

DESCRIPTION

TITLE

5 HOT-DIP AL-ZN-SI-MG COATED STEEL SHEET, SURFACE-TREATED
STEEL SHEET, AND PREPAINTED STEEL SHEET

TECHNICAL FIELD

10 **[0001]** The present disclosure relates to a hot-dip Al-Zn-Si-Mg coated steel sheet, a surface-treated steel sheet, and a prepainted steel sheet that have excellent surface appearance.

BACKGROUND

15 **[0002]** Hot-dip Al-Zn coated steel sheets, as typified by 55 % Al-Zn coated steel sheets, for example as described in Patent Literature (PTL) 1, combine the sacrificial protection properties of Zn and the high corrosion resistance of Al, and are therefore known to exhibit high corrosion resistance compared to various coated steel sheets. Further, because of their excellent corrosion resistance, hot-dip Al-Zn coated steel sheets are used mainly in the field of building materials, as roofs, walls, and the like that are exposed to outdoor environments for long periods of time, and in the field of civil engineering and construction, as guardrails, wiring and piping, soundproof walls, and the like.

20 Demand for hot-dip Al-Zn coated steel sheets has been increasing in recent years, in particular due to the demand for materials having superior corrosion resistance and maintenance-free materials under more severe operating environments, such as exposure to acid rain caused by air pollution, exposure to snow-melting agents applied to prevent roads from freezing in snowy regions, and in coastal area development.

25 **[0003]** The coating of a hot-dip Al-Zn coated steel sheet is composed of a dendrite-like solidified portion of Al supersaturated with Zn (α -Al phase) and a Zn-Al eutectic structure existing in dendrite gaps (interdendrites), and is characterized by a multi-layered structure of α -Al phase stacked in the thickness direction of the coating. It is also known that such characteristic coating structure makes the corrosion path from surfaces complicated and makes corrosion less likely to propagate, with the result that a hot-dip Al-Zn coated steel sheet has better corrosion resistance than a hot-dip galvanized steel sheet that has the same coating thickness.

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[0004] Attempts are being made to further extend the service life of such hot-dip Al-Zn coated steel sheets, and hot-dip Al-Zn-Si-Mg coated steel sheets with Mg added are known.

As such a hot-dip Al-Zn-Si-Mg coated steel sheet, for example, PTL 1
5 describes a hot-dip Al-Zn-Si-Mg coated steel sheet having a coating containing an Al-Zn-Si alloy and including Mg, in which the Al-Zn-Si alloy contains 45 wt% to 60 wt% elemental aluminum, 37wt% to 46 wt% elemental zinc, and 1.2 wt% to 2.3 wt% Si, and a concentration of the Mg is 1 wt% to 5 wt%.

Further, PTL 2 describes a hot-dip Al-Zn-Si-Mg coated steel sheet
10 having a coating containing at least one of 2 mass% to 10 mass% Mg or 0.01 mass% to 10 mass% Ca to improve corrosion resistance and to enhance a protective action after exposure of a base steel sheet.

Further, PTL 3 describes a hot-dip Al-Zn-Si-Mg coated steel sheet with improved corrosion resistance on flat and edge surfaces, in which a coating
15 layer is formed by forming a layer containing, in mass%, Mg: 1 % to 15 %, Si: 2 % to 15 %, and Zn: 11 % to 25 %, with the balance being Al and inevitable impurity, with intermetallic compounds such as Mg_2Si and $MgZn_2$ phases present in the coating being controlled to a size of 10 μm or less.

[0005] However, hot-dip Al-Zn-Si-Mg coated steel sheets have a problem in
20 that surface appearance is significantly degraded due to the occurrence of wrinkle-like irregularity defects, which are described later. When Mg is added to a hot-dip Al-Zn-Si bath and a steel sheet is coated, Mg is an element that oxidizes more easily than the other coating constituent elements. Therefore, during a cooling and solidification process of the coating, Mg reacts with
25 oxygen in the outermost layer that comes into contact with air, producing Mg oxides. As a result, Mg concentration in the vicinity of the outermost layer decreases, and to compensate for this, Mg gradually diffuses from the interior of the coating to the outermost layer. As a result, a thick layer of Mg oxides forms in the outermost layer before the coating completely solidifies to its
30 interior. This creates a difference in flowability between the interior of the coating, which is prone to flow before solidification, and the Mg oxide layer, and the Mg oxide layer is unable to keep up with the flow inside the coating, resulting in the formation of wrinkle-like irregularity defects (wrinkle defects) on the coating surface of the hot-dip Al-Zn-Si-Mg coated steel sheet that is
35 produced.

Therefore, there has been a demand for the development of technology

for improvements related to wrinkle defects in hot-dip Al-Zn-Si-Mg coated steel sheets.

[0006] PTL 4 and 5 describe a technology in which Sr is contained in a coating to suppress oxidation of Mg in the coating surface layer and thereby suppress occurrence of wrinkle defects. These technologies utilize the phenomenon that Sr is oxidized preferentially over Mg in the surface layer of an unsolidified coating that comes out of the coating bath.

[0007] Further, the above-mentioned hot-dip Al-Zn-Si-Mg coated steel sheets have a problem that white rust occurs due to corrosion of the coating when used in a severe corrosion environment. Since this white rust causes deterioration in the appearance of steel sheets, coated steel sheets having an improved anti-white rust property are being developed.

PTL 6 and 7 describe surface-treated steel sheets that have an improved anti-white rust property by formation of a chemical conversion layer containing urethane resin on the coating of a hot-dip Al-Zn-Si-Mg coated steel sheet.

However, even in the case of surface-treated steel sheets such as those described in PTL 6 and 7, the steel sheets are affected by the underlying hot-dip Al-Zn-Si-Mg coated steel sheet, and therefore there is still a need for improvements related to surface appearance degradation caused by the occurrence of the wrinkle defects described above.

[0008] Further, the above-mentioned hot-dip Al-Zn-Si-Mg coated steel sheets may be used as prepainted steel sheets by forming a chemical conversion layer or a primer paint layer on the surface and then forming various paint layers thereon.

Such prepainted steel sheets are subjected to various forms of working, including 90-degree or 180-degree bending, by press forming, roll forming, or embossing, and are required to have paint layer durability over a long period of use. To meet these requirements, it has been common to apply a chromate-containing chemical conversion treatment to hot-dip Al-Zn coated steel sheets, incorporate a chromate-based rust-preventive pigment into the primer paint layer, and then coat the primer with a thermosetting polyester resin coating or, for higher weather resistance, a fluororesin coating as a top coating.

However, in recent years, the use of chromate, an environmentally hazardous substance, in such prepainted steel sheets has come to be seen as a problem, and there has been a strong demand for chromate-free prepainted steel sheets that do not contain chromate. For example, a chromate-free prepainted

steel sheet has been proposed, as described in PTL 8.

CITATION LIST

- [0009]** PTL 1: JP 5020228 B2
5 PTL 2: JP 5000039 B2
PTL 3: JP 2002-012959 A
PTL 4: JP 2000-328214 A
PTL 5: WO 2020/179147 A1
PTL 6: JP 2019-155872 A
10 PTL 7: JP 2021-181214 A
PTL 8: JP 2005-169765 A

SUMMARY

(Technical Problem)

- 15 **[0010]** With the technologies described in any of the Patent Literature, it was difficult to suppress the occurrence of the wrinkle defects described above without degrading other physical properties.

The technologies described in PTL 4 and 5 have a problem in that, during the production of a hot-dip Al-Zn-Si-Mg coated steel sheet in which Sr is added to the coating, the surface of the coating bath to which Sr is added is easily oxidized, and the resulting oxide dross adheres to the coating, causing new dross defects and degrading the surface appearance.

- 20 **[0011]** Further, although the technologies of PTL 6 and 7 can improve anti-white rust property, even surface-treated steel sheets are affected by the underlying hot-dip Al-Zn-Si-Mg coated steel sheet, and improvements related to surface appearance degradation caused by the occurrence of wrinkle defects are still desired.

Further, with regard to the technology of PTL 8, the surface appearance of a coated steel sheet, particularly image clarity, is obviously affected by the surface shape of the coated steel sheet that serves as the base, and a height difference of unevenness caused by the occurrence of the wrinkle defects and dross defects described above can reach some tens of μm . Therefore, even when the surface is smoothed by a paint layer, the unevenness cannot be completely eliminated, and improvement of the surface appearance of a prepainted steel sheet remains a problem. In addition, the paint layer formed on a convex portion of the coating has a thin film thickness, which raises concerns about

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localized reductions in corrosion resistance. Therefore, there has been a demand for improving the surface appearance, particularly the surface shape, of the underlying coated steel sheet.

[0012] In view of the above circumstances, it would be helpful to provide a
5 hot-dip Al-Zn-Si-Mg coated steel sheet that is free from other defects such as dross defects, suppresses occurrence of wrinkle defects, and has an excellent surface appearance.

Further, it would be helpful to provide a surface-treated steel sheet having excellent surface appearance and anti-white rust property, and a
10 prepainted steel sheet having excellent surface appearance and excellent corrosion resistance.

(Solution to Problem)

[0013] As a result of investigations aimed at solving the above-mentioned problems, the inventors noticed that adding Mn to the coating of a hot-dip Al-
15 Zn-Si-Mg coated steel sheet can suppress wrinkle defects without causing dross defects and the like, and have found that the occurrence of wrinkle defects can be suppressed by adjusting the amount of Mn added and limiting a height difference on the steel sheet surface (coating surface).

[0014] The present disclosure was completed based on these findings, and
20 primary features of the present disclosure are as described below.

1. A hot-dip Al-Zn-Si-Mg coated steel sheet comprising a coating, wherein

the coating has a composition containing (consisting of) Al: 45 mass% to 65 mass%, Si: 1.0 mass% to 3.0 mass%, Mg: 1.0 mass% to 10.0 mass%, and
25 Mn: 0.01 mass% to 0.5 mass%, with the balance being Zn and inevitable impurity, and

a height difference of a steel sheet surface per mm of length is 10 μ m or less in an area excluding 50 mm from both ends of the steel sheet.

2. The hot-dip Al-Zn-Si-Mg coated steel sheet according to 1, above,
30 wherein Mn content in the coating is 0.1 mass% to 0.3 mass%.

3. The hot-dip Al-Zn-Si-Mg coated steel sheet according to 1 or 2, above, further comprising an alloy layer containing Mn at an interface between the coating and a base steel sheet.

4. The hot-dip Al-Zn-Si-Mg coated steel sheet according to any one of
35 1 to 3, above, wherein the coating further contains one or more elements selected from B, Ca, Ti, V, Cr, Sr, Mo, In, Sn, Sb, Ce, or Bi in a total amount

of 0.01 mass% to 3.0 mass%.

5. A surface-treated steel sheet comprising the coating according to any one of 1 to 4, above, and a chemical conversion layer formed on the coating, wherein

5 the chemical conversion layer contains at least one resin selected from an epoxy resin, a urethane resin, an acrylic resin, an acrylic silicon resin, an alkyd resin, a polyester resin, a polyalkylene resin, an amino resin, or a fluororesin, and at least one metal compound selected from a P compound, a Si compound, a Co compound, a Ni compound, a Zn compound, an Al compound,
10 a Mg compound, a V compound, a Mo compound, a Zr compound, a Ti compound, or a Ca compound.

6. A prepainted steel sheet comprising a paint layer formed either directly on the coating according to any one of 1 to 4, above, or on a chemical conversion layer on top of the coating, wherein

15 the chemical conversion layer contains: a resin component containing (a) an anionic polyurethane resin having an ester bond and (b) an epoxy resin having a bisphenol skeleton, in a total amount of 30 mass% to 50 mass%, in which a content ratio of (a) to (b), (a):(b), is in a range from 3:97 to 60:40 by mass; and an inorganic compound containing 2 mass% to 10 mass% of a
20 vanadium compound, 40 mass% to 60 mass% of a zirconium compound, and 0.5 mass% to 5 mass% of a fluorine compound, and

 the paint layer includes at least a primer paint layer, the primer paint layer containing: a polyester resin having a urethane bond; and an inorganic compound containing a vanadium compound, a phosphoric acid compound, and
25 a magnesium oxide.

(Advantageous Effect)

[0015] According to the present disclosure, it is possible to provide a hot-dip Al-Zn-Si-Mg coated steel sheet that is free from other defects such as dross defects, suppresses the occurrence of wrinkle defects, and has an excellent
30 surface appearance.

 Further, according to the present disclosure, it is possible to provide a surface-treated steel sheet having excellent surface appearance and anti-white rust property, and a prepainted steel sheet having excellent surface appearance and excellent corrosion resistance.

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DETAILED DESCRIPTION

[0016] <Hot-dip Al-Zn-Si-Mg coated steel sheet>

The hot-dip Al-Zn-Si-Mg coated steel sheet comprises a coating on the steel sheet surface.

The coating has a composition containing Al: 45 mass% to 65 mass%,
5 Si: 1.0 mass% to 3.0 mass%, Mg: 1.0 mass% to 10.0 mass%, and Mn: 0.01 mass% to 0.5 mass%, with the balance being Zn and inevitable impurity.

[0017] From the viewpoint of balancing corrosion resistance with actual operation requirements, Al content in the coating is 45 mass% to 65 mass%. Al content in the coating is preferably 50 mass% to 60 mass%.

10 This is because when the Al content in the coating is at least 45 mass%, dendrite solidification of Al occurs and a coating structure mainly composed of α -Al phase dendrite solidification microstructure can be obtained. Such dendrite solidification microstructure stacked in the thickness direction of the coating makes the corrosion path complex and improves corrosion resistance
15 of the coating itself. Further, the more dendrite portions of α -Al phase are stacked, the more complex the corrosion path becomes, and the harder it is for corrosion to reach the base steel sheet, resulting in improved corrosion resistance. Therefore, the Al content is preferably 50 mass% or more. On the other hand, when the Al content in the coating exceeds 65 mass%, the
20 microstructure changes to one in which most Zn is a solid solute in α -Al, a dissolution reaction of the α -Al phase cannot be suppressed, which may result in the corrosion resistance of the hot-dip Al-Zn-Si-Mg coated steel sheet degrading. For this reason, the Al content in the coating is 65 mass% or less. The Al content in the coating is preferably 60 mass% or less.

25 **[0018]** Si in the coating is mainly added to inhibit the growth of Fe-Al and/or Fe-Al-Si interfacial alloy layer that forms at the interface with the base steel sheet and to prevent degradation of adhesion between the coating and the steel sheet. In practice, when a steel sheet is dipped in an Al-Zn coating bath containing Si, Fe on the steel sheet surface reacts with Al and Si in the bath to
30 form an alloy, and an Fe-Al and/or Fe-Al-Si intermetallic compound layer forms at the interface between the base steel sheet and the coating. At this point, the Fe-Al-Si alloy grows more slowly than the Fe-Al alloy, and therefore the higher the proportion of Fe-Al-Si alloy, the more the overall growth of the interfacial alloy layer is suppressed.

35 Si content in the coating is therefore 1.0 mass% or more. On the other hand, when the Si content in the coating exceeds 4.0 mass%, not only does the

effect of inhibiting the growth of the interfacial alloy layer become saturated, but corrosion is also accelerated due to the presence of excess Si phase in the coating. The Si content in the coating is therefore 4.0 mass% or less. In addition, from the viewpoint of suppressing the presence of excess Si phase, the Si content in the coating is preferably 3.0 mass% or less.

[0019] The coating contains 1.0 mass% to 10.0 mass% of Mg. The presence of Mg in the coating allows the above-mentioned Si to exist in the form of an intermetallic compound of Mg_2Si phase, thereby suppressing promotion of corrosion.

Further, when Mg is contained in the coating, an intermetallic compound, MgZn_2 phase, is also formed in the coating, which has the effect of further improving corrosion resistance. When the Mg content in the coating is less than 1.0 mass%, sufficient corrosion resistance cannot be ensured because Mg is used for solid dissolution in α -Al phase, which is the main phase, rather than for formation of intermetallic compounds (Mg_2Si , MgZn_2). On the other hand, when the Mg content in the coating increases, the effect of improving corrosion resistance is saturated, and workability decreases due to the weakening of α -Al phase. Therefore, the Mg content is 10.0 mass% or less.

Further, from the viewpoint of suppressing dross production during coating formation and facilitating coating bath control, the Mg content in the coating is preferably 5.0 mass% or less.

[0020] Further, in the hot-dip Al-Zn-Si-Mg steel sheet, the coating contains 0.01 mass% to 0.5 mass% of Mn. When the coating contains 0.01 mass% or more of Mn, acicular and/or blocky Mn-Fe interfacial alloy layer is formed between the coating and the steel substrate, and the alloy layer has an anchoring effect that suppresses movement of the coating solution until the coating is completely solidified, thereby suppressing the occurrence of wrinkle defects caused by Mg oxides formed on the surface of the coating.

On the other hand, when the Mn content in the coating exceeds 0.5 mass%, the melting point of the coating bath increases, forcing the coating treatment to be carried out at a high bath temperature, which causes abnormal growth of an interfacial alloy layer formed between the coating and the steel substrate, degrading workability, increasing the amount of dross produced, and degrading the coating appearance, particularly surface shape. When the Mn content in the coating is 0.5 mass% or less, the amount of dross produced in the coating bath is equivalent to when no Mn is added, and therefore the

occurrence of dross defects can be suppressed, making it possible to stably obtain an excellent surface appearance.

Therefore, the Mn content in the coating is 0.01 mass% to 0.5 mass%. From the same viewpoint, the Mn content in the coating is preferably 0.1 mass% to 0.3 mass%.

[0021] Here, from the viewpoint of a balance between the effects of improving corrosion resistance, suppressing wrinkle defects, and suppressing dross defects, it is preferable that the ratio of the Mn content to the Mg content in the coating (Mn/Mg) be 0.02 or more ($\text{Mn/Mg} \geq 0.02$) in mass ratio. From the same viewpoint, the ratio of the Mn content to the Mg content (Mn/Mg) is more preferably 0.03 or more ($\text{Mn/Mg} \geq 0.03$).

[0022] Further, the coating contains Zn and inevitable impurity in addition to the Al, Si, Mg, and Mn.

Among these, the inevitable impurity includes Fe. Fe is inevitably contained in the coating as a result of inevitable liquation of the steel sheet or bath apparatus into the coating bath and Fe supply by diffusion from the base steel sheet during the formation of the interfacial alloy layer. Fe content in the coating is normally around 0.3 mass% to 2.0 mass%. Other inevitable impurity includes, for example, Ni and Cu.

The total content of the inevitable impurity is not particularly limited, yet is preferably 5.0 mass% or less in total, since excessive content may affect various properties of the coated steel sheet.

[0023] Further, the coating preferably contains, as required, one or more elements selected from B, Ca, Ti, V, Cr, Sr, Mo, In, Sn, Sb, Ce, or Bi in a total amount of 0.1 mass% to 3 mass%. These elements can obtain an effect of improving the stability of corrosion products when the coating corrodes, thereby delaying the progress of corrosion, and an effect of stabilizing spangle size on the coating surface, thereby improving the surface appearance.

[0024] The chemical composition of the coating can be confirmed, for example, by immersing the coating in hydrochloric acid or the like to dissolve the coating, and then analyzing the solution by ICP atomic emission spectroscopy, atomic absorption spectroscopy, or the like. These methods are only examples and by no means a limitation of the disclosure. Any method that can accurately quantify the chemical composition of the coating may be used.

Further, the composition of the coating of the hot-dip Al-Zn-Si-Mg coated steel sheet obtained according to the present disclosure is, as a whole,

almost equivalent to the composition of the coating bath. Therefore, the composition of the coating can be precisely controlled by controlling the coating bath composition.

[0025] The hot-dip Al-Zn-Si-Mg coated steel sheet of the present disclosure is characterized in that the height difference of the coating surface per mm of length is 10 μm or less in an area excluding 50 mm from both ends of the steel sheet surface. When the height difference of the steel sheet surface, that is, the coating surface, is 10 μm or less, wrinkle defects are absent and an excellent surface appearance is obtainable.

As described above, the wrinkle defects are defects resulting from Mg oxides that cause the surface of the coating to have wrinkled irregularities, and appear as white streaks on the coating surface. Therefore, suppression of wrinkle defects means that the streaks are not visible. Therefore, by limiting the height difference in a 1 mm length range on the steel sheet surface to 10 μm or less, it is possible to obtain an excellent surface appearance without visually recognizable streaks. From the same viewpoint, the height difference in a 1 mm length of the steel sheet surface is preferably 5 μm or less.

The steel sheet surface refers to the outermost surface of the steel sheet, and in the case of a hot-dip Al-Zn-Si-Mg coated steel sheet, refers to the coating surface.

[0026] Here, the height difference of the steel sheet surface refers to the difference in height between the highest point and the lowest point on the steel sheet (on the coating), when the height is defined as the direction perpendicular to the surface of the base steel sheet (direction of the coating thickness).

Further, the height difference in a 1 mm length range on the steel sheet surface can be obtained, for example, by using a laser microscope to measure height differences in a 1 mm length range at any 100 locations on the hot-dip Al-Zn-Si-Mg coated steel sheet on which the coating has been formed, and then calculating an average of the measured values.

[0027] Further, a reason for controlling the height difference on the steel sheet surface in the range excluding 50 mm from both ends of the steel sheet surface is that it is typically difficult to control the coating weight at both ends of a hot-dip coated steel sheet compared to the center of the steel sheet, and the cooling rate is also different, and therefore wrinkle defects are more likely to occur. In addition, both ends of such steel sheets are often trimmed before use, and the surface appearance is of little concern.

[0028] The method of controlling the height difference on the steel sheet surface per mm of length of the coating to 10 μm or less is not particularly limited, other than the Mn content (0.01 mass% to 0.5 mass%) in the coating as described above. For example, the height difference on the coating surface
5 can be decreased by adjusting the content ratio of Mg and Mn in the coating or by carrying out other surface treatment to decrease the height difference.

[0029] In the hot-dip Al-Zn-Si-Mg coated steel sheet of the present disclosure, it is preferable that an alloy layer containing Mn is formed at the interface between the coating and the steel substrate. The alloy layer is formed by an
10 alloying reaction between Mn and Al, Fe, Si, and the like in the bath, and is mainly an Fe-Al-Mn or Fe-Al-Si-Mn intermetallic compound. The alloy layer has an uneven shape in the direction of the coating surface, and can therefore improve the adhesion between the coating and the base steel sheet by providing an anchoring effect.

15 Further, the anchoring effect of the Mn-containing alloy layer is exerted when the coating solidifies, and the Mn-containing interfacial alloy layer acts to minimize the movement of the coating solution, thereby also achieving the effect of suppressing the occurrence of wrinkle defects.

[0030] Further, in the hot-dip Al-Zn-Si-Mg coated steel sheet according to the
20 present disclosure, in order to impart excellent corrosion resistance, it is preferable that the diffraction intensities of Si and Mg_2Si in the coating, as measured by X-ray diffraction, satisfy the following relationship (1):

$$\text{Si}(111)/\text{Mg}_2\text{Si}(111) \leq 0.8 \quad \dots(1)$$

Here, Si(111) represents a diffraction intensity of a (111) plane of Si
25 with interplanar spacing d of 0.3135 nm, and $\text{Mg}_2\text{Si}(111)$ represents a diffraction intensity of a (111) plane of Mg_2Si with interplanar spacing d of 0.3668 nm.

As mentioned above, according to the present disclosure, the proportions of Mg_2Si and Si phases, formed in the coating by the inclusion of
30 Mg and Si, are preferably controlled to a specific ratio. Although the effects of these factors on corrosion resistance are still under investigation and unclear, the following mechanisms can be inferred.

When a hot-dip Al-Zn-Si-Mg coating is exposed to a corrosion environment, the intermetallic compounds dissolve preferentially over $\alpha\text{-Al}$
35 phase, resulting in a Mg-rich environment near the corrosion products formed. It is presumed that in such a Mg-rich environment, the corrosion products

formed are less likely to be decomposed, and as a result, the protective action effect of the coating is enhanced. Further, this effect of improving the protective action effect of the coating is more surely expressed when Si in the coating exists as Mg_2Si phase rather than Si phase, and therefore it is
5 considered effective to decrease the proportion of the Si phase relative to the Mg_2Si phase.

[0031] The proportions of Mg_2Si and Si in the coating preferably satisfy the relation (1) of $\text{Si}(111)/\text{Mg}_2\text{Si}(111) \leq 0.8$, using the diffraction peak intensities obtained by an X-ray diffraction method. However, when the proportions of
10 Mg_2Si and Si in the coating do not satisfy the relation (1), that is when $\text{Si}(111)/\text{Mg}_2\text{Si}(111) > 0.8$, the amount of Si phase present in the coating will increase, and the Mg-rich environment cannot be obtained in the vicinity of the corrosion products, making it difficult to obtain the effect of improving the protective action of the coating. From the same perspective, the ratio of Si to
15 Mg_2Si , $\text{Si}(111)/\text{Mg}_2\text{Si}(111)$, is preferably 0.5 or less. The ratio of Si to Mg_2Si is more preferably 0.3 or less. The ratio of Si to Mg_2Si is particularly preferably 0.2 or less.

In the relation (1), $\text{Si}(111)$ represents a diffraction intensity of the (111) plane of Si with interplanar spacing d of 0.3135 nm and $\text{Mg}_2\text{Si}(111)$ represents
20 a diffraction intensity of the (111) plane of Mg_2Si with interplanar spacing d of 0.3668 nm.

[0032] The method of measuring $\text{Si}(111)$ and $\text{Mg}_2\text{Si}(111)$ by X-ray diffraction may include mechanically scraping off a part of the coating and carrying out X-ray diffraction on the scraped off part in powder form (that is, powder X-ray
25 diffraction measurement). For the measurement of diffraction intensities, the diffraction peak intensity of Si corresponding to interplanar spacing d of 0.3135 nm and the diffraction peak intensity of Mg_2Si corresponding to interplanar spacing d of 0.3668 nm can be measured and the ratio of these can be calculated to obtain $\text{Si}(111)/\text{Mg}_2\text{Si}(111)$.

30 The amount of the coating required for powder X-ray diffraction measurement (that is, the amount of the coating to be scraped off) may be at least 0.1 g, preferably at least 0.3 g, from the viewpoint of measuring $\text{Si}(111)$ and $\text{Mg}_2\text{Si}(111)$ with high precision. Further, although steel sheet components other than the coating may be included in the powder when the coating is
35 scraped off, these intermetallic compound phases are included only in the coating and the peak intensities are not affected. Further, X-ray diffraction is

carried out on the coating in powder form because calculating the proportions of phases correctly is difficult when X-ray diffraction is carried out on the coating formed on the coated steel sheet due to the influence of planar orientation of coating solidification microstructure.

- 5 **[0033]** Further, in the hot-dip Al-Zn-Si-Mg coated steel sheet disclosed herein, from the viewpoint of more stably improving the corrosion resistance, it is preferable that the diffraction intensity of Si in the coating as measured by the X-ray diffraction method satisfy the following relation (2):

$$\text{Si}(111) = 0 \quad \dots(2)$$

- 10 Here, Si(111) represents diffraction intensity for the (111) plane of Si with interplanar spacing d of 0.3135 nm.

- In general, it is known that in the dissolution reaction of Al alloys in aqueous solution, the presence of Si phase as a cathodic site promotes the dissolution of surrounding α -Al phase. Accordingly, the best way to stabilize corrosion resistance is to make the coating free from Si phase (that is, to make the Si(111) diffraction peak intensity zero), as in relation (2).

The method of measuring the diffraction peak intensity of the (111) plane of Si by X-ray diffraction is as described above.

- [0034]** There is no particular limitation on how to satisfy the relations (1) and (2). For example, in order to satisfy the relations (1) and (2), the proportions of Mg_2Si and Si (diffraction intensities of $\text{Mg}_2\text{Si}(111)$ and $\text{Si}(111)$) may be controlled by adjusting the balance between the Si content, the Mg content, and the Al content in the coating. The balance of the Si content, the Mg content, and the Al content in the coating does not necessarily satisfy the relation (1) or the relation (2) by setting the content ratios to a certain content ratio. For example, the content ratios of Mg and Al may need to be changed depending on the Si content (mass%).

- In addition to adjusting the balance between the Si content, the Mg content, and the Al content in the coating, by adjusting the conditions during coating formation (for example, cooling conditions after coating), the diffraction intensities of $\text{Mg}_2\text{Si}(111)$ and $\text{Si}(111)$ can be controlled to satisfy the relations (1) and (2).

- [0035]** From the viewpoint of satisfying various properties, the coating weight of the coating is preferably 45 g/m² to 120 g/m² per surface. When the coating weight of the coating is 45 g/m² or more, sufficient corrosion resistance is obtainable for applications requiring long-term corrosion resistance such as in

building materials, and when the coating weight of the coating is 120 g/m² or less, excellent corrosion resistance is achievable while suppressing the occurrence of defects such as coating cracks during working. From the same perspective, the coating weight of the coating is more preferably 45 g/m² to 100 g/m².

The coating weight of the coating can be derived, for example, by dissolving and stripping a specific area of the coating with a mixture of hydrochloric acid and hexamethylenetetramine as indicated in JIS H 0401:2013, and calculating the difference in weight of the steel sheet before and after the stripping. To determine the coating weight per surface using this method, the non-target surface may be sealed with tape prior to the dissolution so that the coated surface is not exposed.

[0036] Further, regarding the base steel sheet of the hot-dip Al-Zn-Si-Mg coated steel sheet, there is no particular limitation, and a cold-rolled steel sheet or a hot-rolled steel sheet, for example, may be used as appropriate depending on required performance and standards.

The method of obtaining the base steel sheet is not particularly limited. For example, in the case of the hot-rolled steel sheet, a steel sheet that has undergone a hot rolling process and a pickling process may be used, and in the case of the cold-rolled steel sheet, a steel sheet that has been additionally subjected to cold rolling may be used. Further, recrystallization annealing and the like may be carried out prior to the hot-dip coating as appropriate for the required properties of the steel sheet.

[0037] There is no particular limitation on the method of producing the hot-dip Al-Zn-Si-Mg coated steel sheet. For example, the method may include cleaning, heating, and dipping the base steel sheet in the coating bath in a continuous galvanizing line. In the heating of the steel sheet, it is effective to carry out recrystallization annealing in order to control the microstructure of the base steel sheet itself, and to carry out the heating in a reducing atmosphere such as a nitrogen-hydrogen atmosphere, in order to prevent oxidation of the steel sheet and to reduce a small amount of oxide film existing on the surface.

[0038] Further, regarding the coating bath used in the production of the hot-dip Al-Zn-Si-Mg coated steel sheet, as mentioned above, the composition of the coating as a whole is almost equivalent to the composition of the coating bath. Therefore, a coating bath may be used that contains Al: 45 mass% to 65 mass%, Si: 1.0 mass% to 3.0 mass%, Mg: 1.0 mass% to 10.0 mass%, and Mn:

0.1 mass% to 0.5 mass%, with the balance being Zn, Fe, and inevitable impurity. **[0039]** Further, the bath temperature of the coating bath is not particularly limited. The bath temperature is preferably in a temperature range from (melting point + 20 °C) to 650 °C.

5 The lower limit of the bath temperature is (melting point + 20 °C) because the bath temperature needs to be equal to or greater than the solidification point in order to carry out the hot-dip coating treatment, and (melting point + 20 °C) reliably prevents the components of the coating bath from being solidified due to a localized drop of the bath temperature of the
10 coating bath. On the other hand, the upper limit of the bath temperature is 650 °C because a bath temperature exceeding 650 °C may make rapid cooling of the coating difficult, thereby increasing the thickness of the interfacial alloy layer formed between the coating and the steel sheet.

[0040] Further, the temperature of the base steel sheet entering the coating
15 bath (entering sheet temperature) is not particularly limited. From the viewpoint of securing proper coating characteristics in the continuous hot-dip coating operation and preventing change in the bath temperature, the entering sheet temperature is preferably controlled to be in ± 20 °C relative to the temperature of the coating bath.

20 Further, an immersion time of the base steel sheet in the coating bath is 0.5 s or longer. This is because when the immersion time is shorter than 0.5 s, there is a possibility that a sufficient coating cannot be formed on the surface of the base steel sheet. An upper limit of the immersion time is not particularly limited. A long immersion time may result in a thicker interfacial alloy layer
25 forming between the coating and the steel sheet, and therefore the immersion time is preferably 8 s or shorter.

[0041] In the hot-dip Al-Zn-Si-Mg coated steel sheet, a paint layer may be formed either directly on the coating or on an intermediate layer on top of the coating, depending on required performance.

30 The method of forming the paint layer is not particularly limited, and may be selected as appropriate depending on the required performance. For example, roll coater coating, curtain flow coating, spray coating, or other formation methods may be used. The paint layer may be formed by applying a paint containing an organic resin, and then heating and drying the applied paint
35 by means of hot air drying, infrared heating, induction heating, or the like.

Further, the intermediate layer is also not particularly limited as long

as the intermediate layer is formed between the coating and the paint layer of the hot-dip coated steel sheet.

[0042] <Surface-treated steel sheet>

5 The surface-treated steel sheet according to the present disclosure comprises a coating on the steel sheet surface, and a chemical conversion layer formed on the coating.

The composition of the coating is the same as that of the coating of the hot-dip Al-Zn-Si-Mg coated steel sheet according to the present disclosure as described above.

10 Other configurations of the coating are also the same as those of the coating of the hot-dip Al-Zn-Si-Mg coated steel sheet according to the present disclosure as described above.

[0043] The surface-treated steel sheet has a chemical conversion layer formed on the coating.

15 The chemical conversion layer may be formed on at least one surface of the surface-treated steel sheet, and may be formed on both surfaces of the surface-treated steel sheet depending on the application and required performance.

[0044] In the surface-treated steel sheet according to the present disclosure,
20 the chemical conversion layer contains: at least one resin selected from the group consisting of an epoxy resin, a urethane resin, an acrylic resin, an acrylic silicon resin, an alkyd resin, a polyester resin, a polyalkylene resin, an amino resin, and a fluororesin; and at least one metal compound selected from the group consisting of a P compound, a Si compound, a Co compound, a Ni
25 compound, a Zn compound, an Al compound, a Mg compound, a V compound, a Mo compound, a Zr compound, a Ti compound, and a Ca compound.

By forming the chemical conversion layer on the coating, enhancing the anti-rust and barrier effects of the chemical conversion layer is possible, in addition to increasing affinity with the coating and enabling uniform formation
30 of the chemical conversion layer on the coating. As a result, corrosion resistance and anti-white rust property of the surface-treated steel sheet may be stably achieved.

[0045] The resin of the chemical conversion layer, from the viewpoint of improving corrosion resistance, may be at least one selected from the group
35 consisting of an epoxy resin, a urethane resin, an acrylic resin, an acrylic silicon resin, an alkyd resin, a polyester resin, a polyalkylene resin, an amino

resin, and a fluoro-resin. From the same perspective, the resin preferably contains at least one of a urethane resin or an acrylic resin. Examples of the resin of the chemical conversion layer also include addition polymerization products of the resins listed above.

- 5 **[0046]** Examples of the epoxy resin include: glycidyl-etherified products of bisphenol-A, bisphenol-F, or novolac epoxy resins; glycidyl-etherified products obtained by adding propylene oxide, ethylene oxide, or polyalkylene glycol to bisphenol-A epoxy resins; aliphatic epoxy resins; alicyclic epoxy resins; and polyether epoxy resins.
- 10 **[0047]** Examples of the urethane resin include oil-modified polyurethane resins, alkyd polyurethane resins, polyester polyurethane resins, polyether polyurethane resins, and polycarbonate polyurethane resins.
- 15 **[0048]** Examples of the acrylic resin include polyacrylic acid and copolymers thereof, polyacrylic acid esters and copolymers thereof, polymethacrylic acid and copolymers thereof, polymethacrylic acid esters and copolymers thereof, urethane-acrylic acid copolymers (or urethane-modified acrylic resins), and styrene-acrylic acid copolymers, and moreover, products obtained by modifying these resins with other resins such as alkyd resins, epoxy resins, or phenolic resins.
- 20 **[0049]** Examples of the acrylic silicon resin include products obtained by adding a curing agent to resins with hydrolysable alkoxysilyl groups on the side chains or ends of acrylic copolymers as the main agent. In addition to corrosion resistance, excellent weather resistance may be obtained when the acrylic silicon resin is used.
- 25 **[0050]** Examples of the alkyd resin include oil-modified alkyd resins, rosin-modified alkyd resins, phenol-modified alkyd resins, styrenated alkyd resins, silicon-modified alkyd resins, acrylic-modified alkyd resins, oil-free alkyd resins, and high molecular weight oil-free alkyd resins.
- 30 **[0051]** Examples of the polyester resin include polycondensates synthesized by dehydration-condensation of polyvalent carboxylic acids and polyalcohols to form ester bonds. Examples of the polyvalent carboxylic acids include terephthalic acid and 2,6-naphthalene dicarboxylic acid. Examples of the polyalcohols include ethylene glycol, 1,3-propanediol, 1,4-butanediol, and 1,4-cyclohexanedimethanol. Specifically, the polyesters include polyethylene terephthalate, polytrimethylene terephthalate, polyethylene naphthalate, and
- 35 polybutylene naphthalate. Further, acrylic-modified products of these polyester

resins may also be used.

[0052] Examples of the polyalkylene resins include: ethylene copolymers such as ethylene-acrylic acid copolymers, ethylene-methacrylic acid copolymers, and carboxyl-modified polyolefin resins; ethylene-unsaturated carboxylic acid
5 copolymers; and ethylene ionomers. In addition, products obtained by modifying these resins with other resins such as alkyd resins, epoxy resins, or phenolic resins may also be used.

[0053] Examples of the amino resin include thermosetting resins formed by the reaction of an amine or amide compound with an aldehyde, including
10 melamine resins, guanamine resins, and thiourea resins. Among these, melamine resins are preferred in terms of, for example, corrosion resistance, weather resistance, and adhesion. Examples of the melamine resin include, but are not limited to, butylated melamine resins, methylated melamine resins, and waterborne melamine resins.

[0054] Examples of the fluororesin include fluoroolefin polymers and
15 copolymers of fluoroolefins and alkyl vinyl ethers, cycloalkyl vinyl ethers, carboxylic acid-modified vinyl esters, hydroxyalkyl allyl ethers, tetrafluoropropyl vinyl ethers, and the like. When using these fluororesins, not only excellent corrosion resistance, but also excellent weather resistance and
20 hydrophobicity can be obtained.

[0055] Further, it is particularly preferable to use a curing agent in the resin that constitutes the chemical conversion layer, with the aim of improving corrosion resistance and workability. As the curing agent, urea resins (such as butylated urea resins), melamine resins (such as butylated melamine resins or
25 butyl ether melamine resins), butylated urea-melamine resins, amino resins such as benzoguanamine resins, block isocyanates, oxazoline compounds, or phenol resins may be used as appropriate.

[0056] Further, the metal compound of the chemical conversion layer is selected from the group consisting of a P compound, a Si compound, a Co
30 compound, a Ni compound, a Zn compound, an Al compound, a Mg compound, a V compound, a Mo compound, a Zr compound, a Ti compound, and a Ca compound. From the same perspective, the metal compound preferably contains at least one of a P compound, a Si compound, or a V compound.

[0057] Here, the P compound can improve corrosion resistance and perspiration resistance by being included in the chemical conversion layer. The
35 P compound is a P-containing compound that can contain, for example, at least

one selected from the group consisting of inorganic phosphoric acid, organic phosphoric acid, and salts thereof.

[0058] As the inorganic phosphoric acid, organic phosphoric acid, and salts thereof, any compounds may be used without any particular limitation. For example, as the inorganic phosphoric acid, it is preferable to use at least one selected from the group consisting of phosphoric acid, primary phosphate, secondary phosphate, tertiary phosphate, pyrophosphoric acid, pyrophosphate, tripolyphosphoric acid, tripolyphosphate, phosphorous acid, phosphite, hypophosphorous acid, and hypophosphite. As the organic phosphoric acid, it is preferable to use phosphonic acid (phosphonic acid compound). As the phosphonic acid, it is preferable to use at least one selected from the group consisting of nitrilotrismethylenephosphonic acid, phosphonobutane tricarboxylic acid, methyl diphosphonic acid, methylene phosphonic acid, and ethylidene diphosphonic acid.

When the P compound is a salt, the salt is preferably a salt of group 1-13 elements in the periodic table. The salt is more preferably a metal salt. The salt is preferably at least one selected from the group consisting of alkali metal salts and alkaline earth metal salts.

[0059] When a chemical conversion treatment liquid containing the P compound is applied to the coated steel sheet, the P compound causes the coating surface to be etched, thereby forming, on the coating side of the chemical conversion layer, an enriched layer in which the constituent elements of the coating, Al, Zn, Si and Mg, are incorporated. The formation of the enriched layer increases the bonding force between the chemical conversion layer and the coating surface, improving the adhesion of the chemical conversion layer.

The concentration of the P compound in the chemical conversion treatment liquid may be, but is not limited to, 0.25 mass% to 5 mass%. When the concentration of the P compound is less than 0.25 mass%, the etching effect is insufficient and adhesion to the coating interface is decreased, resulting not only in decreased corrosion resistance in flat parts but also in decreased corrosion resistance and perspiration resistance in defective parts, cut edges, and those parts of the coating or coating damaged by working or the like. From the same perspective, the concentration of the P compound is preferably 0.35 mass% or more. The concentration of the P compound is more preferably 0.50 % or more. On the other hand, when the concentration of the P compound

exceeds 5 mass%, not only is the life of the chemical conversion treatment liquid shortened, but the appearance after the formation of the coating is likely to become uneven, and the amount of P leaching out from the chemical conversion layer may increase, resulting in a decrease in blackening resistance.

5 From the same perspective, the concentration of the P compound is preferably 3.5 mass% or less. The concentration of the P compound is more preferably 2.5 mass% or less. For the content of the P compound in the chemical conversion layer, for example, by applying and drying a chemical conversion treatment liquid with the concentration of the P compound ranging from 0.25 mass% to
10 5 mass%, the coating weight of P in the chemical conversion layer after drying can be 5 mg/m² to 100 mg/m².

[0060] The Si compound is a component that, together with the resin, forms the backbone of the chemical conversion layer, and enhances affinity with the coating and allows the chemical conversion layer to be formed uniformly. The
15 Si compound is a Si-containing compound that preferably contains at least one selected from the group consisting of, for example, silica, trialkoxysilane, tetraalkoxysilane, and silane coupling agents.

[0061] The silica may be any silica without any particular limitation. For example, at least one of wet silica or dry silica may be used as the silica. As
20 colloidal silica, which is a type of the wet silica, for example, SNOWTEX O, C, N, S, 20, OS, OXS, NS, and the like produced by Nissan Chemical Corporation may be suitably used. As the dry silica, for example, AEROSIL 50, 130, 200, 300, 380, and the like produced by Nippon Aerosil Co., Ltd. may be suitably used.

25 **[0062]** The trialkoxysilane may be any trialkoxysilane without any particular limitation. For example, trialkoxysilanes represented by the general formula: $R_1Si(OR_2)_3$ (where R_1 is hydrogen or an alkyl group having 1-5 carbon atoms, and R_2 is the same or different alkyl group having 1-5 carbon atoms) are preferred. Such trialkoxysilanes include, for example, trimethoxysilane,
30 triethoxysilane, and methyltriethoxysilane.

[0063] The tetraalkoxysilane may be any tetraalkoxysilane without any particular limitation. For example, tetraalkoxysilanes represented by the general formula: $Si(OR)_4$ (where R is the same or different alkyl group having 1-5 carbon atoms) are preferred. Such tetraalkoxysilanes include, for example,
35 tetramethoxysilane, tetraethoxysilane, and tetrapropoxysilane.

[0064] The silane coupling agent may be any silane coupling agent without

any particular limitation. Examples of the silane coupling agent include γ -glycidoxypolytrimethoxysilane, γ -glycidoxypolydimethoxysilane, γ -glycidoxypolytriethoxysilane, γ -aminopropyltrimethoxysilane, γ -aminopropylmethyldiethoxysilane, γ -aminopropyltriethoxysilane, γ -methacryloxypropyltrimethoxysilane, γ -methacryloxypropyltriethoxysilane, γ -mercaptopropylmethyldimethoxysilane, and γ -mercaptopropyltrimethoxysilane, vinyltriethoxysilane, and γ -isocyanate propyltriethoxysilane.

[0065] By including the Si compound in the chemical conversion layer, the Si compound dehydrates and condenses to form an amorphous chemical conversion layer with siloxane bonds that have a high barrier effect in shielding against corrosion factors. Further, the chemical conversion layer with higher barrier properties is formed by bonding with any of the aforementioned resins. Further, in a corrosion environment, dense and stable corrosion products are formed in defective parts or those parts of the coating or coating damaged by working, thereby providing the combined effect with the coating to suppress corrosion of the base steel sheet. From the viewpoint of being highly effective in forming stable corrosion products, it is preferable to use at least one of colloidal silica and dry silica as the Si compound.

[0066] The concentration of the Si compound in the chemical conversion treatment liquid to form the chemical conversion layer is 0.2 mass% to 9.5 mass%. When the concentration of the Si compound in the chemical conversion treatment liquid is 0.2 mass% or more, a barrier effect by siloxane bonding can be obtained, resulting in improved corrosion resistance and perspiration resistance in defective parts, cut edges, and those parts damaged by working or the like, in addition to improved corrosion resistance in flat parts. When the concentration of the Si compound is 9.5 mass% or less, the life of the chemical conversion treatment liquid can be extended. By applying and drying a chemical conversion treatment liquid with the concentration of the Si compound in the range from 0.2 mass% to 9.5 mass%, the coating weight of Si in the chemical conversion layer after drying can be 2 mg/m² to 95 mg/m².

[0067] The Co compound and the Ni compound can be included in the chemical conversion layer to improve blackening resistance. This may be due to the fact that Co and Ni have the effect of delaying the leaching of water-soluble components out from the coating in a corrosion environment. Further, Co and Ni are elements that are less susceptible to oxidation than Al, Zn, Si,

and Mg. Therefore, by enriching (forming an enriched layer of) at least one of the Co compound or the Ni compound at the interface between the chemical conversion layer and the coating, the enriched layer becomes a barrier against corrosion, resulting in improved blackening resistance.

5 **[0068]** By using a chemical conversion treatment liquid containing the Co compound, Co can be included in the chemical conversion layer and incorporated into the enriched layer. A cobalt salt is preferred as the Co compound. Use of at least one of cobalt sulfate, cobalt carbonate, or cobalt chloride as the cobalt salt is more preferable.

10 By using a chemical conversion treatment liquid containing the Ni compound, Ni can be included in the chemical conversion layer and incorporated into the enriched layer. A nickel salt is preferred as the Ni compound. Use of at least one of nickel sulfate, nickel carbonate, and nickel chloride as the nickel salt is more preferable.

15 **[0069]** The concentration of the Co compound and/or the Ni compound in the chemical conversion treatment liquid is not particularly limited, yet can be 0.25 mass% to 5 mass% in total. When the concentration of the Co compound and/or the Ni compound is less than 0.25 mass%, the interfacial enriched layer will be non-uniform, and not only will the corrosion resistance in flat parts be
20 decreased, but also the corrosion resistance in defective parts, cut edges, and those parts of the coating or coating damaged by working or the like may be decreased. From the same perspective, the total concentration is preferably 0.5 mass% or more. The total concentration is more preferably 0.75 mass% or more. On the other hand, when the total concentration of the Co compound and/or the
25 Ni compound exceeds 5 mass%, the appearance after the formation of the coating is likely to become non-uniform and corrosion resistance may decrease. From the same perspective, the total concentration is preferably 4.0 mass% or less. The total concentration is more preferably 3.0 mass% or less. By applying and drying a chemical conversion treatment liquid with a total concentration
30 of 0.25 mass% to 5 mass% of the Co compound and/or the Ni compound, the total coating weight of Co and Ni in the chemical conversion layer after drying can be 5 mg/m² to 100 mg/m².

[0070] Regarding the Al compound, the Zn compound, and the Mg compound, by including them in the chemical conversion treatment liquid, an enriched
35 layer containing at least one of Al, Zn, or Mg can be formed on the coating side of the chemical conversion layer. The enriched layer formed can improve

corrosion resistance.

The Al, Zn, and Mg compounds are not limited as long as they are compounds containing Al, Zn, and Mg, respectively, yet are preferably inorganic compounds, and are preferably salts, chlorides, oxides, or hydroxides.

- 5 **[0071]** Examples of the Al compound include at least one selected from the group consisting of aluminum sulfate, aluminum carbonate, aluminum chloride, aluminum oxide, and aluminum hydroxide.

- 10 Examples of the Zn compound include at least one selected from the group consisting of zinc sulfate, zinc carbonate, zinc chloride, zinc oxide, and zinc hydroxide.

Examples of the Mg compound include at least one selected from the group consisting of magnesium sulfate, magnesium carbonate, magnesium chloride, magnesium oxide, and magnesium hydroxide.

- 15 **[0072]** The total concentration of the Al, Zn, and/or Mg compounds in the chemical conversion treatment liquid to form the chemical conversion layer is preferably 0.25 mass% to 5 mass%. When the total concentration is 0.25 mass% or more, the enriched layer can be formed more effectively, resulting in further improvement of corrosion resistance. When the total concentration is 5 mass% or less, the appearance of the chemical conversion layer becomes more uniform and the corrosion resistance is further improved in flat parts, defective parts, 20 and those parts of the coating damaged by working or the like.

- [0073]** The inclusion of the V compound in the chemical conversion layer allows V to leach out moderately under a corrosion environment and combine with zinc ions and other coating components that also leach out under a corrosion environment to form a dense protective layer. The protective layer 25 thus formed can further enhance corrosion resistance against corrosion that propagates not only in flat parts of the steel sheet, but also in defective parts, those parts of the coating damaged by working, cut edges to flat parts, and so on.

- 30 **[0074]** The V compound is a V-containing compound including, for example, at least one selected from the group consisting of sodium metavanadate, vanadyl sulfate, and vanadium acetylacetonate.

- [0075]** The V compound in the chemical conversion treatment liquid to form the chemical conversion layer is preferably 0.05 mass% to 4 mass%. When the 35 concentration of the V compound is 0.05 mass% or more, the V compound is more likely to leach out in a corrosion environment to form a protective layer,

improving corrosion resistance in defective parts, cut edges, and those parts of the coating damaged by working. When the concentration of the V compound exceeds 4 mass%, the appearance of the chemical conversion layer tends to be non-uniform and blackening resistance also decreases.

5 **[0076]** The Mo compound may be included in the chemical conversion layer to increase the blackening resistance of the surface-treated steel sheet. The Mo compound is a Mo-containing compound that can be obtained by adding one or both of molybdic acid and molybdate to the chemical conversion treatment liquid.

10 Examples of the molybdate include, for example, at least one selected from the group consisting of sodium molybdate, potassium molybdate, magnesium molybdate, and zinc molybdate.

[0077] The concentration of the Mo compound in the chemical conversion treatment liquid to form the chemical conversion layer is preferably 0.01
15 mass% to 3 mass%. When the concentration of the Mo compound is 0.01 mass% or more, the formation of oxygen-deficient zinc oxide can be further suppressed, making it possible to further improve blackening resistance. When the concentration of the Mo compound is 3 mass% or less, the life of the chemical conversion treatment liquid can be further extended and corrosion
20 resistance can be further improved.

[0078] The Zr and Ti compounds can be included in the chemical conversion layer to prevent the chemical conversion layer from becoming porous and to densify the layer. As a result, corrosion factors are less likely to penetrate the chemical conversion layer, thereby enhancing corrosion resistance.

25 **[0079]** The Zr compound is a Zr-containing compound. As the Zr compound, for example, at least one selected from the group consisting of zirconyl acetate, zirconyl sulfate, zirconyl potassium carbonate, zirconyl sodium carbonate, and zirconyl ammonium carbonate may be used. Among these, organotitanium chelate compounds are suitable because they densify the resulting layer and
30 provide even better corrosion resistance when the chemical conversion treatment liquid is dried to form the layer.

[0080] The Ti compound is a Ti-containing compound. As the Ti compound, for example, at least one selected from the group consisting of titanium sulfate, titanium chloride, titanium hydroxide, titanium acetylacetonato, titanium
35 octyleneglycolate, and titanium ethylacetoacetate may be used.

[0081] The total concentration of the Zr compound and/or the Ti compound in

the chemical conversion treatment liquid to form the chemical conversion layer is preferably 0.2 mass% to 20 mass%. When the total concentration of the Zr compound and/or the Ti compound is 0.2 mass% or more, the effect of suppressing permeation of corrosion factors is enhanced, and the corrosion resistance can be further improved not only in flat parts but also in defective parts, cut edges, and those parts of the coating damaged by working. When the total concentration of the Zr compound and/or the Ti compound is 20 mass% or less, the life of the chemical conversion treatment liquid can be further extended.

10 **[0082]** The Ca compound has the effect of decreasing the corrosion rate when included in the chemical conversion layer.

[0083] The Ca compound is a Ca-containing compound. Examples of the Ca compound include Ca oxides, Ca nitrates, Ca sulfates, and Ca-containing intermetallic compounds. More specifically, examples of the Ca compound include CaO, CaCO₃, Ca(OH)₂, Ca(NO₃)₂·4H₂O, and CaSO₄·2H₂O. The content of the Ca compound in the chemical conversion layer is not particularly limited.

15 **[0084]** The chemical conversion layer may contain various known components normally used in the field of paints, if necessary. For example, such components include: surface adjustment agents such as leveling agents and defoamers; additives such as dispersants, anti-settling agents, ultraviolet absorbers, light stabilizers, silane coupling agents, and titanate coupling agents; pigments such as colored pigments, extender pigments, and optical brightening agents; curing catalysts; organic solvents; and lubricants.

20 **[0085]** In the surface-treated steel sheet, the chemical conversion layer preferably does not contain harmful components such as hexavalent chromium, trivalent chromium, and fluorine. The chemical conversion treatment liquid used to form the chemical conversion layer not containing these harmful components increases safety and is less harmful to the environment.

25 **[0086]** The coating weight of the chemical conversion layer is not particularly limited. For example, from the viewpoint of preventing separation of the chemical conversion layer while securing more reliable corrosion resistance, the coating weight of the chemical conversion layer is preferably 0.1 g/m² to 3.0 g/m². The coating weight of the chemical conversion layer is more preferably 0.5 g/m² to 2.5 g/m². By setting the coating weight of the chemical conversion layer to 0.1 g/m² or more, corrosion resistance can be more reliably secured, and by setting the coating weight of the chemical conversion layer to

3.0 g/m² or less, cracking and separation of the chemical conversion layer may be prevented.

The coating weight of the chemical conversion layer may be determined by a method appropriately selected from existing methods, such as
5 measuring the proportions of elements whose content in the layer is known beforehand by X-ray fluorescence analysis of the layer.

[0087] The method of forming the chemical conversion layer is not particularly limited, and may be selected according to the required performance, production line, and so on. For example, the chemical conversion layer can be
10 formed by continuously applying the chemical conversion treatment liquid on the coating using a roll coater or the like, followed by drying at a peak metal temperature (PMT) from about 60 °C to about 200 °C using hot air drying, induction heating, or the like. Aside from a roll coater, other known means such as airless spray, electrostatic spray, curtain flow coater, or the like may
15 be employed as appropriate for the application of the chemical conversion treatment liquid. Further, the chemical conversion layer may be in the form of either monolayer or multilayer, as long as it contains the aforementioned resins and metal compounds, and is not limited to any particular type.

[0088] The surface-treated steel sheet of the present disclosure has a height
20 difference of 10 µm or less per mm of length in a range excluding 50 mm from both ends of the steel sheet surface (chemical conversion layer surface), similar to the surface of the hot-dip Al-Zn-Si-Mg coated steel sheet of the present disclosure described above.

When the height difference on the chemical conversion layer surface is
25 10 µm or less, wrinkle defects are absent and an excellent surface appearance is obtainable.

As described above, wrinkle defects are defects resulting from Mg oxides that cause wrinkled irregularities on the surface of the chemical conversion layer, and appear as white streaks on the surface of the chemical
30 conversion layer. Therefore, suppressing wrinkle defects means making such streaks not be visibly recognizable. Therefore, by limiting the height difference in a 1 mm length range on the steel sheet surface, that is, the chemical conversion layer surface, to 10 µm or less, it is possible to obtain an excellent surface appearance without visually recognizable streaks. From the same
35 viewpoint, the height difference in a 1 mm length of the steel sheet surface is preferably 5 µm or less.

The steel sheet surface refers to the outermost surface of the steel sheet, and in the case of a surface-treated steel sheet, refers to the chemical conversion layer surface.

5 **[0089]** Here, the height difference on the steel sheet surface refers to the difference in height between the highest point and the lowest point on the steel sheet (on the chemical conversion layer), when the height is defined as the direction perpendicular to the surface of the base steel sheet (direction of the coating thickness).

10 Further, the method of obtaining the height difference in a 1 mm length range of the chemical conversion layer surface can be the same as in the case of the coating surface described above, in which the height difference in a 1 mm range at any 100 locations on the surface-treated steel sheet is measured using a laser microscope, and the average of the measured values is calculated.

15 **[0090]** Further, a reason for controlling the height difference on the steel sheet surface in the range excluding 50 mm from both ends of the steel sheet is that it is typically difficult to control the coating amount at both ends of a hot-dip coated steel sheet compared to the center of the steel sheet, and the cooling rate is also different, and therefore wrinkle defects are more likely to occur. In addition, both ends of such steel sheets are often trimmed before use, and the surface appearance is of little concern.

20 **[0091]** Regarding the method of controlling the height difference of the coating surface per 1 mm of length on the steel sheet surface to 10 μm or less, it is important to suppress the height difference of the coating surface as described above. The height difference of the coating surface can be suppressed by adjusting the content ratio of Mg and Mn in the coating or by carrying out other surface treatments to suppress the height difference.

25 **[0092]** In the surface-treated steel sheet according to the present disclosure, a paint layer may be formed on the chemical conversion layer, as required.

30 **[0093]** The method of producing a surface-treated steel sheet of the present disclosure is a method of producing a surface-treated steel sheet having a coating and a chemical conversion layer formed on the coating.

35 In the production method according to the present disclosure, the chemical conversion layer is made to contain at least one resin selected from the group consisting of an epoxy resin, a urethane resin, an acrylic resin, an acrylic silicon resin, an alkyd resin, a polyester resin, a polyalkylene resin, an amino resin, and a fluororesin; and at least one metal compound selected from

the group consisting of a P compound, a Si compound, a Co compound, a Ni compound, a Zn compound, an Al compound, a Mg compound, a V compound, a Mo compound, a Zr compound, a Ti compound, and a Ca compound, and

forming the coating includes a hot-dip coating treatment process that
5 includes immersing a base steel sheet in a coating bath having a composition containing Al: 45 mass% to 65 mass%, Si: 1.0 mass% to 4.0 mass%, and Mg: 1.0 mass% to 10.0 mass%, with the balance being Zn and inevitable impurity.
[0094] The conditions for the hot-dip coating treatment process are the same as those explained in the description of the hot-dip Al-Zn-Si-Mg coated steel
10 sheet of the present disclosure.

[0095] <Prepainted steel sheet>

The prepainted steel sheet according to the present disclosure is a prepainted steel sheet in which a paint layer is formed either directly on the coating or on the chemical conversion layer on top of the coating.

15 The composition of the coating is the same as that of the coating of the hot-dip Al-Zn-Si-Mg coated steel sheet according to the present disclosure as described above.

Other configurations of the coating are also the same as those of the coating of the hot-dip Al-Zn-Si-Mg coated steel sheet according to the present
20 disclosure as described above.

[0096] According to the prepainted steel sheet, the chemical conversion layer can be formed on the coating.

The chemical conversion layer may be formed on at least one surface of the prepainted steel sheet, and can be formed on both surfaces of the
25 prepainted steel sheet depending on the application and required performance.

[0097] • Chemical conversion layer

According to the prepainted steel sheet, the chemical conversion layer contains: a resin component containing (a) an anionic polyurethane resin having an ester bond and (b) an epoxy resin having a bisphenol skeleton, in a
30 total amount of 30 mass% to 50 mass%, in which a content ratio of (a) to (b), (a):(b), is in the range from 3:97 to 60:40 by mass; and an inorganic compound containing 2 mass% to 10 mass% of a vanadium compound, 40 mass% to 60 mass% of a zirconium compound, and 0.5 mass% to 5 mass% of a fluorine compound.

35 By forming the chemical conversion layer on the coating, the strength and adhesion of the chemical conversion layer can be improved, while

corrosion resistance can also be enhanced.

[0098] The resin component of the chemical conversion layer contains (a) the anionic polyurethane resin having an ester bond and (b) the epoxy resin having a bisphenol skeleton.

5 **[0099]** Examples of (a) the anionic polyurethane resin having an ester bond include resins obtained by copolymerizing dimethylolalkyl acid with a reaction product of polyester polyol and diisocyanate or polyisocyanate having two or more isocyanate groups. Further, (a) the anionic polyurethane resin having an ester bond can be dispersed in water or other liquids using a known method to
10 obtain a chemical conversion treatment liquid.

[0100] Examples of the polyester polyol include: polyesters obtained by dehydration-condensation reactions from glycol components and acid components such as ester-forming derivatives of hydroxyl carboxylic acids; polyesters obtained by ring-opening polymerization reactions of cyclic ester
15 compounds such as ϵ -caprolactone; and copolymerized polyesters of these compounds.

Examples of the polyisocyanate include aromatic polyisocyanates, aliphatic polyisocyanates, and alicyclic polyisocyanates. Examples of the aromatic polyisocyanate include 2,4-tolylene diisocyanate, 2,6-tolylene
20 diisocyanate, m-xylene diisocyanate, diphenylmethane diisocyanate, 2,4-diphenylmethane diisocyanate, 2,2-diphenylmethane diisocyanate, triphenylmethane triisocyanate, polymethylene polyphenyl polyisocyanate, naphthalene diisocyanate, and their derivatives (for example, prepolymers obtained by reaction with polyols, modified polyisocyanates such as
25 carbodiimide compounds of diphenylmethane diisocyanate).

[0101] When synthesizing urethane by reacting the polyester polyol with the diisocyanate or polyisocyanate, for example, (a) the anionic polyurethane resin having an ester bond can be obtained by copolymerizing dimethylolalkyl acid and self-emulsifying the product to become water soluble (water dispersion).
30 In this case, examples of the dimethylolalkyl acid include dimethylolalkyl acids having 2-6 carbon atoms, more specifically, dimethylolethane acid, dimethylolpropanoic acid, dimethylolbutanoic acid, dimethylolheptanoic acid, and dimethylolhexanoic acid.

[0102] Further, (b) the epoxy resin having a bisphenol skeleton may be any
35 known epoxy resin. Examples thereof include bisphenol-A epoxy resins, bisphenol-F epoxy resins, bisphenol-AD epoxy resins, and bisphenol-S epoxy

resins. These epoxy resins can be obtained by reacting bisphenol compounds such as bisphenol A, bisphenol F, bisphenol AD, and bisphenol S with epichlorohydrin in the presence of an alkali catalyst. Among these it is preferable that the component [A] contain a bisphenol-A epoxy resin or a bisphenol-F epoxy resin; among these a bisphenol-A epoxy resin is more preferred. (b) The epoxy resin having a bisphenol skeleton can be dispersed in a liquid such as water using a known method to obtain a chemical conversion treatment liquid.

[0103] The resin component acts as a binder of the conversion chemical conversion layer. (a) The anionic polyurethane resin having an ester bond, which constitutes the binder, can achieve the effect of making the chemical conversion layer less likely to be destroyed (separated) when subjected to working because of its flexibility. (b) The epoxy resin having a bisphenol skeleton can achieve the effect of improving the adhesion with the Al-Zn coated steel sheet as the base steel sheet with the primer paint layer thereon.

The resin component content is a total of 30 mass% to 50 mass% in the chemical conversion layer. When the content of the resin component is less than 30 mass%, the binder effect of the chemical conversion layer is decreased, and when the content exceeds 50 mass%, the function of the inorganic components described below, such as inhibitor action, is decreased. From the same perspective, the content of the resin component in the chemical conversion layer is preferably 35 mass% to 45 mass%.

[0104] Further, in the resin component, the content ratio of (a) the anionic polyurethane resin having an ester bond to (b) the epoxy resin having a bisphenol skeleton, (a):(b), is required to be in the range from 3:97 to 60:40 by mass. When the ratio (a):(b) is outside this range, sufficient corrosion resistance cannot be obtained due to a decrease in flexibility and adhesion as a chemical conversion layer. From the same perspective, the ratio (a):(b) is preferably in a range from 10:90 to 55:45.

[0105] The resin component may include resins other than (a) the anionic polyurethane resin having an ester bond and (b) the epoxy resin having a bisphenol skeleton (that is, other resin components), depending on required performance. The other resin components include, but are not limited to, for example, at least one or a combination of two or more of acrylic resins, acrylic silicon resins, alkyd resins, polyester resins, polyalkylene resins, amino resins, and fluororesins.

When the resin component contains the other resins, the total content of (a) the anionic polyurethane resin having an ester bond and (b) the epoxy resin having a bisphenol skeleton is preferably 50 mass% or more. The total content is more preferably 75 mass% or more. This is to more reliably obtain flexibility and adhesion as the chemical conversion treatment layer.

[0106] The chemical conversion layer also contains, as inorganic compounds, 2 mass% to 10 mass% of a vanadium compound, 40 mass% to 60 mass% of a zirconium compound, and 0.5 mass% to 5 mass% of a fluorine compound.

The inclusion of these compounds can enhance the corrosion resistance of the chemical conversion layer.

[0107] The vanadium compound is added to the chemical conversion treatment liquid to act as an anti-rust agent (inhibitor). The inclusion of the vanadium compound in the chemical conversion layer allows the vanadium compound to leach out moderately under a corrosion environment and combine with zinc ions and other coating components that also leach out under a corrosion environment to form a dense protective layer. The protective layer thus formed can further enhance corrosion resistance against corrosion that propagates not only in flat parts of the steel sheet, but also in defective parts, those parts of the coating damaged by working, cut edges to flat parts, and so on.

Examples of the vanadium compound include vanadium pentoxide, metavanadate, ammonium metavanadate, vanadium oxytrichloride, vanadium trioxide, vanadium dioxide, magnesium vanadate, vanadyl acetylacetonate, and vanadium acetylacetonate. Among these, in particular, it is desirable to use tetravalent vanadium compounds or tetravalent vanadium compounds obtained by reduction or oxidation.

[0108] The content of the vanadium compound in the chemical conversion layer is 2 mass% to 10 mass%. When the content of the vanadium compound in the chemical conversion layer is less than 2 mass%, the inhibitor effect is not sufficient, resulting in a decrease in corrosion resistance. When the content of the vanadium compound exceeds 10 mass%, the moisture resistance of the chemical conversion layer decreases.

[0109] The zirconium compound is contained in the chemical conversion layer and is expected to improve the strength and corrosion resistance of the chemical conversion layer by reacting with the coating metal and coexisting with the resin components. Further, the zirconium compound itself contributes to the formation of a dense chemical conversion layer and exhibits good

coverability, and is therefore expected to have a barrier effect.

Examples of the zirconium compound include neutralized salts of zirconium sulfate, zirconium carbonate, zirconium nitrate, zirconium lactate, zirconium acetate, and zirconium chloride.

5 **[0110]** The content of the zirconium compound in the chemical conversion layer is 40 mass% to 60 mass%. When the content of the zirconium compound in the chemical conversion layer is less than 40 mass%, the strength and corrosion resistance as the chemical conversion layer decreases. When the content of the zirconium compound exceeds 60 mass%, the chemical
10 conversion layer becomes brittle, resulting in destruction and separation of the chemical conversion layer under severe working.

[0111] The fluorine compound is contained in the chemical conversion layer and acts as an agent to impart adhesion with the coating. As a result, the corrosion resistance of the chemical conversion layer can be increased.

15 As the fluorine compound, fluoride salts such as ammonium salts, sodium salts, and potassium salts, or fluorine compounds such as ferrous fluorides and ferric fluorides may be used. Among these, fluoride salts such as ammonium fluoride, sodium fluoride, and potassium fluoride are preferred.

[0112] The content of the fluorine compound in the chemical conversion layer
20 is 0.5 mass% to 5 mass%. When the content of the fluorine compound in the chemical conversion layer is less than 0.5 mass%, sufficient adhesion cannot be obtained in worked portions. When the content of the fluorine compound exceeds 5 mass%, the moisture resistance of the chemical conversion layer is decreased.

25 **[0113]** The coating weight of the chemical conversion layer is not particularly limited. For example, from the viewpoint of improving the adhesion of the chemical conversion layer while more reliably ensuring corrosion resistance, the coating weight of the chemical conversion layer is preferably 0.025 g/m² to 0.5 g/m². By setting the coating weight of the chemical conversion layer to
30 0.025 g/m² or more, corrosion resistance can be more reliably obtained, and by setting the coating weight of the chemical conversion layer to 0.5 g/m² or less, separation of the chemical conversion layer can be suppressed.

The coating weight of the chemical conversion layer may be determined by a method appropriately selected from existing methods, such as
35 measuring the proportions of elements whose content in the layer is known beforehand by X-ray fluorescence analysis of the layer.

[0114] The method of forming the chemical conversion layer is not particularly limited, and may be selected according to the required performance, production line, and so on. For example, the chemical conversion layer can be formed by continuously applying the chemical conversion treatment liquid on the coating using a roll coater or the like, followed by drying at a peak metal temperature (PMT) from about 60 °C to about 200 °C using hot air drying, induction heating, or the like. Aside from a roll coater, other known means such as airless spray, electrostatic spray, curtain flow coater, or the like may be employed as appropriate for the application of the chemical conversion treatment liquid. Further, the chemical conversion layer may be in the form of either monolayer or multilayer, as long as it contains the aforementioned resins and metal compounds, and is not limited to any particular type.

[0115] • Paint layer

As described above, in the prepainted steel sheet according to the present disclosure, a paint layer is formed either directly on the coating or on a chemical conversion layer on top of the coating, and the paint layer comprises at least a primer paint layer.

[0116] According to the present disclosure, the primer paint layer contains a polyester resin having a urethane bond and an inorganic compound including a vanadium compound, a phosphoric acid compound, and a magnesium oxide.

The inclusion of the polyester resin having a urethane bond and the inorganic compound in the primer paint layer allows improvement of corrosion resistance while enhancing the adhesion of the paint layer.

[0117] The primer paint layer contains a polyester resin having a urethane bond as its main component. The polyester resin having a urethane bond has both flexibility and strength, which makes it difficult for the primer paint layer to crack when subjected to working, and its high affinity with the chemical conversion layer containing a urethane resin can contribute to improving corrosion resistance, especially in worked portions.

In this case, the term "main component" means the component with the highest content in each component in the primer paint layer.

[0118] As the polyester resin having a urethane bond, known resins such as those obtained by the reaction of polyester polyol and diisocyanate or polyisocyanate having two or more isocyanate groups can be used. Further, resins that are obtained by curing resins made by reacting the polyester polyol with the diisocyanate or polyisocyanate in excess of hydroxyl groups

(urethane-modified polyester resins) with blocked polyisocyanate may also be used.

[0119] The polyester polyol can be obtained by a known method using a dehydration-condensation reaction between a polyhydric alcohol component
5 and a polybasic acid component.

Examples of the polyhydric alcohol include glycol and trivalent or higher valent alcohols. Examples of the glycols include ethylene glycol, propylene glycol, diethylene glycol, triethylene glycol, tetraethylene glycol, dipropylene glycol, polyethylene glycol, polypropylene glycol, neopentyl
10 glycol, hexylene glycol, 1,3-butanediol, 1,4-butanediol, 1,5-pentanediol, 1,6-hexanediol, 2-butyl-2-ethyl-1,3-propanediol, methylpropanediol, cyclohexanedimethanol, and 3,3-diethyl-1,5 pentanediol. Examples of the trivalent or higher valent alcohols include glycerin, trimethylolethane, trimethylolpropane, pentaerythritol, and dipentaerythritol. These polyhydric
15 alcohols can be used alone or in combination of two or more.

As the polybasic acid, a polyvalent carboxylic acid is usually used. However, monovalent fatty acids and other acids can be used in combination, as required. Examples of the polyvalent carboxylic acid include phthalic acid, tetrahydrophthalic acid, hexahydrophthalic acid, 4-methylhexahydrophthalic
20 acid, bicyclo[2,2,1]heptane-2,3-dicarboxylic acid, trimellitic acid, adipic acid, sebacic acid, succinic acid, azelaic acid, fumaric acid, maleic acid, itaconic acid, pyromellitic acid, dimeric acid, and their acid anhydrides, as well as 1,4-cyclohexanedicarboxylic acid, isophthalic acid, tetrahydroisophthalic acid, hexahydroisophthalic acid, and hexahydro terephthalic acid. These polybasic
25 acids can be used alone or in combination of two or more.

[0120] Examples of the polyisocyanate include: aliphatic diisocyanates such as hexamethylene diisocyanate, trimethylhexamethylene diisocyanate, and dimer diisocyanate; aromatic diisocyanates such as xylylene diisocyanate (XDI), meta-xylylene diisocyanate, tolylene diisocyanate (TDI), and 4,4-
30 diphenylmethane diisocyanate (MDI); cyclic aliphatic diisocyanates such as isophorone diisocyanate, hydrogenated XDI, hydrogenated TDI, and hydrogenated MDI; and their adducts, biurets, and isocyanurates. These polyisocyanates can be used alone or in combination of two or more.

[0121] The hydroxyl group value of the polyester resin having a urethane bond
35 is not particularly limited. From the viewpoint of solvent resistance and workability, the hydroxyl group value is preferably 5 mg KOH/g to 120 mg

KOH/g. The hydroxyl group value is more preferably 7 mg KOH/g to 100 mg KOH/g. The hydroxyl group value is even more preferably 10 mg KOH/g to 80 mg KOH/g.

Further, in terms of solvent resistance and workability, the number-average molecular weight of the polyester resin having a urethane bond is
5 preferably from 500 to 15,000. The number average molecular weight is more preferably from 700 to 12,000. The number average molecular weight is even more preferably from 800 to 10,000.

[0122] The content of the polyester resin having a urethane bond in the primer
10 paint layer is preferably 40 mass% to 88 mass%. When the content of the polyester resin having a urethane bond is less than 40 mass%, the binder function as the primer paint layer may decrease, while when the content of polyester resin having a urethane bond exceeds 88 mass%, the function by the inorganic substances described below, such as inhibitor action, may decrease.

[0123] The vanadium compound, one of the inorganic compounds, acts as an
15 inhibitor. Examples of the vanadium compound include vanadium pentoxide, metavanadate, ammonium metavanadate, vanadium oxytrichloride, vanadium trioxide, vanadium dioxide, magnesium vanadate, vanadyl acetylacetonate, and vanadium acetylacetonate. Among these, in particular, it is desirable to use
20 tetravalent vanadium compounds or tetravalent vanadium compounds obtained by reduction or oxidation.

The vanadium compound added to the primer paint layer may be the same as or different from the vanadium compound added to the chemical
conversion layer. According to the vanadate compound, it is believed that
25 vanadate ions, which are gradually leached into moisture entering from the outside, react with ions on the surface of the zinc or zinc alloy coated steel sheet to form a passive layer with good adhesion, protecting exposed metal parts and helping prevent rust.

[0124] The content of the vanadium compound in the primer paint layer is not
30 particularly limited. From the viewpoint of compatibility between corrosion resistance and moisture resistance, the content of the vanadium compound in the primer paint layer is preferably 4 mass% to 20 mass%. When the content of the vanadium compound is less than 4 mass%, the inhibitor effect may be decreased, resulting in a decrease in corrosion resistance. When the content of
35 the vanadium compound exceeds 20 mass%, the moisture resistance of the primer paint layer may be decreased.

[0125] The phosphate compound, one of the inorganic compounds, also acts as an inhibitor. Example of the phosphate compound include phosphoric acid, ammonium salts of phosphoric acid, alkali metal salts of phosphoric acid, and alkaline earth metal salts of phosphoric acid. Alkali metal salts of phosphoric acid, such as calcium phosphate, are particularly suitable.

[0126] The content of the phosphoric acid compound in the primer paint layer is not particularly limited. From the viewpoint of compatibility between corrosion resistance and moisture resistance, the content of the phosphoric acid compound in the primer paint later is preferably 4 mass% to 20 mass%. When the content of the phosphoric acid compound is less than 4 mass%, the inhibitor effect may decrease, resulting in a decrease in corrosion resistance. When the content of the phosphoric acid compound exceeds 20 mass%, the moisture resistance of the primer paint layer may decrease.

[0127] Magnesium oxide, one of the inorganic compounds, produces Mg-containing products due to initial corrosion and has the effect of increasing stability and improving corrosion resistance as an insoluble magnesium salt.

[0128] The content of the magnesium oxide in the primer paint layer is not particularly limited. From the viewpoint of compatibility between corrosion resistance and corrosion resistance in worked portions, the content of the magnesium oxide in the primer paint layer is preferably 4 mass% to 20 mass%. When the content of the magnesium oxide is less than 4 mass%, the above effect may decrease and corrosion resistance may decrease. When the content of the magnesium oxide exceeds 20 mass%, the flexibility of the primer paint layer may decrease, resulting in decreased corrosion resistance in worked portions.

[0129] The primer paint layer may also contain components other than the polyester resin having a urethane bond and inorganic compounds mentioned above.

An example of such a component is a crosslinking agent used to form the primer paint layer. The crosslinking agent reacts with the polyester resin having a urethane bond to form a cross-linked paint layer. Examples of the crosslinking agent include oxazoline compounds, epoxy compounds, melamine compounds, isocyanate compounds, carbodiimide compounds, and silane coupling compounds. Two or more crosslinking agents may be used in combination. Among these, blocked polyisocyanate compounds, for example, are preferably used from the viewpoint of corrosion resistance in worked

portions of the resulting prepainted steel sheet. Examples of the blocked polyisocyanate include one in which an isocyanate group of a polyisocyanate compound is blocked by alcohols such as butanol, oximes such as methyl ethyl ketoxime, lactams such as ϵ -caprolactam, diketones such as acetoacetic acid diester diketones, imidazoles such as imidazole and 2-ethylimidazole, or phenols such as m-cresol.

[0130] Further, the primer paint layer may also contain various known components normally used in the field of paints, as required. Specifically, examples of such components include various surface adjustment agents such as leveling agents and defoamers, dispersants, anti-settling agents, ultraviolet absorbers, light stabilizers, various additives such as silane coupling agents and titanate coupling agents, various pigments such as colored pigments and extender pigments, optical brightening materials, curing catalysts, and organic solvents.

[0131] The thickness of the primer paint layer is preferably 1.5 μm or more. The primer paint layer having a thickness of 1.5 μm or more helps reliably obtain the improvement of corrosion resistance and adhesion with the chemical conversion layer and a top coating layer formed on top of the primer paint layer.

[0132] There is no particular limitation on the method used to form the primer paint layer. As the application method of the paint composition of the primer paint layer, the paint composition may preferably be applied by roll coater coating, curtain flow coating, or the like. After the application, the applied paint composition is baked by heating means such as hot air drying, infrared heating, or induction heating to form the primer paint layer. The baking is typically carried out at a peak metal temperature approximately in a range from 180 $^{\circ}\text{C}$ to 270 $^{\circ}\text{C}$ for about 30 s to 3 min in this temperature range.

[0133] Further, in the paint layer of the prepainted steel sheet, the top coating layer is preferably formed on the primer paint layer.

In addition to being able to impart aesthetic qualities such as color, gloss, and surface conditions to the prepainted steel sheet, the top coating layer can enhance various performances such as workability, weather resistance, chemical resistance, stain resistance, water resistance, and corrosion resistance.

[0134] The configuration of the top coating layer is not particularly limited, and the material, thickness, and other conditions may be selected as appropriate according to required performance.

For example, the top coating layer may be formed using polyester resin

paint, silicon polyester resin paint, polyurethane resin paint, acrylic resin paint, fluoropolymer resin paint, or the like.

Further, the top coating layer may contain: colored pigments such as titanium oxide, red iron oxide, mica, carbon black, and the like; metallic pigments such as aluminum powder and mica; extender pigments composed of carbonates, sulfates, and the like; microparticles such as silica microparticles, nylon resin beads, and acrylic resin beads; curing catalysts such as p-toluene sulfonic acid and dibutyl tin dilaurate; waxes; and other additives in appropriate quantities.

5 [0135] The thickness of the top coating layer is preferably 5 μm to 30 μm in terms of both appearance and workability. When the thickness of the top coating layer is 5 μm or more, the color appearance can be more reliably stabilized, and when the thickness of the top coating layer is 30 μm or less, a decrease in workability (cracking of the top coating layer) can be more reliably suppressed.

15 [0136] The method of applying the paint composition to form the top coating layer is not particularly limited. For example, the paint composition can be applied by roll coater coating, curtain flow coating, or other methods. After the application, the applied paint composition can be baked by heating means such as hot air drying, infrared heating, or induction heating to form the top coating layer. The baking is typically carried out at a peak metal temperature approximately in a range from 180 $^{\circ}\text{C}$ to 270 $^{\circ}\text{C}$ for about 30 s to 3 min in this temperature range.

20 [0137] The prepainted steel sheet of the present disclosure is characterized in that, like the surface of the hot-dip Al-Zn-Si-Mg coated steel sheet described above, the height difference of the steel sheet surface (paint layer surface) per mm of length is 10 μm or less in an area excluding 50 mm from both ends of the steel sheet.

When the height difference on the paint layer surface is 10 μm or less, wrinkle defects are absent and an excellent surface appearance is obtainable.

As described above, wrinkle defects are defects resulting from Mg oxides that cause wrinkled irregularities on the surface of the paint layer, and appear as white streaks on the surface of the paint layer. Therefore, suppressing wrinkle defects means making such streaks not be visibly recognizable.

35 Therefore, by limiting the height difference in a 1 mm length range on the steel sheet surface, that is, the paint layer surface, to 10 μm or less, it is possible to

obtain an excellent surface appearance without visually recognizable streaks. From the same viewpoint, the height difference in a 1 mm length of the steel sheet surface is preferably 5 μm or less.

The steel sheet surface refers to the outermost surface of the steel sheet, and in the case of a prepainted steel sheet, refers to the paint layer surface.

[0138] Here, the height difference on the steel sheet surface refers to the difference in height between the highest point and the lowest point on the steel sheet (on the paint layer), when the height is defined as the direction perpendicular to the surface of the base steel sheet (direction of the coating thickness).

Further, the method of obtaining the height difference in a 1 mm length range of the paint layer surface can be the same as in the case of the coating surface described above, in which the height difference in a 1 mm range at any 100 locations on the prepainted steel sheet is measured using a laser microscope, and the average of the measured values is calculated.

[0139] Further, a reason for controlling the height difference on the steel sheet surface in the range excluding 50 mm from both ends of the steel sheet is that it is typically difficult to control the coating amount at both ends of a hot-dip coated steel sheet compared to the center of the steel sheet, and the cooling rate is also different, and therefore wrinkle defects are more likely to occur. In addition, both ends of such steel sheets are often trimmed before use, and the surface appearance is of little concern.

[0140] Regarding the method of controlling the height difference of the paint layer surface per 1 mm of length on the steel sheet surface to 10 μm or less, it is important to suppress the height difference of the coating surface as described above. The height difference of the coating surface can be suppressed by adjusting the content ratio of Mg and Mn in the coating or by carrying out other surface treatments to suppress the height difference.

[0141] A method of producing a prepainted steel sheet according to the present disclosure is a method of producing a prepainted steel sheet in which a paint layer is formed on the coating directly or via the chemical conversion layer.

In the production method according to the present disclosure, the chemical conversion layer contains: a resin component containing (a) an anionic polyurethane resin having an ester bond and (b) an epoxy resin having a bisphenol skeleton, in a total amount of 30 mass% to 50 mass%, in which a content ratio of (a) to (b), (a):(b), is in a range from 3:97 to 60:40 by mass;

and an inorganic compound containing 2 mass% to 10 mass% of a vanadium compound, 40 mass% to 60 mass% of a zirconium compound, and 0.5 mass% to 5 mass% of a fluorine compound,

the paint layer includes at least a primer paint layer, the primer paint
5 layer containing: a polyester resin having a urethane bond; and an inorganic compound containing a vanadium compound, a phosphoric acid compound, and a magnesium oxide, and

forming the coating includes a hot-dip coating treatment process that includes immersing a base steel sheet in a coating bath having a composition
10 containing Al: 45 mass% to 65 mass%, Si: 1.0 mass% to 4.0 mass%, and Mg: 1.0 mass% to 10.0 mass%, with the balance being Zn and inevitable impurity.

[0142] The conditions for the hot-dip coating treatment process are the same as those explained in the description of the hot-dip Al-Zn-Si-Mg coated steel sheet of the present disclosure.

15

EXAMPLES

[0143] [Example 1: Samples 1 to 28]

In each case, a cold-rolled steel sheet having a thickness of 0.8 mm, produced by a conventional method, was used as a base steel sheet, and was
20 subjected to degreasing treatment, annealing treatment, and coating treatment in a continuous galvanizing line, thereby producing Samples 1 to 28 of hot-dip Al-Zn-Si-Mg coated steel sheets under the conditions listed in Table 1.

The composition of the coating bath used in producing the hot-dip Al-Zn-Si-Mg coated steel sheets was varied within the ranges of Al: 45 mass% to
25 65 mass%, Si: 1.5 mass% to 2.5 mass%, Mg: 1.0 mass% to 4.5 mass%, Mn: 0.00 mass% to 1.0 mass%, Sr: 0.00 mass% to 1.0 mass%, B: 0.00 mass% to 0.05 mass%, Ca: 0.00 mass% to 1.0 mass%, Cr: 0.00 mass% to 0.2 mass%, Ti: 0.00 mass% to 0.2 mass%, and V: 0.00 mass% to 0.2 mass%, so as to obtain the composition of the coating of each sample listed in Table 1. The bath
30 temperature of the coating bath was controlled to be 590 °C in the case of Al being in the range of 45 mass% to 55 mass%, and to be 630 °C in the case of Al being 65 mass%, so that the sheet temperature of the base steel sheet at the time of entering the coating bath was the same as the bath temperature of the coating bath. Further, the coating treatment was carried out under the condition
35 that the sheet temperature cooled down to the temperature range of 520 °C to 500 °C in 3 s.

The coating weight of the coating was controlled to be $85 \pm 5 \text{ g/m}^2$ per surface for Samples 1 to 23 and Samples 27 and 28, and 50 g/m^2 to 125 g/m^2 per surface for Samples 24 to 26.

[0144] <Evaluation>

5 Each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets obtained as described above was evaluated as follows. The evaluation results are listed in Table 1.

(1) Composition of coating (coating weight, composition, X-ray diffraction intensity)

10 For each sample after coating, a 100 mm diameter was punched out, the non-measured surface was sealed with tape, and the coating was dissolved and stripped with a mixture of hydrochloric acid and hexamethylenetetramine, as specified in JIS H 0401:2013. Then, from the mass difference before and after the stripping for each sample, the coating weight of the coating was
15 calculated. The coating weight of each coating obtained by the calculation is listed in Table 1.

The stripping solution was then filtered and the filtrate and solids were analyzed respectively. Specifically, the filtrate was analyzed by ICP emission spectroscopy to quantify the components other than insoluble Si.

20 The solids were dried and ashed in a heating furnace at 650°C and then melted by adding sodium carbonate and sodium tetraborate. In addition, the melt was dissolved in hydrochloric acid and the dissolved solution was analyzed by ICP emission spectroscopy to quantify the insoluble Si. The concentration of Si in the coating was the concentration of soluble Si obtained
25 by filtrate analysis plus the concentration of insoluble Si obtained by solids analysis. The composition of each coating obtained by the calculations is listed in Table 1.

After shearing each sample to a size of $100 \text{ mm} \times 100 \text{ mm}$, the coating on the evaluation surface was mechanically scraped off until the base steel
30 sheet was exposed. After mixing the obtained powder well, 0.3 g was taken out from the mixture and subjected to qualitative analysis using an X-ray diffractometer (SmartLab by Rigaku Holdings Corporation) under a set of conditions including X-ray used: Cu-K α (wavelength = 1.54178 angstrom), K β ray removal: Ni filter, tube voltage: 40 kV, tube current: 30 mA, scanning
35 speed: $4^\circ/\text{min}$, sampling interval: 0.020° , divergence slit: $2/3^\circ$, solar slit: 5° , detector: high-speed one-dimensional detector (D/teX Ultra). The diffraction

intensities of the (111) plane of Mg_2Si with interplanar spacing d of 0.3668 nm and the (111) plane of Si with interplanar spacing d of 0.3135 nm were measured, with each diffraction intensity (cps) being the peak intensity minus the base intensity.

5 **[0145]** (2) Surface appearance

(2-1) Wrinkle defects

The surface appearance of each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets obtained was visually inspected to check for the occurrence of wrinkle defects. Further, for each sample, 100 locations were randomly
10 selected from the area excluding 50 mm from both ends of the strip, and the height difference of the coating surface in a 1 mm long range was measured using a laser microscope ("VK-X3000", by Keyence Corporation), and an average value was quantified as the surface shape. The occurrence of wrinkle defects was evaluated based on the presence or absence of wrinkle defects and
15 the surface shape, according to the following criteria.

◎: no wrinkle defects were observed (height difference 5 mm or less)

○: no wrinkle defects were observed (height difference 10 mm or less)

×: wrinkle defect occurrence was observed (height difference exceeds
10 μm)

20 **[0146]** (2-2) Dross defects

The surface appearance of each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets obtained was visually inspected, and the presence or absence of dross defects was evaluated according to the following criteria.

○: granular dross adhesion was not observed

25 ×: granular dross adhesion was observed

[0147] (3) Evaluation of corrosion resistance

Each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets obtained was sheared to a size of 120 mm $\times$ 120 mm, and 10 mm from each edge of the surface to be evaluated as well as each end and the surface not to be evaluated
30 were sealed with tape so that the exposed size of the surface to be evaluated was 100 mm $\times$ 100 mm. These were used as evaluation samples. In each case, three identical evaluation samples were prepared.

The three evaluation samples prepared as described above were all subjected to the Japanese Automobile Standards Organization Cyclic Corrosion
35 Test (JASO-CCT). After 300 cycles of the accelerated corrosion test starting from wet, the corrosion loss of each sample was measured by the method

prescribed in JIS Z 2383 and ISO 8407, and evaluated according to the following criteria.

◎: corrosion loss of all three samples was 45 g/m² or less

○: corrosion loss of all three samples was 90 g/m² or less

5 ×: corrosion loss of at least one sample exceeded 90 g/m²

[0148] [Table 1]

No.		Coating										Surface appearance			Corrosion resistance				Remarks
		Chemical composition (mass%)						Coating weight (g/m ²)	Si(111)/Mg ₂ Si(111) (keps)	Wrinkle defects		Dross defects	Corrosion loss (g/m ²)			Evaluation			
		Al	Si	Mg	Fe	Mn	Other			Mn/Mg	Surface height difference (μm)		Evaluation	N1	N2		N3		
1	55	1.5	4.5	0.60	-	-	-	85	0.00	0.00	×	○	-	-	-	-	-	Comparative Example	
2	55	1.5	4.4	0.58	0.01	-	-	83	0.00	0.00	○	○	41	41	42	42	⊙	Example	
3	55	1.5	4.5	0.58	0.05	-	-	83	0.00	0.00	○	○	42	40	43	43	⊙	Example	
4	55	1.5	4.5	0.60	0.1	-	-	85	0.00	0.00	⊙	○	40	42	40	40	⊙	Example	
5	55	1.5	4.5	0.61	0.3	-	-	85	0.00	0.00	⊙	○	44	43	44	44	⊙	Example	
6	55	1.5	4.4	0.65	0.5	-	-	82	0.00	0.00	○	○	43	42	42	42	⊙	Example	
7	55	1.5	4.5	0.75	1.0	-	-	84	0.00	0.00	○	×	-	-	-	-	-	Comparative Example	
8	55	1.5	4.5	0.56	-	1.0 Sr	-	83	0.00	0.00	○	×	-	-	-	-	-	Comparative Example	
9	55	1.5	4.5	0.62	0.1	0.2 Sr	0.02	87	0.00	0.00	⊙	○	43	43	40	40	⊙	Example	
10	55	1.5	4.5	0.63	0.1	0.05 B 0.2 Ti	0.02	85	0.00	0.00	⊙	○	40	38	37	37	⊙	Example	
11	55	1.5	4.5	0.61	0.1	1.0 Ca	0.02	84	0.00	0.00	⊙	○	39	40	40	40	⊙	Example	
12	55	1.5	4.5	0.60	0.1	0.5 Ca 0.2 Cr	0.02	86	0.00	0.00	⊙	○	39	39	37	37	⊙	Example	
13	55	1.5	4.5	0.61	0.1	0.2 V	0.02	84	0.00	0.00	⊙	○	38	36	40	40	⊙	Example	
14	55	1.5	1.0	0.58	0.3	-	0.30	85	no Mg ₂ Si	0.90	⊙	○	81	82	83	83	×	Example	
15	55	1.5	2.0	0.59	0.3	-	0.15	85	0.56	0.63	⊙	○	49	50	49	49	○	Example	
16	55	2.5	1.1	0.59	0.01	-	0.01	82	no Mg ₂ Si	3.26	○	○	102	106	103	103	○	Example	
17	55	2.5	1.1	0.59	0.2	-	0.18	83	no Mg ₂ Si	3.44	⊙	○	96	110	98	98	○	Example	
18	55	2.5	2.0	0.56	0.2	-	0.10	82	3.18	2.43	⊙	○	80	63	71	71	○	Example	
19	55	2.5	3.4	0.61	0.2	-	0.06	86	0.11	0.32	⊙	○	62	59	60	60	○	Example	
20	55	2.5	4.5	0.57	0.2	-	0.04	85	0.12	0.19	⊙	○	56	55	50	50	○	Example	
21	55	2.5	6.4	0.57	0.2	-	0.03	85	0.02	0.1	⊙	○	55	60	49	49	○	Example	
22	55	2.5	9.7	0.61	0.2	-	0.02	87	0.00	0.00	⊙	○	42	41	43	43	⊙	Example	
23	55	2.5	9.8	0.58	0.1	-	0.01	87	0.00	0.00	○	○	43	44	41	41	⊙	Example	
24	55	1.5	4.5	0.61	0.3	-	0.07	50	0.00	0.00	⊙	○	39	39	43	43	⊙	Example	
25	55	1.5	4.5	0.61	0.3	-	0.07	100	0.00	0.00	⊙	○	39	39	41	41	⊙	Example	
26	55	1.5	4.5	0.61	0.3	-	0.07	125	0.00	0.00	⊙	○	41	44	40	40	⊙	Example	
27	45	1.5	4.5	0.49	0.03	-	0.01	85	0.00	0.00	○	○	41	44	40	40	⊙	Example	
28	65	1.5	4.5	0.81	0.03	-	0.01	86	0.00	0.00	○	○	41	44	40	40	⊙	Example	

[0149] The results in Table 1 demonstrate that the samples of Examples according to the present disclosure have superior surface appearance compared to the samples of Comparative Examples.

[0150] [Example 2: Samples 1 to 34]

5 (1) In each case, a cold-rolled steel sheet having a thickness of 0.8 mm, produced by a conventional method, was used as a base steel sheet, and was subjected to degreasing treatment, annealing treatment, and coating treatment in a continuous galvanizing line, thereby producing Samples 1 to 34 of hot-dip Al-Zn-Si-Mg coated steel sheets under the conditions listed in Table 3.

10 The composition of the coating bath used in producing the hot-dip Al-Zn-Si-Mg coated steel sheets was varied within the ranges of Al: 45 mass% to 65 mass%, Si: 1.5 mass% to 2.5 mass%, Mg: 1.0 mass% to 4.5 mass%, Mn: 0.00 mass% to 1.0 mass%, Sr: 0.00 mass% to 1.0 mass%, B: 0.00 mass% to 0.05 mass%, Ca: 0.00 mass% to 1.0 mass%, Cr: 0.00 mass% to 0.2 mass%, Ti:
15 0.00 mass% to 0.2 mass%, and V: 0.00 mass% to 0.2 mass%, so as to obtain the composition of the coating of each sample listed in Table 3. The bath temperature of the coating bath was controlled to be 590 °C in the case of Al being in the range of 45 mass% to 55 mass%, and to be 630 °C in the case of Al being 65 mass%, so that the sheet temperature of the base steel sheet at the
20 time of entering the coating bath was the same as the bath temperature of the coating bath. Further, the coating treatment was carried out under the condition that the sheet temperature cooled down to the temperature range of 520 °C to 500 °C in 3 s.

The coating weight of the coating was controlled to be 85 ± 5 g/m² per
25 surface for Samples 1 to 29 and Samples 33 and 34, and 50 g/m² to 125 g/m² per surface for Samples 30 to 32.

[0151] (2) Then, a chemical conversion treatment liquid was applied to the coating of each of the prepared hot-dip Al-Zn-Si-Mg coated steel sheet samples using a bar coater and dried in a hot air oven (heating rate: 60 °C/s, PMT:
30 120 °C) to form a chemical conversion layer. As a result, surface-treated steel sheet samples were prepared as listed in Table 2.

For the chemical conversion treatment liquids, surface-treatment solutions A to F were prepared by dissolving the corresponding components in water as a solvent. The types of the components (resins and metal compounds)
35 contained in the surface-treatment solutions were as follows.

(Resins)

Urethane resin: SUPERFLEX 130, SUPERFLEX 126 (produced by DKS Co. Ltd.)

Acrylic resin: VONCOAT EC-740EF (produced by DIC Corporation)

(Metal compounds)

5 P compound: aluminum dihydrogen triphosphate

Si compound: silica

V compound: sodium metavanadate

Mo compound: molybdic acid

Zr compound: potassium zirconyl carbonate

10 The compositions of the prepared chemical conversion treatment liquids A to F and the coating weight of the formed chemical conversion layers are listed in Table 1. The concentration of each component in Table 1 is the concentration of solid content (in mass%).

[0152] [Table 2]

Chemical conversion treatment	Chemical conversion treatment liquid								Coating weight of chemical conversion layer (g/m ²)
	Resin (mass%)		Metal compound (mass%)						
			Acrylic resin	P compound	Si compound	V compound	Mo compound	Zr compound	
	SUPERFLEX 130	SUPERFLEX 126	VONCOAT EC-740EF	Aluminum dihydrogen triphosphate	Silica	Sodium metavanadate	Molybdic acid	Potassium zirconyl carbonate	
A	8.0	-	2.0	0.5	1.0	1.0	0.3	-	1.6
B	8.0	-	2.0	0.5	1.0	1.0	0.5	-	1.6
C	8.0	-	2.0	0.5	1.0	1.0	0.8	-	1.6
D	9.0	1.0	-	0.5	1.0	1.0	0.3	-	1.6
E	-	-	-	1.5	1.0	1.5	-	6.0	0.7
F	10.0	-	-	-	-	-	-	-	2.0

Table 2

[0153] <Evaluation>

The following evaluations were carried out on the surface-treated steel sheet samples thus obtained. The evaluation results are listed in Table 3.

(1) Composition of coating (coating weight, composition, X-ray
5 diffraction intensity)

For each sample after coating, a 100 mm diameter was punched out, the non-measured surface was sealed with tape, and the coating was dissolved and stripped with a mixture of hydrochloric acid and hexamethylenetetramine, as specified in JIS H 0401:2013. Then, from the mass difference before and
10 after the stripping for each sample, the coating weight of the coating was calculated. The coating weight of each coating according to the calculation is listed in Table 3.

The stripping solution was then filtered and the filtrate and solids were analyzed respectively. Specifically, the filtrate was analyzed by ICP emission
15 spectroscopy to quantify the components other than insoluble Si.

The solids were dried and ashed in a heating furnace at 650 °C and then melted by adding sodium carbonate and sodium tetraborate. In addition, the melt was dissolved in hydrochloric acid and the dissolved solution was analyzed by ICP emission spectroscopy to quantify the insoluble Si. The
20 concentration of Si in the coating was the concentration of soluble Si obtained by filtrate analysis plus the concentration of insoluble Si obtained by solids analysis. The composition of each coating as obtained by the calculations is listed in Table 3.

After shearing each sample to a size of 100 mm × 100 mm, the coating
25 on the evaluation surface was mechanically scraped off until the base steel sheet was exposed. After mixing the obtained powder well, 0.3 g was taken out from the mixture and subjected to qualitative analysis using an X-ray diffractometer (SmartLab by Rigaku Holdings Corporation) under a set of conditions including X-ray used: Cu-K α (wavelength = 1.54178 angstrom), K β ray removal: Ni filter, tube voltage: 40 kV, tube current: 30 mA, scanning
30 speed: 4°/min, sampling interval: 0.020°, divergence slit: 2/3°, solar slit: 5°, detector: high-speed one-dimensional detector (D/teX Ultra). The diffraction intensities of the (111) plane of Mg₂Si with interplanar spacing d of 0.3668 nm and the (111) plane of Si with interplanar spacing d of 0.3135 nm were
35 measured, with each diffraction intensity (cps) being the peak intensity minus the base intensity. Table 3 lists the measurement results.

[0154] (2) Surface appearance

(2-1) Wrinkle defects

The surface appearance of each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets and surface-treated steel sheets obtained was visually
5 inspected to check for the occurrence of wrinkle defects. Further, for each sample, 100 locations were randomly selected from the area excluding 50 mm from both ends of the strip, and the height difference of the coating surface in a 1 mm long range was measured using a laser microscope ("VK-X3000", by Keyence Corporation), and an average value was quantified as the surface
10 shape. The occurrence of wrinkle defects was evaluated based on the presence or absence of wrinkle defects and the surface shape, according to the following criteria.

◎: no wrinkle defects were observed (height difference 5 μm or less)

○: no wrinkle defects were observed (height difference 10 μm or less)

15 ×: wrinkle defect occurrence was observed (height difference exceeds 10 μm)

[0155] (2-2) Dross defects

The surface appearance of each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets obtained was visually inspected, and the presence or
20 absence of dross defects was evaluated according to the following criteria.

○: granular dross adhesion was not observed

×: granular dross adhesion was observed

[0156] (3) Anti-white rust property

Each hot-dip Al-Zn-Si-Mg coated steel sheet sample and each surface-
25 treated steel sheet sample was sheared to a size of 120 mm $\times$ 120 mm, and 10 mm from each edge of the surface to be evaluated as well as each end and the surface not to be evaluated of each sample were sealed with tape so that the exposed size of the surface to be evaluated was 100 mm $\times$ 100 mm. These were used as evaluation samples.

30 Using the evaluation samples, the salt spray test described in JIS Z 2371 was conducted for 90 h, and evaluation was based on the following criteria.

◎: no white rust on the flat parts

○: the area of white rust on the flat parts was less than 10 %

35 ×: the area of white rust on the flat parts was 10 % or more

[0157] (4) Evaluation of corrosion resistance

Each sample of the hot-dip Al-Zn-Si-Mg coated steel sheets and the surface-treated steel sheets was sheared to a size of 120 mm × 120 mm, and 10 mm from each edge of the surface to be evaluated as well as each end and the surface not to be evaluated of each sample were sealed with tape so that the
5 exposed size of the surface to be evaluated was 100 mm × 100 mm. These were used as evaluation samples. In each case, three identical evaluation samples were prepared.

The three evaluation samples prepared as described above were all subjected to the Japanese Automobile Standards Organization Cyclic Corrosion
10 Test (JASO-CCT). After 300 cycles of the accelerated corrosion test starting from wet, the corrosion loss of each sample was measured by the method prescribed in JIS Z 2383 and ISO 8407, and evaluated according to the following criteria.

- ◎: corrosion loss of all three samples was 30 g/m² or less
- 15 ○: corrosion loss of all three samples was 70 g/m² or less
- ×: corrosion loss of at least one sample exceeded 70 g/m²

[0158] [Table 3]

No.		Coating										Chemical conversion treatment	Surface appearance			Anti-white rust property	Corrosion resistance			Remarks
		Chemical composition (mass%)						Coating weight (g/m ²)	Si(111)/Mg ₂ Si(111)	Si(111) (kfps)	Wrinkle defects		Dross defects	Corrosion loss (g/m ²)			Evaluation			
		Al	Si	Mg	Fe	Mn	Other				Mn/Mg			Surface height difference (μm)	Evaluation			N1	N2	
1	55	1.5	4.5	0.60	-	-	-	85	0.00	0.00	A	19.4	○	○	○	-	-	-	Comparative Example	
2	55	1.5	4.4	0.58	0.01	-	-	83	0.00	0.00	A	7.1	○	○	○	23	28	24	Example	
3	55	1.5	4.5	0.58	0.05	-	0.01	83	0.00	0.00	A	6.6	○	○	○	23	23	25	Example	
4	55	1.5	4.5	0.60	0.1	-	0.02	85	0.00	0.00	A	3.8	◎	◎	◎	25	24	26	Example	
5	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	-	3.6	◎	◎	○	44	43	44	Reference example	
6	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	A	3.7	◎	◎	◎	25	26	24	Example	
7	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	B	3.6	◎	◎	◎	24	22	23	Example	
8	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	C	3.3	◎	◎	◎	23	21	27	Example	
9	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	D	4.2	◎	◎	◎	25	24	25	Example	
10	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	E	3.8	◎	◎	◎	26	25	28	Example	
11	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	F	3.7	◎	◎	◎	29	28	26	Example	
12	55	1.5	4.4	0.65	0.5	-	0.11	82	0.00	0.00	A	5.3	◎	◎	◎	23	23	24	Example	
13	55	1.5	4.5	0.75	1.0	-	0.22	84	0.00	0.00	A	9.2	○	○	○	-	-	-	Comparative Example	
14	55	1.5	4.5	0.56	-	1.0 Sr	-	83	0.00	0.00	A	6.9	○	○	○	-	-	-	Comparative Example	
15	55	1.5	4.5	0.62	0.1	0.2 Sr	0.02	87	0.00	0.00	A	4.1	◎	◎	◎	23	23	22	Example	
16	55	1.5	4.5	0.63	0.1	0.05 B 0.2 Ti	0.02	85	0.00	0.00	A	3.7	◎	◎	◎	28	38	37	Example	
17	55	1.5	4.5	0.61	0.1	1.0 Ca	0.02	84	0.00	0.00	A	3.9	◎	◎	◎	26	27	28	Example	
18	55	1.5	4.5	0.60	0.1	0.5 Ca 0.2 Cr	0.02	86	0.00	0.00	A	4.1	◎	◎	◎	25	24	25	Example	
19	55	1.5	4.5	0.61	0.1	0.2 V	0.02	84	0.00	0.00	A	4.0	◎	◎	◎	24	25	28	Example	
20	55	1.5	1.0	0.58	0.3	-	0.30	85	no Mg ₂ Si	0.90	A	3.9	◎	◎	◎	76	71	72	Example	
21	55	1.5	2.0	0.59	0.3	-	0.15	85	0.56	0.63	A	3.5	◎	◎	◎	43	44	41	Example	
22	55	2.5	1.1	0.59	0.01	-	0.01	82	no Mg ₂ Si	3.26	A	5.5	○	○	○	77	84	83	Example	
23	55	2.5	1.1	0.59	0.2	-	0.18	83	no Mg ₂ Si	3.44	A	3.6	◎	◎	◎	78	81	86	Example	
24	55	2.5	2.0	0.56	0.2	-	0.10	82	3.18	2.43	A	3.4	◎	◎	◎	73	74	68	Example	
25	55	2.5	3.4	0.61	0.2	-	0.06	86	0.11	0.32	A	3.9	◎	◎	◎	43	41	42	Example	
26	55	2.5	4.5	0.57	0.2	-	0.04	85	0.12	0.19	A	3.4	◎	◎	◎	38	37	32	Example	
27	55	2.5	6.4	0.57	0.2	-	0.03	85	0.02	0.10	A	4.8	◎	◎	◎	37	42	31	Example	
28	55	2.5	9.7	0.61	0.2	-	0.02	87	0.00	0.00	A	5.0	◎	◎	◎	29	28	29	Example	
29	55	2.5	9.8	0.58	0.1	-	0.01	87	0.00	0.00	A	6.2	◎	◎	◎	29	29	29	Example	
30	55	1.5	4.5	0.61	0.3	-	0.07	51	0.00	0.00	A	3.3	◎	◎	◎	21	21	25	Example	
31	55	1.5	4.5	0.61	0.3	-	0.07	100	0.00	0.00	A	4.3	◎	◎	◎	21	21	23	Example	
32	55	1.5	4.5	0.61	0.3	-	0.07	125	0.00	0.00	A	4.5	◎	◎	◎	23	26	22	Example	
33	45	1.5	4.5	0.49	0.03	-	0.01	85	0.00	0.00	A	7.8	○	○	○	23	26	22	Example	
34	65	1.5	4.5	0.81	0.03	-	0.01	86	0.00	0.00	A	5.8	○	○	○	23	26	22	Example	

[0159] The results in Table 3 demonstrate that the samples of Examples according to the present disclosure have superior surface appearance compared to the samples of Comparative Examples.

[0160] [Example 3: Samples 1 to 37]

5 (1) In each case, a cold-rolled steel sheet having a thickness of 0.8 mm, produced by a conventional method, was used as a base steel sheet, and was subjected to degreasing treatment, annealing treatment, and coating treatment in a continuous galvanizing line, thereby producing Samples 1 to 37 of hot-dip Al-Zn-Si-Mg coated steel sheets under the conditions listed in Table 5.

10 The composition of the coating bath used in producing the hot-dip Al-Zn-Si-Mg coated steel sheets was varied within the ranges of Al: 45 mass% to 65 mass%, Si: 1.5 mass% to 2.5 mass%, Mg: 1.0 mass% to 4.5 mass%, Mn: 0.00 mass% to 1.0 mass%, Sr: 0.00 mass% to 1.0 mass%, B: 0.00 mass% to 0.05 mass%, Ca: 0.00 mass% to 1.0 mass%, Cr: 0.00 mass% to 0.2 mass%, Ti:
15 0.00 mass% to 0.2 mass%, and V: 0.00 mass% to 0.2 mass%, so as to obtain the composition of the coating of each sample listed in Table 5. The bath temperature of the coating bath was controlled to be 590 °C in the case of Al being in the range of 45 mass% to 55 mass%, and to be 630 °C in the case of Al being 65 mass%, so that the sheet temperature of the base steel sheet at the
20 time of entering the coating bath was the same as the bath temperature of the coating bath. Further, the coating treatment was carried out under the condition that the sheet temperature cooled down to the temperature range of 520 °C to 500 °C in 3 s.

 The coating weight of the coating was controlled to be 85 ± 5 g/m² per
25 surface for Samples 1 to 32 and Samples 36 and 37, and 50 g/m² to 125 g/m² per surface for Samples 33 to 35.

[0161] (2) Then, a chemical conversion treatment liquid listed in Table 4 was applied to the coating of each of the prepared hot-dip coated steel sheet samples using a bar coater and dried in a hot-air drying furnace (peak metal
30 temperature: 90 °C) to form a chemical conversion layer having a coating weight of 0.1 g/m².

 The chemical conversion treatment liquids used were chemical conversion treatment liquids with a pH of 8 to 10, prepared by dissolving the corresponding components in water as a solvent. The types of the components
35 (resin components and inorganic compounds) contained in the chemical conversion treatment liquids were as follows.

(Resin components)

Resin A: a mixture of (a) an anionic polyurethane resin having an ester bond (SUPERFLEX 210, produced by DKS Co. Ltd. and (b) an epoxy resin having a bisphenol skeleton (Yuka Resin RE-1050, produced by Yoshimura Oil
5 Chemical Co., Ltd.) mixed at a content mass ratio, (a):(b), of 50:50

Resin B: acrylic resin (VONCOAT EC-740EF, produced by DIC Corporation)

(Inorganic compounds)

Vanadium compound: organic vanadium compound chelated with
10 acetylacetone

Zirconium compound: ammonium zirconium carbonate

Fluorine compound: ammonium fluoride

[0162] (3) A primer paint was applied to each chemical conversion layer formed as described above using a bar coater, and baking was carried out at an
15 end-point temperature of each steel sheet of 230 °C for a baking time of 35 s to form primer paint layers with the chemical compositions as listed in Table 4. Subsequently, a top coating paint composition was applied to each primer paint layer thus formed using a bar coater, and baking was carried out at an end-point temperature of each steel sheet in the range from 230 °C to 260 °C
20 for a baking time of 40 s to form top coatings with the resin conditions and layer thicknesses as listed in Table 4. In this way, prepainted steel sheet samples were prepared.

The primer paint was obtained by mixing the components and stirring the mixture in a ball mill for approximately 1 h. The resin components and
25 inorganic compounds of each primer paint layer were as follows.

(Resin components)

Resin α : urethane-modified polyester resin (obtained by reacting 455 mass parts of polyester resin with 45 mass parts of isophorone diisocyanate; resin acid number was 3, number-average molecular weight was 5,600, and
30 hydroxyl group value was 36) cured with blocked isocyanate.

The polyester resin to be urethane modified was prepared under the following conditions. In a flask equipped with a stirrer, a rectifying column, a water separator, a cooling pipe, and a thermometer, 320 parts by mass of isophthalic acid, 200 parts by mass of adipic acid, 60 parts by mass of trimethylolpropane, and 420 parts by mass of cyclohexanedimethanol were
35 supplied, heated, and stirred. The temperature was increased at a constant rate

- from 160 °C to 230 °C over a period of 4 h while allowing the condensation water generated to evaporate out of the system. After the temperature reached 230 °C, 20 parts by mass of xylene were added gradually, and the condensation reaction was continued while maintaining the temperature at 230 °C. The
- 5 reaction was terminated when the acid number became 5 or less, and after cooling to 100 °C, 120 parts by mass of Solvesso 100 (trade name, produced by ExxonMobil, an aromatic hydrocarbon solvent having a high boiling point) and 100 parts by mass of butyl Cellosolve were added to obtain a polyester resin solution.
- 10 Resin β : urethane-cured polyester resin ("Evaclad 4900", produced by Kansai Paint Co., Ltd.)
- (Inorganic compounds)
- Vanadium compound: magnesium vanadate
- Phosphate compound: calcium phosphate
- 15 Magnesium oxide compound: magnesium oxide
- The following paints were used for the resins used in the top coating layers listed in Table 4.
- Resin I: melamine-cured polyester paint (Precolor HD0030HR, produced by BASF Japan Ltd.)
- 20 Resin II: organosol baking-type fluororesin paint (Precolor #8800HR, produced by BASF Japan Ltd.) with the mass ratio of polyvinylidene fluoride to acrylic resin of 80:20

[0163] [Table 4]

Paint layer conditions	Chemical conversion layer					Primer paint layer					Top coating layer		Remarks
	Resin		Vanadium compound (mass%)	Zirconium compound (mass%)	Fluorine compound (mass%)	Resin		Vanadium compound (mass%)	Phosphate compound (mass%)	Magnesium oxide compound (mass%)	Other (pigments, etc.) (mass%)	Type	
	Type	mass%				Type	mass%					Paint layer thickness μm	
T1	A	30	6	50	1	α	60	12	12	6	10	I	Example
T2	A	30	6	50	1	α	60	12	12	6	10	II	Example
T3	B	30	6	50	1	α	60	12	12	6	10	I	Comparative Example
T4	A	30	0	50	1	α	60	12	12	6	10	I	Comparative Example
T5	A	30	6	0	1	α	60	12	12	6	10	I	Comparative Example
T6	A	30	6	50	0	α	60	12	12	6	10	I	Comparative Example
T7	A	30	6	50	1	β	60	12	12	6	10	I	Comparative Example
T8	A	30	6	50	1	α	60	0	12	6	10	I	Comparative Example
T9	A	30	6	50	1	α	60	12	0	6	10	I	Comparative Example
T10	A	30	6	50	1	α	60	12	12	0	10	I	Comparative Example

Table 4

[0164] <Evaluation>

The following evaluations were carried out on the prepainted steel sheet samples thus obtained. The evaluation results are listed in Table 5.

(1) Composition of coating (coating weight, composition, X-ray
5 diffraction intensity)

For each sample after coating, a 100 mm diameter was punched out, the non-measured surface was sealed with tape, and the coating was dissolved and stripped with a mixture of hydrochloric acid and hexamethylenetetramine, as specified in JIS H 0401:2013. Then, from the mass difference before and
10 after the stripping for each sample, the coating weight of the coating was calculated. The coating weight of each coating according to the calculation is listed in Table 5.

The stripping solution was then filtered and the filtrate and solids were analyzed respectively. Specifically, the filtrate was analyzed by ICP emission
15 spectroscopy to quantify the components other than insoluble Si.

The solids were dried and ashed in a heating furnace at 650 °C and then melted by adding sodium carbonate and sodium tetraborate. In addition, the melt was dissolved in hydrochloric acid and the dissolved solution was analyzed by ICP emission spectroscopy to quantify the insoluble Si. The
20 concentration of Si in the coating was the concentration of soluble Si obtained by filtrate analysis plus the concentration of insoluble Si obtained by solids analysis. The composition of each coating as obtained by the calculations is listed in Table 5.

After shearing each sample to a size of 100 mm × 100 mm, the coating
25 on the evaluation surface was mechanically scraped off until the base steel sheet was exposed. After mixing the obtained powder well, 0.3 g was taken out from the mixture and subjected to qualitative analysis using an X-ray diffractometer (SmartLab by Rigaku Holdings Corporation) under a set of conditions including X-ray used: Cu-K α (wavelength = 1.54178 angstrom), K β ray removal: Ni filter, tube voltage: 40 kV, tube current: 30 mA, scanning
30 speed: 4°/min, sampling interval: 0.020°, divergence slit: 2/3°, solar slit: 5°, detector: high-speed one-dimensional detector (D/teX Ultra). The diffraction intensities of the (111) plane of Mg₂Si with interplanar spacing d of 0.3668 nm and the (111) plane of Si with interplanar spacing d of 0.3135 nm were
35 measured, with each diffraction intensity (cps) being the peak intensity minus the base intensity.

[0165] (2) Surface appearance

(2-1) Wrinkle defects

The surface appearance of each sample of the prepainted steel sheets obtained was visually inspected to check for the occurrence of wrinkle defects.

5 Further, for each sample, 100 locations were randomly selected from the area excluding 50 mm from both ends of the strip, and the height difference of the coating surface in a 1 mm long range was measured using a laser microscope ("VK-X3000", by Keyence Corporation), and an average value was quantified as the surface shape. The occurrence of wrinkle defects was evaluated based
10 on the presence or absence of wrinkle defects and the surface shape, according to the following criteria.

◎: no wrinkle defects were observed (height difference 5 mm or less)

○: no wrinkle defects were observed (height difference 10 mm or less)

×: wrinkle defect occurrence was observed (height difference exceeds
15 10 μm)

[0166] (2-2) Dross defects

The surface appearance of each sample of the prepainted steel sheet obtained was visually inspected, and the presence or absence of dross defects was evaluated according to the following criteria.

20 ○: granular dross adhesion was not observed

×: granular dross adhesion was observed

[0167] (3) Evaluation of corrosion resistance

Each sample of the prepainted steel sheets obtained was sheared to a size of 120 mm x 120 mm, and then 10 mm from the edges of three of the four
25 sides of the evaluation surface, as well as the end surface and the non-target surface, were sealed with tape, and only one edge was not sealed with tape, leaving the sheared end surface exposed, and this was used as the evaluation sample. The shearing was carried out so that the burrs on the sheared end surface faced the surface to be evaluated.

30 The evaluation samples were subjected to the Japanese Automobile Standards Organization Cyclic Corrosion Test (JASO-CCT). The accelerated corrosion test was started from wet, and every 20 cycles, the sample was removed, washed with water, dried, and then visually inspected. The number of cycles at which red rust was confirmed on the sheared edge of one side that
35 was not sealed with tape was evaluated according to the following criteria.

◎: number of cycles to initial red rust in 3 samples $\geq$ 600 cycles

○: number of cycles to initial red rust in 3 samples ≥ 400 cycles

×: number of cycles to initial red rust in one or more samples < 400

cycles

[0168] [Table 5]

No.		Coating										Painting conditions	Painted appearance		Corrosion resistance				Remarks
		Chemical composition (mass%)					Coating weight (g/m ²)	Si(111)/Mg ₂ Si(111) (keps)	Si(111)	Wrinkle defects			Dross defects	Cycles to initial red rust (cycles)			Evaluation		
		Al	Si	Mg	Fe	Mn				Other	Mn/Mg			Surface height difference (μm)	Evaluation	N1		N2	
1	55	1.5	4.5	0.60	-	-	-	85	0.00	0.00	T1	24.8	○	○	-	-	-	-	Comparative Example
2	55	1.5	4.4	0.58	0.01	-	-	83	0.00	0.00	T1	8.6	○	○	680	700	660	680	Example
3	55	1.5	4.5	0.58	0.05	-	0.01	83	0.00	0.00	T1	7.5	○	○	700	680	700	693	Example
4	55	1.5	4.5	0.60	0.1	-	0.02	85	0.00	0.00	T1	3.5	◎	◎	620	660	640	640	Example
5	55	1.5	4.5	0.61	0.3	-	0.07	85	0.00	0.00	T1	3.6	○	○	640	680	660	660	Example
6	55	1.5	4.4	0.65	0.5	-	0.11	82	0.00	0.00	T1	5.1	○	○	700	700	680	693	Example
7	55	1.5	4.5	0.75	1.0	-	0.22	84	0.00	0.00	T1	9.5	○	○	-	-	-	-	Comparative Example
8	55	1.5	4.5	0.56	-	1.0 Sr	-	83	0.00	0.00	T1	6.8	○	○	-	-	-	-	Comparative Example
9	55	1.5	4.5	0.62	0.1	0.2 Sr	0.02	87	0.00	0.00	T1	3.9	◎	◎	680	700	680	687	Example
10	55	1.5	4.5	0.63	0.1	0.05 B 0.2 Ti	0.02	85	0.00	0.00	T1	4.1	◎	◎	700	700	700	700	Example
11	55	1.5	4.5	0.61	0.1	1.0 Ca	0.02	84	0.00	0.00	T1	4.5	◎	◎	720	720	740	727	Example
12	55	1.5	4.5	0.60	0.1	0.5 Ca 0.2 Cr	0.02	86	0.00	0.00	T1	4.5	◎	◎	740	720	700	720	Example
13	55	1.5	4.5	0.61	0.1	0.2 V	0.02	84	0.00	0.00	T1	4.2	◎	◎	700	720	720	713	Example
14	55	1.5	0.9	0.58	0.3	-	0.33	85	no Mg ₂ Si	0.90	T1	3.2	◎	◎	420	440	440	433	Example
15	55	1.5	2.0	0.59	0.3	-	0.15	85	0.56	0.63	T1	3.3	◎	◎	580	600	540	573	Example
16	55	1.5	2.0	0.59	0.3	-	0.15	85	0.56	0.63	T2	3.4	◎	◎	560	620	600	593	Example
17	55	1.5	2.0	0.59	0.3	-	0.15	81	0.56	0.63	T3	3.9	◎	◎	400	380	420	400	Comparative Example
18	55	1.5	2.0	0.59	0.3	-	0.15	85	0.56	0.63	T4	3.5	◎	◎	380	380	420	393	Comparative Example
19	55	1.5	2.0	0.59	0.3	-	0.15	83	0.56	0.63	T5	3.6	◎	◎	380	360	400	380	Comparative Example
20	55	1.5	2.0	0.59	0.3	-	0.15	84	0.56	0.63	T6	3.5	◎	◎	340	360	340	347	Comparative Example
21	55	1.5	2.0	0.59	0.3	-	0.15	86	0.56	0.63	T7	3.2	◎	◎	320	320	320	320	Comparative Example
22	55	1.5	2.0	0.59	0.3	-	0.15	83	0.56	0.63	T8	3.1	◎	◎	340	360	360	353	Comparative Example
23	55	1.5	2.0	0.59	0.3	-	0.15	85	0.56	0.63	T9	3.8	◎	◎	340	360	420	373	Comparative Example
24	55	1.5	2.0	0.59	0.3	-	0.15	82	0.56	0.63	T10	3.6	◎	◎	360	360	420	380	Comparative Example
25	55	2.5	1.1	0.59	0.01	-	0.01	82	no Mg ₂ Si	3.26	T1	5.4	○	○	420	440	440	433	Comparative Example
26	55	2.5	1.1	0.59	0.2	-	0.18	83	no Mg ₂ Si	3.44	T1	3.4	◎	◎	440	420	400	420	Example
27	55	2.5	2.0	0.56	0.2	-	0.10	82	3.18	2.43	T1	3.5	◎	◎	460	480	480	473	Example
28	55	2.5	3.4	0.61	0.2	-	0.06	86	0.11	0.32	T1	3.2	◎	◎	540	520	540	533	Example
29	55	2.5	4.5	0.57	0.2	-	0.04	85	0.12	0.19	T1	3.0	◎	◎	520	560	560	547	Example
30	55	2.5	6.4	0.57	0.2	-	0.03	85	0.02	0.1	T1	4.5	◎	◎	540	520	560	540	Example
31	55	2.5	9.7	0.61	0.2	-	0.02	87	0.00	0.00	T1	4.6	◎	◎	520	560	540	540	Example
32	55	2.5	9.8	0.58	0.1	-	0.01	87	0.00	0.00	T1	5.2	○	○	520	520	540	527	Example
33	55	1.5	4.5	0.61	0.3	-	0.07	51	0.00	0.00	T1	3.3	◎	◎	620	620	620	620	Example
34	55	1.5	4.5	0.61	0.3	-	0.07	100	0.00	0.00	T1	4.5	◎	◎	680	640	620	647	Example
35	55	1.5	4.5	0.61	0.3	-	0.07	125	0.00	0.00	T1	4.5	◎	◎	740	760	720	740	Example
36	45	1.5	4.5	0.49	0.03	-	0.01	85	0.00	0.00	T1	7.6	○	○	680	700	680	687	Example
37	65	1.5	4.5	0.81	0.03	-	0.01	86	0.00	0.00	T1	5.5	○	○	680	680	660	673	Example

Table 5

[0169] The results in Table 5 demonstrate that the samples of Examples according to the present disclosure have superior surface appearance and corrosion resistance compared to the samples of Comparative Examples.

5 **INDUSTRIAL APPLICABILITY**

[0170] According to the present disclosure, it is possible to provide a hot-dip Al-Zn-Si-Mg coated steel sheet that is free from other defects such as dross defects, suppresses the occurrence of wrinkle defects, and has an excellent surface appearance.

10 Further, according to the present disclosure, it is possible to provide a surface-treated steel sheet having excellent surface appearance and anti-white rust property, and a prepainted steel sheet having excellent surface appearance and excellent corrosion resistance.

CLAIMS

- [Claim 1] A hot-dip Al-Zn-Si-Mg coated steel sheet comprising a coating, wherein
- 5 the coating has a composition containing Al: 45 mass% to 65 mass%, Si: 1.0 mass% to 3.0 mass%, Mg: 1.0 mass% to 10.0 mass%, and Mn: 0.01 mass% to 0.5 mass%, with the balance being Zn and inevitable impurity, and a height difference of a steel sheet surface per mm of length is 10 μ m or less in an area excluding 50 mm from both ends of the steel sheet.
- 10
- [Claim 2] The hot-dip Al-Zn-Si-Mg coated steel sheet according to claim 1, wherein Mn content in the coating is 0.1 mass% to 0.3 mass%.
- [Claim 3] The hot-dip Al-Zn-Si-Mg coated steel sheet according to claim
- 15 1 or 2, further comprising an alloy layer containing Mn at an interface between the coating and a base steel sheet.
- [Claim 4] The hot-dip Al-Zn-Si-Mg coated steel sheet according to any one of claims 1 to 3, wherein the coating further contains one or more elements
- 20 selected from B, Ca, Ti, V, Cr, Sr, Mo, In, Sn, Sb, Ce, or Bi in a total amount of 0.01 mass% to 3.0 mass%.
- [Claim 5] A surface-treated steel sheet comprising the coating according to any one of claims 1 to 4, and a chemical conversion layer formed on the
- 25 coating, wherein the chemical conversion layer contains at least one resin selected from an epoxy resin, a urethane resin, an acrylic resin, an acrylic silicon resin, an alkyd resin, a polyester resin, a polyalkylene resin, an amino resin, or a fluororesin, and at least one metal compound selected from a P compound, a Si
- 30 compound, a Co compound, a Ni compound, a Zn compound, an Al compound, a Mg compound, a V compound, a Mo compound, a Zr compound, a Ti compound, or a Ca compound.
- [Claim 6] A prepainted steel sheet comprising a paint layer formed either
- 35 directly on the coating according to any one of claims 1 to 4, or on a chemical conversion layer on top of the coating, wherein

the chemical conversion layer contains: a resin component containing (a) an anionic polyurethane resin having an ester bond and (b) an epoxy resin having a bisphenol skeleton, in a total amount of 30 mass% to 50 mass%, in which a content ratio of (a) to (b), (a):(b), is in a range from 3:97 to 60:40 by mass; and an inorganic compound containing 2 mass% to 10 mass% of a vanadium compound, 40 mass% to 60 mass% of a zirconium compound, and 0.5 mass% to 5 mass% of a fluorine compound, and

the paint layer includes at least a primer paint layer, the primer paint layer containing: a polyester resin having a urethane bond; and an inorganic compound containing a vanadium compound, a phosphoric acid compound, and a magnesium oxide.