

HOT-DIP Al-Zn-Mg-Si-Sr COATED STEEL SHEET AND METHOD OF PRODUCING SAME

TECHNICAL FIELD

5 **[0001]** This disclosure relates to a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance and having excellent corrosion resistance in flat parts and worked parts, and to a method of producing the same.

BACKGROUND

10 **[0002]** Hot-dip Al-Zn alloy-coated steel sheets have both the sacrificial protection of Zn and the high corrosion resistance of Al, and thus rank highly in terms of corrosion resistance among hot-dip galvanized steel sheets. For example, PTL 1 (JP S46-7161 B) describes a hot-dip Al-Zn alloy-coated steel sheet in which the hot-dip coating layer contains 25 mass% to 75 mass% of
15 Al. Due to their excellent corrosion resistance, hot-dip Al-Zn alloy-coated steel sheets have been the subject of increased demand in recent years, particularly in the field of building materials for roofs, walls and the like that undergo long-term exposure to outdoor environments, and the field of civil engineering and construction for guardrails, wiring, piping, soundproof walls,
20 and the like.

[0003] The hot-dip coating layer of a hot-dip Al-Zn alloy-coated steel sheet includes a main layer and an interfacial alloy layer present at an interface of the main layer with a base steel sheet. The main layer is mainly composed of regions where Zn is contained and Al is solidified by dendrite solidification
25 (α -Al phase dendritic regions), and remaining interdendritic regions mainly composed of Zn between the dendrites, and has a structure with the α -Al phase stacked in multiple layers in the thickness direction of the hot-dip coating layer. Due to such characteristic hot-dip coating structure, the corrosion path from the surface becomes complex, rendering it difficult for
30 corrosion to reach the base steel sheet. Therefore, better corrosion resistance can be achieved with a hot-dip Al-Zn alloy-coated steel sheet than with a hot-dip galvanized steel sheet having the same hot-dip coating thickness.

[0004] The inclusion of Mg in the hot-dip Al-Zn alloy coating layer is a known technique for further improving the corrosion resistance. In one
35 example of the technique relating to a hot-dip Al-Zn alloy-coated steel sheet containing Mg (hot-dip Al-Zn-Mg-Si coated steel sheet), PTL 2 (JP 5020228

5 [0005] However, although the hot-dip Al-Zn alloy-coated steel sheet containing Mg described in PTL 2 has excellent corrosion resistance, crease-like defects of a length of about several mm to several hundred mm (hereinafter referred to as “crease-like defect”), which are caused by an oxide layer formed on the surface of the hot-dip coating layer, tend to occur, and the
10 appearance of the hot-dip coating layer surface is damaged.

For this reason, PTL 3 (JP 3983932 B), for example, describes a technique for improving the surface appearance of a hot-dip Al-Zn-Mg alloy-coated steel sheet by containing Sr in the hot-dip coating layer.

Further, PTL 4 (JP 6368730 B) describes a technique for improving
15 the workability of a hot-dip Al-Zn-Mg alloy-coated steel sheet by containing
Sr in the hot-dip coating layer.

CITATION LIST

Patent Literature

20 **[0006]** PTL 1: JP S46-7161 B
 PTL 2: JP 5020228 B
 PTL 3: JP 3983932 B
 PTL 4: JP 6368730 B

SUMMARY

(Technical Problem)

[0007] The hot-dip Al-Zn-Mg alloy-coated steel sheets of PTL5 3 and 4 described above contain Sr in the hot-dip coating layer, which can suppress the occurrence of crease-like defects and improve the surface appearance.

30 However, regarding the Sr-containing hot-dip Al-Zn-Mg alloy-coated steel sheets of PTLs 3 and 4, the content of Mg_2Si in the vicinity of the hot-dip coating layer surface is reduced due to the inclusion of Sr. As a result, the corrosion resistance may be deteriorated.

Regarding the hot-dip Al-Zn alloy-coated steel sheets described in
35 PTLS 2 and 3, although Mg_2Si formed in the hot-dip coating layer has an
effect of improving corrosion resistance, the hot-dip coating layer cracks

when it is subjected to a bending process. As a result, the corrosion resistance in worked parts (corrosion resistance of worked parts) is deteriorated.

[0008] In view of these situations, it could be helpful to provide a hot-dip
5 Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in flat parts and worked parts, and a method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having excellent corrosion resistance in flat parts and worked parts.

(Solution to Problem)

10 **[0009]** We made intensive studies to solve the above problems. As a result, we found that the effect of improving corrosion resistance by the inclusion of Mg is exhibited by, when a hot-dip coating layer is corroded, preferentially dissolving Mg_2Si present in the hot-dip coating layer and concentrating the dissolved Mg in corrosion products formed on the surface of the hot-dip
15 coating layer. Therefore, we focused on the importance of Mg_2Si existing in the vicinity of the surface of the hot-dip coating layer. As a result of further intensive research, we found that most of the Mg_2Si contained in the main layer of the hot-dip coating layer (hereinafter may be referred to as “main layer of hot-dip coating” or “main layer”) is concentrated in the vicinity of the
20 surface of the main layer of hot-dip coating. Therefore, even if Sr is contained in the hot-dip coating layer, sufficient Mg_2Si present in the surface of the hot-dip coating layer can not only suppress the occurrence of crease-like defects but also realize excellent corrosion resistance.

In addition, we focused on the fact that, although the Mg_2Si in the
25 main layer of hot-dip coating has an effect of improving corrosion resistance, it forms a propagation path of cracks occurred in an interfacial alloy layer to the surface of the main layer of hot-dip coating in a bending process and deteriorates the workability. As a result, the desired corrosion resistance in worked parts cannot be obtained. Further, we found that, by reducing the
30 amount of Mg_2Si extending from the interfacial alloy layer to the surface of the main layer of hot-dip coating, it is possible to suppress the propagation of cracks starting from the interfacial alloy layer to the surface of the main layer of hot-dip coating that penetrates the main layer of hot-dip coating during the working of the steel sheet, which can also improve the corrosion resistance in
35 worked parts.

[0010] The present disclosure was completed based on these findings, and primary features thereof are as follows.

1. A hot-dip Al-Zn-Mg-Si-Sr coated steel sheet comprising a hot-dip coating layer having a composition containing (consisting of) 40
5 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the balance being Zn and inevitable impurities, wherein

the hot-dip coating layer comprises an interfacial alloy layer present at an interface with a base steel sheet, and a main layer present on the alloy
10 layer, and

for Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer, an area ratio of Mg_2Si existing within a range from a surface of the main layer to 50 % of the thickness of the main layer is 50 % or more, and an area ratio of Mg_2Si that is continuously present in interdendritic
15 regions (hereinafter may be referred to as “extending”) from the interfacial alloy layer to a surface of the main layer is 50 % or less.

[0011] 2. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to 1., wherein for Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer, an area ratio of Mg_2Si existing within a range from a
20 surface of the main layer to 50 % of the thickness of the main layer is 60 % or more, and an area ratio of Mg_2Si extending from a surface of the main layer to the interfacial alloy layer is 50 % or less.

[0012] 3. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to 2., wherein for Mg_2Si observed in a cross section in a thickness direction of the
25 hot-dip coating layer, an area ratio of Mg_2Si existing within a range from a surface of the main layer to 50 % of the thickness of the main layer is 60 % or more, and an area ratio of Mg_2Si extending from a surface of the main layer to the interfacial alloy layer is 40 % or less.

[0013] 4. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to any one of 1. to 3., wherein a ratio of an area ratio of Si phase observed in a cross section in a thickness direction of the hot-dip coating layer to a total
30 area ratio of Mg_2Si and Si phase observed in the cross section in the thickness direction of the hot-dip coating layer is 30 % or less.

[0014] 5. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to
35 any one of 1. to 4., wherein the main layer has α -Al phase dendritic regions,

and an average distance between dendritic arms of the dendritic regions and a thickness of the hot-dip coating layer satisfy the following expression (1),

$$t/d \geq 1.5 \quad (1)$$

where t is the thickness of the hot-dip coating layer in μm , and d is the average distance between dendritic arms in μm .

5 **[0015]** 6. A method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet, comprising using a molten bath having a composition containing (consisting of) 40 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the
10 balance being Zn and inevitable impurities, and a bath temperature of 585 °C or lower to perform hot dip coating on a steel sheet, wherein

 a temperature of the steel sheet at the time of entering the molten bath, which is a sheet temperature at entry, is equal to or lower than a temperature of adding 20 °C to the bath temperature of the molten bath, which is molten
15 bath temperature + 20 °C.

[0016] 7. The method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to 6., wherein the sheet temperature at entry of the steel sheet is equal to or lower than the bath temperature of the molten bath.

[0017] 8. The method of producing a hot-dip Al-Zn-Mg-Si-Sr coated
20 steel sheet according to 6. or 7., wherein after performing hot dip coating on the steel sheet, the steel sheet is cooled at an average cooling rate of 10 °C/s or higher until the sheet temperature reaches a temperature of subtracting 150 °C from the bath temperature of the molten bath, which is molten bath temperature – 150 °C.

25 (Advantageous Effect)

[0018] According to the present disclosure, it is possible to provide a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in flat parts and worked parts, and a method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface
30 appearance as well as excellent corrosion resistance in flat parts and worked parts.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In the accompanying drawings:

FIG. 1A illustrates the state of a hot-dip Al-Zn-Mg alloy-coated steel sheet before and after corrosion, and FIG. 1B illustrates the state of a hot-dip Al-Zn alloy-coated steel sheet before and after corrosion;

FIG. 2A illustrates the state of each element of the hot-dip
5 Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure obtained by energy dispersive X-ray spectroscopy using a scanning electron microscope (SEM-EDX), and FIG. 2B illustrates a method of observing Mg_2Si and Si phase in a part of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet illustrated in FIG. 2A;

10 FIG. 3 illustrates a method of calculating the area ratio of Mg_2Si existing within a range from a surface of a main layer to 50 % of the thickness among Mg_2Si observed in a cross section in the thickness direction of a hot-dip coating layer;

FIG. 4 illustrates a method of calculating the area ratio of Mg_2Si
15 extending from a surface of a main layer to an interfacial alloy layer among Mg_2Si observed in a cross section in the thickness direction of a hot-dip coating layer;

FIG. 5 illustrates a method of measuring the distance between dendritic arms; and

20 FIG. 6 illustrates the flow of the Combined Cycle Test of Japanese Automobile Standards Organization (JASO-CCT).

DETAILED DESCRIPTION

[0020] (Hot-dip Al-Zn-Mg-Si-Sr coated steel sheet)

25 The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure includes a base steel sheet and a hot-dip coating layer on a surface of the base steel sheet. The hot-dip coating layer includes an interfacial alloy layer present at an interface with the base steel sheet, and a main layer present on the alloy layer. The hot-dip coating layer has a composition
30 containing 40 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the balance being Zn and inevitable impurities.

[0021] The Al content in the hot-dip coating layer is set to 40 mass% to 70 mass% and preferably 45 mass% to 65 mass% from a viewpoint of balancing
35 corrosion resistance with actual operation requirements. When the Al content of the main layer of the hot-dip coating layer is 40 mass% or more,

good corrosion resistance can be ensured. This realizes a structure having excellent corrosion resistance in which the main layer is composed mainly of regions where Zn is in a supersaturated state and Al is solidified by dendrite solidification (α -Al phase dendritic regions) and remaining interdendritic regions between the dendrites, and in which the dendritic regions are stacked in the thickness direction of the hot-dip coating layer. The corrosion resistance is improved as the number of stacked α -Al phase dendritic regions increases because the corrosion path becomes complex, rendering it difficult for corrosion to reach the base steel sheet. From the same viewpoint, the Al content in the hot-dip coating layer is preferably 45 mass% or more. On the other hand, when the Al content in the hot-dip coating layer exceeds 70 mass%, the content of Zn having sacrificial corrosion protection ability with respect to Fe decreases, and the corrosion resistance deteriorates. Accordingly, the Al content in the hot-dip coating layer is set to 70 mass% or less. In addition, when the Al content in the hot-dip coating layer is 65 mass% or less, the sacrificial corrosion protection ability with respect to Fe is ensured and sufficient corrosion resistance is obtained even if the coating weight of the hot-dip coating is reduced and the base steel sheet tends to be exposed. Accordingly, the Al content of the main layer of hot-dip coating is preferably 65 mass% or less.

[0022] Si in the hot-dip coating layer inhibits the growth of the interfacial alloy layer formed at the interface with the base steel sheet and is added to a molten bath for improving the corrosion resistance and the workability. Therefore, Si is necessarily contained in the main layer. When hot-dip coating treatment is performed in a molten bath containing Si in the case of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, an alloying reaction takes place between Fe in the surface of the base steel sheet and Al or Si in the bath upon immersion of the base steel sheet in the molten bath, whereby alloys containing an Fe-Al compound and/or an Fe-Al-Si compound is formed. The formation of the Fe-Al-Si interfacial alloy layer can inhibit the growth of the interfacial alloy layer. When the Si content in the hot-dip coating layer is 0.6 mass% or more, the growth of the interfacial alloy layer can be sufficiently suppressed. On the other hand, when the Si content of the hot-dip coating layer exceeds 5 %, the workability of the hot-dip coating layer is deteriorated, and precipitation of a Si phase that acts as a cathode site in the hot-dip coating layer is facilitated. Although the

precipitation of the Si phase can be suppressed by increasing the Mg content and giving a certain relationship between the Si content and the Mg content as described later, this method leads to increased production cost, causes deterioration in workability due to an increased amount of Mg_2Si , and
5 complicates management of the molten bath composition. Accordingly, the Si content in the hot-dip coating layer is set to 5 % or less. Further, from a viewpoint of more reliably suppressing the growth of the interfacial alloy layer and the precipitation of the Si phase and a viewpoint of handling a case where Si is consumed as Mg_2Si , the Si content in the hot-dip coating layer is
10 preferably from more than 2.3 % to 3.5 %.

[0023] The hot-dip coating layer contains 0.1 mass% to 10 mass% of Mg. When the main layer of the hot-dip coating layer is corroded, Mg becomes included in corrosion products, which improves the stability of the corrosion products and delays corrosion progression. As a result, the corrosion
15 resistance is improved. More specifically, Mg present in the main layer of the hot-dip coating layer bonds to the Si described above to form Mg_2Si . As illustrated in FIG 1A, when the hot-dip coated steel sheet is corroded, the Mg_2Si dissolves in an initial stage of the corrosion, and thus Mg is included in corrosion products. The Mg included in the corrosion products has an effect
20 of densifying the corrosion products, which can improve the stability of the corrosion products and the barrier properties against external causes of corrosion. On the other hand, when the hot-dip coating layer contains no Mg, no Mg is included in corrosion products as illustrated in FIG. 1B, and the desired corrosion resistance cannot be obtained.

25 The reason for setting the Mg content of the hot-dip coating layer to 0.1 mass% or more is that, when the hot-dip coating layer contains Si in the concentration range described above, Mg_2Si can be formed and a corrosion delaying effect can be obtained by setting the Mg concentration to 0.1 mass% or more. From the same viewpoint, the Mg content of the hot-dip coating
30 layer is preferably 1 mass% or more and more preferably 3 mass% or more. On the other hand, the reason for setting the Mg content of the hot-dip coating layer to 10 mass% or less is that, when the Mg content of the hot-dip coating layer exceeds 10 mass%, the effect of improving corrosion resistance is saturated, production cost is increased, and management of the molten bath
35 composition becomes complicated. From the same viewpoint, the Mg content of the hot-dip coating layer is preferably 6 mass% or less.

[0024] Further, when the Mg content in the hot-dip coating layer is 1 mass% or more, the post-coating corrosion resistance can be improved. In the case of a conventional hot-dip Al-Zn alloy-coated steel sheet that contains no Mg, a dense and stable oxide film of Al_2O_3 forms at the periphery of a α -Al phase straight after the hot-dip coating layer is exposed to the atmosphere. Through the protective action of this oxide film, solubility of the α -Al phase becomes significantly low compared to that of a Zn-rich phase in the interdendritic regions. Consequently, upon scarring of the coating film of a coated steel sheet obtained using the conventional hot-dip Al-Zn alloy-coated steel sheet as a base, the scar acts as a start point for selective corrosion of the Zn-rich phase at an interface between the coating film and the hot-dip coating, and this corrosion progresses deep into a part where the coating film is not scarred, causing large coating film blisters. As a result, the post-coating corrosion resistance is poor. Therefore, from the viewpoint of obtaining excellent post-coating corrosion resistance, the Mg content in the hot-dip coating layer is preferably 1 mass% or more and more preferably 3 mass% or more.

On the other hand, in the case of a coated steel sheet obtained using the above-described hot-dip Al-Zn alloy-coated steel sheet that contains Mg in the hot-dip coating layer, a Mg_2Si phase that precipitates in the interdendritic regions or Mg-Zn compound (MgZn_2 , $\text{Mg}_{32}(\text{Al},\text{Zn})_{49}$, etc.) dissolves in an initial stage of corrosion, and Mg is taken into corrosion products. Corrosion products including Mg are highly stable, which inhibits corrosion in an initial stage. Therefore, this can inhibit large coating film blisters caused by selective corrosion of the Zn-rich phase, which is a problem in the case of a coated steel sheet obtained using the conventional hot-dip Al-Zn alloy-coated steel sheet as a base. Consequently, a hot-dip Al-Zn alloy-coated steel sheet having a Mg-containing hot-dip coating layer displays excellent post-coating corrosion resistance. When the Mg content in the hot-dip coating layer is less than 1 mass%, the amount of Mg that dissolves during corrosion is small, and the post-coating corrosion resistance may not be improved. Conversely, when the Mg content in the hot-dip coating layer exceeds 10 mass%, the effect is saturated, strong corrosion of Mg compound occurs, and the solubility of the hot-dip coating layer as a whole is excessively increased. As a result, a large blister width may arise and the post-coating corrosion resistance may deteriorate even if the corrosion

products are stabilized, because the dissolution rate is increased. Accordingly, the Mg content in the hot-dip coating layer is preferably 10 mass% or less so as to stably obtain excellent post-coating corrosion resistance.

- 5 **[0025]** The hot-dip coating layer contains 0.001 mass% to 1.0 mass% of Sr. The inclusion of Sr in the hot-dip coating layer can suppress the occurrence of crease-like defects and improve the surface appearance of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure.

10 The crease-like defect is a defect that is formed on the surface of the hot-dip coating layer in crease-like unevenness and is observed as a whitish streak on the surface of the hot-dip coating layer. Such a streak-like defect is likely to occur when a large amount of Mg is added to the hot-dip coating layer. Therefore, by containing Sr in the hot-dip coating layer of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, Sr is
15 preferentially oxidized over Mg in the surface layer of the hot-dip coating layer, and the oxidation reaction of Mg is suppressed. As a result, it is possible to suppress the occurrence of the streak-like defects.

20 **[0026]** The Sr content in the hot-dip coating layer should be set to 0.001 mass% or more. This is to obtain the effect of suppressing the occurrence of the streak-like defects described above. From the same viewpoint, the Sr content in the hot-dip coating layer is preferably 0.005 mass% or more, more preferably 0.01 mass% or more, and particularly preferably 0.05 mass% or more. On the other hand, the Sr content in the hot-dip coating layer should be set to 1.0 mass% or less. The reason is that, when the Sr content is too
25 large, the effect of suppressing the occurrence of streak-like defects is saturated, which is disadvantageous in terms of cost. From the same viewpoint, the Sr content in the hot-dip coating layer is preferably 0.7 mass% or less, more preferably 0.5 mass% or less, and particularly preferably 0.3 mass% or less.

30 **[0027]** Note that the hot-dip coating layer also contains base steel sheet components taken from the base steel sheet into the coating due to the reaction between the molten bath and the base steel sheet during the coating treatment, and inevitable impurities contained in an ingot used when preparing the molten bath. The base steel sheet components taken into the coating include
35 about several percent of Fe. Examples of the inevitable impurities in the molten bath include Fe, Mn, P, S, C, Nb, Ti and B, as the base steel sheet

components. In addition, examples of the impurities in an ingot include Fe, Pb, Sb, Cd, As, Ga, and V. Regarding Fe in the hot-dip coating layer, it is impossible to distinguish between those taken from the base steel sheet and those in the molten bath or quantify them. The total content of the inevitable
5 impurities is not particularly limited. However, from the viewpoint of maintaining the corrosion resistance and uniform solubility of the coating, the content of inevitable impurities excluding Fe is preferably 1 mass% or less in total.

The hot-dip coating layer of the hot-dip Al-Zn-Mg-Si-Sr coated steel
10 sheet of the present disclosure may further contain at least one element selected from Cr, Ni, Co, Mn, Ca, V, Ti, B, Mo, Sn, Zr, Li, Ag or the like, which are known as elements for stabilizing corrosion products in Zn-Al alloy-coating, in a content of less than 1 % of each element. When the content of each of these elements is less than 1 %, the effects disclosed herein
15 are not hindered, and the corrosion resistance can be further improved by the effect of stabilizing corrosion products.

[0028] The interfacial alloy layer is a layer present in the interface with a base steel sheet in the hot-dip coating layer. As described above, it is an Fe-Al compound and/or an Fe-Al-Si compound necessarily formed by alloying
20 reaction between Fe in the steel sheet surface and Al or Si in the bath. Because the interfacial alloy layer is hard and brittle, it serves as a start point of cracks during working when it grows thick. Therefore, the thickness of the interfacial alloy layer is preferably minimized.

[0029] For the Mg_2Si observed in a cross section in the thickness direction of
25 the hot-dip coating layer in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the area ratio of Mg_2Si existing within a range from the surface of the main layer to 50 % of the thickness of the main layer is 50 % or more, and the area ratio of Mg_2Si extending from the surface of the main layer to the interfacial alloy layer is 50 % or less.

30 In this way, good surface appearance can be achieved, and the corrosion resistance in flat parts and worked parts can be improved.

[0030] For the Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the area ratio of Mg_2Si existing within a range from the
35 surface of the main layer to 50 % of the thickness of the main layer is 50 % or more. By including Mg_2Si in the hot-dip coating layer, the Mg_2Si is

preferentially dissolved during corrosion of the hot-dip coating layer, and by concentrating the dissolved Mg in corrosion products formed on the surface of the hot-dip coating layer, excellent corrosion resistance can be achieved. However, when Sr is contained in the hot-dip coating layer for the purpose of suppressing crease-like defects or the like, there is a problem that the Mg_2Si on the surface of the main layer of the hot-dip coating layer is insufficient, which renders it difficult to concentrate Mg in the corrosion products and deteriorates the corrosion resistance. Therefore, in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, it is possible to secure sufficient Mg_2Si on the surface of the main layer by concentrating a large portion (specifically, 50 % or more) of the Mg_2Si contained in the main layer of the hot-dip coating layer in the vicinity of the surface of the main layer of hot-dip coating, even if Sr is contained in the hot-dip coating layer. In this way, a sufficient amount of Mg_2Si is dissolved during the corrosion, and Mg can be concentrated in the corrosion products. As a result, excellent corrosion resistance can be achieved while suppressing the occurrence of crease-like defects.

[0031] In other words, because the area ratio of Mg_2Si existing within the range from the surface of the main layer to 50 % of the thickness of the main layer is large (50 % or more) in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, most of the Mg_2Si on the surface of the main layer is dissolved during the corrosion, and the Mg concentration of the corrosion products formed on the hot-dip coating surface after corrosion increases. Therefore, the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure can achieve excellent corrosion resistance while suppressing the occurrence of crease-like defects.

On the other hand, because the amount of Mg_2Si existing within the range from the surface of the main layer to 50 % of the thickness of the main layer is small (less than 50 %) in a conventional hot-dip Al-Zn-Mg-Si-Sr coated steel sheet, the amount of Mg_2Si dissolved during the corrosion is insufficient, and the Mg concentration of the corrosion products on the hot-dip coating surface after corrosion is relatively low. Therefore, although the conventional hot-dip Al-Zn-Mg-Si-Sr coated steel sheet can suppress the occurrence of crease-like defects, its corrosion resistance deteriorates.

[0032] The area ratio of Mg_2Si described above (the area ratio of Mg_2Si existing within the range from the surface of the main layer to 50 % of the

thickness) can be derived, for example, by energy dispersive X-ray spectroscopy using a scanning electron microscope (SEM-EDX).

For example, the cross-sectional state of the hot-dip coating layer in the thickness direction is obtained as illustrated in FIG. 2A, and then mapping is performed for Mg and Si, respectively, as illustrated in FIG. 2B (where Mg is indicated in red, and Si is indicated in blue). After that, a part of the mapped Mg and Si where they overlap at the same position (the part indicated in purple in FIG. 2B) can be taken as Mg_2Si .

For the Mg_2Si thus obtained, a ratio (A %) of the area of the Mg_2Si with respect to the area of the entire main layer of the hot-dip coating layer is measured as illustrated in FIG. 3. After that, the main layer is divided into halves in the thickness direction, and a ratio (B %) of the area of Mg_2Si existing within the range from the surface to 50 % of the thickness with respect to the area of the entire main layer is measured. Then, a ratio of the area ratio (B %) of the Mg_2Si existing within the range from the surface of the main layer to 50 % of the thickness with respect to the area ratio (A %) of the Mg_2Si in the entire main layer of the hot-dip coating layer $((B \%) / (A \%) \times 100 \%)$ is calculated, thereby obtaining an area ratio (X %) occupied by the Mg_2Si existing within the range from the surface of the main layer to 50 % of the thickness among the Mg_2Si existing in the observation field.

[0033] Further, in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the area ratio of Mg_2Si extending from the surface of the main layer to the interfacial alloy layer is 50 % or less. In this way, the corrosion resistance in worked parts can also be significantly improved. Although the Mg_2Si included in the main layer of hot-dip coating has an effect of improving corrosion resistance, it serves as a propagation path of cracks occurred in the interfacial alloy layer and deteriorates the workability as described above. Therefore, a conventional hot-dip Al-Zn-Mg alloy-coated steel sheet cannot obtain sufficient workability and thus cannot obtain sufficient corrosion resistance in worked parts. Accordingly, in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the amount of Mg_2Si that reaches from the interfacial alloy layer to the surface of the main layer of hot-dip coating is reduced (the area ratio of the Mg_2Si is set to 50 % or less). In this way, even if cracks occur in the hard interfacial alloy layer during the working of the steel sheet, most of the cracks propagate only to the vicinity of the interfacial alloy layer and do not reach the surface of the main

layer of the hot-dip coating layer. As a result, good workability and post-working corrosion resistance can be ensured.

On the other hand, when cracks occur from the interfacial alloy layer in a conventional hot-dip Al-Zn-Mg alloy-coated steel sheet, most of the cracks reach the surface of the main layer of hot-dip coating. As a result, sufficient corrosion resistance in worked parts cannot be obtained.

[0034] The area ratio of Mg_2Si described above (the area ratio of Mg_2Si extending from the surface of the main layer to the interfacial alloy layer) can also be derived, for example, by energy dispersive X-ray spectroscopy using a scanning electron microscope (SEM-EDX).

As described above, the cross-sectional state of the hot-dip coating layer in the thickness direction is obtained (FIG. 2A), and then mapping is performed for Mg and Si, respectively (FIG. 2B). After that, a part of the mapped Mg and Si where they overlap at the same position can be taken as Mg_2Si (FIG. 2B).

For the Mg_2Si thus obtained, a ratio (A %) of the area of the Mg_2Si with respect to the area of the entire main layer of the hot-dip coating layer is measured as illustrated in FIG. 4. After that, a ratio (C %) of the area of Mg_2Si particles extending from the surface of the main layer to the interfacial alloy layer (particles indicated by arrows in FIG. 4) among the Mg_2Si particles existing in the observation field with respect to the entire main layer of the hot-dip coating layer is measured. Then, a ratio of the area ratio (C %) of the Mg_2Si extending from the surface of the main layer to the interfacial alloy layer in the entire main layer of the hot-dip coating layer with respect to the area ratio (A %) of the Mg_2Si in the entire main layer of the hot-dip coating layer $((C \%)/(A \%)) \times 100 \%$ is calculated, thereby obtaining an area ratio (Y %) of the Mg_2Si extending from the surface of the main layer to the interfacial alloy layer among the Mg_2Si particles existing in the observation field.

[0035] Note that in the present disclosure, the words of the Mg_2Si “extending from the surface of the main layer to the interfacial alloy layer” not only refer to a case where the Mg_2Si extends from the surface of the main layer until it reaches (contacts) the interfacial alloy layer, but also include a case where the distance between a lower end of the Mg_2Si and an upper end of the interfacial alloy layer is very small and the Mg_2Si substantially reaches the interfacial layer (e.g. a case where the distance between a lower end of the Mg_2Si and the

upper end of the interfacial alloy layer is 1.0 μm or less when observed in a cross section in the thickness direction of the hot-dip coating layer). This is because, when cracks occur from the interfacial alloy layer in such a case, most of the cracks reach the surface of the main layer of hot-dip coating as well.

5 [0036] For the Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer, the area ratio of Mg_2Si existing within the range from the surface of the main layer to 50 % of the thickness of the main layer is preferably 60 % or more, from the viewpoint of achieving better corrosion resistance.

10 In addition, for the Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer, the area ratio of Mg_2Si extending from the surface of the main layer to the interfacial alloy layer is preferably 40 % or less, from the viewpoint of achieving better corrosion resistance in worked parts.

15 Further, for the Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer, it is more preferable that the area ratio of Mg_2Si existing within the range from the surface of the main layer to 50 % of the thickness be 60 % or more and that the area ratio of Mg_2Si extending from the surface of the main layer to the interfacial alloy layer be 40 % or less, from the viewpoint of achieving better corrosion resistance and corrosion resistance in worked parts.

20 [0037] The area ratio of Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer is obtained by averaging area ratios of Mg_2Si observed in ten randomly selected cross sections of the hot-dip coating layer.

25 [0038] Because the hot-dip coating layer contains Si as a compositional component, a Si phase may be formed in the hot-dip coating layer due to the composition of Si and Mg in the hot-dip coating layer as described above. However, from the viewpoint of further improving the corrosion resistance and the workability, it is preferable to suppress the formation of the Si phase as much as possible.

30 In particular, we found that the content ratio of Mg_2Si , which improves the corrosion resistance, and Si phase, which acts as a cathode site during corrosion of the hot-dip coating layer and deteriorates the corrosion resistance, is important in the present disclosure. In other words, the essence

of the present disclosure is to control the ratio below a certain value, because even if the absolute amount of Mg_2Si that improves the corrosion resistance is large, good corrosion resistance cannot be secured with a large amount of Si phase that deteriorates the corrosion resistance.

5 **[0039]** Therefore, in the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, a ratio of an area ratio of Si phase observed in a cross section in the thickness direction of the hot-dip coating layer with respect to a total area ratio of Mg_2Si and Si phase observed in the cross section in the thickness direction of the hot-dip coating layer (area ratio of Si phase/total
10 area ratio of Mg_2Si and Si phase), which is measured with the method described below, is preferably 30 % or less and more preferably 10 % or less.

The method of deriving the area ratio of Si phase may be, for example, the same as the one for Mg_2Si described above, which is performed by energy dispersive X-ray spectroscopy using a scanning electron microscope
15 (SEM-EDX).

As described above, the cross-sectional state of the hot-dip coating layer in the thickness direction is obtained (FIG. 2A), and then mapping is performed for Mg and Si, respectively (FIG. 2B). After that, a position in the mapped Mg and Si where Si exists while Mg does not exist, which is a part
20 indicated in blue in FIG. 2B, can be taken as the Si phase. The area ratio of Si phase (D %) can be calculated from a ratio of the total area of the blue parts with respect to the area of the hot-dip coating layer in the observed field. Further, a ratio of an area ratio of Si phase observed in a cross section in the thickness direction of the hot-dip coating layer with respect to the total area
25 ratio of Mg_2Si and Si phase (area ratio of Si phase/total area ratio of Mg_2Si and Si phase) can be calculated as $(D \% / (A \% + D \%) \times 100 \%)$.

The ratio of the area of Si phase with respect to the total area of Mg_2Si and Si phase observed in a cross section in the thickness direction of the hot-dip coating layer described above is obtained by averaging area ratios of
30 Si phase observed in ten randomly selected cross sections of the hot-dip coating layer.

[0040] The area ratio of Si phase observed in a cross section in the thickness direction of the hot-dip coating layer (area ratio of Si phase in the observation field: D %) is preferably 10 % or less and more preferably 3 % or less.

35 The area ratio of Si phase observed in a cross section in the thickness direction of the hot-dip coating layer described above is obtained by

averaging area ratios of Si phase observed in ten randomly selected cross sections of the hot-dip coating layer.

[0041] From the viewpoint of further improving the initial corrosion resistance of the hot-dip coated steel sheet, the area ratio of Si phase observed
5 in the surface of the hot-dip coating layer (area ratio of Si phase in the observation field) is preferably 1 % or less and more preferably 0.5 % or less. The method of deriving the area ratio of Si phase on the surface of the hot-dip coating layer may be the same as the one in the case of observing a cross section, which is performed by energy dispersive X-ray spectroscopy using a
10 scanning electron microscope (SEM-EDX). The area ratio can be determined according to a cross-sectional observation method, and it can be obtained by averaging area ratios of Si phase observed in ten randomly selected locations of the surface of the hot-dip coating layer.

[0042] Also from the viewpoint of further improving the initial corrosion
15 resistance, a ratio of the area of Si phase observed in a cross section in the thickness direction of the hot-dip coating layer with respect to the total area of Mg₂Si and Si phase observed on the surface of the hot-dip coating layer (area of Si phase/total area of Mg₂Si and Si phase) is preferably 20 % or less and more preferably 10 % or less. The actual observation method and the method
20 of determining the area ratio are the same as the ones of the cross-sectional observation method described above.

[0043] When observing the main layer of the hot-dip coating layer and the interfacial alloy layer under a scanning electron microscope, the cross section or surface of the hot-dip coating layer is observed after polishing and/or
25 etching. Although there are several types of polishing methods and etching methods for a cross section or surface, no particular limitations are placed on these methods as long as they are generally used when observing a cross section or surface of a hot-dip coating layer. Regarding the observation conditions under a scanning electron microscope, it is possible to clearly
30 observe a cross section of the hot-dip coating layer, for example, in secondary electron beam images or reflected electron images at a magnification of about 500 times to 5000 times, with an acceleration voltage of 5 kV to 20 kV. In the case of mapping by EDX, the area ratio mentioned above can be obtained by analyzing at the same magnification.

[0044] The main layer of the hot-dip coating layer has α -Al phase dendritic
35 regions, where the average distance between dendritic arms of the dendritic

regions and the thickness of the hot-dip coating layer preferably satisfy the following expression (1),

$$t/d \geq 1.5 \quad (1)$$

where t is the thickness (μm) of the hot-dip coating layer, and d is the average
5 distance (μm) between dendritic arms.

By satisfying the expression (1) above, the arm of the dendritic regions of $\alpha\text{-Al}$ phase described above can be relatively small, and a long interdendritic path that is preferentially corroded is secured. As a result, the corrosion resistance can be further improved.

10 **[0045]** The distance between dendritic arms of the dendritic region refers to a distance between centers of adjacent dendritic arms (dendritic arm spacing). In the present disclosure, as the example illustrated in FIG. 5, the surface of the main layer of the hot-dip coating layer is magnified and observed (e.g. at a magnification of 200 times) using a scanning electron microscope (SEM) or
15 the like, and the second widest distance between dendrite arms (secondary dendritic arms) in a randomly selected field of view is measured as follows. An area where three or more secondary dendritic arms are standing in a row is selected (in FIG. 5, three arms between A and B are selected), and the distance along the direction in which the arms stand (in FIG. 5, the distance L) is
20 measured. The measured distance is then divided by the number of dendritic arms ($L/3$ in FIG. 5) to calculate the distance between dendritic arms. The distance between dendritic arms is measured at three or more locations in one field of view, and the average of all the obtained distances between dendritic arms is calculated and taken as the average distance between dendritic arms.

25 **[0046]** The thickness of the hot-dip coating layer is preferably 10 μm to 30 μm and more preferably 20 μm to 25 μm , from the viewpoint of achieving both workability and corrosion resistance at a high level. This is because sufficient corrosion resistance can be secured when the hot-dip coating layer is 10 μm or more, and sufficient workability can be secured when the hot-dip
30 coating layer is 30 μm or less.

[0047] Moreover, the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure may be a surface-treated steel sheet further having a chemical conversion treatment coating and/or a coating film on the surface thereof.

35 **[0048]** (Method of producing hot-dip Al-Zn-Mg-Si-Sr coated steel sheet)

Next, a method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure will be described.

The method of producing the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure includes using a molten bath having a composition containing 40 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the balance being Zn and inevitable impurities, and a bath temperature of 585 °C or lower to perform hot dip coating on a steel sheet, where a temperature of the steel sheet at the time of entering the molten bath (sheet temperature at entry) is equal to or lower than a temperature of adding 20 °C to the bath temperature of the molten bath (molten bath temperature + 20 °C).

The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet obtained with the above production method has good surface appearance and excellent corrosion resistance in flat parts and worked parts.

[0049] Although there is no particular limitation on the method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, a continuous galvanizing line (CGL) is usually employed from the viewpoint of production efficiency and quality stability.

[0050] The base steel sheet used for the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure is not limited to a particular type. For example, a hot-rolled steel sheet or steel strip that has been subjected to acid pickling descaling, or a cold-rolled steel sheet or steel strip obtained by subjecting the hot-rolled steel sheet or steel strip to cold rolling may be used.

Conditions of the pretreatment process and the annealing process are not particularly limited, and any method may be adopted.

[0051] In the method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the molten bath has a composition containing 40 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the balance being Zn and inevitable impurities.

In this way, a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet with a desired composition can be obtained. The type, content and action of each element contained in the molten bath have been described above in the description of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure.

[0052] The composition of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet obtained with the production method of the present disclosure is almost the

same as that of the molten bath as a whole. Therefore, the composition of the main layer can be accurately controlled by controlling the composition of the molten bath.

[0053] In the method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the contents of Mg and Si in the molten bath preferably satisfy the following expression (2),

$$M_{\text{Mg}}/(M_{\text{Si}}-0.6) \geq 1.0 \quad (2)$$

where M_{Mg} is the content of Mg (mass%), and M_{Si} is the content of Si (mass%).

When the contents of Mg and Si in the molten bath satisfy the above expression, the formation of Si phase is suppressed in the formed hot-dip coating layer (e.g. the area ratio of Si phase observed in a cross section in the thickness direction of the hot-dip coating layer is 10 % or less, and the area ratio of Si phase observed on the surface of the hot-dip coating layer is 1 % or less), and the workability and the corrosion resistance can be further improved.

From the same viewpoint, the $M_{\text{Mg}}/(M_{\text{Si}}-0.6)$ is preferably 2.0 or more and more preferably 3.0 or more.

[0054] In the method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the bath temperature of the molten bath is 585 °C or lower and preferably 580 °C or lower. This setting of the bath temperature can reduce the amount of large Mg_2Si extending from the surface of the main layer of the hot-dip coating layer to the interfacial alloy layer. It also has the effect of inhibiting the growth of the interfacial alloy layer. The reason why a low bath temperature is effective is that it can shorten the time that the steel sheet stays in high-temperature regions where the Mg_2Si and the interfacial alloy layer grow. When the bath temperature of the molten bath exceeds 585 °C, even if the temperature of the steel sheet at the time of entering the molten bath is optimized, the amount of large Mg_2Si extending from the surface of the main layer to the interfacial alloy layer increases, and the interfacial alloy layer grows thick. As a result, the desired workability and corrosion resistance in worked parts cannot be obtained.

[0055] In the method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the temperature of the steel sheet at the time of entering the molten bath (sheet temperature at entry) is equal to or lower than a temperature of adding 20 °C to the bath temperature of the molten bath

(molten bath temperature + 20 °C). In this way, the amount of large Mg₂Si extending from the surface of the main layer of the hot-dip coating layer to the interfacial alloy layer can be reduced. The reason why the amount of large Mg₂Si can be reduced by lowering the sheet temperature at entry is that it can shorten the time that the steel sheet stays in high-temperature regions where the Mg₂Si and the interfacial alloy layer grow, which is similar to the effect of lowering the bath temperature described above.

From the same viewpoint, the sheet temperature at entry of the steel sheet is preferably equal to or lower than a temperature of adding 10 °C to the bath temperature of the molten bath (molten bath temperature + 10 °C) and more preferably equal to or lower than the bath temperature of the molten bath.

[0056] Further, in the method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the steel sheet is preferably cooled at an average cooling rate of 10 °C/s or higher until the sheet temperature reaches a temperature of subtracting 150 °C from the bath temperature of the molten bath (molten bath temperature – 150 °C), after performing hot dip coating on the steel sheet. It is known that the Mg₂Si formed in the hot-dip coating layer tends to be formed in a temperature range up to a temperature of subtracting 150 °C from the bath temperature of the molten bath (molten bath temperature – 150 °C). By increasing the cooling rate in the temperature range to an average of 10 °C/s or higher, it is possible to suppress the growth of Mg₂Si and reduce the amount of large Mg₂Si extending from the surface of the main layer of the hot-dip coating layer to the interfacial alloy layer. In addition, by increasing the cooling rate of the steel sheet after the hot dip coating, the growth of the interfacial alloy layer can also be suppressed. As a result, excellent corrosion resistance in worked parts can be obtained.

The average cooling rate is obtained by determining the time it takes for the steel sheet to reach a temperature of subtracting 150 °C from the temperature of the molten bath, and dividing 150 °C by that time.

[0057] Furthermore, it is possible to increase the amount of Mg₂Si in the vicinity of the surface of the main layer of hot-dip coating to 50 % or more of the total by increasing the cooling rate in the temperature range to an average of 10 °C/s or higher. The reason for this is as follows. The interfacial alloy layer is formed by a solid-liquid reaction (reaction between Al in the bath and the steel sheet) in the molten bath, and Si is also taken into the interfacial

alloy layer during the reaction. Therefore, the Si concentration in the vicinity of the interfacial alloy layer during the solidification of interdendrite is lower than the average Si concentration in the main layer of hot-dip coating, and the distribution of Mg_2Si is larger on the surface of the main layer of hot-dip coating than on the interfacial alloy layer side. On the other hand, in the cooling process after the hot dip coating, the coated steel sheet is cooled from the surface, so that the solidification of interdendrite starts from the surface. The solubility of Mg_2Si in Zn decreases as the temperature lowers, and Mg and Si are discharged to the liquid phase side at a solid-liquid interface and concentrated in the interdendritic regions of the liquid. This phenomenon becomes pronounced as the state reaches equilibrium, that is, as the cooling rate decreases. Therefore, the Mg_2Si tends to be unevenly distributed in the vicinity of the interfacial alloy layer when the cooling rate is low. In other words, by increasing the cooling rate (to an average of 10 °C/s or higher), the uneven distribution of Mg_2Si in the vicinity of the interfacial alloy layer can be suppressed, and the original distribution of Mg_2Si can be maintained. That is, it is possible to secure a state where more Mg_2Si in the hot-dip coating layer is distributed on the surface of the main layer than in the vicinity of the interfacial alloy layer.

From the same viewpoint, the cooling of the steel sheet after the hot dip coating is more preferably performed at an average cooling rate of 20 °C/s or higher, still more preferably at an average cooling rate of 30 °C/s or higher, and particularly preferably at an average cooling rate of 40 °C/s or higher.

[0058] In the production method of the present disclosure, the conditions other than those for bath temperature and sheet temperature at entry during the hot dip coating and those for cooling after the hot-dip coating are not particularly limited, and a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet may be produced according to any conventional method.

[0059] The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet obtained with the production method of the present disclosure may further have a chemical conversion treatment coating formed on its surface (chemical conversion treatment process) or further have a coating film formed on its surface in a separate coating apparatus (coating film forming process).

The chemical conversion treatment coating may be formed, for example, by chromating treatment or chromate-free chemical conversion treatment where a chromating treatment liquid or a chromate-free chemical

conversion treatment liquid is applied and drying treatment is performed without washing the liquid with water until the steel sheet temperature reaches 80 °C to 300 °C. These chemical conversion treatment coatings may have a single-layer structure or a multilayer structure. In the case of a multiple
5 layer structure, chemical conversion treatment may be performed multiple times sequentially.

Further, methods of forming the coating film include roll coater coating, curtain flow coating, and spray coating. The coating film can be formed by applying paint containing organic resin and then performing
10 heating and drying by means such as hot air drying, infrared heating, and induction heating.

EXAMPLES

[0060] (Samples 1 to 25)

15 Using cold-rolled steel sheets with a sheet thickness of 0.5 mm produced with a conventional method as a base steel sheet, hot-dip Al-Zn alloy-coated steel sheets of Samples 1 to 25 were produced in a continuous galvanizing line (CGL). The composition of a molten bath used in the production was almost the same as that of a hot-dip coating layer of each
20 sample listed in Table 1, and the bath temperature of the molten bath, the sheet temperature at entry of the steel sheet, and the cooling rate to a temperature of subtracting 150 °C from the bath temperature of the molten bath are listed in Table 1.

Each sample of hot-dip Al-Zn alloy-coated steel sheet thus obtained
25 was then subjected to energy dispersive X-ray spectroscopy using a scanning electron microscope (SEM-EDX), where a cross section was observed at a randomly selected location.

Next, for each sample, all the conditions of the formed hot-dip coating layer and all the production conditions of the hot dip coating were measured
30 or calculated, which are listed in Table 1.

[0061] <Evaluation>

Each sample of hot-dip Al-Zn alloy-coated steel sheet thus obtained was subjected to the following evaluation. The evaluation results are listed in Table 1.

35 [0062] (1) Surface appearance

For each sample of hot-dip Al-Zn alloy-coated steel sheet, the surface of the hot-dip coating layer (both sides of each sample) was visually observed in an observation field of about 1000 mm to 1600 mm width × 1000 mm length of the steel sheet.

5 The observation results were evaluated based on the following criteria.

Good: no crease-like defects were observed at all on either the surface or the back surface.

10 Poor: crease-like defects were observed on either or both of the surface and the back surface.

[0063] (2) Corrosion resistance evaluation (corrosion resistance in flat parts)

Each sample of hot-dip Al-Zn alloy-coated steel sheet was subjected to the Combined Cycle Test of Japanese Automobile Standards Organization (JASO-CCT). The JASO-CCT is a test including one cycle of salt spraying, 15 drying, and wetting under specific conditions, as illustrated in FIG. 6.

The number of cycles until red rust occurred in each sample was measured, and evaluation was performed based on the following criteria.

Excellent: number of cycles until red rust occurred ≥ 400

Good: $300 \leq$ number of cycles until red rust occurred < 400

20 Poor: number of cycles until red rust occurred < 300

(3) Evaluation of corrosion resistance in bent parts (corrosion resistance in worked parts)

Each sample of hot-dip Al-Zn-Mg-Si-Sr coated steel sheet was subjected to bending where three sheets with the same sheet thickness were 25 placed inside and 180-degree bending (3T bending) was performed, and then the Combined Cycle Test of Japanese Automobile Standards Organization (JASO-CCT) was performed in the outside of the bending. The JASO-CCT is a test including one cycle of salt spraying, drying, and wetting under specific conditions, as illustrated in FIG. 6.

30 The number of cycles until red rust occurred in the worked parts of each sample was measured, and evaluation was performed based on the following criteria.

Excellent: number of cycles until red rust occurred ≥ 400

Good: $300 \leq$ number of cycles until red rust occurred < 400

35 Poor: number of cycles until red rust occurred < 300

[0064]

Table 1

No.		Hot-dip coating layer conditions										Production conditions					Evaluation			Remarks			
		Composition (mass%)		Area ratio of Mg ₂ Si existing within a range from main layer surface to 50% thickness (%) : B	Area ratio of Mg ₂ Si extending from main layer surface to interfacial alloy layer (%) : C	Area ratio of Mg ₂ Si existing within a range from main layer surface to 50% thickness among Mg ₂ Si (%) : X	Area ratio of Mg ₂ Si extending from main layer surface to interfacial alloy layer among Mg ₂ Si (%) : Y	Area ratio of Si phase in main layer observed in cross section in thickness direction (%) : D	Average distance between dendritic arms (μm)	Left side of expression (l)	Thick-ness of hot-dip coating layer (μm)	Molten bath temperature (°C)	Sheet temper-ature at entry (°C)	Cooling rate to molten bath temper-ature -150°C (°C/s)	Relation-ship between Mg and Si in molten bath: N*	Surface appear-ance	Corrosion resistance						
																	Flat part	Worked part					
		Al	Si	Mg	Sr																		
1	55	1.5	3.0	0		8	6.0	3.6	75	45	0.2	2.4	11	2.2	24	590	600	30	0.0	Poor	Excellent	Good	Comparative Example
2	55	0.5	0.05	0.0005			0.004	0.003	40	30	0	0.0	10	2.2	23	580	585	45	-0.5	Poor	Poor	Good	Comparative Example
3	55	1.5	3.0	0.01		7	4.9	2.8	70	40	0.3	4.1	12	1.9	23	580	590	40	3.3	Good	Excellent	Good	Example
4	55	1.5	3.0	0.1		9	5.4	3.2	60	35	0.4	4.3	9	2.3	21	570	565	50	3.3	Good	Good	Good	Example
5	55	1.5	3.0	1.0		10	5.5	3.0	55	30	0.2	2.0	7	3.1	22	575	575	60	3.3	Good	Good	Excellent	Example
6	55	1.5	1.0	0.01		1	0.7	0.4	70	35	0.02	2.0	10	2.3	23	585	600	65	1.1	Good	Excellent	Good	Example
7	55	1.5	5.0	0.01		12	8.4	4.6	70	38	0.2	1.6	11	2.4	26	580	590	55	5.6	Good	Excellent	Good	Example
8	55	1.5	10.0	0.01		15	10.5	6.8	70	45	0.1	0.7	12	1.8	22	580	595	45	11.1	Good	Excellent	Good	Example
9	55	0.7	3.0	0.01		3	2.1	1.1	70	38	0.05	1.6	8	2.9	23	585	580	30	30.0	Good	Excellent	Good	Example
10	55	1.0	3.0	0.01		5	3.5	2.3	70	45	0.1	2.0	10	2.1	21	575	590	40	7.5	Good	Excellent	Good	Example
11	55	2.0	3.0	0.01		10	7.0	2.5	70	25	1	9.1	11	2.0	22	565	585	50	2.1	Good	Excellent	Excellent	Example
12	55	2.5	3.0	0.01		15	10.5	4.5	70	30	2	11.8	12	1.8	22	575	570	60	1.6	Good	Good	Excellent	Example
13	55	3.0	3.0	0.01		18	12.6	6.3	70	35	3	14.3	9	2.6	23	580	575	70	1.3	Good	Good	Good	Example
14	55	5.0	3.0	0.01		20	14.0	8.0	70	40	11	35.5	7	3.7	26	570	575	65	0.7	Good	Poor	Poor	Comparative Example
15	55	10.0	12.0	2.0		30	15.0	16.0	50	53	20	40.0	8	3.7	22	565	580	55	1.3	Good	Poor	Poor	Comparative Example
16	55	5.0	5.0	0.01		20	14.0	8.0	70	40	7	25.9	7	3.7	26	570	575	65	1.1	Good	Good	Good	Example
17	55	2.5	5.0	0.01		12	8.4	4.6	70	38	3	20.0	8	2.8	22	575	570	55	2.6	Good	Good	Good	Example
18	55	2.5	5.0	0.1		14	9.1	4.8	65	34	4	22.2	10	2.4	24	585	575	45	2.6	Good	Good	Good	Example
19	55	2.5	5.0	1.0		13	7.8	3.9	60	30	5	27.8	10	2.4	24	585	570	35	2.6	Good	Good	Good	Example
20	45	1.5	3.0	0.01		7	4.9	3.1	70	44	0.2	2.8	7	3.1	22	580	575	50	3.3	Good	Excellent	Good	Example
21	65	1.5	3.0	0.01		8	5.6	3.2	70	40	0.3	3.6	8	2.8	22	585	580	60	3.3	Good	Excellent	Good	Example
22	55	1.5	3.0	0.01		10	2.0	5.5	20	55	0.2	2.0	9	2.9	26	605	605	65	3.3	Good	Poor	Poor	Comparative Example
23	55	1.5	3.0	0.01		7	2.1	3.2	30	45	0.3	4.1	16	1.4	22	580	600	8	3.3	Good	Poor	Good	Comparative Example
24	55	1.5	3.0	0.01		8	1.2	4.8	15	60	0.4	4.8	11	2.2	24	580	620	45	3.3	Good	Poor	Poor	Comparative Example
25	55	1.5	0	0		-	-	-	-	-	-	-	12	1.7	20	590	600	35	-	Good	Poor	Poor	Comparative Example

*N=Mg/(Mg+Si) in the bath, and M is the Si concentration (mass%) in the bath

[0065] It can be understood from Table 1 that each sample of Examples is well-balanced and superior to each sample of Comparative Examples in all terms of surface appearance, corrosion resistance, and corrosion resistance in worked parts.

5

INDUSTRIAL APPLICABILITY

[0066] According to the present disclosure, it is possible to provide a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in flat parts and worked parts, and a method of
10 producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in flat parts and worked parts.

CLAIMS

1. A hot-dip Al-Zn-Mg-Si-Sr coated steel sheet comprising a hot-dip coating layer having a composition containing 40 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the balance being Zn and inevitable impurities, wherein
the hot-dip coating layer comprises an interfacial alloy layer present at an interface with a base steel sheet, and a main layer present on the alloy layer, and
for Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer, an area ratio of Mg_2Si existing within a range from a surface of the main layer to 50 % of the thickness of the main layer is 50 % or more, and an area ratio of Mg_2Si extending from a surface of the main layer to the interfacial alloy layer is 50 % or less.
2. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to claim 1, wherein for Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer, an area ratio of Mg_2Si existing within a range from a surface of the main layer to 50 % of the thickness of the main layer is 60 % or more, and an area ratio of Mg_2Si extending from a surface of the main layer to the interfacial alloy layer is 50 % or less.
3. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to claim 1 or 2, wherein for Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer, an area ratio of Mg_2Si existing within a range from a surface of the main layer to 50 % of the thickness of the main layer is 60 % or more, and an area ratio of Mg_2Si extending from a surface of the main layer to the interfacial alloy layer is 40 % or less.
4. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to any one of claims 1 to 3, wherein a ratio of an area ratio of Si phase observed in a cross section in a thickness direction of the hot-dip coating layer to a total area ratio of Mg_2Si and Si phase observed in the cross section in the thickness direction of the hot-dip coating layer is 30 % or less.

5. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to any one of claims 1 to 4, wherein the main layer has α -Al phase dendritic regions, and an average distance between dendritic arms of the dendritic regions and a thickness of the hot-dip coating layer satisfy the following expression (1),

$$t/d \geq 1.5 \quad (1)$$

where t is the thickness of the hot-dip coating layer in μm , and d is the average distance between dendritic arms in μm .

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6. A method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet, comprising using a molten bath having a composition containing 40 mass% to 70 mass% of Al, 0.6 mass% to 5 mass% of Si, 0.1 mass% to 10 mass% of Mg, and 0.001 mass% to 1.0 mass% of Sr, with the balance being Zn and inevitable impurities, and a bath temperature of 585 °C or lower to perform hot dip coating on a steel sheet, wherein

a temperature of the steel sheet at the time of entering the molten bath, which is a sheet temperature at entry, is equal to or lower than a temperature of adding 20 °C to the bath temperature of the molten bath, which is molten bath temperature + 20 °C.

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7. The method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to claim 6, wherein the sheet temperature at entry of the steel sheet is equal to or lower than the bath temperature of the molten bath.

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8. The method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to claim 6 or 7, wherein after performing hot dip coating on the steel sheet, the steel sheet is cooled at an average cooling rate of 10 °C/s or higher until the sheet temperature reaches a temperature of subtracting 150 °C from the bath temperature of the molten bath, which is molten bath temperature – 150 °C.

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