

DESCRIPTION

Title of Invention

HOT-DIP ZN-ALLOY-PLATED STEEL SHEET AND METHOD FOR PRODUCING
SAME

5

Technical Field

[0001] The present invention relates to a hot-dip Zn alloy-plated steel sheet excellent in blackening resistance and a method of producing the same.

10 Background Art

[0002] As a plated steel sheet excellent in corrosion resistance, a hot-dip Zn alloy-plated steel sheet having a base steel sheet with a surface coated with a hot-dip Zn alloy plating layer including Al and Mg is known. The composition of the plating layer of a hot-dip Zn alloy-plated steel sheet includes, for example, 4.0 to 15.0% by mass of Al, 1.0 to 4.0% by
15 mass of Mg, 0.002 to 0.1% by mass of Ti, 0.001 to 0.045% by mass of B, and the balance of Zn and unavoidable impurities. The hot-dip Zn alloy-plated steel sheet includes a plating layer of mixed metal structure of [primary crystal Al] and [single phase Zn] in a matrix of [Al/Zn/Zn₂Mg ternary eutectic structure], having sufficient corrosion resistance and surface appearance as an industrial product.

20 [0003] The hot-dip Zn alloy-plated steel sheet described above can be continuously produced by the following steps. First, a base steel sheet (steel strip) is passed through a furnace, dipped in a hot-dip Zn alloy plating bath, and then passed through, for example, a gas wiping apparatus, such that the amount of the molten metal adhered to the surface of the base steel sheet is adjusted to a specified amount. Subsequently, the steel strip with
25 the specified amount of molten metal adhered thereto is passed through an air jet cooler and a mist cooling zone, so that the molten metal is cooled to form a hot-dip Zn alloy

plating layer. Further, the steel strip with the hot-dip Zn alloy plating layer is passed through a water quenching zone, so as to come in contact with cooling water. A hot-dip Zn alloy-plated steel sheet is thus obtained.

[0004] The hot-dip Zn alloy-plated steel sheet thus produced, however, allows the surface of the plating layer to be blackened over time in some cases. Since the progress of blackening of a hot-dip Zn alloy-plated steel sheet spoils the appearance with a dark gray color without metallic luster, a method for suppressing the blackening has been needed.

[0005] As a method for preventing the blackening, adjusting the temperature of the surface of a plating layer in the water quenching zone has been proposed (e.g. refer to PTL

1). In the invention described in PTL 1, the temperature of the surface of a plating layer is adjusted at lower than 105°C when to be contacted with cooling water in the water quenching zone so that blackening of the surface of a plating layer is prevented. Alternatively, instead of the temperature control of the surface of a plating layer at lower than 105°C, readily oxidizable elements (rare earth elements, Y, Zr or Si) are added into a plating bath and the temperature of the surface of a plating layer is adjusted at 105 to 300°C so that blackening of the surface of the plating layer is prevented.

Citation List

Patent Literature

[0006]

PTL 1

Japanese Patent Application Laid-Open No.2002-226958

Summary of Invention

Technical Problem

[0007] In the invention described in PTL 1, since the surface of a plating layer is required

to be cooled to a specified temperature before passed through a water quenching zone, the production of hot-dip Zn alloy-plated steel sheets is restricted in some cases. For example, the feed rate of a plated steel sheet having a large thickness is required to be slow so that the plated steel sheet is cooled to a specified temperature, resulting in reduced productivity.

5 In addition, in the case of adding a readily oxidizable element into a plating bath, the readily oxidizable element tends to form a dross. Consequently, complicated concentration control of the readily oxidizable element is required, resulting in a complicated production process, which has been a problem.

[0008] An object of the present invention is to provide a hot-dip Zn alloy-plated steel
10 sheet excellent in blackening resistance which can be produced without reduction in productivity and without complicated control of the components of a plating bath, and a method of producing the same.

Solution to Problem

15 [0009] The present inventors have found that the problem can be solved by reducing the ratio of $Zn(OH)_2$ at the surface of a plating layer, and accomplished the present invention through further study.

[0010] The present invention relates to the following hot-dip Zn alloy-plated steel sheet.

[0011]

20 [1] A hot-dip Zn alloy-plated steel sheet comprising: a steel sheet; and a hot-dip Zn alloy plating layer disposed on a surface of the steel sheet, wherein the hot-dip Zn alloy plating layer satisfies, at the whole of a surface of the hot-dip Zn alloy plating layer, the following Equation 1:

$$\frac{S[Zn(OH)_2]}{S[Zn(OH)_2] + S[Zn]} \times 100 \leq 40 \quad (\text{Equation 1})$$

25 wherein $S[Zn]$ is a peak area derived from metal Zn and centered at approximately

1022 eV in an intensity profile of XPS analysis of the surface of the hot-dip Zn alloy plating layer; and S[Zn(OH)₂] is a peak area derived from Zn(OH)₂ and centered at approximately 1023 eV in the intensity profile of XPS analysis of the surface of the hot-dip Zn alloy plating layer.

5 [2] The hot-dip Zn alloy-plated steel sheet according to [1], wherein: the hot-dip Zn alloy plating layer comprises 1.0 to 22.0% by mass of Al, 0.1 to 10.0% by mass of Mg, and the balance of the hot-dip Zn alloy plating layer being Zn and unavoidable impurities.

 [3] The hot-dip Zn alloy-plated steel sheet according to [2], wherein: the hot-dip Zn alloy plating layer further comprises at least one selected from the group consisting of
10 0.001 to 2.0% by mass of Si, 0.001 to 0.1% by mass of Ti, and 0.001 to 0.045% by mass of B.

[0012] The present invention also relates to the following method of producing a hot-dip Zn alloy-plated steel sheet.

[0013]

15 [4] A method of producing a hot-dip Zn alloy-plated steel sheet comprising: dipping a base steel sheet in a hot-dip Zn alloy plating bath to form a hot-dip Zn alloy plating layer on a surface of the base steel sheet; and contacting an aqueous solution containing a water-soluble corrosion inhibitor with the surface of the hot-dip Zn alloy plating layer to cool the base steel sheet and the hot-dip Zn alloy plating layer having a
20 raised temperature through formation of the hot-dip Zn alloy plating layer,

 wherein a temperature of the surface of the hot-dip Zn alloy plating layer when the aqueous solution is to be contacted with the surface of the hot-dip Zn alloy plating layer is equal to or more than 100°C and equal to or less than a solidifying point of the plating layer; and wherein the aqueous solution containing the water-soluble corrosion inhibitor
25 satisfies the following Equation 2:

$$\frac{Z_0 - Z_1}{Z_0} \times 100 \geq 20 \quad (\text{Equation 2})$$

Z_0 is a corrosion current density of the hot-dip Zn alloy-plated steel sheet measured in a 0.5 M NaCl aqueous solution not containing the water-soluble corrosion inhibitor, and Z_1 is a corrosion current density of the hot-dip Zn alloy-plated steel sheet measured in the aqueous solution containing the water-soluble corrosion inhibitor, in which NaCl is further dissolved so that a final concentration of NaCl is 0.5 M.

Advantageous Effects of Invention

[0014] According to the present invention, a hot-dip Zn alloy-plated steel sheet excellent in blackening resistance can be easily produced at high productivity.

Brief Description of Drawings

[0015]

FIG. 1A is a graph illustrating an exemplary polarization curve of a hot-dip Zn alloy-plated steel sheet in 0.5 M NaCl aqueous solution including no water-soluble corrosion inhibitor;

FIG. 1B is a graph illustrating an exemplary polarization curve of a hot-dip Zn alloy-plated steel sheet in 0.5 M NaCl aqueous solution containing a water-soluble corrosion inhibitor;

FIG. 2A illustrates an exemplary method for contacting a cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer by a spraying process;

FIG. 2B illustrates an exemplary method for contacting a cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer by a dipping process;

FIGS. 3A and 3B illustrate the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn at the surface of a hot-dip Zn alloy plating layer

cooled with use of a cooling water to temporarily form a water film;

FIGS. 4A and 4B illustrate the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Al at the surface of a hot-dip Zn alloy plating layer cooled with use of a cooling water to temporarily form a water film;

5 FIGS. 5A and 5B illustrate the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Mg at the surface of a hot-dip Zn alloy plating layer cooled with use of a cooling water to temporarily form a water film;

FIG. 6 illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn at the surface of a hot-dip Zn alloy plating layer cooled with use of
10 a cooling water, without formation of a water film;

FIG. 7 illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn at the surface of a hot-dip Zn alloy plating layer cooled with use of a cooling aqueous solution containing V^{5+} to temporarily form a water film;

FIGS. 8A to 8D illustrate the intensity profile of the chemical binding energy
15 corresponding to the 2p orbitals of Zn at the surface of a plating layer; and

FIG. 9 is a schematic diagram illustrating the configuration of a part of the production line of a hot-dip Zn alloy-plated steel sheet.

Description of Embodiments

20 [0016] (Method of producing hot-dip Zn alloy-plated steel sheet of the present invention)

The method of producing a hot-dip Zn alloy-plated steel sheet of the present invention (hereinafter, also referred to as "plated steel sheet") includes: (1) a first step of forming a hot-dip Zn alloy plating layer (hereinafter, also referred to as "plating layer") on the surface of a base steel sheet; and (2) a second step of contacting a specified aqueous
25 solution with the surface of the plating layer to cool the base steel sheet and the plating layer at a raised temperature through formation of the plating layer.

[0017] One of the features of the production method of the present invention is that after formation of a hot-dip Zn alloy plating layer, a specified cooling aqueous solution is contacted with the surface of the plating layer so as to suppress blackening of the plating layer. Each of the steps is described as follows.

5 [0018] (1) First step

In the first step, a base steel sheet is dipped in a hot-dip Zn alloy plating bath, so that a hot-dip Zn alloy plating layer is formed on the surface of the base steel sheet.

[0019] First, a base steel sheet is dipped in a hot-dip Zn alloy plating bath, and a specified amount of molten metal is allowed to adhere on the surface of the base steel sheet
10 by gas wiping or the like.

[0020] The type of the base steel sheet is not particularly limited. For example, a steel sheet made of low-carbon steel, medium-carbon steel, high-carbon steel, alloy steel or the like may be used as the base steel sheet. When excellent press formability is required, a steel sheet for deep drawing made of low-carbon Ti-alloyed steel, low-carbon Nb-alloyed
15 steel or the like is preferably used as the base steel sheet. Alternatively, a high-strength steel sheet containing P, Si, Mn and the like may be used.

[0021] The composition of a plating bath may be appropriately selected corresponding to the composition of a hot-dip Zn alloy plating layer to be formed. For example, the plating bath includes 1.0 to 22.0% by mass of Al, 0.1 to 10.0% by mass of Mg, and the balance of
20 Zn and unavoidable impurities. The plating bath may further include at least one selected from the group consisting of 0.001 to 2.0% by mass of Si, 0.001 to 0.1% by mass of Ti, and 0.001 to 0.045% by mass of B. Examples of the hot-dip Zn alloy plating include a molten Zn-0.18% by mass of Al-0.09% by mass of Sb alloy plating, a molten Zn-0.18% by mass of Al-0.06% by mass of Sb alloy plating, a molten Zn-0.18% by mass Al alloy plating, a
25 molten Zn-1% by mass of Al-1% by mass of Mg alloy plating, a molten Zn-1.5% by mass of Al-1.5% by mass of Mg alloy plating, a molten Zn-2.5% by mass of Al-3% by mass of

Mg alloy plating, a molten Zn-2.5% by mass of Al-3% by mass of Mg-0.4% by mass of Si alloy plating, a molten Zn-3.5% by mass of Al-3% by mass of Mg alloy plating, a molten Zn-4% by mass of Al-0.75% by mass of Mg alloy plating, a molten Zn-6% by mass of Al-3% by mass of Mg-0.05% by mass of Ti-0.003% by mass of B alloy plating, a molten Zn-6% by mass of Al-3% by mass of Mg-0.02% by mass of Si-0.05% by mass of Ti-0.003% by mass of B alloy plating, a molten Zn-11% by mass of Al-3% by mass of Mg alloy plating, a molten Zn-11% by mass of Al-3% by mass of Mg-0.2% by mass of Si alloy plating, and a molten Zn-55% by mass of Al-1.6% by mass of Si alloy plating. Although blackening of a plating layer can be suppressed by addition of Si as described in PTL 1, blackening of a plating layer can be suppressed without addition of Si in the case of producing a plated steel sheet by the production method of the present invention.

[0022] The adhering amount of the hot-dip Zn alloy plating layer is not specifically limited. The adhering amount of the plating layer may be, for example, approximately 60 to 500 g/m².

[0023] Subsequently, the molten metal adhered to the surface of a base steel sheet is cooled to a temperature equal to or more than 100°C and equal to or less than the solidifying point of the plating layer so as to be solidified. A plated steel sheet is thus formed, having a plating layer with a composition approximately the same as the composition of the plating bath, on the surface of the base steel sheet.

[0024] (2) Second step

In the second step, a specified cooling aqueous solution is contacted with the surface of the hot-dip Zn alloy plating layer, so that the base steel sheet and the plating layer at a raised temperature through formation of the hot-dip Zn alloy plating layer are cooled. From the viewpoint of productivity, the second step is performed preferably by water quenching (water cooling). In this case, the temperature of the surface of the hot-dip Zn alloy plating layer when the cooling aqueous solution is to be contacted with the surface of

the hot-dip Zn alloy plating layer is equal to or more than 100°C and approximately equal to or less than the solidifying point of the plating layer.

[0025] The cooling aqueous solution is formed of an aqueous solution containing a water-soluble corrosion inhibitor, satisfying the following equation 3. The following equation 3 indicates that the cooling aqueous solution has a reduction ratio of the corrosion current density of 20% or more.

$$\frac{Z_0 - Z_1}{Z_0} \times 100 \geq 20 \quad (\text{Equation 3})$$

wherein Z_0 is the corrosion current density of a hot-dip Zn alloy-plated steel sheet, measured in a 0.5 M NaCl aqueous solution containing no water-soluble corrosion inhibitor; and Z_1 is the corrosion current density of a hot-dip Zn alloy-plated steel sheet, measured in the aqueous solution (cooling aqueous solution) containing the water-soluble corrosion inhibitor, with further dissolved NaCl at a final concentration of 0.5 M.

[0026] Although NaCl is added to the cooling aqueous solution to have a final concentration of 0.5 M in the measurement of the corrosion current density in the cooling aqueous solution as described above, the hot-dip Zn alloy-plated steel sheet is cooled with the cooling aqueous solution as it is, without addition of NaCl to the cooling aqueous solution.

[0027] The corrosion current density values Z_0 and Z_1 for use in the equation 3 are obtained from a polarization curve by Tafel extrapolation method. The measurement of the polarization curve is performed using an electrochemical measurement system (HZ-3000, produced by Hokuto Denko Corp.). The corrosion current is calculated using software (data analysis software) attached to the electrochemical measurement system.

FIG. 1A is a graph illustrating an exemplary polarization curve of a hot-dip Zn alloy-plated steel sheet in 0.5 M NaCl aqueous solution including no water-soluble corrosion inhibitor.

FIG. 1B is a graph illustrating an exemplary polarization curve of a hot-dip Zn alloy-plated

steel sheet in 0.5 M NaCl aqueous solution containing a water-soluble corrosion inhibitor. As shown therein, the corrosion current density in the 0.5 M NaCl aqueous solution containing a water-soluble corrosion inhibitor is at least 20% smaller than the corrosion current density measured in the 0.5 M NaCl aqueous solution containing no water-soluble corrosion inhibitor.

[0028] The method for preparing the aqueous solution (cooling aqueous solution) containing a water-soluble corrosion inhibitor is not specifically limited. For example, a water-soluble corrosion inhibitor capable of reducing the corrosion current density, and a dissolution promoter on an as needed basis, may be dissolved in water (solvent). The type of the water-soluble corrosion inhibitor is not specifically limited as long as capable of reducing the corrosion current density. Examples of the water-soluble corrosion inhibitor include a V compound, a Si compound, and a Cr compound. Preferable examples of the V compound include acetylacetone vanadyl, vanadium acetylacetonate, vanadium oxysulfate, vanadium pentoxide, and ammonium vanadate. Further, preferable examples of the Si compound include sodium silicate. Further, preferable examples of the Cr compound include ammonium chromate and potassium chromate. These water-soluble corrosion inhibitors may be used singly or in combination. The amount of the water-soluble corrosion inhibitor added is selected to satisfy the equation 3.

[0029] In the case of adding a dissolution promoter, the amount of the dissolution promoter added is not specifically limited. For example, 90 to 130 parts by mass of the dissolution promoter may be added to 100 parts by mass of the water-soluble corrosion inhibitor. With an excessively small amount of the dissolution promoter added, the water-soluble corrosion inhibitor cannot be sufficiently dissolved in some cases. On the other hand, with an excessively large amount of the dissolution promoter added, the effect is saturated, resulting in a cost disadvantage.

[0030] Examples of the dissolution promoter include 2-aminoethanol,

tetraethylammonium hydroxide, ethylene diamine, 2,2'-iminodiethanol, and 1-amino-2-propanol.

[0031] The method for contacting the cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer is not specifically limited. Examples of the method for contacting the cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer include a spraying process and a dipping process.

[0032] FIGS. 2A and 2B illustrate exemplary methods for contacting a cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer. FIG. 2A illustrates an exemplary method for contacting a cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer by a spraying process. FIG. 2B illustrates an exemplary method for contacting a cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer by a dipping process.

[0033] As shown in FIG. 2A, cooling apparatus 100 for spraying process includes a plurality of spray nozzles 110, squeeze rollers 120 disposed downstream of spray nozzles 110 in the feed direction of a steel strip S, and housing 130 which covers the nozzles and the rollers. Spray nozzles 110 are disposed on both sides of the steel strip S. The steel strip S is cooled by a cooling aqueous solution supplied from spray nozzles 110 such that a water film is temporarily formed on the surface of the plating layer, inside housing 130. The cooling aqueous solution is then removed with squeeze roller 120.

[0034] As shown in FIG. 2B, cooling apparatus 200 for dipping process includes dip tank 210 in which a cooling aqueous solution is stored, dip roller 220 disposed inside dip tank 210, and squeeze rollers 230 disposed downstream of dip roller 220 in the feed direction of the steel strip S so as to remove the extra cooling aqueous solution adhered to the steel strip S. The steel strip S fed into dip tank 210 is then contacted with the cooling aqueous solution so as to be cooled. The steel strip S is then subjected to a turn of direction by the rotating dip roller 220, and pulled upward. The cooling aqueous solution is removed with

squeeze rollers 230.

[0035] According to the procedure described above, a hot-dip Zn alloy-plated steel sheet excellent in blackening resistance can be produced.

[0036] The reason is not clear why the production method of the present invention can
5 suppress the temporal blackening at the surface of a plating layer of a hot-dip Zn alloy-plated steel sheet. In the following, a presumed mechanism of the occurrence of blackening of a hot-dip Zn alloy plating layer is described, and then a presumed mechanism of the suppression of blackening is described when a hot-dip Zn alloy-plated steel sheet is produced according to the production method of the present invention. The
10 mechanism of the suppression of blackening, however, is not limited to the hypotheses.

[0037] (Mechanism of occurrence of blackening)

First, the process leading to the presumed mechanisms of the occurrence of blackening of the surface of a plating layer and the suppression of the blackening is described as follows. The present inventors produced a hot-dip Zn alloy-plated steel sheet
15 by forming a hot-dip Zn alloy plating layer having a plating composition including 6% by mass of Al, 3% by mass of Mg, 0.024% by mass of Si, 0.05% by mass of Ti, 0.003% by mass of B, and the balance of Zn on the surface of a base steel sheet, and then temporarily forming a water film from cooling water (in-factory water having a pH of 7.6, at 20°C) in a water quenching zone for a spraying process. The term "temporarily forming a water
20 film" means a state allowing a water film in contact with the surface of a hot-dip Zn alloy-plated steel sheet to be visually observed for one second or more. On this occasion, the surface temperature of the hot-dip Zn alloy-plated steel sheet was estimated to be approximately 160°C immediately before formation of the water film from the cooling water.

25 [0038] The produced hot-dip Zn alloy-plated steel sheet was stored in a room (at a room temperature of 20°C, with a relative humidity of 60%) for one week. After storage for

one week, the surface of the hot-dip Zn alloy-plated steel sheet was visually observed. The blackening developed on the whole surface of the hot-dip Zn alloy-plated steel sheet and a dark part where blackening particularly proceeded compared with the periphery was observed.

5 [0039] Furthermore, for 30 regions randomly selected on the surface of a hot-dip Zn alloy-plated steel sheet immediately after production, the chemical binding states of Zn, Al and Mg were analyzed by XPS analysis (X-ray Photoelectron Spectroscopy). Then, the analyzed hot-dip Zn alloy-plated steel sheet was stored in a room (at a room temperature of 20°C, with a relative humidity of 60%) for one week. After storage for one week, the
10 surface of the hot-dip Zn alloy-plated steel sheet was visually observed. As a result, a dark part was observed in a part of the hot-dip Zn alloy-plated steel sheet. For the region where the dark part was formed and the region where no dark part was observed (normal part), the XPS analysis results of the hot-dip Zn alloy-plated steel sheet obtained immediately after production were compared.

15 [0040] FIGS. 3A and 3B to FIGS. 5A and 5B are charts illustrating the XPS analysis results of the hot-dip Zn alloy-plated steel sheet obtained immediately after production for the normal part and the dark part. FIG. 3A illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn in a normal part. FIG. 3B illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn
20 in a dark part. FIG. 4A illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Al in a normal part. FIG. 4B illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Al in a dark part. FIG. 5A illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Mg in a normal part. FIG. 5B illustrates the intensity profile of the chemical
25 binding energy corresponding to the 2p orbitals of Mg in a dark part.

[0041] As shown in FIG. 3A, in the analysis of Zn in a normal part, a peak derived from

metal Zn at approximately 1022 eV and a peak derived from Zn(OH)₂ at approximately 1023 eV having a strength weaker than that of the peak derived from metal Zn were observed. From the analysis results, it is found that Zn is present not only as metal Zn, but also present as hydroxide (Zn(OH)₂) in the normal part. From the strength ratio
5 between Zn and Zn(OH)₂, it is found that the Zn is present in larger amount than Zn(OH)₂ in the normal part.

[0042] On the other hand, as shown in FIG. 3B, also in the analysis of Zn in a dark part, a peak derived from metal Zn at approximately 1022 eV and a peak derived from Zn(OH)₂ at approximately 1023 eV having a strength stronger than that of the peak derived from metal
10 Zn were observed. From the analysis results, it is found that Zn is present not only as metal Zn, but also present as hydroxide (Zn(OH)₂) in the dark part, in the same manner as in the normal part. From the strength ratio between Zn and Zn(OH)₂, it is found that the Zn(OH)₂ is present in larger amount than Zn in the dark part.

[0043] As shown in FIGS. 4A and 4B, in the analysis of Al in the normal part and the
15 dark part, a peak derived from metal Al at approximately 72 eV and a peak derived from Al₂O₃ at approximately 74 eV having a strength weaker than that of the peak derived from metal Al were observed. From the analysis results, it is found that Al is present as metal Al and as oxide (Al₂O₃) in the normal part and the dark part. In both of the normal part and the dark part, Al₂O₃ is present in larger amount than Al, and no major change in the
20 ratio of presence was observed between the normal part and the dark part.

[0044] As shown in FIGS. 5A and 5B, in the analysis of Mg in the normal part and the dark part, peaks derived from metal Mg, Mg(OH)₂, and MgO at approximately 49 to 50 eV were observed. From the analysis results, it is found that Mg is present as metal Mg, as oxide (MgO), and as hydroxide (Mg(OH)₂) in the normal part and the dark part. No
25 major change in the ratio of presence of metal Mg, Mg(OH)₂, and MgO was observed between the normal part and the dark part.

[0045] From the results, it is presumed that the binding state of Zn has an effect on formation of the dark part, i.e., the rate of progress in blackening. Accordingly, it is presumed that the dark part is formed, or blackening is accelerated, due to increase in the presence ratio of $\text{Zn}(\text{OH})_2$.

5 [0046] Next, the present inventors produced a hot-dip Zn alloy-plated steel sheet by contacting in-factory water (cooling water) with the surface of the hot-dip Zn alloy plating layer by a mist cooling apparatus, without formation of a water film. The produced hot-dip Zn alloy-plated steel sheet was stored in a room (at a room temperature of 20°C , with a relative humidity of 60%) for one week. After storage for one week, the surface of
10 the hot-dip Zn alloy-plated steel sheet was visually observed. The hot-dip Zn alloy-plated steel sheet had a uniform surface gloss, and no formation of a dark part was observed. The degree of gloss at the surface of the plating layer is approximately the same as in the normal part in the hot-dip Zn alloy-plated steel sheet produced through temporary formation of a water film.

15 [0047] The surface of the plating layer of the hot-dip Zn alloy-plated steel sheet immediately after production without formation of a water film was then analyzed by XPS analysis. FIG. 6 illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn. The intensity profiles of Al and Mg are omitted. As shown in FIG. 6, a peak derived from metal Zn at approximately 1022 eV and a peak
20 derived from $\text{Zn}(\text{OH})_2$ at approximately 1023 eV were observed, even in the case of contact with cooling water without formation of a water film. From the strength ratio between Zn and $\text{Zn}(\text{OH})_2$, it is found that the Zn is present in larger amount than $\text{Zn}(\text{OH})_2$ in the normal part. Accordingly, it is presumed that the formation of $\text{Zn}(\text{OH})_2$ is not accelerated even in the case of contact with cooling water when a water film is not formed.

25 [0048] From the results, it is suggested that the formation of a water film in the cooling step has an effect on the formation of $\text{Zn}(\text{OH})_2$. In the case of no formation of a water

film, $\text{Zn}(\text{OH})_2$ is not easily formed, and it is therefore presumed that the blackening is suppressed.

[0049] As described above, regarding blackening of the plating layer of a hot-dip Zn alloy-plated steel sheet, the present inventors found that: 1) $\text{Zn}(\text{OH})_2$ is formed on the surface of the plating layer through formation of a water film in the cooling step; and 2) blackening tends to occur in a region where $\text{Zn}(\text{OH})_2$ is formed in the surface of the plating layer. Accordingly, the present inventors presume that the mechanism of blackening of the plating layer to be as follows.

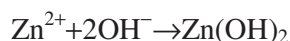
[0050] First, when a cooling water comes in contact with the surface of a plating layer at high temperature (e.g. 100°C or higher), partial elution of Zn from the oxide film on the surface of the plating layer or from the Zn phase in the plating layer occurs.



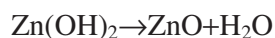
[0051] A part of oxygen dissolved in the cooling water is reduced to form OH^- .



[0052] Zn^{2+} eluted into cooling water bonds with OH^- in the cooling water to form $\text{Zn}(\text{OH})_2$ on the surface of the plating layer.



[0053] As time passes, a part of $\text{Zn}(\text{OH})_2$ on the surface of the plating layer forms ZnO through a dehydration reaction.



[0054] Subsequently, oxygen is taken from a part of ZnO by Al and Mg in the plating layer, so that ZnO_{1-X} is produced. ZnO_{1-X} forms a color center, visually exhibiting a black color.

[0055] (Mechanism for suppressing blackening)

Subsequently, the present inventors produced a hot-dip Zn alloy-plated steel sheet by using an aqueous solution of a V compound (reduction ratio of the corrosion current

density: 20% or more) instead of in-factory water so as to temporarily form a water film on the surface of the plating layer in the water quenching zone for a spraying process. On this occasion, the surface temperature of the hot-dip Zn alloy-plated steel sheet immediately before contact with the cooling aqueous solution was estimated to be
5 approximately 160°C.

[0056] The produced hot-dip Zn alloy-plated steel sheet was stored in a room (at a room temperature of 20°C, with a relative humidity of 60%) for one week. After storage for one week, the surface of the hot-dip Zn alloy-plated steel sheet was visually observed. The hot-dip Zn alloy-plated steel sheet had a practically uniform surface gloss, and no
10 formation of a dark part was observed. The hot-dip Zn alloy-plated steel sheet had higher surface gloss in comparison with the normal part in the hot-dip Zn alloy-plated steel sheet produced through temporary formation of a water film using in-factory water.

[0057] Subsequently, the surface of the plating layer of the hot-dip alloy plated steel sheet immediately after production through temporary formation of a water film using the
15 cooling aqueous solution was analyzed by XPS analysis. FIG. 7 illustrates the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn in the normal part in the case of using the cooling aqueous solution. The intensity profiles of Al and Mg are omitted. As shown in FIG. 7, a peak derived from metal Zn at approximately 1022 eV and a peak derived from Zn(OH)₂ at approximately 1023 eV were observed, even in the
20 case of using the cooling aqueous solution. From the strength ratio between Zn and Zn(OH)₂, it is found that the Zn is present in larger amount than Zn(OH)₂. Accordingly, it is presumed that the formation of Zn(OH)₂ is not accelerated even in the case of temporary formation of a water film when an aqueous solution of the V compound (a reduction ratio of the corrosion current density of 20% or more) is used.

25 [0058] In the case of using an aqueous solution having a reduction ratio of the corrosion current density of 20% or more as cooling water, the progress rate of the series of reactions

involved in the formation of Zn(OH)_2 is reduced. It is presumed that the formation of Zn(OH)_2 is thereby suppressed, resulting in suppressed blackening of the plating layer.

[0059] (Hot-dip Zn alloy-plated steel sheet of the present invention)

In the hot-dip Zn alloy-plated steel sheet produced by the production method of the present invention (hot-dip Zn alloy-plated steel sheet of the present invention), the amount of Zn(OH)_2 at the surface of the hot-dip Zn alloy plating layer is small. Accordingly, the hot-dip Zn alloy plating layer satisfies, at the entire surface, the following equation 4.

$$\frac{S[\text{Zn(OH)}_2]}{S[\text{Zn(OH)}_2] + S[\text{Zn}]} \times 100 \leq 40 \quad (\text{Equation 4})$$

wherein $S[\text{Zn}]$ is a peak area derived from metal Zn and centered at approximately 1022 eV in an intensity profile of XPS analysis of the surface of the hot-dip Zn alloy plating layer; and $S[\text{Zn(OH)}_2]$ is a peak area derived from Zn(OH)_2 and centered at approximately 1023 eV in the intensity profile of XPS analysis of the surface of the hot-dip Zn alloy plating layer.

[0060] The equation 4 indicates that the ratio of the peak area derived from Zn(OH)_2 and centered at approximately 1023 eV (hereinafter referred to as " Zn(OH)_2 ratio") is 40% or less relative to the total of the peak area derived from metal Zn and centered at approximately 1022 eV, and peak area derived from Zn(OH)_2 and centered at approximately 1023 eV in the intensity profile measured in the XPS analysis.

[0061] FIGS. 8A to 8D illustrate the intensity profile of the chemical binding energy corresponding to the 2p orbitals of Zn at the surface of a plating layer of the hot-dip Zn alloy-plated steel sheet. FIG. 8A illustrates the intensity profile with a Zn(OH)_2 ratio of approximately 80%, FIG. 8B illustrates the intensity profile with a Zn(OH)_2 ratio of approximately 45%, FIG. 8C illustrates the intensity profile with a Zn(OH)_2 ratio of approximately 15%, and FIG. 8D illustrates the intensity profile with a Zn(OH)_2 ratio of approximately 10%. A dotted line is the base line, a broken line is the intensity profile

derived from metal Zn (a peak centered at approximately 1022 eV), and a solid line is the intensity profile derived from Zn(OH)₂ (a peak centered at approximately 1023 eV). In the hot-dip Zn alloy-plated steel sheet of the present invention, the Zn(OH)₂ ratio is 40% or less over the whole surface of the plating layer as shown in FIGS. 8C and 8D.

5 [0062] The XPS analysis of the surface of the plating layer of a hot-dip Zn alloy-plated steel sheet is performed using an XPS analyzer (AXIS Nova, produced by Kratos Group PLC.). The peak area derived from metal Zn and centered at approximately 1022 eV, and the peak area derived from Zn(OH)₂ and centered at approximately 1023 eV are calculated using software (Vision 2) attached to the XPS analyzer.

10 [0063] The position of the peak derived from metal Zn is precisely at 1021.6 eV, and the position of the peak derived from Zn(OH)₂ is precisely at 1023.3 eV. These values may change in some cases due to characteristics of XPS analysis, contamination of a sample, and charging of a sample. Those skilled in the art, however, are capable of distinguishing the peak derived from metal Zn from the peak derived from Zn(OH)₂.

15 [0064] (Production line)

The method of producing the hot-dip Zn alloy-plated steel sheet of the present invention described above may be performed, for example, in the following production line.

[0065] FIG. 9 is a schematic diagram illustrating a part of production line 300 of a
20 hot-dip Zn alloy-plated steel sheet. Production line 300 forms a plating layer on the surface of a base steel sheet (steel strip), and can continuously produce hot-dip Zn alloy-plated steel sheets. Production line 300 may further form a chemical conversion coating on the surface of the plating layer on an as needed basis, and can continuously produce plated steel sheets with chemical conversion treatment.

25 [0066] As shown in FIG. 9, production line 300 includes furnace 310, plating bath 320, air jet cooler 340, mist cooling zone 350, water quenching zone 360, skin pass mill 370,

and tension leveler 380.

[0067] The steel strip S fed from a feeding reel not shown in drawing through a predetermined step is heated in furnace 310. The heated steel strip S is dipped in plating bath 320, so that molten metal adheres to both sides of the steel strip S. An excess
5 amount of molten metal is then removed with a wiping apparatus having wiping nozzle 330, allowing a specified amount of molten metal to adhere to the surface of the steel strip S.

[0068] The steel strip S with a specified amount of molten metal adhered thereto is cooled to the solidifying point of the molten metal or lower by air jet cooler 340 or in mist cooling zone 350. Air jet cooler 340 is a facility for cooling the steel strip S by spraying a
10 gas. Mist cooling zone 350 is a facility for cooling the steel strip S by spraying atomized fluid (e.g. cooling water) and a gas. The molten metal is thereby solidified, so that a hot-dip Zn alloy plating layer is formed on the surface of the steel strip S. When the steel strip s is cooled in mist cooling zone 350, no water film is formed on the surface of the plating layer. The temperature after cooling is not specifically limited, and may be, for
15 example, 100 to 250°C.

[0069] The hot-dip Zn alloy-plated steel sheet cooled to a specified temperature is further cooled in water quenching zone 360. Water quench zone 360 is a facility for cooling the steel strip S through contact with a large amount of cooling water in comparison with mist cooling zone 350, supplying an amount of water to form a temporary water film on the
20 surface of the plating layer. For example, water quenching zone 360 includes headers having 10 flat spray nozzles disposed at intervals of 150 mm in the width direction of the steel strip S, which are disposed in 7 rows in the feeding direction of the base steel sheet S. In water quenching zone 360, an aqueous solution containing a water-soluble corrosion inhibitor (a reduction ratio of the corrosion current density of 20% or more) is used as
25 cooling aqueous solution. The steel strip S is cooled in water quenching zone 360, with the cooling aqueous solution in an amount to temporarily form a water film on the surface

of the plating layer being supplied. For example, the cooling aqueous solution has a water temperature of approximately 20°C, a water pressure of approximately 2.5 kgf/cm², and a water quantity of approximately 150 m³/h. The phrase "a water film is temporarily formed" means a state allowing a water film in contact with a hot-dip Zn alloy-plated steel sheet to be visually observed for approximately one seconds or more.

[0070] The water-cooled hot-dip Zn alloy-plated steel sheet is rolled for thermal refining by skin pass mill 370, corrected to flat by tension leveler 380, and then wound onto tension reel 390.

[0071] When a chemical conversion coating is further formed on the surface of a plating layer, a specified chemical conversion treatment liquid is applied to the surface of the hot-dip Zn alloy-plated steel sheet corrected by tension leveler 380, with roll coater 400. The hot-dip Zn alloy-plated steel sheet through the chemical conversion treatment is dried and cooled in drying zone 410 and air cooling zone 420, and then wound onto tension reel 390.

[0072] As described above, the hot-dip Zn alloy-plated steel sheet of the present invention has excellent blackening resistance and can be easily produced at high productivity. The method of producing a hot-dip Zn alloy-plated steel sheet of the present invention allows a hot-dip Zn alloy-plated steel sheet having excellent blackening resistance to be easily produced at high productivity, only by contacting a specified cooling aqueous solution with the surface of a hot-dip Zn alloy plating layer.

[0073] The present invention is described in detail with reference to Examples as follows. The present invention is, however, not limited to the Examples.

Examples

[0074] (Experiment 1)

In Experiment 1, the blackening resistance of the hot-dip Zn alloy plating layer of a

hot-dip Zn alloy-plated steel sheet cooled by using a cooling water containing a water-soluble corrosion inhibitor was examined.

[0075] 1. Production of hot-dip Zn alloy-plated steel sheet

Using production line 300 shown in FIG. 9, hot-dip Zn alloy-plated steel sheets were
5 produced. A hot-rolled steel strip with a sheet thickness of 2.3 mm was prepared as base steel sheet (steel strip) S. Plating was applied to the base steel sheet using the plating bath compositions and conditions described in Table 1, so that 14 types of hot-dip Zn alloy-plated steel sheets having different plating layer compositions from each other were produced. The composition of the plating bath and the composition of the plating layer
10 are approximately the same.

[0076]

[Table 1]

Plating No.	Plating bath composition (balance: Zn) (% by mass)						Plating conditions		
	Al	Mg	Si	Ti	B	Sb	Bath temperature (°C)	Adhering amount (g/m ²)	Sheet passing speed (m/min)
1	0.18	—	—	—	—	0.09	430	90	80
2	0.18	—	—	—	—	0.06	430	90	80
3	0.18	—	—	—	—	—	430	90	80
4	1	1	—	—	—	—	430	90	80
5	1.5	1.5	—	—	—	—	430	90	80
6	2.5	3	—	—	—	—	430	90	80
7	2.5	3	0.4	—	—	—	430	90	80
8	3.5	3	—	—	—	—	430	90	80
9	4	0.75	—	—	—	—	430	90	80
10	6	3	—	0.05	0.003	—	430	90	80
11	6	3	0.02	0.05	0.003	—	430	90	80
12	11	3	—	—	—	—	450	90	80
13	11	3	0.2	—	—	—	450	90	80
14	55	—	1.6	—	—	—	600	90	80

[0077] In production of a hot-dip Zn alloy-plated steel sheet, the cooling conditions in air jet cooler 340 were changed, such that the temperature of the steel sheet (the surface of plating layer) is adjusted at 80°C, 150°C, or 300°C immediately before passing through water quenching zone 360. In water quenching zone 360, any one of the aqueous solutions described in Table 2 and Table 3 was used as cooling aqueous solution. Each of the cooling aqueous solutions was prepared by dissolving a water-soluble corrosion inhibitor described in Table 2 or Table 3 and a dissolution promoter on an as needed basis dissolved in water with a pH of 7.6, at a specified ratio, and then adjusting the water temperature to 20°C. A cooling aqueous solution No. 42 is a water with a pH of 7.6 containing no water-soluble corrosion inhibitor and no dissolution promoter. The spray apparatus in water quenching zone 360 for use includes headers having 10 flat spray nozzles disposed at intervals of 150 mm in the width direction, which are disposed in 7 rows in the feeding direction of the base steel sheet S. Each of the cooling aqueous solutions supplied from water quenching zone 360 was under conditions with a water pressure of 2.5 kgf/cm² and a water quantity of 150 m³/h.

[0078] The reduction ratio of corrosion current density of each of the cooling aqueous solutions is also described in Table 2 and Table 3. The reduction ratio of corrosion current density is the value calculated from the equation 3 (refer to FIGS. 1A and 1B). The corrosion current density is a value obtained from a polarization curve by Tafel extrapolation method. The reduction ratio of corrosion current density of each of cooling aqueous solutions Nos. 10 to 36 is 20% or more, and the reduction ratio of corrosion current density of each of cooling aqueous solutions Nos. 1 to 9 and Nos. 37 to 42 is less than 20%.

[0079]

[Table 2]

Category	Cooling water No.	Water-soluble corrosion inhibitor (A)		Dissolution promoter (B)		Reduction ratio of corrosion current density (%)
		Name	Amount added (mg/L)	Name	Ratio of amount added (B/A)	
Comparative Example	1	Sodium silicate	0.1	—	—	3
	2	Vanadium acetylacetonate	0.1	Ethylene diamine	1.1	2
	3	Acetylacetone vanadyl	0.1	Ethylene diamine	1.3	-2
	4	Vanadium oxysulfate	0.1	2-Aminoethanol	10	3
	5	Vanadium pentoxide	0.1	1-Amino-2-propanol	1.1	5
	6	Vanadium pentoxide	0.1	Tetraethylammonium hydroxide	0.9	-4
	7	Vanadium pentoxide	0.1	2,2'-Iminodietanol	0.9	-1
	8	Ammonium chromate	0.1	—	—	2
	9	Potassium chromate	0.1	—	—	3
	10	Sodium silicate	30	—	—	61
Example	11	Vanadium acetylacetonate	30	Ethylene diamine	1.1	40
	12	Acetylacetone vanadyl	30	Ethylene diamine	1.3	45
	13	Vanadium oxysulfate	30	2-Aminoethanol	10	33
	14	Vanadium pentoxide	30	1-Amino-2-propanol	1.1	57
	15	Vanadium pentoxide	30	Tetraethylammonium hydroxide	0.9	46
	16	Vanadium pentoxide	30	2,2'-Iminodietanol	0.9	43
	17	Ammonium chromate	30	—	—	81
	18	Potassium chromate	30	—	—	72
	19	Sodium silicate	500	—	—	92
	20	Vanadium acetylacetonate	500	Ethylene diamine	1.1	84

[0080]

[Table 3]

Category	Cooling water No.	Water-soluble corrosion inhibitor (A)		Dissolution promoter (B)		Reduction ratio of corrosion current density (%)
		Name	Amount added (mg/L)	Name	Ratio of amount added (B/A)	
Example	21	Acetylacetone vanadyl	500	Ethylene diamine	1.3	83
	22	Vanadium oxysulfate	500	2-Aminoethanol	10	84
	23	Vanadium pentoxide	500	1-Amino-2-propanol	1.1	84
	24	Vanadium pentoxide	500	Tetraethylammonium hydroxide	0.9	88
	25	Vanadium pentoxide	500	2,2'-Iminodiethanol	0.9	85
	26	Ammonium chromate	500	—	—	95
	27	Potassium chromate	500	—	—	97
	28	Sodium silicate	3000	—	—	97
	29	Vanadium acetylacetonate	3000	Ethylene diamine	1.1	91
	30	Acetylacetone vanadyl	3000	Ethylene diamine	1.3	90
	31	Vanadium oxysulfate	3000	2-Aminoethanol	10	91
	32	Vanadium pentoxide	3000	1-Amino-2-propanol	1.1	91
	33	Vanadium pentoxide	3000	Tetraethylammonium hydroxide	0.9	91
	34	Vanadium pentoxide	3000	2,2'-Iminodiethanol	0.9	93
	35	Ammonium chromate	3000	—	—	99
	36	Potassium chromate	3000	—	—	99
Comparative Example	37	Chromium nitrate	500	—	—	-67
	38	Chromium sulfate	800	—	—	-87
	39	Cobalt sulfate	1200	—	—	-125
	40	Vanadium oxysulfate	20000	—	—	-180
	41	Copper chloride	1500	—	—	-80
	42	—	—	—	—	0

[0081] 2. Evaluation of hot-dip Zn alloy-plated steel sheet

(1) Measurement of ratio of Zn(OH)_2 on surface of plating layer

The ratio of Zn(OH)_2 on the surface of plating layer was measured for each of the hot-dip Zn alloy-plated steel sheets, using an XPS analyzer (AXIS Nova, produced by
5 Kratos Group PLC.). The ratio of Zn(OH)_2 was calculated using software (Vision 2) attached to the XPS analyzer.

[0082] (2) Treatment for accelerating deterioration of gloss

A test piece was cut out from each of the produced hot-dip Zn alloy-plated steel sheets. Each of the test pieces was placed in a thermo-hygrostat (LHU-113, produced by
10 Espec Corp.), and subjected to a treatment for accelerating deterioration of the gloss at a temperature 60°C , with a relative humidity of 90%, for 40 hours.

[0083] (3) Measurement of degree of blackening

The brightness (L^* value) at the surface of the plating layer for each of the hot-dip Zn alloy-plated steel sheets was measured before and after the treatment for accelerating
15 deterioration of the gloss. The brightness (L^* value) at the surface of the plating layer was measured using a spectroscopic color difference meter (TC-1800, produced by Tokyo Denshoku Co., Ltd), by spectral reflectance measurement in accordance with JIS K 5600. The measurement conditions are as follows:

Optical condition: $d/8^\circ$ method (double beam optical system)

20 Field of view: 2-degree field of view

Measurement method: reflectometry

Standard illuminant: C

Color system: CIELAB

Measurement wavelength: 380 to 780 nm

25 Measurement wavelength interval: 5 nm

Spectroscope: 1200/mm diffraction grating

Lighting: halogen lamp (voltage: 12 V, power: 50 W, rating life: 2000 hours)

Measurement area: 7.25 mm diameter

Detection element: photomultiplier tube (R928 produced by Hamamatsu Photonics K.K.)

5 Reflectance: 0 to 150%

Measurement temperature: 23°C

Standard plate: white

[0084] For each of the plated steel sheets, the evaluation was ranked as "A" for a difference in L^* values (ΔL^*) between before and after the treatment for accelerating deterioration of the gloss of less than 0.5, "B" for a difference of 0.5 or more and less than 10 3, and "C" for a difference of 3 or more. It can be determined that a plated steel sheet evaluated as "A" has blackening resistance.

[0085] (4) Evaluation results

For each of the plated steel sheets, the relations among the type of the cooling aqueous solution for use, the temperature of the steel sheet (the surface of the plating layer) 15 immediately before cooling in water quenching zone 360, the ratio of $Zn(OH)_2$, and the evaluation results of the degree of blackening are described in Table 4 to Table 7.

[0086]

[Table 4]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Blackening test result
Comp. Ex.	1	11	1	80	72	B
Comp. Ex.	2	11	2	80	77	B
Comp. Ex.	3	11	3	80	72	B
Comp. Ex.	4	11	4	80	73	B
Comp. Ex.	5	11	5	80	74	B
Comp. Ex.	6	11	6	80	70	B
Comp. Ex.	7	11	7	80	70	B
Comp. Ex.	8	11	8	80	74	B
Comp. Ex.	9	11	9	80	70	B
Ex.	10	11	10	80	21	A
Ex.	11	11	11	80	28	A
Ex.	12	11	12	80	26	A
Ex.	13	11	13	80	30	A
Ex.	14	11	14	80	28	A
Ex.	15	11	15	80	25	A
Ex.	16	11	16	80	28	A
Ex.	17	11	17	80	16	A
Ex.	18	11	18	80	15	A
Ex.	19	11	19	80	9	A
Ex.	20	11	20	80	14	A
Ex.	21	11	21	80	16	A
Ex.	22	11	22	80	16	A
Ex.	23	11	23	80	14	A
Ex.	24	11	24	80	15	A
Ex.	25	11	25	80	13	A
Ex.	26	11	26	80	4	A
Ex.	27	11	27	80	5	A
Ex.	28	11	28	80	6	A
Ex.	29	11	29	80	5	A
Ex.	30	11	30	80	5	A
Ex.	31	11	31	80	3	A
Ex.	32	11	32	80	5	A
Ex.	33	11	33	80	4	A
Ex.	34	11	34	80	3	A
Ex.	35	11	35	80	5	A
Ex.	36	11	36	80	5	A
Comp. Ex.	37	11	37	80	94	C
Comp. Ex.	38	11	38	80	95	C
Comp. Ex.	39	11	39	80	94	C
Comp. Ex.	40	11	40	80	94	C
Comp. Ex.	41	11	41	80	94	C
Comp. Ex.	42	11	42	80	78	B

[0087]

[Table 5]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Blackening test result
Comp. Ex.	43	11	1	150	88	C
Comp. Ex.	44	11	2	150	93	C
Comp. Ex.	45	11	3	150	92	C
Comp. Ex.	46	11	4	150	91	C
Comp. Ex.	47	11	5	150	93	C
Comp. Ex.	48	11	6	150	91	C
Comp. Ex.	49	11	7	150	91	C
Comp. Ex.	50	11	8	150	91	C
Comp. Ex.	51	11	9	150	88	C
Ex.	52	11	10	150	26	A
Ex.	53	11	11	150	35	A
Ex.	54	11	12	150	31	A
Ex.	55	11	13	150	37	A
Ex.	56	11	14	150	34	A
Ex.	57	11	15	150	33	A
Ex.	58	11	16	150	37	A
Ex.	59	11	17	150	20	A
Ex.	60	11	18	150	19	A
Ex.	61	11	19	150	11	A
Ex.	62	11	20	150	18	A
Ex.	63	11	21	150	20	A
Ex.	64	11	22	150	20	A
Ex.	65	11	23	150	19	A
Ex.	66	11	24	150	19	A
Ex.	67	11	25	150	16	A
Ex.	68	11	26	150	5	A
Ex.	69	11	27	150	6	A
Ex.	70	11	28	150	7	A
Ex.	71	11	29	150	6	A
Ex.	72	11	30	150	6	A
Ex.	73	11	31	150	4	A
Ex.	74	11	32	150	6	A
Ex.	75	11	33	150	6	A
Ex.	76	11	34	150	3	A
Ex.	77	11	35	150	5	A
Ex.	78	11	36	150	6	A
Comp. Ex.	79	11	37	150	95	C
Comp. Ex.	80	11	38	150	95	C
Comp. Ex.	81	11	39	150	96	C
Comp. Ex.	82	11	40	150	97	C
Comp. Ex.	83	11	41	150	97	C
Comp. Ex.	84	11	42	150	90	C

[0088]

[Table 6]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Blackening test result
Comp. Ex.	85	11	1	300	90	C
Comp. Ex.	86	11	2	300	95	C
Comp. Ex.	87	11	3	300	93	C
Comp. Ex.	88	11	4	300	93	C
Comp. Ex.	89	11	5	300	95	C
Comp. Ex.	90	11	6	300	93	C
Comp. Ex.	91	11	7	300	93	C
Comp. Ex.	92	11	8	300	91	C
Comp. Ex.	93	11	9	300	90	C
Ex.	94	11	10	300	28	A
Ex.	95	11	11	300	35	A
Ex.	96	11	12	300	33	A
Ex.	97	11	13	300	38	A
Ex.	98	11	14	300	36	A
Ex.	99	11	15	300	34	A
Ex.	100	11	16	300	37	A
Ex.	101	11	17	300	20	A
Ex.	102	11	18	300	22	A
Ex.	103	11	19	300	13	A
Ex.	104	11	20	300	18	A
Ex.	105	11	21	300	22	A
Ex.	106	11	22	300	22	A
Ex.	107	11	23	300	22	A
Ex.	108	11	24	300	20	A
Ex.	109	11	25	300	18	A
Ex.	110	11	26	300	8	A
Ex.	111	11	27	300	9	A
Ex.	112	11	28	300	9	A
Ex.	113	11	29	300	9	A
Ex.	114	11	30	300	8	A
Ex.	115	11	31	300	7	A
Ex.	116	11	32	300	8	A
Ex.	117	11	33	300	8	A
Ex.	118	11	34	300	5	A
Ex.	119	11	35	300	8	A
Ex.	120	11	36	300	8	A
Comp. Ex.	121	11	37	300	95	C
Comp. Ex.	122	11	38	300	96	C
Comp. Ex.	123	11	39	300	96	C
Comp. Ex.	124	11	40	300	99	C
Comp. Ex.	125	11	41	300	99	C
Comp. Ex.	126	11	42	300	98	C

[0089]

[Table 7]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Blackening test result
Comp. Ex.	127	9	1	150	84	C
Comp. Ex.	128	14	2	150	95	C
Comp. Ex.	129	2	3	150	89	C
Comp. Ex.	130	10	4	150	85	C
Comp. Ex.	131	1	5	300	92	C
Comp. Ex.	132	12	6	150	90	C
Comp. Ex.	133	5	7	150	90	C
Comp. Ex.	134	8	8	300	99	C
Comp. Ex.	135	13	9	150	91	C
Ex.	136	3	10	150	28	A
Ex.	137	10	11	150	32	A
Ex.	138	4	12	300	29	A
Ex.	139	13	13	150	38	A
Ex.	140	7	14	150	34	A
Ex.	141	12	15	150	33	A
Ex.	142	9	16	300	37	A
Ex.	143	7	17	150	20	A
Ex.	144	5	18	150	20	A
Ex.	145	12	19	150	10	A
Ex.	146	9	20	300	19	A
Ex.	147	4	21	150	22	A
Ex.	148	1	22	150	21	A
Ex.	149	14	23	150	19	A
Ex.	150	3	24	300	17	A
Ex.	151	10	25	300	15	A
Ex.	152	8	26	150	5	A
Ex.	153	13	27	150	7	A
Ex.	154	10	28	300	7	A
Ex.	155	6	29	150	6	A
Ex.	156	12	30	150	6	A
Ex.	157	5	31	150	5	A
Ex.	158	9	32	300	6	A
Ex.	159	1	33	300	5	A
Ex.	160	2	34	150	3	A
Ex.	161	13	35	300	6	A
Ex.	162	6	36	150	6	A
Comp. Ex.	163	13	37	150	88	C
Comp. Ex.	164	12	38	150	91	C
Comp. Ex.	165	10	39	300	103	C
Comp. Ex.	166	9	40	150	104	C
Comp. Ex.	167	14	41	300	101	C
Comp. Ex.	168	13	42	300	90	C

[0090] As shown in Table 4 to Table 7, in the case of cooling using an aqueous solution with a reduction ratio of corrosion current density of 20% or more, a ratio of Zn(OH)_2 at the surface of a plating layer became 40% or less and blackening resistance was excellent. In contrast, in the case of cooling using an aqueous solution with a reduction ratio of corrosion current density of less than 20%, a ratio of Zn(OH)_2 at the surface of a plating layer became more than 40% and suppression of blackening was insufficient.

[0091] From the results, it is found that cooling using an aqueous solution with a reduction ratio of corrosion current density of 20% or more allows the surface of a plating layer to have a ratio of Zn(OH)_2 of 40% or less, and a plated steel sheet with a plating layer having a ratio of Zn(OH)_2 of 40% or less at the surface of the plating layer is excellent in blackening resistance.

[0092] (Experiment 2)

In Experiment 2, a plating layer was formed on a base steel sheet using each of the plating bath compositions (Nos. 1 to 14) and conditions described in Table 1, so that 14 types of hot-dip Zn alloy-plated steel sheets having different plating layer compositions were produced. In production of the hot-dip Zn alloy-plated steel sheets, each of 42 types of cooling aqueous solutions described in Table 2 and Table 3 was used for cooling in water quenching zone 360. Furthermore, each of the test pieces was subjected to a chemical conversion treatment under the following chemical conversion treatment conditions A to C. Subsequently, the test piece was subjected to the treatment for accelerating deterioration of the gloss in the same manner as in Experiment 1, for the measurement of blackening resistance.

[0093] In chemical conversion treatment conditions A, ZINCHROME 3387N (chrome concentration: 10 g/L, produced by Nihon Parkerizing Co., Ltd.) was used as chemical conversion treatment liquid. The chemical conversion treatment liquid was applied to have an amount of chromium adhering of 10 mg/m^2 by a spray ringer roll method.

- [0094] In chemical conversion treatment conditions B, an aqueous solution containing 50 g/L of magnesium phosphate, 10 g/L of potassium fluorotitanate, and 3 g/L of an organic acid was used as chemical conversion treatment liquid. The chemical conversion treatment liquid was applied to have an amount of metal components adhering of 50 mg/m² by a roll coat method.
- [0095] In chemical conversion treatment conditions C, an aqueous solution containing 20 g/L of a urethane resin, 3 g/L of ammonium dihydrogen phosphate, and 1 g/L of vanadium pentoxide was used as chemical conversion treatment liquid. The chemical conversion treatment liquid was applied to have a dried film thickness of 2 μm by a roll coat method.
- [0096] For each of the plated steel sheets, the relations among the type of the cooling aqueous solution for use, the temperature of the steel sheet (the surface of the plating layer) immediately before cooling in water quenching zone 360, the ratio of Zn(OH)₂, and the evaluation results of the degree of blackening are described in Table 8 to Table 11. Since the accurate measurement of the ratio of Zn(OH)₂ after the chemical conversion treatment is difficult, the ratio of Zn(OH)₂ is the same as the measurement value in the case of without chemical conversion treatment (the same as the values in Table 4 to Table 7).

[0097]

[Table 8]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Chemical conversion treatment	Blackening test result
Comp. Ex.	169	11	1	80	72	A	B
Comp. Ex.	170	11	2	80	77	B	B
Comp. Ex.	171	11	3	80	72	C	B
Comp. Ex.	172	11	4	80	73	A	B
Comp. Ex.	173	11	5	80	74	B	B
Comp. Ex.	174	11	6	80	70	C	B
Comp. Ex.	175	11	7	80	70	A	B
Comp. Ex.	176	11	8	80	74	B	B
Comp. Ex.	177	11	9	80	70	C	B
Ex.	178	11	10	80	21	A	A
Ex.	179	11	11	80	28	B	A
Ex.	180	11	12	80	26	C	A
Ex.	181	11	13	80	30	A	A
Ex.	182	11	14	80	28	B	A
Ex.	183	11	15	80	25	C	A
Ex.	184	11	16	80	28	A	A
Ex.	185	11	17	80	16	B	A
Ex.	186	11	18	80	15	C	A
Ex.	187	11	19	80	9	A	A
Ex.	188	11	20	80	14	B	A
Ex.	189	11	21	80	16	C	A
Ex.	190	11	22	80	16	A	A
Ex.	191	11	23	80	14	B	A
Ex.	192	11	24	80	15	C	A
Ex.	193	11	25	80	13	A	A
Ex.	194	11	26	80	4	B	A
Ex.	195	11	27	80	5	C	A
Ex.	196	11	28	80	6	A	A
Ex.	197	11	29	80	5	B	A
Ex.	198	11	30	80	5	C	A
Ex.	199	11	31	80	3	A	A
Ex.	200	11	32	80	5	B	A
Ex.	201	11	33	80	4	C	A
Ex.	202	11	34	80	3	A	A
Ex.	203	11	35	80	5	B	A
Ex.	204	11	36	80	5	C	A
Comp. Ex.	205	11	37	80	94	A	C
Comp. Ex.	206	11	38	80	95	B	C
Comp. Ex.	207	11	39	80	94	C	C
Comp. Ex.	208	11	40	80	94	A	C
Comp. Ex.	209	11	41	80	94	B	C
Comp. Ex.	210	11	42	80	78	B	B

[0098]

[Table 9]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Chemical conversion treatment	Blackening test result
Comp. Ex.	211	11	1	150	88	A	C
Comp. Ex.	212	11	2	150	93	B	C
Comp. Ex.	213	11	3	150	92	C	C
Comp. Ex.	214	11	4	150	91	A	C
Comp. Ex.	215	11	5	150	93	B	C
Comp. Ex.	216	11	6	150	91	C	C
Comp. Ex.	217	11	7	150	91	A	C
Comp. Ex.	218	11	8	150	91	B	C
Comp. Ex.	219	11	9	150	88	C	C
Ex.	220	11	10	150	26	A	A
Ex.	221	11	11	150	35	B	A
Ex.	222	11	12	150	31	C	A
Ex.	223	11	13	150	37	A	A
Ex.	224	11	14	150	34	B	A
Ex.	225	11	15	150	33	C	A
Ex.	226	11	16	150	37	A	A
Ex.	227	11	17	150	20	B	A
Ex.	228	11	18	150	19	C	A
Ex.	229	11	19	150	11	A	A
Ex.	230	11	20	150	18	B	A
Ex.	231	11	21	150	20	C	A
Ex.	232	11	22	150	20	A	A
Ex.	233	11	23	150	19	B	A
Ex.	234	11	24	150	19	C	A
Ex.	235	11	25	150	16	A	A
Ex.	236	11	26	150	5	B	A
Ex.	237	11	27	150	6	C	A
Ex.	238	11	28	150	7	A	A
Ex.	239	11	29	150	6	B	A
Ex.	240	11	30	150	6	C	A
Ex.	241	11	31	150	4	A	A
Ex.	242	11	32	150	6	B	A
Ex.	243	11	33	150	6	C	A
Ex.	244	11	34	150	3	A	A
Ex.	245	11	35	150	5	B	A
Ex.	246	11	36	150	6	C	A
Comp. Ex.	247	11	37	150	95	A	C
Comp. Ex.	248	11	38	150	95	B	C
Comp. Ex.	249	11	39	150	96	C	C
Comp. Ex.	250	11	40	150	97	A	C
Comp. Ex.	251	11	41	150	97	B	C
Comp. Ex.	252	11	42	150	90	B	C

[0099]

[Table 10]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Chemical conversion treatment	Blackening test result
Comp. Ex.	253	11	1	300	90	A	C
Comp. Ex.	254	11	2	300	95	B	C
Comp. Ex.	255	11	3	300	93	C	C
Comp. Ex.	256	11	4	300	93	A	C
Comp. Ex.	257	11	5	300	95	B	C
Comp. Ex.	258	11	6	300	93	C	C
Comp. Ex.	259	11	7	300	93	A	C
Comp. Ex.	260	11	8	300	91	B	C
Comp. Ex.	261	11	9	300	90	C	C
Ex.	262	11	10	300	28	A	A
Ex.	263	11	11	300	35	B	A
Ex.	264	11	12	300	33	C	A
Ex.	265	11	13	300	38	A	A
Ex.	266	11	14	300	36	B	A
Ex.	267	11	15	300	34	C	A
Ex.	268	11	16	300	37	A	A
Ex.	269	11	17	300	20	B	A
Ex.	270	11	18	300	22	C	A
Ex.	271	11	19	300	13	A	A
Ex.	272	11	20	300	18	B	A
Ex.	273	11	21	300	22	C	A
Ex.	274	11	22	300	22	A	A
Ex.	275	11	23	300	22	B	A
Ex.	276	11	24	300	20	C	A
Ex.	277	11	25	300	18	A	A
Ex.	278	11	26	300	8	B	A
Ex.	279	11	27	300	9	C	A
Ex.	280	11	28	300	9	A	A
Ex.	281	11	29	300	9	B	A
Ex.	282	11	30	300	8	C	A
Ex.	283	11	31	300	7	A	A
Ex.	284	11	32	300	8	B	A
Ex.	285	11	33	300	8	C	A
Ex.	286	11	34	300	5	A	A
Ex.	287	11	35	300	8	B	A
Ex.	288	11	36	300	8	C	A
Comp. Ex.	289	11	37	300	95	A	C
Comp. Ex.	290	11	38	300	96	B	C
Comp. Ex.	291	11	39	300	96	C	C
Comp. Ex.	292	11	40	300	99	A	C
Comp. Ex.	293	11	41	300	99	B	C
Comp. Ex.	294	11	42	300	98	B	C

[0100]

[Table 11]

Category	Test piece No.	Plating No.	Cooling water No.	Sheet temperature before water cooling (°C)	Ratio of Zn(OH) ₂	Chemical conversion treatment	Blackening test result
Comp. Ex.	295	9	1	150	84	A	C
Comp. Ex.	296	14	2	150	95	B	C
Comp. Ex.	297	2	3	150	89	C	C
Comp. Ex.	298	10	4	150	85	A	C
Comp. Ex.	299	1	5	300	92	B	C
Comp. Ex.	300	12	6	150	90	C	C
Comp. Ex.	301	5	7	150	90	A	C
Comp. Ex.	302	8	8	300	99	B	C
Comp. Ex.	303	13	9	150	91	C	C
Ex.	304	3	10	150	28	A	A
Ex.	305	10	11	150	32	B	A
Ex.	306	4	12	300	29	C	A
Ex.	307	13	13	150	38	A	A
Ex.	308	7	14	150	34	B	A
Ex.	309	12	15	150	33	C	A
Ex.	310	9	16	300	37	A	A
Ex.	311	7	17	150	20	B	A
Ex.	312	5	18	150	20	C	A
Ex.	313	12	19	150	10	A	A
Ex.	314	9	20	300	19	B	A
Ex.	315	4	21	150	22	C	A
Ex.	316	1	22	150	21	A	A
Ex.	317	14	23	150	19	B	A
Ex.	318	3	24	300	17	C	A
Ex.	319	10	25	300	15	A	A
Ex.	320	8	26	150	5	B	A
Ex.	321	13	27	150	7	C	A
Ex.	322	10	28	300	7	A	A
Ex.	323	6	29	150	6	B	A
Ex.	324	12	30	150	6	C	A
Ex.	325	5	31	150	5	A	A
Ex.	326	9	32	300	6	B	A
Ex.	327	1	33	300	5	C	A
Ex.	328	2	34	150	3	A	A
Ex.	329	13	35	300	6	B	A
Ex.	330	6	36	150	6	C	A
Comp. Ex.	331	13	37	150	88	A	C
Comp. Ex.	332	12	38	150	91	B	C
Comp. Ex.	333	10	39	300	103	C	C
Comp. Ex.	334	9	40	150	104	A	C
Comp. Ex.	335	14	41	300	101	B	C
Comp. Ex.	336	13	42	300	90	C	C

[0101] As shown in Table 8 to Table 11, in the case of cooling using an aqueous solution with a reduction ratio of corrosion current density of 20% or more, excellent blackening resistance was obtained even with the chemical conversion treatment. In contrast, in the case of cooling using an aqueous solution with a reduction ratio of corrosion current
5 density of less than 20%, the suppression of blackening was insufficient even with the chemical conversion treatment.

[0102] From the results, it is found that cooling using an aqueous solution with a reduction ratio of corrosion current density of 20% or more can sufficiently suppress blackening regardless of the type of chemical conversion treatment.

10 [0103] This application claims priority based on Japanese patent Application No. 2013-250143, filed on December 3, 2013, the entire contents of which including the specification and the drawings are incorporated herein by reference.

Industrial Applicability

15 [0104] The hot-dip Zn alloy-plated steel sheet obtained by the production method of the present invention is excellent in blackening resistance, and useful as plated steel sheet for use in, for example, roof materials and exterior materials for buildings, home appliances, and automobiles.

Reference Signs List

20 [0105]
100, 200 Cooling apparatus
110 Spray nozzle
120, 230 Squeeze roll
130 Housing
25 210 Dip tank
220 Dip roller

- 300 Production line
- 310 Furnace
- 320 Plating bath
- 330 Wiping nozzle
- 5 340 Air jet cooler
- 350 Mist cooling zone
- 360 Water quenching zone
- 370 Skin pass mill
- 380 Tension leveler
- 10 390 Tension reel
- 400 Roll coater
- 410 Drying zone
- 420 Air cooling zone
- S: Steel strip

CLAIMS

1. A hot-dip Zn alloy-plated steel sheet comprising:

a steel sheet; and

a hot-dip Zn alloy plating layer disposed on a surface of the steel sheet,

5 wherein the hot-dip Zn alloy plating layer satisfies, at a whole of a surface of the hot-dip Zn alloy plating layer, following Equation 1:

$$\frac{S[Zn(OH)_2]}{S[Zn(OH)_2] + S[Zn]} \times 100 \leq 40 \quad (\text{Equation 1})$$

S[Zn] is a peak area derived from metal Zn and centered at approximately 1022 eV in an intensity profile of XPS analysis of the surface of the hot-dip Zn alloy plating layer; and S[Zn(OH)₂] is a peak area derived from Zn(OH)₂ and centered at approximately 1023 eV in the intensity profile of XPS analysis of the surface of the hot-dip Zn alloy plating layer.

2. The hot-dip Zn alloy-plated steel sheet according to claim 1, wherein:

15 the hot-dip Zn alloy plating layer comprises 1.0 to 22.0% by mass of Al, 0.1 to 10.0% by mass of Mg, and the balance of the hot-dip Zn alloy plating layer being Zn and unavoidable impurities.

3. The hot-dip Zn alloy-plated steel sheet according to claim 2, wherein:

20 the hot-dip Zn alloy plating layer further comprises at least one selected from the group consisting of 0.001 to 2.0% by mass of Si, 0.001 to 0.1% by mass of Ti, and 0.001 to 0.045% by mass of B.

4. A method of producing a hot-dip Zn alloy-plated steel sheet comprising:

25 dipping a base steel sheet in a hot-dip Zn alloy plating bath to form a hot-dip Zn

alloy plating layer on a surface of the base steel sheet; and

contacting an aqueous solution containing a water-soluble corrosion inhibitor with a surface of the hot-dip Zn alloy plating layer to cool the base steel sheet and the hot-dip Zn alloy plating layer having a raised temperature through formation of the hot-dip Zn alloy plating layer,

wherein a temperature of the surface of the hot-dip Zn alloy plating layer when the aqueous solution is to be contacted with the surface of the hot-dip Zn alloy plating layer is equal to or more than 100°C and equal to or less than a solidifying point of the plating layer; and

wherein the aqueous solution containing the water-soluble corrosion inhibitor satisfies following Equation 2:

$$\frac{Z_0 - Z_1}{Z_0} \times 100 \geq 20 \quad (\text{Equation 2})$$

Z_0 is a corrosion current density of the hot-dip Zn alloy-plated steel sheet measured in a 0.5 M NaCl aqueous solution not containing the water-soluble corrosion inhibitor, and

Z_1 is a corrosion current density of the hot-dip Zn alloy-plated steel sheet measured in the aqueous solution containing the water-soluble corrosion inhibitor, in which NaCl is further dissolved so that a final concentration of NaCl is 0.5 M.