

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 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

B) discloses an Al-Zn-Mg-Si coated steel sheet in which the hot-dip coating layer contains a Mg-containing Al-Zn-Si alloy, where the Al-Zn-Si alloy contains 45 wt% to 60 wt% of aluminum, 37 wt% to 46 wt% of zinc, and 1.2 wt% to 2.3 wt% of silicon, and has a Mg concentration of 1 wt% to 5 wt%.

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 caused by an oxide layer formed on the surface of the hot-dip coating layer (hereinafter referred to as “crease-like defect”) tend to occur, and the appearance of the hot-dip coating layer surface is damaged.

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

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

CITATION LIST

Patent Literature

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

SUMMARY

25 (Technical Problem)

[0007] The hot-dip Al-Zn alloy-coated steel sheets of PTLs 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.

However, regarding the Sr-containing hot-dip Al-Zn alloy-coated steel
30 sheets of PTLs 3 and 4, corrosion progresses from cracks formed during the working of the steel sheets. As a result, the corrosion resistance in worked parts is deteriorated.

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

hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in worked parts.

(Solution to Problem)

[0009] We made intensive studies to solve the above problems. As a result, we found that, during the corrosion of the hot-dip coating layer, Mg_2Si formed in the hot-dip coating layer is preferentially dissolved, and the dissolved Mg is concentrated in corrosion products formed on the surface of the hot-dip coating layer, so that high corrosion resistance can be obtained. Therefore, even if cracks occur in the hot-dip coating layer, the corrosion products can fill the cracks and prevent the base steel sheet from being exposed if the crack has a certain width, so that the corrosion resistance of worked parts can be sufficiently maintained. As a result of further intensive research, we found that an Al-Si-Sr alloy present between the interfacial alloy layer, which is present at an interface with the base steel sheet, and the main layer present on the alloy layer (hereinafter also referred to as “main layer of hot-dip coating”) is hard and has low ductility, and the surface shape of the interfacial alloy layer is uneven. As a result, cracks are likely to occur in the main layer of hot-dip coating, and the corrosion resistance of worked parts is adversely affected if the width of the formed cracks is large. Further, we found that by keeping the size of the Al-Si-Sr alloy as small as possible (specifically, to an average major axis of 1 μm or less), an increase in the width of cracks can be suppressed even if cracks occur in the main layer of the hot-dip coating layer during the working of the steel sheet. As a result, the corrosion product acts to fill the formed cracks, and excellent corrosion resistance of worked parts can be achieved.

[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) 25 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 an Al-Si-Sr alloy having an average major axis of 1 μm or less is present between the main layer and the interfacial alloy layer.

[0011] 2. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to 1., wherein the interfacial alloy layer contains 0.001 mass% or more of Sr.

[0012] 3. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to 1. or 2., wherein Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer all has a major axis of 10 μm 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 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 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 .

[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) 25 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 so as 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.

[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 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 30 °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.

(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 worked parts, and a method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in worked parts.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In the accompanying drawings:

FIG. 1 illustrates the state of the interface between the main layer and the interfacial alloy layer in a cross section in the thickness direction of the hot-dip coating layer of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure when it is observed under a scanning transmission electron microscope;

FIG. 2A illustrates the state of each element of the hot-dip 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 present in the main layer of the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet illustrated in FIG. 2A;

FIG. 3 illustrates a method of measuring the distance between dendritic arms; and

FIG. 4 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)

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 containing 25 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% from a viewpoint of balancing corrosion resistance with actual operation requirements. When the Al content of the main layer of the hot-dip coating layer is 25 mass% or more, good corrosion resistance can be ensured.

5 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
10 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 40 mass% or more. On the other hand, when the Al content in
15 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
20 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
25 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
30 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
35 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 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 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 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 . 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 of densifying the corrosion products, which can improve the stability of the corrosion products and the barrier properties against external causes of corrosion.

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 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 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 as to stably obtain excellent post-coating corrosion resistance.

[0025] The hot-dip coating layer contains 0.001 mass% to 1.0 mass% of Sr.

5 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.

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
10 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 preferentially oxidized over Mg in the surface layer of the hot-dip coating
15 layer, and the oxidation reaction of Mg is suppressed. As a result, it is possible to suppress the occurrence of the streak-like defects.

[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
20 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 large, the effect of suppressing the occurrence of streak-like defects is
25 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.

[0027] Note that the hot-dip coating layer also contains base steel sheet
30 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 about several percent of Fe. Examples of the inevitable impurities in the
35 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. With regard to 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 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 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 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 reaction between Fe in the steel sheet surface and Al or Si in the molten 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] The interfacial alloy layer preferably contains 0.001 mass% or more of Sr. This is because, when the interfacial alloy layer contains 0.001 mass% or more of Sr, the surface energy of Fe-Al alloy formed at the interface in the molten Al-Zn is lowered by Sr. As a result, the unevenness of the interfacial shape of the interfacial alloy layer on the hot-dip coating main layer side is smoothed, and the workability (crack resistance) during a bending process can be further improved. After the main layer of hot-dip coating is corroded, the steel sheet is corroded, and red rust is formed. When Sr is contained in the interfacial alloy layer, the corrosion resistance of the interfacial alloy layer is improved, so that the time until red rust is formed can be prolonged. From the same viewpoint, the content of Sr in the interfacial alloy layer is preferably 0.005 mass% or more and more preferably 0.01 mass% or more.

The Sr concentration in the interfacial alloy layer is desirably 10 mass% or less. This is because, when the Sr concentration in the interfacial

alloy layer exceeds 10 mass%, the hardness of the interfacial alloy layer increases, and the workability may deteriorate.

The Sr in the interfacial alloy layer can be quantitatively analyzed by STEM-EDX analysis as described below.

5 **[0030]** In the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, an Al-Si-Sr alloy having an average major axis of 1 μm or less is partially present between the main layer and the interfacial alloy layer in the hot-dip coating layer.

10 In the present disclosure, containing Sr in the hot-dip coating layer necessarily leads to the formation of an Al-Si-Sr alloy at the interface between the main layer and the interfacial alloy layer of the hot-dip coating layer. By controlling the size of the Al-Si-Sr alloy, good surface appearance can be achieved, and the corrosion resistance of worked parts can also be improved.

[0031] By including Mg_2Si in the hot-dip coating layer of the hot-dip
15 Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure, the Mg_2Si is preferentially dissolved during the 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
20 purpose of suppressing crease-like defects or the like, an Al-Si-Sr alloy is formed at the interface between the main layer and the interfacial alloy layer (sandwiched between the main layer and the interfacial alloy layer) as described above. As a result, cracks tend to occur in the hot-dip coating layer during the working of the steel sheet, and the width of the formed cracks
25 increases, which causes deterioration in the corrosion resistance of worked parts. Therefore, the hot-dip Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure suppresses the Al-Si-Sr alloy to a small size at the formation (so that the average major axis is 1 μm or less). In this way, even if cracks occur in the hot-dip coating layer, the cracks can be filled with a
30 sufficient amount of corrosion product during the corrosion of the steel sheet, and Mg can be concentrated in the vicinity the surface of the corrosion products. As a result, excellent corrosion resistance in worked parts can be achieved while suppressing the occurrence of crease-like defects.

[0032] FIG. 1 is a photograph of a cross section of the hot-dip
35 Al-Zn-Mg-Si-Sr coated steel sheet of the present disclosure when it is observed under a scanning transmission electron microscope (STEM). As

can be seen from FIG.1, an Al-Si-Sr alloy is present between the main layer and the interfacial alloy layer of the hot-dip coating layer.

In addition, the following Table 1 lists the analysis results of the chemical composition of the portions indicated by *1 to *4 in FIG. 1. As can be seen from Table 1, all the portions indicated by *1 to *3 in FIG. 1 are in the interfacial alloy layer composed mainly of Fe, Al, Si and Zn, whereas the portion indicated by *4 in FIG. 1 is composed basically of Al, Si and Sr, which means it is an Al-Si-Sr alloy and is an alloy different from the interfacial alloy layer.

The Al-Si-Sr alloy does not have to be present at the entire interface between the main layer and the interfacial alloy layer. It is partially present at the interface between the main layer and the interfacial alloy layer, as illustrated in FIG 1. Further, the Al-Si-Sr alloy is present at the interface between the main layer and the interfacial alloy layer (sandwiched between the main layer and the interfacial alloy layer) and is not formed inside the main layer or the interfacial alloy layer.

[0033]

Table 1

Table 1

	Chemical composition (mass%)					Judgment
	Fe	Al	Si	Zn	Sr	
*1	33	47	7	13	0.1	Interfacial alloy layer
*2	32	52	7	9	0.1	Interfacial alloy layer
*3	32	49	7	11	0.2	Interfacial alloy layer
*4	1	31	30	0.1	37	≠Interfacial alloy layer

[0034] The Al-Si-Sr alloy present between the main layer and the interfacial alloy layer should have an average major axis of 1 μm or less. As described above, when the size of the Al-Si-Sr alloy is suppressed to an average major axis of 1 μm or less, even if cracks occur in the hot-dip coating layer, the cracks can be filled with a sufficient amount of corrosion product during the corrosion of the steel sheet, thereby achieving excellent corrosion resistance in worked parts. From the same viewpoint, the average major axis of the Al-Si-Sr alloy is preferably 0.8 μm or less.

[0035] The major axis of the Al-Si-Sr alloy refers to the longest diameter of a particle of the Al-Si-Sr alloy in the observation field.

The calculation of the average major axis of the Al-Si-Sr alloy can be performed by, for example, a scanning transmission electron microscope (STEM). As illustrated in FIG. 1, a cross section in the thickness direction of the hot-dip coating layer is observed, the major axis of each particle of the Al-Si-Sr alloy in the observation field is measured, and the average diameter is calculated. TEM observation is performed at five randomly selected locations, the major axis of the Al-Si-Sr alloy in all locations are measured, and the average of these major axes can be taken as the major axis of the Al-Si-Sr alloy.

[0036] For Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer, the major axis of all the Mg_2Si is preferably 10 μm or less and more preferably 8 μm or less. Although the Mg_2Si included in the main layer of hot-dip coating contributes to the effect of improving corrosion resistance as described above, it hardens the main layer of hot-dip coating and deteriorates the workability. 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, by reducing the size of the Mg_2Si in the hot-dip coating layer (so that the major axis is 10 μm or less), the width and length of cracks can be kept small even if cracks occur in the hot-dip coating layer. As a result, the cracks can be filled with a sufficient amount of corrosion product during the corrosion of the steel sheet, Mg can be concentrated in the vicinity the surface of the corrosion products, and the corrosion resistance of worked parts can be significantly improved.

[0037] The major axis of Mg_2Si observed in a cross section in the thickness direction of the hot-dip coating layer is the longest diameter in one Mg_2Si . The major axis of Mg_2Si means that the average major axis of the Mg_2Si particles observed in a cross section in the thickness direction of the hot-dip coating layer is 10 μm or less. For example, it is possible to observe ten randomly selected cross sections and confirm whether or not the average major axis of all Mg_2Si particles is 10 μm or less.

[0038] The Mg_2Si in a cross section in the thickness direction of the hot-dip coating layer described above can be observed, 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 . The area ratio (B%) of Mg_2Si can be calculated from a ratio of the total area of the purple parts to the area of the hot-dip coating layer in the observed field.

[0039] 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.

Particularly, 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.

[0040] 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 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 (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 indicated in blue in FIG. 2B, can be taken as the Si phase. The area ratio of Si phase (A %) 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 ratio of Mg₂Si and Si phase observed in the cross section in the thickness direction of the hot-dip coating layer (area ratio of Si phase/total area ratio of Mg₂Si and Si phase: Z%) can be calculated as $(A \%/ (A \% + B \%) \times 100 \%)$.

The ratio of the area of Si phase with respect to the total area of Mg₂Si 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 Si phase observed in ten randomly selected cross sections of the hot-dip coating layer.

[0041] 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: A %) is preferably 10 % or less and more preferably 3 % or less.

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.

[0042] From the viewpoint of further improving the initial corrosion resistance of the hot-dip coated steel sheet, the area ratio of Si phase observed 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 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.

Also, from the viewpoint of further improving the initial corrosion 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 of determining the area ratio are the same as the ones of the cross-sectional observation method described above.

5 [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 etching. Although there are several types of polishing methods and etching methods for a cross section or surface, no particular limitations are placed on
10 these methods as long as they are generally used when observing a cross section or surface of a hot-dip coating layer. The observation and analysis under a scanning electron microscope may be performed, 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
15 of 5 kV to 20 kV.

Regarding the observation conditions under the scanning transmission electron microscope (STEM-EDX), it is possible to clearly observe and analyze the hot-dip coating layer of a cross-section sample of FIB-processed hot-dip coating layer, for example, at a magnification of about 1000 times to
20 5000 times with an acceleration voltage of 200 kV.

[0044] The main layer of the hot-dip coating layer has α -Al phase dendritic 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),

25
$$t/d \geq 1.5 \quad (1)$$

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

By satisfying the expression (1) above, the arm of the dendritic regions of α -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.
30

[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. 3, the polished
35 and/or etched 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 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. 3, three arms between A and B are selected), and the distance along the direction in which the arms stand (in FIG. 3, the distance L) is measured. The measured distance is then divided by the number of dendritic arms (L/3 in FIG. 3) 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.

[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 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.

[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 25 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 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.

5 **[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.

10 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 25 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.

20 **[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),

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

30 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 $M_{Mg}/(M_{Si}-0.6)$ is preferably 2.0 or more and more preferably 3.0 or more.

5 **[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. By controlling the bath temperature to 585 °C or lower, the coarse growth of the Al-Si-Sr alloy, which adversely affects the workability described above, can be suppressed, and the amount of large Mg_2Si can be reduced. It also has the effect of inhibiting the growth of the interfacial alloy layer. 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 size of the Al-Si-Sr alloy increases, the amount of large Mg_2Si increases, and the interfacial alloy layer grows thick. As a result, the desired workability and corrosion resistance in worked parts cannot be obtained.

10 **[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). The reason for controlling the sheet temperature at entry to a certain temperature or lower is that when the sheet temperature at entry is high, the bath temperature in the vicinity of the steel sheet rises when the steel sheet enters the bath, which produces the same adverse effect as high bath temperatures. In addition, it is because by controlling the sheet temperature at entry, the increase in size of the Al-Si-Sr alloy present between the main layer and the interfacial alloy layer and the Mg_2Si in the hot-dip coating layer can be suppressed, and the growth of the interfacial alloy layer can also be suppressed.

25 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.

30 **[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 30 °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. The Mg₂Si formed in the hot-dip coating layer and the Al-Si-Sr alloy formed between the main layer and the interfacial alloy layer tend to be formed in a temperature range to about a temperature of subtracting 150 °C from the bath temperature of the molten bath (molten bath temperature – 150 °C). Therefore, by increasing the average cooling rate in the temperature range to 30 °C/s or higher, the growth of the Mg₂Si particles and the Al-Si-Sr alloy can be suppressed, and the amount of large Mg₂Si and Al-Si-Sr alloy can be reduced more reliably. 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. 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 35 °C/s or higher and still more preferably performed at an average cooling rate of 40 °C/s or higher.

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 molten bath temperature, and dividing 150 °C by that time.

[0057] 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.

[0058] 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 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 heating and drying by means such as hot air drying, infrared heating, and induction heating.

EXAMPLES

[0059] (Samples 1 to 31)

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 31 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 sample listed in Table 2, 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 2.

Each sample of hot-dip Al-Zn alloy-coated steel sheet thus obtained 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 or calculated, which are listed in Table 2.

[0060] <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 2.

[0061] (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.

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.

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

[0062] (2) Evaluation of corrosion resistance in bent parts (corrosion resistance in worked parts)

10 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 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
15 specific conditions, as illustrated in FIG. 4.

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

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

Poor: number of cycles until red rust occurred < 300

[0063]

Table 2

No.	Hot-dip coating layer conditions										Production conditions				Evaluation		Remarks			
	Composition (mass%)		Sr concentration in interfacial alloy layer (mass%)	Average major axis of Al-Si-Sr alloy (μm)	Average major axis of Mg ₂ Si (μm)	Area ratio of Si phase in main layer observed in cross section in thickness direction (%): A	Area ratio of Mg ₂ Si in main layer observed in cross section in thickness direction (%): B	Area ratio of Si phase in main layer A/(A+B) * 100 (%): Z	Average distance between dendritic arms (μm)	Left side of expression (1)	Thickness of hot-dip coating layer (μm)	Bath temperature (°C)	Sheet temperature at entry (°C)	Cooling rate to molten bath temperature -150°C (°C/s)	Relationship between Mg and Si in molten bath: N*	Surface appearance		Corrosion resistance in worked part		
1	55	1.5	3.0	0	0	-	7.0	0.2	8.0	2.4	11	2.2	24	585	600	50	3.3	Poor	Excellent	Comparative Example
2	55	1.5	3.0	0.01	0.1	0.8	9.0	0.3	7.0	4.1	12	1.9	23	580	580	30	3.3	Good	Excellent	Example
3	55	1.5	3.0	0.0005	0.0005	0.1	9.0	0.3	7.0	4.1	12	1.9	23	560	565	40	3.3	Poor	Excellent	Comparative Example
4	55	0.5	0.05	0.0005	0.0005	0.1	1.0	0.1	0.2	33.3	11	1.9	23	565	570	40	-0.5	Poor	Poor	Comparative Example
5	55	1.5	3.0	0.1	1	0.7	8.0	0.4	9.0	4.3	9	2.3	21	570	565	40	3.3	Good	Excellent	Example
6	55	1.5	3.0	1.0	10.0	0.8	6.0	0.2	10.0	2.0	7	3.1	22	575	585	60	3.3	Good	Excellent	Example
7	55	1.5	1.0	0.01	0.1	0.7	4.0	0.0	1.0	2.0	6	3.8	23	580	575	80	1.1	Good	Excellent	Example
8	55	1.5	5.0	0.01	0.1	0.8	7.0	0.2	12.0	1.6	11	2.4	26	585	570	50	5.6	Good	Excellent	Example
9	55	1.5	10.0	0.01	0.1	0.8	9.0	0.1	15.0	0.7	12	1.8	22	580	595	30	11.1	Good	Excellent	Example
10	55	0.7	3.0	0.01	0.1	0.8	5.0	0.1	3.0	1.6	8	2.9	23	580	595	70	30.0	Good	Excellent	Example
11	55	1.0	3.0	0.01	0.1	0.9	4.0	0.1	5.0	2.0	6	3.5	21	585	595	80	7.5	Good	Excellent	Example
12	55	2.0	3.0	0.01	0.1	0.7	7.0	1.0	10.0	9.1	11	2.0	22	565	550	50	2.1	Good	Excellent	Example
13	55	2.5	3.0	0.01	0.1	0.8	9.0	2.0	15.0	11.8	12	1.8	22	575	580	30	1.6	Good	Good	Example
14	55	3.0	3.0	0.01	0.1	0.8	8.0	3.0	18.0	14.3	9	2.6	23	580	575	40	1.3	Good	Good	Example
15	55	5.0	3.0	0.01	0.1	0.7	6.0	11.0	20.0	35.5	7	3.7	26	570	565	60	0.7	Good	Poor	Comparative Example

*N=Mmg/(Mst+0.6), where Mmg is the Mg concentration (mass%) in the bath, and Mst is the Si concentration (mass%) in the bath

Table 2 (cont'd)

No.	Hot-dip coating layer conditions										Production conditions				Evaluation		Remarks		
	Composition (mass%)			Sr concentration in interfacial alloy layer (mass%)	Average major axis of Al-Si-Sr alloy (μm)	Area ratio of Si phase in main layer observed in cross section in thickness direction (%): A	Area ratio of Mg ₂ Si in main layer observed in cross section in thickness direction (%): B	Area ratio of Si phase in main layer A/(A+B) * 100 (%): Z	Average distance between dendritic arms (μm)	Left side of expression (l)	Thickness of hot-dip coating layer (μm)	Bath temperature (°C)	Sheet temperature at entry (°C)	Cooling rate to molten bath temperature -150°C (°C/s)	Relationship between Mg and Si in molten bath: N*	Surface appearance		Corrosion resistance in worked part	
	Al	Si	Mg																Sr
16	55	5.0	5.0	0.01	0.1	0.7	6.0	7.0	25.0	21.9	7	3.7	26	570	565	60	1.1	Good	Example
17	55	2.5	5.0	0.01	0.1	0.8	5.0	3.0	12.0	20.0	8	2.8	22	575	570	70	2.6	Good	Example
18	55	2.5	5.0	0.1	1	0.8	5.0	4.0	14.0	22.2	8	2.8	22	575	570	70	2.6	Good	Example
19	55	2.5	5.0	1	10	0.9	4.0	5.0	13.0	27.8	6	4.0	24	585	575	80	2.6	Good	Example
20	55	10.0	12.0	2	20	1.5	12.0	20.0	30.0	40.0	7	4.0	24	570	575	70	1.3	Good	Comparative Example
21	30	1.5	3.0	0.01	0.1	0.8	7.0	0.2	7.0	2.8	11	2.2	24	580	605	50	3.3	Good	Example
22	30	1.5	3.0	0.01	0.1	0.7	9.0	0.3	8.0	3.6	12	1.9	23	565	530	30	3.3	Good	Example
23	35	1.5	3.0	0.01	0.1	0.9	8.0	0.4	9.0	4.3	9	2.3	21	585	590	40	3.3	Good	Example
24	45	1.5	3.0	0.01	0.1	0.9	6.0	0.2	10.0	2.0	7	3.1	22	585	595	60	3.3	Good	Example
25	65	1.5	3.0	0.01	0.1	0.7	5.0	0.3	7.0	4.1	8	2.8	22	585	560	70	3.3	Good	Example
26	55	1.5	3.0	0.01	0.1	1.1	9.0	0.3	8.0	3.6	9	2.9	26	605	605	30	3.3	Good	Comparative Example
27	55	1.5	3.0	0.01	0.1	1.5	8.0	0.4	9.0	4.3	12	1.8	22	620	650	40	3.3	Good	Comparative Example
28	55	1.5	3.0	0.01	0.1	0.9	13.0	0.2	10.0	2.0	18	1.2	21	585	560	10	3.3	Good	Comparative Example
29	55	1.5	3.0	0.01	0.1	1.2	5.0	0.3	7.0	4.1	14	1.7	24	585	620	70	3.3	Good	Comparative Example
30	55	1.5	5.0	0.01	0.1	0.8	11.0	0.4	8.0	4.8	10	2.2	22	575	590	20	5.6	Good	Comparative Example
31	55	1.5	0.0	0	0	-	4.0	-	-	-	6	3.3	20	580	590	80	-	Good	Comparative Example

*N=Mmg/(Msi+0.6), where Mmg is the Mg concentration (mass%) in the bath, and Msi is the Si concentration (mass%) in the bath

[0064] It can be understood from the results of Table 2 that each sample of Examples is well-balanced and superior to each sample of Comparative Examples in all terms of surface appearance and corrosion resistance in worked parts.

5

INDUSTRIAL APPLICABILITY

[0065] 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 worked parts, and a method of producing a hot-dip Al-Zn-Mg-Si-Sr coated steel sheet having good surface appearance as well as excellent corrosion resistance in worked parts.

10

CLAIMS

1. A hot-dip Al-Zn-Mg-Si-Sr coated steel sheet comprising a hot-dip coating layer having a composition containing 25 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 an Al-Si-Sr alloy having an average major axis of 1 μm or less is present between the main layer and the interfacial alloy layer.

2. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to claim 1, wherein the interfacial alloy layer contains 0.001 mass% or more of Sr.

3. The hot-dip Al-Zn-Mg-Si-Sr coated steel sheet according to claim 1 or 2, wherein Mg_2Si observed in a cross section in a thickness direction of the hot-dip coating layer all has a major axis of 10 μm 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 .

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 25 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 so as 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.

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.

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 30 °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.