7	0	0	0	
35	Example	550	5	13	16.2	5.4	0.000	5.40	550	57.4	30.0	12.0	12.0	0.5	0.1	0	0	0	

[0107]

[Table 1C]

No.	Type	Pre-annealing temperature (°C)	Manufacturing method																
			Average cooling rate (°C/sec)		Diffusion-plated layer (mass%)				Bath temperature (°C)	Plating bath component (mass%)									
550-450°C	450-350°C	Zn	Cu	Ag	Σ	Zn	Al	Mg	Ca	Si	Cu	Ag	Cu + Ag	Others					
36	Example	600	4	6	18.2	6.075	0.000	6.08	550	59.5	35.0	5.0	0	0.5	0	0	0		
37	Comparative Example	550	15	25	0.8	0.27	0.000	0.27	600	60	35.0	5.0	0	0	0	0	0		
38	Comparative Example	550	15	5	0.8	0.27	0.000	0.27	600	60	35.0	5.0	0	0	0	0	0		
39	Example	550	10	8	0.2	0.0675	0.000	0.07	600	57.8	35.0	7.0	0.1	0.1	0	0	0		
40	Example	550	7	1	20.3	6.75	0.000	6.75	600	54.6	35.0	9.0	0.2	1.2	0	0	0		
41	Example	550	10	8	24.3	8.1	0.000	8.10	600	49.2	40.0	10.0	0.4	0.4	0	0	0	Y = 0.01	
42	Example	550	10	8	20.3	6.75	0.000	6.75	600	46.3	42.0	10.0	0.2	1.5	0	0	0		
43	Comparative Example	550	6	2	28.4	9.45	0.000	9.45	600	46.3	42.0	10.0	0.2	1.5	0	0	0		
44	Example	550	9	1	12.2	4.05	0.000	4.05	600	49.2	44.0	5.0	0	1.8	0	0	0		
45	Example	550	6	6	4.1	1.35	0.000	1.35	600	38.5	44.0	15.0	0.5	2.0	0	0	0		
46	Comparative Example	550	9	9	1.2	0.405	0.000	0.41	600	48	45.0	5.0	0.5	1.5	0	0	0		
47	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	In = 0.1	
48	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Sr = 0.1	
49	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Li = 0.1	
50	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Sb = 0.1	
51	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Pb = 0.1	
52	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	P = 0.1	
53	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Ti = 0.1	
54	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Nb = 0.1	
55	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	Zr = 0.1	
56	Example	470	9	9	2.0	0.675	0.680	1.36	550	80.3	12.0	7.0	0.2	0.5	0	0	0	W = 0.1	

[0108]

[Table 2A]

		Plated layer																Performance		
No.	Adhesion amount (g/m ²)	Chemical composition (mass%)										GDS analysis				β phase region		(*)	Corrosion potential + SST	Corrosion current density + SST
		Zn	Al	Mg	Ca	Si	Cu	Ag	Cu + Ag	Others	CAZmin	CAZmax	CAZmax/CAZmin	Area fraction	Expression (4)					
1	135	85.2	10.0	4.0	0.2	0.2	0.2	0.2	0.4		0.0004	0.0040	10.00	0	-	0	E	E		
2	135	83.2	11.0	5.0	0.2	0.2	0.2	0.2	0.4		0.0023	0.0024	1.04	15	0.86	12	B	C		
3	145	83.2	11.0	5.0	0.2	0.2	0.0	0.4	0.4		0.0023	0.0025	1.09	14	0.86	4	B	D		
4	135	82.79	12.0	5.0	0	0.01	0.2	0	0.2	Ce = 0.1	0.0023	0.0024	1.04	7	0.86	4	C	D		
5	135	82.79	12.0	5.0	0	0.01	0.2	0	0.2	La = 0.1	0.0022	0.0024	1.09	8	0.87	0	D	D		
6	135	82.8	12.0	5.0	0	0	0.2	0	0.2		0.0023	0.0024	1.04	0	-	0	E	E		
7	135	82.8	12.0	5.0	0	0	0.2	0	0.2		0.0023	0.0024	1.04	0	-	0	E	E		
8	135	82.79	12.0	5.0	0	0.01	0.2	0	0.2	La = 0.1	0.0023	0.0024	1.04	2	0.88	4	D	D		
9	135	81.3	12.0	6.0	0	0.3	0.3	0.1	0.4	La = 0.1 Ce = 0.1	0.0050	0.0052	1.04	11	0.88	23	B	B		
10	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Bi = 0.1	0.0110	0.0120	1.09	12	0.88	31	A	S		
11	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0		0.0140	0.0142	1.01	13	0.88	0	C	C		
12	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0		0.0140	0.0142	1.01	2	0.88	33	C	S		
13	135	79.79	15.0	5.0	0	0.01	0.1	0.1	0.2	Sn = 0.1	0.0011	0.0012	1.09	6	0.95	8	C	D		
14	135	77.4	15.0	7.0	0.1	0.1	0.4	0	0.4		0.0049	0.0051	1.04	14	0.95	23	B	B		
15	135	75.8	19.0	5.0	0	0.1	0.1	0	0.1	V = 0.1	0.0013	0.0013	1.00	7	0.95	5	C	D		
16	135	74.5	19.0	6.0	0	0.2	0.2	0.1	0.3	Y = 0.1	0.0027	0.0028	1.04	6	0.95	16	C	C		
17	135	74.6	19.0	6.0	0	0.2	0.2	0.0	0.2	Cr = 0.5%	0.0025	0.0026	1.04	8	0.95	0	D	D		
18	135	82.7	12.0	5.0	0	0	0.2	0.1	0.3		0.0024	0.0035	1.46	0	-	0	E	E		
19	135	82.8	12.0	5.0	0	0	0.2	0	0.2		0.0023	0.0030	1.30	0	-	0	E	E		
20	135	82.79	12.0	5.0	0	0.01	0.2	0	0.2		0.0023	0.0023	1.00	2	0.85	4	D	D		

[0109]

[Table 2B]

Plated layer																		Performance	
No.	Adhesion amount (g/m ²)	Chemical composition (mass%)								GDS analysis				β phase region		(*)	Corrosion potential + SST	Corrosion current density + SST	
		Zn	Al	Mg	Ca	Si	Cu	Ag	Cu + Ag	Others	CAZmin	CAZmax	CAZmax/CAZmin	Area fraction	Expression (4)				
21	135	72.1	19.0	8.0	0.3	0.3	0.3	0	0.3	Mo = 0.1	0.0041	0.0042	1.02	8	0.98	18	C	C	
22	135	69.5	19.0	10.0	0.4	0.1	0.8	0.2	1.0	B = 0.1	0.0123	0.0130	1.06	12	0.88	34	A	S	
23	135	69.5	19.0	10.0	0.4	0.1	0.8	0.2	1.0	B = 0.1	0.0123	0.0140	1.14	3	0.85	33	C	S	
24	135	69.7	19.0	10.0	0.2	0.1	1.0	0	1.0		0.0140	0.0142	1.01	13	1.10	35	A	S	
25	135	69.7	19.0	10.0	0.2	0.1	1.0	0	1.0	Mo = 0.1	0.0141	0.0146	1.03	13	1.10	0	A	C	
26	135	69.7	19.0	10.0	0.2	0.1	1.0	0	1.0		0.0134	0.0170	1.27	0	-	0	E	E	
27	135	69.7	19.0	10.0	0.2	0.1	1.0	0	1.0		0.0140	0.0170	1.21	0	-	0	E	E	
28	135	74.77	20.0	5.0	0	0.2	0.0	0	0.0		0.0005	0.0005	1.00	8	1.00	2	C	D	
29	135	72.4	20.0	6.0	0	0.1	1.5	0	1.5	Co = 0.1	0.0210	0.0220	1.05	13	0.95	35	A	S	
30	135	62.4	25.0	10.0	0.3	0.3	2.0	0	2.0		0.0320	0.0330	1.03	12	0.95	33	A	S	
31	135	59.2	30.0	7.0	0.6	0.2	3.0	0	3.0		0.0510	0.0520	1.02	12	0.95	31	A	S	
32	135	59.2	30.0	7.0	0.6	0.2	0.0	3.0	3.0		0.0500	0.0520	1.04	13	0.95	33	A	S	
33	135	56.5	30.0	9.0	0.3	0.7	3.5	0	3.5		0.0620	0.0630	1.02	11	0.90	33	A	S	
34	135	56.5	30.0	9.0	0.3	0.7	3.5	0	3.5		0.0620	0.0630	1.02	4	0.90	32	C	S	
35	135	53.4	30.0	12.0	0.5	0.1	4.0	0	4.0		0.0750	0.0762	1.02	13	0.90	35	A	S	

[0110]

[Table 2C]

Plated layer																			Performance	
No.	Adhesion amount (g/m ²)	Chemical composition (mass%)										GDS analysis				β phase region		(*)	Corrosion potential + SST	Corrosion current density + SST
		Zn	Al	Mg	Ca	Si	Cu	Ag	Cu + Ag	Others	CAZmin	CAZmax	CAZmax/CAZmin	Area fraction	Expression (4)					
36	135	55	35.0	5.0	0	0.5	4.5	0	4.5		0.0810	0.0823	1.02	11	1.10	0	B	D		
37	135	59.8	35.0	5.0	0	0	0.2	0	0.2		0.0024	0.0029	1.21	0	-	0	E	E		
38	135	59.8	35.0	5.0	0	0	0.2	0	0.2		0.0023	0.0031	1.35	0	-	0	E	E		
39	135	57.75	35.0	7.0	0.1	0.1	0.1	0	0.1		0.0080	0.0080	1.00	6	1.00	2	C	D		
40	135	49.6	35.0	9.0	0.2	1.2	5.0	0	5.0		0.0990	0.0990	1.00	11	1.10	36	B	A		
41	135	43.2	40.0	10.0	0.4	0.4	6.0	0	6.0	Y = 0.01	0.0970	0.1000	1.03	11	1.10	34	B	A		
42	135	41.3	42.0	10.0	0.2	1.5	5.0	0	5.0		0.1000	0.1000	1.00	11	1.10	40	B	A		
43	135	39.3	42.0	10.0	0.2	1.5	7.0	0	7.0		0.3000	0.3900	1.30	3	1.20	0	E	E		
44	135	46.2	44.0	5.0	0	1.8	3.0	0	3.0		0.0650	0.0660	1.02	11	1.10	31	A	S		
45	135	37.5	44.0	15.0	0.5	2	1.0	0	1.0		0.0270	0.0270	1.00	12	1.10	31	A	S		
46	135	47.7	45.0	5.0	0.5	1.5	0.3	0	0.3		0.0080	0.0090	1.13	0	1.10	0	E	E		
47	135	79.3	12.0	7.0	0.2	0.5	0.5	1	1.0	In = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
48	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Sr = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
49	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Li = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
50	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Sb = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
51	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Pb = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
52	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	P = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
53	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Ti = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
54	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Nb = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
55	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	Zr = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		
56	135	79.3	12.0	7.0	0.2	0.5	0.5	0.5	1.0	W = 0.1	0.0110	0.0120	1.09	12	0.95	31	A	S		

INDUSTRIAL APPLICABILITY

[0111]

According to the above-described aspects of the present invention, it is possible to provide the hot-dip plated steel material capable of minimizing white rust generated at

5 the initial stage of corrosion.

CLAIMS

[Claim 1] A hot-dip plated steel material comprising:

a steel material; and

a plated layer disposed on a surface of the steel material, wherein

5 the plated layer has a chemical composition including, in terms of mass%,

more than 10.0% and less than 45.0% of Al,

4.0% or more and 15.0% or less of Mg,

0.01% or more and 2.0% or less of Si, and

at least one of 0.03% or more and 5.0% or less of Cu, or 0.03% or more and

10 6.0% or less of Ag, and

further including

0% or more and 0.7% or less of Sn,

0% or more and 0.3% or less of Bi,

0% or more and 0.3% or less of In,

15 0% or more and 0.6% or less of Ca,

0% or more and 0.3% or less of Y,

0% or more and 0.3% or less of La,

0% or more and 0.3% or less of Ce,

0% or more and 0.3% or less of Sr,

20 0% or more and 0.3% or less of Li,

0% or more and 1.0% or less of Ni,

0% or more and 0.5% or less of Cr,

0% or more and 0.3% or less of Mo,

0% or more and 0.25% or less of Sb,

25 0% or more and 0.25% or less of Pb,

0% or more and 0.5% or less of B,

0% or more and 0.5% or less of P,

0% or more and 0.25% or less of Ti,

0% or more and 0.25% or less of Co,

5 0% or more and 0.25% or less of V,

0% or more and 0.25% or less of Nb,

0% or more and 0.25% or less of Mn,

0% or more and 0.25% or less of Zr,

0% or more and 0.25% or less of W,

10 0% or more and 5.0% or less of Fe, and

a remainder of Zn and impurities, and

a total amount of Cu and Ag satisfying 0.03% or more and 6.0% or less, and

in a case where, in an elemental distribution profile obtained by quantitative

analysis using a glow discharge optical emission spectrometry in a direction from a

15 surface of the plated layer toward the steel material, a thickness of the plated layer is

denoted by t , and a ratio of a total concentration of a Cu concentration and an Ag

concentration to a concentration of Zn in an internal region between a $1/3t$ position and a

$2/3t$ position from the surface of the plated layer is denoted by CAZ, an absolute

maximum value CAZ_{max} of CAZ and an absolute minimum value CAZ_{min} of CAZ satisfy

20 Expressions (1) to (3),

$$CAZ_{max}/CAZ_{min} \leq 1.20 \dots (1)$$

$$0.0005 \leq CAZ_{min} \dots (2)$$

$$CAZ_{max} \leq 0.1000 \dots (3).$$

[Claim 2] The hot-dip plated steel material according to claim 1, wherein

25 an area fraction of a β phase is 3% or more in a cross section along a thickness

direction of the plated layer, and

concentrations of Al, Zn, Cu, and Al in the β phase satisfy Expression (4),

$$0.85 \leq [\text{Al}]/([\text{Zn}] + [\text{Cu}] + [\text{Ag}]) \leq 1.15 \dots (4)$$

wherein, each of [Al], [Zn], [Cu], and [Ag] in Expression (4) is a quantitative

5 analysis value (at%) obtained by energy dispersive X-ray spectrometry in the β phase.

[Claim 3] The hot-dip plated steel material according to claim 1 or 2, wherein 10 or more (Zn + Al) - (Cu + Ag) compounds having an average grain size of 1 μm or more are contained as intermetallic compound particles within a range of 10000 μm^2 in a cross section along the thickness direction of the plated layer.