

DESCRIPTION

TITLE

HOT-DIP AL-ZN ALLOY COATED STEEL SHEET AND METHOD OF PRODUCING SAME

TECHNICAL FIELD

[0001] This disclosure relates to a hot-dip Al-Zn alloy coated steel sheet having stable and excellent workability and corrosion resistance at processed parts, and a method of producing the same.

BACKGROUND

[0002] Hot-dip Al-Zn alloy coated steel sheets, typically represented by 55 % Al-Zn alloy coated steel sheets, are known to exhibit high corrosion resistance among hot-dip galvanized steel sheets, because they combine the sacrificial protection effect of Zn with the high corrosion resistance of Al, as described, for example, in JP S46-7161 B (PTL 1).

Hot-dip Al-Zn coated steel sheets, owing to their excellent corrosion resistance, are mainly used in the field of building materials such as roofs and walls that are exposed to outdoor environments for a long period of time, and the field of civil engineering and construction such as guardrails, wiring and piping, and soundproof walls. In recent years, the demand for hot-dip Al-Zn alloy coated steel sheets has been increasing due to the growing need for materials with excellent corrosion resistance and materials with maintenance-free properties to be used in harsher operating environments, such as in acid rain caused by air pollution, in snowy areas where snow-melting agents are applied to prevent roads from freezing, and in coastal area development.

[0003] The coating of the hot-dip Al-Zn alloy coated steel sheet is characterized by a structure composed of dendritically solidified Al containing supersaturated Zn (α -Al phase) and a Zn-Al eutectic structure present in the interdendritic regions, with multiple layers of the α -Al phase stacked in the thickness direction of the coating. Due to this characteristic coating structure, the corrosion path from the surface becomes more complex, making it more difficult for corrosion to proceed. As a result, it is also known that hot-dip Al-Zn alloy coated steel sheets can achieve excellent corrosion resistance compared to hot-dip galvanized steel sheets with the same coating thickness.

[0004] In general, hot-dip Al-Zn alloy coated steel sheets are produced by

5 It is common practice to add Si to the molten bath, in addition to Al and Zn at predetermined concentrations, in order to suppress excessive growth of the interfacial alloy layer formed at the interface between the base steel sheet and the coating. Owing to the effect of Si, the thickness of the interfacial alloy layer in hot-dip Al-Zn alloy coated steel sheets can be controlled to approximately 1 μm to 5 μm . It is known that, when the coating thickness is the same, suppressing the growth of the interfacial alloy layer leads to improved corrosion resistance, since a thinner interfacial alloy layer allows the main layer, which exhibits high corrosion resistance, to be thicker.

15 CITATION LIST

Patent Literature

[0005] PTL 1: JP S46-7161 B

PTL 2: JP 2004-285387 A

PTL 3: JP 2016-540885 A

20 SUMMARY

(Technical Problem)

[0006] However, it is known that when hot-dip Al-Zn alloy coated steel sheets are subjected to processing such as bending, cracks may occur in the coating at the processed parts depending on the degree of deformation. In hot-dip Al-Zn alloy coated steel sheets, the aforementioned thick interfacial alloy layer tends to serve as an initiation point for cracks, and the interdendritic regions in the coating act as crack propagation paths. As a result, even when the same degree of bending deformation is applied, cracks tend to open wider in hot-dip Al-Zn alloy coated steel sheets than in hot-dip galvanized steel sheets with the same coating thickness. Therefore, in applications involving a high degree of deformation, there have been problems such as deterioration in appearance due to the formation of large cracks visible to the naked eye, and a significant reduction in corrosion resistance at the cracked areas where the base steel sheet is exposed, compared to areas without cracks (i.e., reduced corrosion resistance at processed parts).

[0007] In hot-dip coating processes, it is generally known that impurities are inevitably introduced into the molten bath, and hot-dip Al-Zn alloy coatings are no exception. Impurities introduced into the coating may originate from impurities contained in the coating materials or from elution from the base
5 steel sheet or in-bath equipment, and include elements such as Fe, Cr, Ni, Cu, Co, W, Mg, and Ca, which are therefore inevitably contained in the coating.

In recent years, the production volume of hot-dip Zn-Al-Mg alloy coated steel sheets and hot-dip Al-Zn-Si-Mg alloy coated steel sheets with high corrosion resistance has been increasing. With the expansion in circulation
10 of Zn materials containing high concentrations of Mg that are produced through the recycling of dross generated during the production of such coated sheets, there has been a growing tendency for Mg to be inevitably introduced into the molten bath and, consequently, into the coating as an impurity.

[0008] As described above, inevitable impurities in the coating may cause
15 deterioration in the properties of hot-dip coated steel sheets, such as appearance, corrosion resistance, and workability. Whether or not impurities affect these properties is often determined by the composition of the coating and the concentration of the impurities. In other words, even the same impurity component may be harmful or harmless to the properties of the coated
20 steel sheet. Therefore, for each type of hot-dip coated steel sheet, the influence of impurities on the properties has been investigated, and technologies have been developed to control the impurity concentration to stably achieve the required properties.

For example, JP 2004-285387 A (PTL 2) describes a hot-dip galvanized
25 steel sheet having excellent appearance, comprising, in mass%, Al: 0.10 % to 0.6 % and Bi: 0.03 % to 0.3 %, with the balance being Zn and inevitable impurities, where the content of each of Pb, Sn, and Cd as the inevitable impurities is controlled to 0.002 %.

Further, JP 2016-540885 A (PTL 3) describes a hot-dip Zn-Al-Mg alloy
30 coated steel sheet having excellent corrosion resistance, comprising Al: 4.4 % to 5.6 % and Mg: 0.3 % to 0.56 %, with the balance being Zn and inevitable impurities, where it is controlled so that Ni is not included as an inevitable impurity.

[0009] However, the technologies described in PTLs 2 and 3 focus on
35 improving corrosion resistance, and do not sufficiently take into account the effects of inevitable impurities on workability and corrosion resistance at

processed parts in hot-dip Zn-Al alloy coated steel sheets that do not contain Mg, or in hot-dip Al-Zn alloy coated steel sheets with high Al content. Accordingly, there has been a demand for the development of technologies that can more reliably and stably achieve excellent workability and corrosion resistance at processed parts.

In addition, not limited to hot-dip Al-Zn alloy coated steel sheets, impurity control in the production of hot-dip coated steel sheets has mostly been limited to concentration control, and no established technologies have been developed for controlling impurity morphology, such as size. There has been a strong demand for the development of technologies capable of more stably achieving excellent workability and corrosion resistance at processed parts.

[0010] It could thus be helpful to provide a hot-dip Al-Zn alloy coated steel sheet having reliably and stably excellent workability and corrosion resistance at processed parts, and a method of producing the same.

(Solution to Problem)

[0011] We conducted investigations to solve the above problems and found that, in hot-dip Al-Zn alloy coated steel sheets, it is important not only to control the concentrations of Al, Zn, and Si in the composition of the hot-dip Al-Zn coating, but also to control the concentrations of elements contained as impurities. Particularly, we found that by appropriately controlling the content of Mg, which is present as an impurity, the deterioration of corrosion resistance can be effectively suppressed. Furthermore, we found that by appropriately controlling the size of Mg-Zn based compounds present as impurities in the coating, the deterioration of both workability and corrosion resistance at processed parts can be more effectively suppressed.

[0012] The present disclosure is based on the above findings, and primary features thereof are as follows.

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

the coating has a chemical composition containing (consisting of) Al: 45 mass% to 65 mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being Zn and inevitable impurities, and

a Mg content in the inevitable impurities is less than 0.5 mass% with respect to the total mass of the coating.

[0013] 2. The hot-dip Al-Zn alloy coated steel sheet according to 1., wherein

the coating contains Mg-Zn based compounds, and a major axis length of the Mg-Zn based compounds is less than 10 μm .

[0014] 3. The hot-dip Al-Zn alloy coated steel sheet according to 1., wherein the coating contains no Mg-Zn based compounds.

5 **[0015]** 4. The hot-dip Al-Zn alloy coated steel sheet according to any one of 1. to 3., wherein the coating further contains, in total, 0.01 mass% to 3.0 mass% of at least one selected from the group consisting of B, Ca, Ti, V, Cr, Mn, Sr, Mo, In, Sn, Sb, Ce, and Bi.

5. The hot-dip Al-Zn alloy coated steel sheet according to any one of
10 1. to 4., wherein a diffraction intensity of MgZn_2 in the coating measured by X-ray diffraction satisfies the following relational expression (1):

$$\text{MgZn}_2(100) = 0 \quad \dots(1)$$

where $\text{MgZn}_2(100)$ is a diffraction intensity from a (100) plane of MgZn_2 having an interplanar spacing $d = 0.4510 \text{ nm}$.

15 **[0016]** 6. A method of producing a hot-dip Al-Zn alloy coated steel sheet comprising a coating, wherein

the method comprises forming the coating on a base steel sheet using a molten bath having a chemical composition containing (consisting of) Al: 45 mass% to 65 mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being
20 Zn and inevitable impurities, and

a Mg content in the inevitable impurities in the molten bath is controlled to be less than 0.5 mass% with respect to the total mass of the molten bath.

7. The method of producing a hot-dip Al-Zn alloy coated steel sheet
25 according to 6., wherein the molten bath further contains, in total, 0.01 mass% to 3.0 mass% of at least one selected from the group consisting of B, Ca, Ti, V, Cr, Mn, Sr, Mo, In, Sn, Sb, Ce, and Bi.

(Advantageous Effect)

[0017] According to the present disclosure, it is possible to provide a hot-dip
30 Al-Zn alloy coated steel sheet having reliably and stably excellent workability and corrosion resistance at processed parts, and a method of producing the same.

BRIEF DESCRIPTION OF THE DRAWINGS

35 **[0018]** In the accompanying drawings:

FIG. 1 is an enlarged schematic view of a cross section of a hot-dip Al-

Zn alloy coated steel sheet according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

5 **[0019]** (Hot-dip Al-Zn alloy coated steel sheet)

As illustrated in FIG. 1, a hot-dip Al-Zn alloy coated steel sheet of the present disclosure comprises a coating 20 on the surface of a base steel sheet 10.

The coating 20 has a chemical composition containing Al: 45 mass% to 65 mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being Zn and inevitable impurities.

[0020] The Al content in the coating is 45 mass% to 65 mass%, preferably 50 mass% to 60 mass%, in view of the balance between corrosion resistance and operability. This is because, when the Al content in the coating is 45 mass% or more, dendritic solidification of Al occurs, and a coating structure mainly composed of a dendritic solidification structure of the α -Al phase can be obtained. The dendritic solidification structure is stacked in the thickness direction of the coating, which complicates the corrosion path and improves the corrosion resistance of the coating itself. In addition, the more the dendritic portions of the α -Al phase are stacked, the more complex the corrosion path becomes, making it more difficult for corrosion to reach the base steel sheet, thereby improving corrosion resistance. Therefore, the Al content in the coating is preferably 50 mass% or more. On the other hand, when the Al content in the coating exceeds 65 mass%, the structure changes such that most of the Zn is dissolved into the α -Al phase, making it difficult to suppress the dissolution reaction of the α -Al phase, which leads to a deterioration in the corrosion resistance of the hot-dip Al-Zn alloy coating. Therefore, the Al content in the coating is required to be 65 mass% or less, and preferably 60 mass% or less.

[0021] Further, Si in the coating is added mainly for the purpose of suppressing the growth of Fe-Al and/or Fe-Al-Si interfacial alloy layers formed at the interface with the base steel sheet, so as not to impair the adhesion between the coating and the steel sheet. In fact, when a steel sheet is immersed in an Al-Zn molten bath containing Si, the Fe on the steel sheet surface reacts with the Al and Si in the bath to form Fe-Al and/or Fe-Al-Si intermetallic compound layers at the interface between the base steel sheet and

the coating. Since the Fe-Al-Si alloy grows more slowly than the Fe-Al alloy, the higher the proportion of the Fe-Al-Si alloy, the more the overall growth of the interfacial alloy layer is suppressed. Therefore, the Si content in the coating is required to be 1.0 mass% or more. On the other hand, when the Si content in the coating exceeds 3.0 mass%, not only does the effect of suppressing the growth of the interfacial alloy layer become saturated, but the presence of excessive Si phases in the coating also deteriorates workability. Therefore, the Si content is set to 3.0 % or less.

5 [0022] The coating contains Zn and inevitable impurities, where the inevitable impurities include Fe. This Fe is inevitably contained in the coating as a result of being eluted from the steel sheet or in-bath equipment into the molten bath and being supplied through diffusion from the base steel sheet during the formation of the interfacial alloy layer. The Fe content in the coating is typically about 0.3 mass% to 2.0 mass%.

15 Other inevitable impurities include Cr, Ni, Cu, Co, W, Mg, Ca, and the like. These elements may be inevitably contained in the coating due to various factors, such as elution into the molten bath from the base steel sheet, stainless-steel in-bath equipment, or thermal sprayed coatings of W-C or Co-Cr-W alloy applied to the equipment; the presence of these elements as impurities in the metal ingots used as raw materials for the molten bath; or the use of pots or in-bath equipment previously employed in the production of coated steel sheets to which such elements were intentionally added.

20 [0023] In the hot-dip Al-Zn alloy coated steel sheet of the present disclosure, the Mg content among the inevitable impurities is less than 0.5 mass% with respect to the total mass of the coating. Since Mg contained in the coating may cause deterioration in the workability and corrosion resistance at processed parts of the hot-dip Al-Zn alloy coated steel sheet, it is possible to suppress such deterioration by not only appropriately controlling the Al, Zn, and Si contents in the coating as described above, but also by suppressing the Mg content as an inevitable impurity. From the same viewpoint, it is preferable that the Mg content among the inevitable impurities be 0.3 mass% or less with respect to the total mass of the coating, and more preferably 0.1 mass% or less. The lower the Mg content in the coating, the better the corrosion resistance of the hot-dip Al-Zn alloy coated steel sheet of the present disclosure. Therefore, the lower limit is not specified. However, it is technically difficult to reduce the Mg content in the coating to a completely

25
30
35

zero level (0.000 mass%), and thus the practical lower limit of the Mg content in the coating is approximately 0.001 mass%.

[0024] When Mg is contained among the inevitable impurities, Mg-Zn based compounds may be present as impurities in the coating of the hot-dip Al-Zn alloy coated steel sheet. Among these, MgZn_2 is commonly formed as the Mg-Zn based compound, but the compound is not limited thereto and may also include other binary intermetallic compounds such as $\text{Mg}_2\text{Zn}_{11}$, or ternary intermetallic compounds such as $\text{Mg}_{21}(\text{Al},\text{Zn})_{17}$ and $\text{Mg}_{32}(\text{Al},\text{Zn})_{49}$.

From the viewpoint of achieving superior workability and corrosion resistance at processed parts, such Mg-Zn based compounds are preferably not present in the coating.

[0025] The presence of Mg-Zn based compounds in the coating can be confirmed, for example, by observing the surface or cross-section of the coating using a scanning electron microscope (SEM) to obtain secondary electron or reflected electron images, followed by analysis using energy dispersive X-ray spectroscopy (EDS). For example, a cross-section of the coating measuring approximately 100 μm may be arbitrarily selected at about 5 to 10 locations, and each location may be observed and subjected to elemental mapping analysis at an accelerating voltage of 5 kV or less. Point analysis can then be performed on areas where Mg is detected to confirm the composition of the Mg-Zn based inclusions. This method is merely an example, and any method capable of confirming the presence of Mg-Zn based compounds may be used. The method is not particularly limited.

[0026] When Mg-Zn based compounds are present in the coating, it is preferable that the major axis length of such compounds be small.

Because Mg-Zn based compounds present in the coating are hard and brittle, they may serve as initiation points for cracks when subjected to severe bending or tensile working, potentially leading to deterioration in workability and corrosion resistance at processed parts. In particular, the presence of coarse Mg-Zn based compounds in the coating may significantly reduce the workability and corrosion resistance at processed parts of hot-dip Al-Zn alloy coated steel sheets. Therefore, in order to obtain a hot-dip Al-Zn alloy coated steel sheet with superior workability and corrosion resistance at processed parts, it is effective to control the size of the Mg-Zn based compounds present as impurities in the coating to be small. Specifically, it is preferable that the major axis length of the Mg-Zn based compounds be less than 10 μm . From

the same viewpoint, the major axis length of the Mg-Zn based compounds is preferably as small as possible.

The major axis length of the Mg-Zn based compounds can be measured, for example, by observing a cross-section of the coating using a scanning electron microscope (SEM) in reflected electron imaging mode, confirming the presence of Mg-Zn based compounds by EDS, and then observing an enlarged reflected electron image of a field containing the Mg-Zn based compounds.

In the present disclosure, the “major axis length” of the Mg-Zn based compounds refers to the average of the five longest major axis lengths measured for Mg-Zn based compounds identified in a continuous cross-sectional area of the coating, where the area is 5 mm in length and is taken parallel to the surface of the base steel sheet.

[0027] In the hot-dip Al-Zn alloy coated steel sheet of the present disclosure, the diffraction intensity of MgZn_2 in the coating, as measured by X-ray diffraction, preferably satisfies the following relational expression (1):

$$\text{MgZn}_2(100) = 0 \quad \dots(1)$$

Where $\text{MgZn}_2(100)$ refers to the diffraction intensity from the (100) plane of MgZn_2 (interplanar spacing $d = 0.4510 \text{ nm}$).

[0028] As described above, in order to stabilize the workability and corrosion resistance at processed parts of hot-dip Al-Zn alloy coated steel sheets, it is important to suppress the inclusion of Mg as an inevitable impurity and to control the formation of Mg-Zn based compounds in the coating to a minimum. Particularly, by minimizing the formation of MgZn_2 that is thermodynamically stable and readily forms even in hot-dip Al-Zn alloy coatings, specifically by reducing the diffraction intensity of $\text{MgZn}_2(100)$ to zero, it is possible to achieve even more stable workability and corrosion resistance at processed parts.

[0029] Here, in the above relational expression (1), $\text{MgZn}_2(100)$ refers to the diffraction intensity from the (100) plane of MgZn_2 , where the interplanar spacing $d = 0.4510 \text{ nm}$.

As a method of measuring $\text{MgZn}_2(100)$ by X-ray diffraction, the measurement can be performed by mechanically extracting a portion of the coating, converting it into powder form, and conducting X-ray diffraction on the powdered sample (powder X-ray diffraction method). To determine the diffraction intensity, it is sufficient to measure the diffraction peak intensity corresponding to the interplanar spacing $d = 0.4510 \text{ nm}$ for MgZn_2 .

[0030] In conducting powder X-ray diffraction measurements, the required amount of the coating to be scraped off should be at least 0.1 g to ensure accurate measurement of MgZn_2 (100), and preferably 0.3 g or more. When scraping the coating, components from the base steel sheet may be included in the resulting powder. However, the intermetallic compound phases of interest exist only in the coating, and these inclusions do not affect the above-described peak intensity. Further, performing X-ray diffraction on the powdered coating is necessary because conducting X-ray diffraction directly on the coating formed on the coated steel sheet can be influenced by the crystallographic orientation of the solidified coating structure, making it difficult to evaluate the amount of a substance based on the diffraction intensity of a specific interplanar spacing.

[0031] The method for satisfying the above relational expression (1) is not particularly limited. For example, by controlling the Mg content in the coating to a low level and reducing the ratio of Mg content to Zn content (e.g., setting the Mg/Zn ratio to 0.008 or less, preferably 0.006 or less), the presence of MgZn_2 and $\text{Mg}_2\text{Zn}_{11}$ (specifically, the diffraction intensities of MgZn_2 (100) and $\text{Mg}_2\text{Zn}_{11}$ (321)) can be controlled to a low level.

Further, in addition to controlling the Mg content in the coating, the relational expression (1) can also be satisfied by adjusting the coating formation conditions, such as the cooling conditions after coating treatment, while maintaining the Mg content of the coating at a specific level.

[0032] It is also preferable that the ratio of Mg content to Fe content (Mg/Fe) among the inevitable impurities in the coating be 1.0 or less. In this case, the amount of Mg solid-dissolved into the Fe-Al and/or Fe-Al-Si interfacial alloy layer reduces, and an increase in the hardness of the interfacial alloy layer due to solid-solution strengthening is suppressed, thereby achieving superior workability and corrosion resistance at processed parts. From the same viewpoint, the Mg/Fe ratio is more preferably 0.6 or less.

[0033] The coating may further contain, in total, 0.01 mass% to 3.0 mass% of at least one selected from the group consisting of B, Ca, Ti, V, Cr, Mn, Sr, Mo, In, Sn, Sb, Ce, and Bi. These elements can provide effects such as improving the stability of corrosion products during corrosion of the coating to delay the progress of corrosion, and stabilizing the spangle size on the coating surface to improve surface appearance.

[0034] It is preferable that the coating weight of the coating be in the range of

45 g/m² to 120 g/m² per side from the viewpoint of satisfying various required properties. When the coating weight is 45 g/m² or more, sufficient corrosion resistance can be obtained even for applications such as building materials that require long-term durability. When the coating weight is 120 g/m² or less, excellent corrosion resistance can be achieved while suppressing the occurrence of coating cracks during processing. From the same viewpoint, the coating weight is more preferably in the range of 45 g/m² to 100 g/m².

[0035] The coating weight of the coating can be determined, for example, by dissolving and removing the coating over a specified area using a mixed solution of hydrochloric acid and hexamethylenetetramine as described in JIS H 0401:2013, and calculating the difference in weight of the steel sheet before and after the removal. To measure the coating weight per side using this method, the surface on the opposite side should be sealed with tape to prevent exposure, and then the dissolution is carried out as described above.

In addition, the chemical composition of the coating can also be determined by dissolving the coating in a hydrochloric acid solution or the like, in the same manner as the above-described method of measuring coating weight, and analyzing the resulting solution using ICP emission spectrometry, atomic absorption spectrometry, or other methods. This method is merely an example, and any method capable of accurately and quantitatively determining the chemical composition of the coating may be used. The method is not particularly limited.

[0036] The coating of the hot-dip Al-Zn alloy coated steel sheet obtained by the present disclosure generally has a composition substantially equivalent to that of the molten bath. Therefore, the composition of the coating can be accurately controlled by controlling the composition of the molten bath.

[0037] The base steel sheet of the hot-dip Al-Zn alloy coated steel sheet of the present disclosure is not particularly limited, and cold-rolled steel sheets, hot-rolled steel sheets, or the like may be appropriately used depending on the required properties and specifications.

Further, the method of obtaining the base steel sheet is also not particularly limited. For example, in the case of a hot-rolled steel sheet, one that has undergone hot rolling and pickling processes may be used, and in the case of a cold-rolled steel sheet, it may be further subjected to a cold rolling process. Additionally, in order to impart specific properties to the steel sheet, a recrystallization annealing process or the like may be applied before the hot-

dip coating process.

[0038] As illustrated in FIG. 1, the hot-dip Al-Zn alloy coated steel sheet of the present disclosure has a coating 20 formed on a base steel sheet 10, and, if necessary, an intermediate layer and/or a coating film may be further formed on the coating.

The type of the coating film and the method of forming it are not particularly limited and may be appropriately selected according to the required performance. Examples of the forming method include roll coating, curtain flow coating, and spray coating. After applying a paint containing an organic resin, the coating film can be formed by heating and drying the paint using hot air drying, infrared heating, induction heating, or the like.

Further, the intermediate layer is not particularly limited as long as it is a layer formed between the coating and the coating film of the hot-dip Al-Zn alloy coated steel sheet. Examples thereof include a chemical conversion coating or a primer layer such as an adhesive layer. The chemical conversion coating can be formed, for example, by chromate treatment or chromium-free conversion treatment, where a chromate treatment solution or a chromium-free conversion treatment solution is applied, followed by a drying treatment at a steel sheet temperature of 80 °C to 300 °C without rinsing. These chemical conversion coatings may be a single layer or multilayer, and in the case of multilayer coatings, multiple chemical conversion treatments may be performed sequentially.

[0039] (Method of producing hot-dip Al-Zn alloy coated steel sheet)

The method of producing a hot-dip Al-Zn alloy coated steel sheet of the present disclosure is a method of producing a hot-dip Al-Zn alloy coated steel sheet having a coating.

[0040] The method of producing the hot-dip Al-Zn alloy coated steel sheet of the present disclosure comprises forming the coating on a base steel sheet using a molten bath having a chemical composition containing Al: 45 mass% to 65 mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being Zn and inevitable impurities.

[0041] The formation of the coating is not particularly limited, except for the molten bath conditions described later.

For example, the coated steel sheet can be produced using a continuous galvanizing line (CGL) by cleaning and heating the base steel sheet and immersing the base steel sheet into the molten bath. When heating the steel

sheet, recrystallization annealing or the like may be performed to control the microstructure of the base steel sheet itself, and heating under a reducing atmosphere such as a nitrogen-hydrogen atmosphere is effective for preventing oxidation of the steel sheet and reducing minute oxide films present on the surface.

[0042] The molten bath used for forming the coating has a chemical composition containing Al: 45 mass% to 65 mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being Zn and inevitable impurities. This is because, as described above, the composition of the coating generally corresponds to that of the molten bath.

[0043] In the method of producing a hot-dip Al-Zn alloy coated steel sheet of the present disclosure, the Mg content among the inevitable impurities in the molten bath is controlled to be less than 0.5 mass% with respect to the total mass of the molten bath.

As described above, Mg contained in the coating may cause deterioration in the workability and corrosion resistance at processed parts of the hot-dip Al-Zn alloy coated steel sheet. Therefore, it is possible to suppress the deterioration in the workability and corrosion resistance at processed parts not only by appropriately controlling the Al, Zn, and Si contents in the molten bath, but also by suppressing the Mg content as an inevitable impurity.

[0044] The Mg content among the inevitable impurities in the molten bath should be controlled to 0.5 mass% or less with respect to the total mass of the molten bath, and preferably to 0.2 mass% or less. When the Mg content in the molten bath is less than 0.5 mass%, the resulting hot-dip Al-Zn alloy coated steel sheet can exhibit sufficiently excellent workability and corrosion resistance at processed parts. When the Mg content is 0.2 mass% or less, even better workability and corrosion resistance at processed parts can be achieved. Because the corrosion resistance of the hot-dip Al-Zn alloy coated steel sheet improves with decreasing Mg content in the molten bath, no specific lower limit is set for the Mg content. However, it is technically difficult to reduce the Mg content in the molten bath completely to 0.000 mass%, and thus the practical lower limit of the Mg content in the coating is approximately 0.001 mass%.

[0045] The method of reducing the Mg content in the molten bath is not particularly limited. For example, it is effective not to intentionally add Mg

to the molten bath, and to avoid using pots or in-bath equipment that were used in the production of Mg-containing coated steel sheets, such as Zn-Al-Mg alloy coated steel sheets or Al-Zn-Si-Mg alloy coated steel sheets, for the production of the hot-dip Al-Zn alloy coated steel sheets. This helps to prevent metal
5 lumps containing Mg, which may have adhered to the pot or in-bath equipment, from dissolving and contaminating the molten bath.

It is preferable to use metal ingots with a low Mg impurity content as raw materials for the molten bath, which is another method of reducing the Mg content in the molten bath.

10 **[0046]** The bath temperature of the molten bath is not particularly limited, but is preferably in the range of (melting point + 20 °C) to 650 °C.

The lower limit of the bath temperature is set to (melting point + 20 °C) to ensure the bath temperature remains above the solidification point, which is necessary for hot-dip coating treatment, and to prevent local
15 solidification in the molten bath due to temperature drops. The upper limit of the bath temperature is set to 650 °C because if the temperature exceeds 650 °C, it becomes difficult to rapidly cool the coating, which may lead to excessive growth of the interfacial alloy layer formed between the coating and the steel sheet.

20 **[0047]** The temperature of the base steel sheet upon immersion into the molten bath (entering sheet temperature) is also not particularly limited. However, from the viewpoint of ensuring coating properties during the continuous hot-dip coating operation and preventing bath temperature fluctuation, it is preferable to control it within ± 20 °C of the molten bath temperature.

25 **[0048]** Further, the immersion time of the base steel sheet in the molten bath is preferably 0.5 seconds or more. This is because when the immersion time is less than 0.5 seconds, there is a risk that a sufficient coating may not be formed on the surface of the base steel sheet. Although the upper limit of the immersion time is not particularly limited, it is more preferable to set it within
30 8 seconds, because an excessively long immersion time may lead to excessive growth of the interfacial alloy layer formed between the coating and the steel sheet.

[0049] In the method of producing a hot-dip Al-Zn alloy coated steel sheet of the present disclosure, in addition to the coating formation and the
35 heating/cooling after coating formation as described above, it is also possible to carry out other processes used in conventional coated steel sheet production,

as appropriate.

EXAMPLES

[0050] [Samples 1 to 32]

5 Cold-rolled steel sheets with a thickness of 0.8 mm, obtained by conventional methods, were used as base steel sheets. Samples 1 to 32 of hot-dip coated steel sheets were produced by annealing and coating processes carried out with a hot-dip coating simulator manufactured by Reska Co., Ltd., under the conditions listed in Table 1.

10 The composition of the molten bath used to produce the hot-dip coated steel sheets was adjusted so that the resulting coating composition of each sample would correspond to those listed in Table 1. The molten bath compositions were varied as follows: Al: 0.2 mass% to 70 mass%, Si: 0.0 mass% to 3.2 mass%, B: 0.00 mass% to 0.02 mass%, Ca: 0.0 mass% to 1.0 mass%, Ti: 0.0 mass% to 0.1 mass%, V: 0.1 mass% to 0.1 mass%, Cr: 0.0 mass% to 0.2 mass%, Mn: 0.0 mass% to 0.1 mass%, Sr: 0.0 mass% to 0.1 mass%, Mo: 0.0 mass% to 0.1 mass%, In: 0.0 mass% to 0.5 mass%, Sn: 0.0 mass% to 0.5 mass%, Sb: 0.0 mass% to 0.1 mass%, Ce: 0.0 mass% to 1.0 mass%, Bi: 0.00 mass% to 0.05 mass%. The molten bath temperature was controlled as follows: 460 °C for Al: 0.2 mass% to 5 mass%, 600 °C for Al: 35 mass% to 55 mass%, and 660 °C for Al exceeding 60 mass%. The temperature of the base steel sheet as it entered the bath was adjusted to be equal to the molten bath temperature. Additionally, for Al contents between 35 mass% and 65 mass%, coating was carried out under a cooling condition in which the sheet temperature was lowered to the range of 520 °C to 500 °C within 3 seconds.

The coating weight per side was controlled as follows: 85 ± 5 g/m² for Samples 1 to 29, 50 ± 5 g/m² for Sample 30, 100 ± 5 g/m² for Sample 31, and 125 ± 5 g/m² for Sample 32.

30 [0051] [Evaluation]

Each of the obtained hot-dip coated steel sheet samples was subjected to the following evaluations. The evaluation results are listed in Table 1.

[0052] (1) Coating (composition, coating weight, and Mg-based compounds)

35 For each of the prepared coated steel sheet samples, a 100 mm diameter disc was punched out, and the non-measured surface was sealed with tape. The coating was then dissolved and removed using a mixed solution of

hydrochloric acid and hexamethylenetetramine, as specified in JIS H 0401:2013. The coating weight was calculated based on the difference in sample weight before and after removal. The calculated coating weights are listed in Table 1.

5 Subsequently, the removal solution was filtered, and the filtrate and the solid residues were analyzed separately. Specifically, the filtrate was analyzed by ICP emission spectrometry to quantify all elements except insoluble Si.

10 The solid residues were dried and ashed in a heating furnace at 650 °C, then fused by adding sodium carbonate and sodium tetraborate. The fused product was then dissolved in hydrochloric acid, and the resulting solution was analyzed by ICP emission spectrometry to quantify the insoluble Si. The Si concentration in the coating was determined by adding the soluble Si concentration from the filtrate analysis and the insoluble Si concentration from
15 the solid residue analysis. The resulting compositions of the coatings are listed in Table 1.

 In addition, for each sample, a 15 mm × 15 mm piece was cut and embedded in conductive resin to allow cross-sectional observation. After mechanical polishing, a scanning electron microscope (ULTRA55, Carl Zeiss)
20 was used to continuously capture reflected electron images of an arbitrarily selected 5 mm-long continuous cross-section of the coating in the direction parallel to the surface of the base steel sheet, under an accelerating voltage of 3 kV and a field width of 100 μm. Furthermore, elemental mapping analysis (Al, Zn, Si, Fe, and Mg) of the cross-sections was performed at an accelerating
25 voltage of 3 kv using an energy-dispersive X-ray spectrometer (Ultim Extreme, Oxford Instruments) in the same apparatus. Spot analysis was conducted at points where strong Mg signals were detected in the elemental mapping analysis, using the same spectrometer at an accelerating voltage of 3 kv, to determine the presence of Mg-based compounds and identify the substances
30 based on the obtained element semi-quantitative values. The major axes of all Mg-based compounds observed in the field of view were measured, and the average of the five longest values was taken as the major axis length. The obtained major axis lengths are listed in Table 1.

 For each sample, a 100 mm × 100 mm piece was cut, and the coating
35 on the evaluation surface was mechanically removed until the base steel sheet was exposed. The resulting powder was thoroughly mixed, and 0.3 g was

extracted for qualitative analysis using an X-ray diffractometer (SmartLab, Rigaku Co., Ltd.) under the following conditions: X-ray source: Cu-K α (wavelength = 1.54178 Å); K β removal: Ni filter; tube voltage: 40 kV; tube current: 30 mA; scanning speed: 4°/min; sampling interval: 0.020°; divergence slit: 2/3°; solar slit: 5°; detector: high-speed 1D detector (D/teX Ultra). The diffraction intensity (kcps) was calculated by subtracting the base intensity from the corresponding peak intensity, and the diffraction intensity (kcps) of the (100) plane of MgZn₂, where interplanar spacing $d = 0.4510$ nm, was measured. The measurement results of diffraction intensity are listed in Table 1.

[0053] (2) Evaluation of workability

Each of the obtained hot-dip coated steel sheet samples was sheared to a size of 70 mm $\times$ 150 mm, then n sheets ($n = 8, 10, 12, 14, 16$) of the same thickness were placed on the inner side, and a 180° bending process (nT bending) was applied to form a vertex of 150 mm. After bending, Sellotape® (Sellotape is a registered trademark in Japan, other countries, or both) was firmly applied to the outer surface of the bent portion and then peeled off. The outer surface of the bent portion (vertex area) was observed using a scanning electron microscope (ULTRA55, Carl Zeiss) under an accelerating voltage of 5 kV to examine the crack formation, and the workability was evaluated based on the following criteria. The evaluation results are listed in Table 1.

O: No occurrence of large cracks with an opening width of 20 μ m or more is observed

×: Occurrence of large cracks with an opening width of 20 μ m or more is observed

[0054] (3) Evaluation of corrosion resistance at processed part

Each of the obtained hot-dip coated steel sheet samples was sheared to a size of 70 mm $\times$ 150 mm, then the end faces were sealed with tape, 14 or 16 sheets of the same thickness were placed on the inner side, and 14T and 16T bending processes were applied respectively to form a vertex of 150 mm.

All the samples prepared as described above were subjected to a cyclic corrosion test according to the Japanese Automotive Standards Organization (JASO-CCT). The corrosion test started in wet condition and continued for 60 cycles. After the test, the outer surface (vertex area) of the bent portion of each sample was visually observed, and the corrosion resistance was

evaluated based on the following criteria. The observation and evaluation results are listed in Table 1.

O: No occurrence of red rust or white rust observed on the sample subjected to 16T bending

5 ×: Occurrence of red rust or white rust observed on the sample subjected to 16T bending

[0055] [Table 1]

[Table 1]

No.		Coating					Mg-based compound				Workability				Corrosion resistance at processed part			Remarks
		Composition (mass%)					Coating weight (g/m ²)	Type			Degree of deformation			Degree of deformation				
		Al	Si	Fe	Mg	Others		Type	Major axis (μm)	MgZn ₂ (100) kcps	8T	10T	12T	14T	16T	14T	16T	
1	0.2	-	0.41	0.002	-	85	-	-	0.00	O	O	O	O	O	×	×	Comparative Example	
2	5	-	0.32	0.002	-	85	-	-	0.00	O	O	O	O	O	×	×	Comparative Example	
3	35	1.5	0.49	0.002	-	84	-	-	0.00	×	O	O	O	O	×	×	Comparative Example	
4	45	1.5	0.55	0.003	-	86	-	-	0.00	×	O	O	O	O	O	O	Example	
5	55	0.4	1.85	0.002	-	85	-	-	0.00	×	×	×	×	×	×	×	Comparative Example	
6	55	1.0	0.68	0.002	-	85	-	-	0.00	×	×	O	O	O	O	O	Example	
7	55	1.6	0.60	0.002	-	85	-	-	0.00	×	O	O	O	O	O	O	Example	
8	55	1.6	0.58	0.220	-	83	-	-	0.00	×	×	O	O	O	O	O	Example	
9	55	1.6	0.57	0.357	-	83	MgZn ₂	3.1	0.11	×	×	O	O	O	O	O	Example	
10	55	1.6	0.55	0.493	-	85	MgZn ₂	7.8	0.53	×	×	×	×	O	×	O	Example	
11	55	1.6	0.59	0.771	-	84	MgZn ₂	10.6	1.02	×	×	×	×	×	×	×	Comparative Example	
12	55	1.6	0.61	1.032	-	85	MgZn ₂	11.2	1.94	×	×	×	×	×	×	×	Comparative Example	
13	55	3.0	0.58	0.003	-	84	-	-	0.00	×	×	×	×	O	O	O	Example	
14	55	3.2	0.60	0.002	-	86	-	-	0.00	×	×	×	×	×	×	×	Comparative Example	
15	65	1.6	0.74	0.002	-	85	-	-	0.00	×	×	O	O	O	O	O	Example	
16	70	1.6	0.81	0.002	-	83	-	-	0.00	×	×	×	O	O	×	×	Comparative Example	
17	55	1.6	0.55	0.002	Ti: 0.1 B: 0.02	85	-	-	0.00	×	O	O	O	O	O	O	Example	
18	55	1.6	0.59	0.002	Ca: 1.0	84	-	-	0.00	×	O	O	O	O	O	O	Example	
19	55	1.6	0.58	0.001	V: 0.1	84	-	-	0.00	×	O	O	O	O	O	O	Example	
20	55	1.6	0.63	0.002	Cr: 0.2	86	-	-	0.00	×	O	O	O	O	O	O	Example	
21	55	1.6	0.68	0.003	Mn: 0.1	85	-	-	0.00	×	×	O	O	O	O	O	Example	
22	55	1.6	0.45	0.002	Sr: 0.1	82	-	-	0.00	×	O	O	O	O	O	O	Example	
23	55	1.6	0.45	0.002	Mo: 0.1	82	-	-	0.00	×	O	O	O	O	O	O	Example	
24	55	1.6	0.45	0.002	In: 0.5	82	-	-	0.00	×	O	O	O	O	O	O	Example	
25	55	1.6	0.56	0.002	Sn: 0.1	84	-	-	0.00	×	O	O	O	O	O	O	Example	
26	55	1.6	0.58	0.284	Sn: 0.5	85	Mg ₂ Sn	2.2	0.00	×	O	O	O	O	O	O	Example	
27	55	1.6	0.56	0.002	Sb: 0.1	85	-	-	0.00	×	O	O	O	O	O	O	Example	
28	55	1.6	0.45	0.002	Ce: 1.0	82	-	-	0.00	×	O	O	O	O	O	O	Example	
29	55	1.6	0.45	0.002	Bi: 0.05	82	-	-	0.00	×	O	O	O	O	O	O	Example	
30	55	1.6	0.60	0.002	-	45	-	-	0.00	×	O	O	O	O	O	O	Example	
31	55	1.6	0.60	0.002	-	100	-	-	0.00	×	×	O	O	O	O	O	Example	
32	55	1.6	0.60	0.002	-	125	-	-	0.00	×	×	×	O	O	O	O	Example	

[0056] The results in Table 1 indicate that the samples of Examples exhibit a well-balanced superiority in both workability and corrosion resistance at processed parts compared to the samples of Comparative Examples.

5 INDUSTRIAL APPLICABILITY

[0057] According to the present disclosure, it is possible to provide a hot-dip Al-Zn alloy coated steel sheet having reliably and stably excellent workability and corrosion resistance at processed parts, and a method of producing the same.

10

REFERENCE SIGNS LIST

[0058]	15	Base steel sheet
	20	Coating
	21	Main layer
15	22	Interfacial alloy layer
	211	Dendrite
	212	Interdendrite

CLAIMS

- [Claim 1] A hot-dip Al-Zn alloy coated steel sheet comprising a coating,
wherein
- 5 the coating has a chemical composition containing Al: 45 mass% to 65
mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being Zn and
inevitable impurities, and
- a Mg content in the inevitable impurities is less than 0.5 mass% with
respect to the total mass of the coating.
- 10
- [Claim 2] The hot-dip Al-Zn alloy coated steel sheet according to claim
1, wherein the coating contains Mg-Zn based compounds, and a major axis
length of the Mg-Zn based compounds is less than 10 μm .
- 15 [Claim 3] The hot-dip Al-Zn alloy coated steel sheet according to claim
1, wherein the coating contains no Mg-Zn based compounds.
- [Claim 4] The hot-dip Al-Zn alloy coated steel sheet according to any one
of claims 1 to 3, wherein the coating further contains, in total, 0.01 mass% to
20 3.0 mass% of at least one selected from the group consisting of B, Ca, Ti, V,
Cr, Mn, Sr, Mo, In, Sn, Sb, Ce, and Bi.
- [Claim 5] The hot-dip Al-Zn alloy coated steel sheet according to any one
of claims 1 to 4, wherein a diffraction intensity of MgZn_2 in the coating
25 measured by X-ray diffraction satisfies the following relational expression (1):
- $$\text{MgZn}_2(100) = 0 \quad \dots(1)$$
- where $\text{MgZn}_2(100)$ is a diffraction intensity from a (100) plane of
 MgZn_2 having an interplanar spacing $d = 0.4510 \text{ nm}$.
- 30 [Claim 6] A method of producing a hot-dip Al-Zn alloy coated steel sheet
comprising a coating, wherein
- the method comprises forming the coating on a base steel sheet using a
molten bath having a chemical composition containing Al: 45 mass% to 65
mass% and Si: 1.0 mass% to 3.0 mass%, with the balance being Zn and
35 inevitable impurities, and
- a Mg content in the inevitable impurities in the molten bath is

controlled to be less than 0.5 mass% with respect to the total mass of the molten bath.

[Claim 7] The method of producing a hot-dip Al-Zn alloy coated steel
5 sheet according to claim 6, wherein the molten bath further contains, in total,
0.01 mass% to 3.0 mass% of at least one selected from the group consisting of
B, Ca, Ti, V, Cr, Mn, Sr, Mo, In, Sn, Sb, Ce, and Bi.