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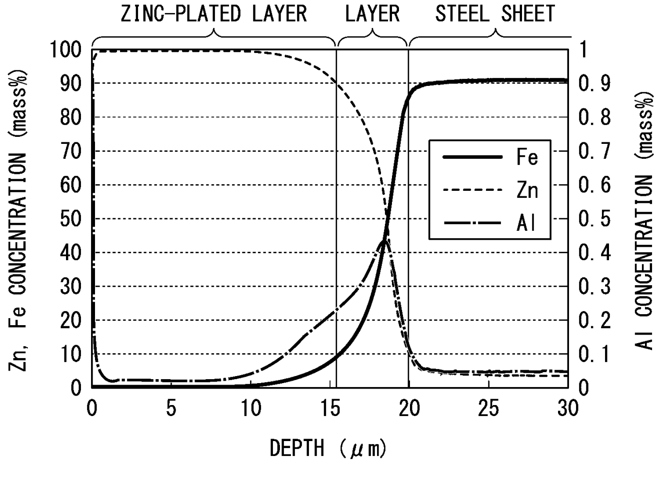
(54) HOT-DIPPED GALVANIZED STEEL SHEET

(57) A hot-dip zinc-plated steel sheet includes a steel sheet, a boundary layer that is provided on a surface of the steel sheet, and a hot-dip zinc-plated layer that is provided on a surface of the boundary layer. In a surface layer region of the steel sheet, an average grain size is 4.0 μm or less and a standard deviation of grain sizes is 2.0 μm or less. In the boundary layer, a maximum Al concentration is 0.30 mass % or more.

FIG. 1



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a hot-dip zinc-plated steel sheet.

[0002] Priority is claimed on Japanese Patent Application No. 2020-057273, filed March 27, 2020, the content of which is incorporated herein by reference.

[Background Art]

[0003] In recent years, a need for increasing the strength of vehicle members has increased from the viewpoint of stricter collision safety criteria for vehicles and the improvement of fuel efficiency. The application of hot stamps has been extended in order to achieve an increase in the strength of vehicle members. Hot stamping is a technique for pressing a blank that is heated to a temperature at which the single-phase region of austenite is formed (Acs point) or more (for example, heated to about 900°C) and then rapidly cooling the blank in a die at the same time as forming to perform quenching. According to this technique, it is possible to manufacture a press-formed product having high shape fixability and high strength.

[0004] Since a Zn component remains on the surface layer of a formed product obtained after hot stamping in a case where hot stamping is applied to a zinc-plated steel sheet, an effect of improving corrosion resistance is obtained as compared to a formed product obtained from the hot stamping of an unplated steel sheet. For this reason, the application of hot stamping to a zinc-plated steel sheet is being extended.

[0005] Patent Document 1 discloses a hot-press formed steel member manufactured by a method which includes a heating step of heating a zinc-plated steel sheet to a temperature equal to or higher than an Ac_3 transformation point and a hot press forming step of performing hot press forming at least twice after the heating step and in which all the hot press forming performed in the hot press forming step are performed to satisfy a predetermined equation.

[0006] In a case where the zinc-plated steel sheet is subjected to hot stamping, electrode sticking (a phenomenon in which a copper electrode and plating provided on the surface of the formed product are melted and adhered to each other) may occur during spot welding in a formed product obtained after hot stamping. Electrode sticking is not preferable because it could cause a poor weld or it will inevitably cause manufacturing downtime to replace the electrode. Electrode sticking during spot welding is not considered in Patent Document 1.

[Prior Art Document]

[Patent Document]

[0007] [Patent Document 1] PCT International Publication No. WO2013/147228

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0008] The present invention has been made in consideration of the above-mentioned circumstances and an object of the present invention is to provide a hot-dip zinc-plated steel sheet from which a hot-stamping formed body excellent in spot weldability can be obtained. Further, another object of the present invention is to provide a hot-dip zinc-plated steel sheet from which a hot-stamping formed body having the above-mentioned property and having strength generally required for a hot-stamping formed body can be obtained.

[Means for Solving the Problem]

[0009] The present inventor investigated the cause of electrode sticking during spot welding. As a result, the present inventor found that electrode sticking during spot welding is further suppressed as the number of voids present in a zinc-plated layer is smaller since electrode sticking during spot welding is greatly affected by voids (vacancy) present in the zinc-plated layer (a hot-dip zinc-plated layer obtained after hot stamping) of a hot-stamping formed body. The present inventor thought that an overcurrent occurs by a narrow electric current path caused by the voids in the zinc-plated layer, and the overcurrent causes overheating which makes electrode sticking between an electrode and zinc plating.

[0010] Further, although a detailed mechanism is uncertain, the present inventor thought that voids formed in the hot-stamping formed body are caused by a difference in thermal contraction between a base metal and a hot-dip zinc-plated layer and a difference in thermal contraction between different phases present in a plating layer during hot stamping forming. The present inventor investigated a method of reducing a difference in thermal contraction during hot stamping forming. As a result, the present inventor found that the occurrence of voids can be suppressed in a case where, in a hot-dip zinc-plated steel sheet, an average grain size in a surface layer region of the steel sheet is set to 4.0 μm or less and a standard deviation of grain sizes is set to 2.0 μm or less and the maximumAl concentration in a boundary layer present between the steel sheet and the hot-dip zinc-plated layer is set to 0.30 mass % or more.

[0011] The present inventor supposes a mechanism, in which the formation of voids in the hot-dip zinc-plated layer is suppressed in a case where the surface layer region of the steel sheet and the boundary layer are formed as described above, as follows. Al is uniformly diffused and concentrated (a Fe-Al alloy layer is formed) in the boundary layer due to the grain refining and grain size regulation of crystal grains of the surface layer region of the steel sheet. It is considered that Al, of which the linear expansion coefficient is intermediate between those of Fe and Zn, is concentrated in the boundary layer and a difference in thermal contraction between the base metal and the hot-dip zinc-plated layer is alleviated, which suppresses the formation of voids.

[0012] Further, it is considered that a boundary between a Γ phase and a Fe-Zn solid solution serves as the origin of the occurrence of voids due to a difference in thermal contraction between different phases in the plating layer, that is, the Γ phase having a high Zn concentration (the Fe concentration is in a range of 10 mass % to 30 mass %) and the Fe-Zn solid solution having a high Fe concentration (the Fe concentration is in a range of 50 mass % to 80 mass %). However, in a case where Al is concentrated in the boundary layer, a Fe-Zn alloying reaction during heating at the time of hot stamping is suppressed, so that an increase in the occurrence origin of voids (a boundary between the Γ phase and the Fe-Zn solid solution) is suppressed. Accordingly, it is supposed that the number of voids formed in the zinc-plated layer of the hot-stamping formed body is reduced.

[0013] The present inventor found that it is effective to control hot rolling condition in order to perform the grain refining and grain size regulation of crystal grains of the surface layer region of the steel sheet. The present inventor found that, in a case where water pressure for descaling performed on the inlet side of the finish rolling is controlled in the finish rolling of hot rolling, the temperature distribution of the surface layer region of the steel sheet can be controlled, which makes it possible to perform the grain refining and grain size regulation of crystal grains of the surface layer region of the steel sheet.

[0014] The gist of the present invention made on the basis of the above-mentioned knowledge is as follows.

[1] A hot-dip zinc-plated steel sheet according to an aspect of the present invention includes a steel sheet, a boundary layer that is provided on a surface of the steel sheet, and a hot-dip zinc-plated layer that is provided on a surface of the boundary layer,

a chemical composition of the steel sheet contains, by mass %,

C: 0.18% to 0.50%,
Si: 0.10% to 1.50%,
Mn: 0.5% to 2.5%,
sol.Al:0.001% to 0.100%,
Ti: 0.010% to 0.100%,
S: 0.0100% or less,
P: 0.100% or less,
N: 0.010% or less,
Nb: 0% to 0.05%
V: 0% to 0.50%,
Cr: 0% to 0.50%,
Mo: 0% to 0.50%,
B: 0% to 0.010%,
Ni: 0% to 2.00%, and
a total of REM, Ca, Co, and Mg: 0% to 0.0300%,

a remainder consists of Fe and impurities,
in a surface layer region of the steel sheet, an average grain size is 4.0 μm or less and a standard deviation of grain sizes is 2.0 μm or less, and
in the boundary layer, a maximum Al concentration is 0.30 mass % or more.

[2] In the hot-dip zinc-plated steel sheet according to [1], the chemical composition may contain, by mass %, one or two or more selected from the group consisting of

Nb: 0.02% to 0.05%,
V: 0.005% to 0.50%,
Cr: 0.10% to 0.50%,
Mo: 0.005% to 0.50%,
B: 0.0001% to 0.010%,
Ni: 0.01% to 2.00%, and
a total of REM, Ca, Co, and Mg: 0.0003% to 0.0300%.

[3] In the hot-dip zinc-plated steel sheet according to [1] or [2], the chemical composition may contain, by mass %, 0.24% to 0.50% of C.

[Effects of the Invention]

[0015] According to the aspect of the present invention, it is possible to provide a hot-dip zinc-plated steel sheet from which a hot-stamping formed body excellent in spot weldability and having strength generally required for a hot-stamping formed body can be obtained.

[Brief Description of the Drawings]

[0016] FIG. 1 is a schematic diagram showing the GDS profile of a hot-dip zinc-plated steel sheet according to an embodiment.

[Embodiments of the Invention]

[0017] A hot-dip zinc-plated steel sheet according to an embodiment will be described in detail below. The hot-dip zinc-plated steel sheet according to this embodiment includes a steel sheet, a boundary layer that is provided on the steel sheet, and a hot-dip zinc-plated layer that is provided on the boundary layer.

[0018] First, a steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment will be described. The reason why the chemical composition of the steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment is to be limited will be described below. All percentages (%) related to the chemical composition mean mass %.

[0019] The chemical composition of the steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment includes, by mass %, C: 0.18% to 0.50%, Si: 0.10% to 1.50%, Mn: 0.5% to 2.5%, sol.Al: 0.001% to 0.100%, Ti: 0.010% to 0.100%, S: 0.0100% or less, P: 0.100% or less, N: 0.010% or less, and a remainder consisting of Fe and impurities. Each element will be described below.

C: 0.18% to 0.50%

[0020] Carbon (C) increases the strength of a hot-stamping formed body obtained after hot stamping. In a case where the C content is excessively low, the above-mentioned effect is not obtained. For this reason, the C content is set to 0.18% or more. The C content is preferably 0.20% or more, 0.24% or more, or 0.25% or more. On the other hand, in a case where the C content is excessively high, the toughness of the hot-dip zinc-plated steel sheet deteriorates. Accordingly, the C content is set to 0.50% or less. The C content is preferably 0.45% or less or 0.40% or less.

Si: 0.10% to 1.50%

[0021] Si is an element that improves the fatigue property of the hot-stamping formed body. Further, Si is also an element that improves a hot-dip galvanizing property, particularly plating wettability, by forming a stable oxide film on the surface of the steel sheet during recrystallization annealing. In order to obtain these effects, the Si content is set to 0.10% or more. The Si content is preferably 0.15% or more or 0.18% or more. On the other hand, in a case where the Si content is excessively high, Si contained in steel is diffused during heating at the time of hot stamping and forms oxide on the surface of the steel sheet. The oxide formed on the surface of the steel sheet deteriorates a phosphate treatment property. Further, Si is also an element that raises the Ac_3 point of the hot-dip zinc-plated steel sheet. In a case where the Ac_3 point of the hot-dip zinc-plated steel sheet is raised, a heating temperature during hot stamping needs to be raised in order to sufficiently austenitize the steel sheet and a heating temperature during hot stamping exceeds the evaporation temperature of the hot-dip zinc-plated layer. For this reason, the Si content is set to 1.50% or less. The Si content is preferably 1.40% or less, 1.20% or less, or 1.00% or less.

Mn: 0.5% to 2.5%

[0022] Mn is an element that improves the hardenability of steel. The Mn content is set to 0.5% or more to improve hardenability and obtain the desired strength of the hot-stamping formed body. The Mn content is preferably 1.0% or more or 1.5% or more. On the other hand, even though the Mn content exceeds 2.5%, an effect of improving hardenability is saturated and steel is embrittled, so that quenching cracks are likely to occur during casting, hot rolling, and cold rolling. For this reason, the Mn content is set to 2.5% or less. The Mn content is preferably 2.1% or less or 2.0% or less.

sol.Al: 0.001% to 0.100%

[0023] Al is an element that deoxidizes molten steel to suppress the formation of oxide serving as the origin of fracture. Further, Al is also an element that has an action of suppressing an alloying reaction between Zn and Fe and an action of improving the corrosion resistance of the hot-stamping formed body. In order to obtain these effects, the sol.Al content is set to 0.001% or more. The sol.Al content is preferably 0.005% or more. On the other hand, in a case where the sol.Al content is excessive, the Ac_3 point of the steel sheet is raised, a heating temperature needs to be raised in order to sufficiently austenitize the steel sheet, and a heating temperature during hot stamping exceeds the evaporation temperature of the hot-dip zinc-plated layer. For this reason, the sol.Al content is set to 0.100% or less. The sol.Al content is preferably 0.090% or less, 0.070% or less, or 0.050% or less.

[0024] In this embodiment, sol.Al means acid-soluble Al, and indicates solute Al that is present in steel in the state of a solid solution.

Ti: 0.010% to 0.100%

[0025] Ti is an element that increases oxidation resistance after hot-dip galvanizing. Further, Ti is also an element that improves the hardenability of the steel sheet by combining with N present in steel to form nitride (TiN) and suppressing the formation of nitride (BN) from B. In order to obtain these effects, the Ti content is set to 0.010% or more. The Ti content is preferably 0.020% or more. On the other hand, in a case where the Ti content is excessive, the Ac_3 point is raised and a heating temperature during hot stamping is raised. For this reason, productivity may deteriorate, and it may be difficult to secure a Γ phase since formation into a Fe-Zn solid solution may be facilitated. Further, in a case where the Ti content is excessive, a large amount of Ti carbide is formed and the amount of solute C is reduced, so that the strength of the hot-stamping formed body is reduced. Furthermore, the wettability of plating may deteriorate, and the toughness of the hot-stamping formed body may deteriorate due to the excessive precipitation of Ti carbide. For this reason, the Ti content is set to 0.100% or less. The Ti content is preferably 0.070% or less.

S: 0.0100% or less

[0026] S is an element that is contained as an impurity and is an element that forms sulfide in steel to cause the deterioration of the toughness of the hot-stamping formed body and to deteriorate a delayed fracture resistance property. For this reason, the S content is set to 0.0100% or less. The S content is preferably 0.0050% or less. It is preferable that the S content is 0%. However, since cost required to remove S is increased in a case where the S content is to be excessively reduced, the S content may be set to 0.0001% or more.

P: 0.100% or less

[0027] P is an element that is included as an impurity, and is an element that segregates at a grain boundary to deteriorate the toughness and delayed fracture resistance property of steel. For this reason, the P content is set to 0.100% or less. The P content is preferably 0.050% or less. It is preferable that the P content is 0%. However, since cost required to remove P is increased in a case where the Pcontent is to be excessively reduced, the P content may be set to 0.001% or more.

N: 0.010% or less

[0028] N is an impurity element, and is an element that forms coarse nitride in steel to deteriorate the toughness of steel. Further, N is also an element that facilitates the occurrence of blow holes during spot welding. Furthermore, in a case where B is contained, N combines with B to reduce the amount of solute B and deteriorates the hardenability of the steel sheet. For this reason, the N content is set to 0.010% or less. The N content is preferably 0.007% or less. It is preferable that the N content is 0%. However, since manufacturing cost is increased in a case where the N content is to be excessively reduced, the N content may be set to 0.0001% or more.

[0029] The remainder of the chemical composition of the steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment is Fe and impurities. Elements, which are unavoidably mixed from a steel raw material or scrap and/or during the manufacture of steel and are allowed in a range where the properties of the hot-stamping formed body obtained from the hot stamping of the hot-dip zinc-plated steel sheet according to this embodiment do not deteriorate, are exemplified as the impurities.

[0030] The steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment may contain the following elements as arbitrary elements instead of a part of Fe. The contents of the following arbitrary elements in a case where the following arbitrary elements are not contained are 0%.

Nb: 0% to 0.05%

[0031] Nb has an action of forming carbide to refine crystal grains during hot stamping. In a case where crystal grains are refined, the toughness of steel is increased. In order to reliably obtain this effect, it is preferable that the Nb content is set to 0.02% or more. However, in a case where the Nb content is excessively high, the above-mentioned effect may be saturated and the hardenability of steel may deteriorate. Accordingly, the Nb content is set to 0.05% or less.

V: 0% to 0.50%

[0032] V is an element that finely forms carbonitride in steel to improve strength. In order to reliably obtain this effect, it is preferable that the V content is set to 0.005% or more. On the other hand, in a case where the V content exceeds 0.50%, the toughness of steel deteriorates during spot welding and cracks are likely to occur. For this reason, the V content is set to 0.50% or less.

Cr: 0% to 0.50%

[0033] Cr is an element that improves the hardenability of steel. In order to reliably obtain this effect, it is preferable that the Cr content is set to 0.10% or more. On the other hand, in a case where the Cr content exceeds 0.50%, Cr carbide is formed in steel and it is difficult for Cr carbide to be dissolved during heating of hot stamping, so that hardenability deteriorates. For this reason, the Cr content is set to 0.50% or less.

Mo: 0% to 0.50%

[0034] Mo is an element that improves the hardenability of steel. In order to reliably obtain this effect, it is preferable that the Mo content is set to 0.005% or more. However, in a case where the Mo content is excessively high, the above-mentioned effect is saturated. Accordingly, the Mo content is set to 0.50% or less.

B: 0% to 0.010%

[0035] B is an element that improves the hardenability of steel. In order to reliably obtain this effect, it is preferable that the B content is set to 0.0001% or more. On the other hand, even though the B content exceeds 0.010%, an effect of improving hardenability is saturated. For this reason, the B content is set to 0.010% or less.

Ni: 0% to 2.00%

[0036] Ni is an element that has an effect of improving the toughness of steel, an effect of suppressing the embrittlement of steel caused by liquid Zn during heating of hot stamping, and an effect of improving the hardenability of steel. In order to reliably obtain these effects, it is preferable that the Ni content is set to 0.01% or more. On the other hand, even though the Ni content exceeds 2.00%, the above-mentioned effects are saturated. For this reason, the Ni content is set to 2.00% or less.

a total of REM, Ca, Co, and Mg: 0% to 0.0300%

[0037] REM, Ca, Co, and Mg are elements that suppress the occurrence of cracks during spot welding by controlling sulfide and oxide in a preferred shape and suppressing the formation of coarse inclusions. In order to reliably obtain this effect, it is preferable that the total content of REM, Ca, Co, and Mg is set to 0.0003% or more. In order to reliably obtain the above-mentioned effect, the content of even any one of REM, Ca, Co, and Mg may be 0.0003% or more. On the other hand, in a case where the total content of REM, Ca, Co, and Mg exceeds 0.0300%, inclusions are excessively generated and cracks are likely to occur during spot welding. For this reason, the total content of REM, Ca, Co, and Mg is set to 0.0300% or less.

[0038] The chemical composition of the steel sheet described above may be measured by a general analysis method. For example, the chemical composition of the steel sheet described above may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). C and S may be measured using a combustion-infrared absorption method and N may be measured using an inert gas fusion-thermal conductivity method. Further, sol.Al may be measured by ICP-AES using a filtrate that is obtained in a case where a sample is decomposed with an acid by heating. The chemical composition may be analyzed after the hot-dip zinc-plated layer provided on the surface of the hot-dip zinc-plated steel sheet is removed by mechanical grinding.

[0039] The steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment has the above-mentioned chemical composition, and has an average grain size of 4.0 μm or less and a standard deviation of grain sizes of 2.0 μm or less in a surface layer region thereof. The surface layer region of the steel sheet of the hot-dip zinc-plated steel sheet according to this embodiment will be described below.

Surface layer region: an average grain size of 4.0 μm or less and a standard deviation of grain sizes of 2.0 μm or less

[0040] In this embodiment, the surface layer region refers to a region between the surface of the steel sheet and a position that is away from the surface of the steel sheet in a depth direction by a distance of 25 μm. In a case where an average grain size in this surface layer region exceeds 4.0 μm or the standard deviation of grain sizes exceeds 2.0 μm, it is not possible to suppress the evaporation of zinc present in the hot-dip zinc-plated layer in the heating during hot stamping. Accordingly, a lot of voids are formed in the hot-stamping formed body. As a result, desired spot weldability cannot be obtained in the hot-stamping formed body. For this reason, in the surface layer region of the steel sheet, an average grain size is set to 4.0 μm or less and the standard deviation of grain sizes is set to 2.0 μm or less. Since a smaller average grain size in the surface layer region of the steel sheet is more preferable, an average grain size in the surface layer region of the steel sheet may be set to 3.5 μm or less or 3.0 μm or less. Further, since a smaller standard deviation of grain sizes in the surface layer region of the steel sheet is more preferable, the standard deviation of grain sizes in the surface layer region of the steel sheet may be set to 1.8 μm or less or 1.5 μm or less.

[0041] The lower limit of an average grain size in the surface layer region of the steel sheet does not need to be particularly limited, but may be set to 1.5 μm. Further, the lower limit of the standard deviation of grain sizes in the surface layer region of the steel sheet does not need to be particularly limited, but may be set to 1.0 μm.

Method of measuring average grain size and standard deviation of grain sizes in surface layer region

[0042] An average grain size and the standard deviation of grain sizes in the surface layer region are measured using electron back scatter diffraction pattern-orientation image microscopy (EBSP-OIM). EBSP-OIM is performed using a device in which a scanning electron microscope and an EBSP analysis device are combined with each other and OIM Analysis (registered trademark) manufactured by AMETEK, Inc.

[0043] In a region between the surface of the steel sheet and a position, which is away from the surface of the steel sheet in the depth direction by a distance of 25 μm, in a cross section parallel to a rolling direction, an analysis is made in at least 5 visual fields in a region having a size of 40 μm × 30 μm with a magnification of 1200. A spot where an angle difference between adjacent measurement points is 5° or more is defined as a grain boundary, and the equivalent circle diameters of crystal grains are calculated and are regarded as grain sizes. The average value of the obtained grain sizes of crystal grains is calculated, so that an average grain size in the surface layer region is obtained. Further, a standard deviation is calculated from the obtained grain sizes of crystal grains, so that the standard deviation of grain sizes in the surface layer region is obtained.

[0044] The steel sheet, the boundary layer, and the hot-dip zinc-plated layer may be specified using a method to be described later, and the above-mentioned measurement may be performed for the steel sheet and the surface layer region of the specified region.

[0045] A method of specifying the steel sheet, the boundary layer, and the hot-dip zinc-plated layer will be described below.

[0046] At an arbitrary position on the hot-dip zinc-plated steel sheet, the concentrations (mass %) of Fe, Zn, and Al are measured using glow discharge optical emission spectrometry (GDS) up to a depth of 50 μm from the surface of the hot-dip zinc-plated steel sheet in the depth direction (sheet thickness direction). In a case where the hot-dip zinc-plated steel sheet according to this embodiment is measured using GDS, a GDS profile shown in FIG. 1 can be obtained. In this embodiment, a depth range in which the Fe concentration is 85 mass % or more is defined as the steel sheet and a depth range in which the Zn concentration is 90 mass % or more is defined as the hot-dip zinc-plated layer. Further, a depth range between the steel sheet and the hot-dip zinc-plated layer is defined as the boundary layer.

[0047] The metallographic structure of the steel sheet is not particularly limited as long as desired strength and desired spot weldability can be obtained after hot stamping. However, the metallographic structure of the steel sheet may consist of, by area %, 20% to 90% of ferrite, 0% to 100% of bainite and martensite, 10% to 80% of pearlite, and 0% to 5% of residual austenite. The metallographic structure of the steel sheet may be measured using the following methods.

(Method of measuring area ratios of ferrite and pearlite)

[0048] The measurement of the area ratios of ferrite and pearlite is performed using the following method. A cross section parallel to the rolling direction is finished as a mirror surface and is polished for 8 minutes at room temperature using colloidal silica, which does not contain an alkaline solution, to remove strain introduced into the surface layer of the sample. A region, which has a length of 50 μm and is present between a depth corresponding to 1/8 of the sheet thickness from the surface and a depth corresponding to 3/8 of the sheet thickness from the surface, is measured at a measurement interval of 0.1 μm with an electron backscatter diffraction method at an arbitrary position in a longitudinal direction on the cross section of the sample so that a region having a depth corresponding to 1/4 of the sheet thickness from the surface can be analyzed. As a result, crystal orientation information is obtained. A device, which includes a schottky emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.) and an EBSP detector (DVC5 detector manufactured by TSL Solutions), is used for the measurement. In this case, the degree of vacuum in the device is set to 9.6×10^{-5} Pa or less, an accelerating voltage is set to 15 kV, an irradiation current level is set to 13, and the irradiation level of an electron beam is set to 62. Further, a reflected electron image is taken in the same visual field.

[0049] First, crystal grains in which ferrite and cementite are precipitated in layers are specified from the reflected electron image and the area ratio of the crystal grains is calculated, so that the area ratio of pearlite is obtained. After that, with regard to crystal grains excluding crystal grains that are determined as pearlite, a region where a grain average misorientation value is 1.0° or less is determined as ferrite from the obtained crystal orientation information using "Grain Average Misorientation" function provided in software "OIM Analysis (registered trademark)" incorporated in the EBSP analysis device. The area ratio of the region determined as ferrite is obtained, so that the area ratio of ferrite is obtained.

(Method of measuring area ratio of residual austenite)

[0050] The area ratio of residual austenite is measured using an electron backscatter diffraction image (EBSP). Analysis using EBSP is performed for a region, which is present between a depth corresponding to 1/8 of the sheet thickness from the surface and a depth corresponding to 3/8 of the sheet thickness from the surface, using a sample taken at the same sampling position as that in a case where the volume percentage of ferrite is measured so that a region having a depth corresponding to 1/4 of the sheet thickness from the surface of a hot-rolled steel sheet can be analyzed. The sample is polished using silicon carbide paper having a grit in a range of #600 to #1500, is finished as a mirror surface using liquid in which diamond powder having a grain size in a range of 1 μm to 6 μm is dispersed in a diluted solution of alcohol or the like or pure water, and is then finished using electrolytic polishing so that strain on the cross section to be measured is sufficiently removed. In the electrolytic polishing, the sample may be polished by a depth of a minimum of 20 μm and a maximum of 50 μm in order to remove mechanical polishing strain on a section to be observed. Considering the shear droop of an end portion, it is preferable that the sample is polished by a depth of 30 μm or less.

[0051] With regard to measurement in EBSP, an accelerating voltage is set in a range of 15 to 25 kV, the measurement is performed at intervals of at least 0.25 μm or less, and crystal orientation information about each measurement point in a range of 150 μm or more in the sheet thickness direction and 250 μm or more in the rolling direction is obtained. In the obtained crystal structure, a measurement point at which a crystal structure is fcc is determined as residual austenite using "PhaseMap" function provided in software "OIM Analysis (registered trademark)" incorporated in the EBSP analysis device. A ratio of the measurement points, which are determined as residual austenite, is obtained, so that the area ratio of residual austenite is obtained.

[0052] Here, since a larger number of measurement points are more preferable, it is preferable that a measurement interval is narrow and a measurement range is wide. However, in a case where a measurement interval is less than 0.01 μm, adjacent points interfere with the expansion width of an electron beam. For this reason, a measurement interval is set to 0.01 μm or more. Further, a measurement range may be set to 200 μm in the sheet thickness direction and 400 μm in a sheet width direction at the maximum. Furthermore, a device, which includes a schottky emission scanning electron microscope (JSM-7001F manufactured by JEOLLtd.) and an EBSP detector (DVC5 detector manufactured by TSL Solutions), is used for the measurement. At this time, the degree of vacuum in the device is set to 9.6×10^{-5} Pa or less, an irradiation current level is set to 13, and the irradiation level of an electron beam is set to 62.

(Method of measuring area ratios of bainite and martensite)

[0053] The sum of the area ratios of bainite and martensite in this embodiment is a value that is obtained in a case where the sum of the area ratios of ferrite and pearlite and the volume percentage of residual austenite measured using the above-mentioned method is subtracted from 100%.

[0054] The hot-dip zinc-plated steel sheet according to this embodiment includes the above-mentioned steel sheet, the boundary layer provided on the steel sheet, and the hot-dip zinc-plated layer provided on the boundary layer. The boundary layer and the hot-dip zinc-plated layer will be described below.

Boundary layer: the maximum Al concentration is 0.30 mass % or more

[0055] In this embodiment, the boundary layer refers to a layer that is present between the above-mentioned steel sheet and the hot-dip zinc-plated layer to be described later. The maximum Al concentration of the boundary layer of the hot-dip zinc-plated steel sheet according to this embodiment is 0.30 mass % or more. In a case where the maximum Al concentration of the boundary layer is less than 0.30 mass %, desired spot weldability cannot be obtained in the hot-stamping formed body. For this reason, the maximum Al concentration of the boundary layer is set to 0.30 mass % or more. The maximum Al concentration of the boundary layer is preferably 0.35 mass % or more or 0.40 mass % or more. Since higher maximum Al concentration of the boundary layer is more preferable, the upper limit thereof does not need to be particularly specified but may be set to 1.00 mass %.

Method of measuring maximum Al concentration of boundary layer

[0056] The maximum Al concentration of the boundary layer is measured using the following method. At arbitrary five points on the hot-dip zinc-plated steel sheet, the concentrations (mass %) of Fe, Zn, and Al are measured using glow discharge optical emission spectrometry (GDS) up to a depth of 50 μm from the surface in the depth direction (sheet thickness direction). In a case where a depth range in which the Fe concentration is 85 mass % or more is defined as the steel sheet, a depth range in which the Zn concentration is 90 mass % or more is defined as the hot-dip zinc-plated layer, and a depth range between the steel sheet and the hot-dip zinc-plated layer is defined as the boundary layer, the maximum Al concentration (mass %) of the boundary layer is obtained at each measurement point. The average value of the maximum Al concentrations of the boundary layer at the respective measurement points is calculated, so that the maximum Al concentration of the boundary layer is obtained.

Hot-dip zinc-plated layer

[0057] In this embodiment, the hot-dip zinc-plated layer refers to a layer of which the Zn concentration is 90 mass % or more. 0.01 mass % to 1.00 mass % of Al is contained in the hot-dip zinc-plated layer as elements other than Zn. Further, 10 mass % or less of Fe may be contained in the hot-dip zinc-plated layer as a remainder.

Sheet thickness

[0058] The sheet thickness of the hot-dip zinc-plated steel sheet according to this embodiment is not particularly limited. However, in terms of reducing the weight of a vehicle body, it is preferable that the sheet thickness of the hot-dip zinc-plated steel sheet according to this embodiment is set in a range of 0.5 mm to 3.5 mm.

[0059] Next, a method of manufacturing the hot-dip zinc-plated steel sheet according to this embodiment will be described.

[0060] First, after a slab having the above-mentioned chemical composition is heated to 1200°C or more and is held in a temperature range of 1200°C or more for 20 minutes or more, hot rolling is performed. Finish rolling is ended in a temperature range of 810°C or more, and the slab is wound in a temperature range of 750°C or less.

[0061] In the method of manufacturing the hot-dip zinc-plated steel sheet according to this embodiment, water pressure for descaling in the finish rolling is controlled to perform the grain refining and grain size regulation of the surface layer region of the steel sheet, that is, to set an average grain size to 4.0 μm or less and the standard deviation of grain sizes to 2.0 μm or less in the surface layer region. Descaling is a step of spraying water to the upper and lower surfaces of a steel sheet with nozzles to remove scale formed on the surface of the steel sheet. In a case where water is sprayed using a plurality of nozzles to perform descaling, the highest water pressure among the water pressures of the plurality of nozzles is controlled to be in the range of water pressure to be described later.

[0062] Rough rolling and finish rolling are performed in the hot rolling. In the finish rolling, a slab having been subjected to rough rolling is subjected to rolling by a plurality of finish mills. In the method of manufacturing the hot-dip zinc-plated steel sheet according to this embodiment, water pressure is controlled in the descaling that is performed after the rough rolling and before a first pass (before F1) of the finish rolling and the descaling that is performed after the first pass (after F1) of the finish rolling. Water pressure for descaling is proportional to cooling power. The temperature distribution of the surface layer region of the steel sheet is controlled through the control of water pressure for descaling before F1 and after F1. Accordingly, it is possible to refine grains by suppressing the growth of austenite grains in the surface layer region of the steel sheet and to make the grain size uniform.

[0063] Water pressure is set in a range of 10 MPa to 40 MPa in the descaling that is performed after the rough rolling and before the first pass (before F1) of the finish rolling. Generally, the descaling performed before F1 is performed to remove scale formed on the surface of the steel sheet. In a case where water pressure for the descaling performed before F1 is lower than 10 MPa, scale peeled off during the finish rolling is jammed and the irregularities of the hot-rolled sheet are remarkable and remains as a pattern even after pickling and cold rolling, which causes poor appearance. Further, in a case where water pressure for the descaling performed before F1 is lower than 10 MPa, a desired average grain size and a desired standard deviation of grain sizes cannot be obtained in the surface layer region of the steel sheet. For this reason, water pressure for the descaling performed before F1 is set to 10 MPa or more.

[0064] As described above, the descaling performed before F1 is generally performed to remove scale. However, in a case where water pressure for the descaling performed before F1 is excessively high, a desired average grain size and a desired standard deviation of grain sizes cannot be obtained in the surface layer region of the steel sheet. For this reason, water pressure for the descaling performed before F1 is set to 40 MPa or less.

[0065] In a case where only the descaling performed after the rough rolling and before the first pass (before F1) of the finish rolling is performed, it is not possible to uniformly cool the steel sheet and to reduce the standard deviation of grain size in the surface layer region of the steel sheet due to a reason, such as the generation of reheat. For this reason, in the method of manufacturing the hot-dip zinc-plated steel sheet according to this embodiment, descaling is performed not only before F1 but also after the first pass (after F1) of the finish rolling. Water pressure for the descaling performed after F1 is set in a range of 2 MPa to 10 MPa. In a case where water pressure for the descaling performed after F1 is lower than 2 MPa and exceeds 10 MPa, a desired standard deviation of grain sizes cannot be obtained in the surface layer region of the steel sheet. Further, in a case where water pressure for the descaling performed after F1 exceeds 10 MPa, the strength of the steel sheet is increased, which may make it difficult to wind the steel sheet after the hot rolling.

[0066] In a case where descaling is performed after the rough rolling and before the first pass (before F1) of the finish rolling and after the first pass (after F1) of the finish rolling, it is preferable that descaling is performed even after a second pass (after F2) of the finish rolling. In a case where descaling is performed after F2, it is possible to further reduce the standard deviation of crystal grains in the surface layer region of the steel sheet. As a result, it is possible to further improve the spot weldability of the hot-dip zinc-plated steel sheet. In a case where descaling is performed after F2, it is preferable that water pressure is set in a range of 2 MPa to 10 MPa.

[0067] Descaling performed after a third pass of the finish rolling is not particularly limited.

[0068] After the finish rolling ends, cold rolling is performed as necessary and hot-dip galvanizing is performed. Pickling may be performed between the hot rolling and the cold rolling. The cold rolling may be cold rolling in which a normal cumulative rolling reduction, for example, a cumulative rolling reduction in a range of 30% to 90% is obtained.

[0069] The hot-dip galvanizing may be performed using a continuous hot-dip galvanizing line. The adhesion amount of the hot-dip zinc-plated layer is not particularly limited and may be a general adhesion amount. For example, the adhesion amount of plating per side may be set in a range of 5 g/m^2 to 150 g/m^2.

[0070] In a case where the hot-dip zinc-plated layer is alloyed and changed into a hot-dip galvannealed layer, a Γ phase having a high Zn concentration in the plating layer exhibiting a sacrificial protection action disappears, so that corrosion resistance deteriorates. Since electrogalvanizing requires additional elements for delaying alloying, manufacturing cost is increased. For this reason, electrogalvanizing is not desirable.

[0071] The hot-dip zinc-plated steel sheet according to this embodiment can be manufactured using the above-mentioned method. In a case where a hot-stamping formed body is to be manufactured, it is preferable that the hot-dip zinc-plated steel sheet according to this embodiment is subjected to hot stamping under the following conditions.

[0072] First, it is preferable that the hot-dip zinc-plated steel sheet according to this embodiment is heated so that a heating temperature is in a range of higher one of "the Ac_3 point and 800°C" to 950°C. Further, it is preferable that a heating time (a time that has passed until the hot-dip zinc-plated steel sheet is out of a heating furnace after being put in the heating furnace and then held at a heating temperature (a time having passed between carrying the hot-dip zinc-plated steel sheet in the heating furnace and carrying the hot-dip zinc-plated steel sheet out the heating furnace)) is set in a range of 60 sec to 600 sec. The Ac_3 point is represented by the following equation (1).

[0073] In a case where a heating temperature is set to a temperature equal to or higher than higher one of "the Ac_3 point and 800°C" and a heating time is set to 60 sec or more, the hot-dip zinc-plated steel sheet can be sufficiently austenitized. As a result, a hot-stamping formed body having desired strength can be obtained. In a case where a heating temperature is set to 950°C or less and a heating time is set to 600 sec or less, the excessive alloying of the hot-dip zinc-plated steel sheet can be suppressed. An average heating rate during heating may be set in a range of 0.1 °C/s to 200 °C/s. The average heating rate mentioned here is a value that is obtained in a case where a temperature difference between the surface temperature of the steel sheet at the time of start of the heating and the heating temperature is divided by a time difference from the start of the heating to a time when a temperature reaches the heating temperature. In a case where the steel sheet is held in a temperature range of higher one of "the Ac_3 point and 800°C" to 950°C, the temperature of the steel sheet may be changed or constant.

[0074] Examples of a heating method to be performed before the hot stamping include heating using an electric furnace, a gas furnace, or the like, flame heating, direct resistance heating, high-frequency heating, induction heating, and the like.

$$Ac_3(°C)=910-203\times C^{0.5}-30\times Mn+44.7\times Si+400\times Ti \ldots (1)$$

[0075] A symbol of an element in Equation (1) represents the content of each element by mass %.

[0076] Hot stamping is performed after the heating and the holding described above. After the hot stamping, it is preferable that cooling is performed at an average cooling rate in a range of 20 °C/s to 500 °C/s up to a temperature range of, for example, 250°C or less.

[0077] A hot-stamping formed body manufactured using the hot-dip zinc-plated steel sheet according to this embodiment can be obtained using the above-mentioned method. Since the formation of voids in a zinc-plated layer (a hot-dip zinc-plated layer obtained after hot stamping) is suppressed, this hot-stamping formed body is excellent in spot weldability and has strength generally required for a hot-stamping formed body.

[Examples]

[0078] Next, examples of the present invention will be described. Conditions in the examples are one condition example that is employed to confirm the feasibility and effects of the present invention, and the present invention is not limited to this condition example. The present invention may employ various conditions to achieve the object of the present invention without departing from the scope of the present invention.

[0079] After slabs manufactured from the casting of molten steel having the chemical composition shown in Tables 1-1 and 1-2 were heated to 1200°C or more and were held for 20 minutes or more, hot rolling was performed so that a finish rolling completion temperature was 810°C or more and cold rolling was further performed. As a result, steel sheets were obtained. During finish rolling of the hot rolling, water was sprayed to the upper and lower surfaces of the steel sheet with water pressure shown in Tables 2-1 and 2-2 to perform descaling. In Tables 2-1 and 2-2, "before F1" indicates water pressure (MPa) for descaling performed after the rough rolling and before the first pass of the finish rolling, "after F1 (between F1 and F2)" indicates water pressure (MPa) for descaling performed after the first pass of the finish rolling, and "after F2 (between F2 and F3)" indicates water pressure (MPa) for descaling performed after the second pass of the finish rolling.

[0080] A cumulative rolling reduction during the cold rolling was set in a range of 30% to 90%. A hot-dip zinc-plated layer was formed on the obtained steel sheets by a continuous hot-dip galvanizing line, so that hot-dip zinc-plated steel sheets shown in Tables 2-1 and 2-2 were obtained. The adhesion amount of the hot-dip zinc-plated layer was set in a range of 5 g/m^2 to 150 g/m^2 per side.

[0081] An average grain size and the standard deviation of grain sizes in the surface layer region of the steel sheet, the metallographic structure of the steel sheet, and the maximum Al concentration of the boundary layer were measured from each of the obtained hot-dip zinc-plated steel sheets using the above-mentioned methods.

[0082] Hot-stamping formed bodies shown in Tables 2-1 and 2-2 were manufactured using the obtained hot-dip zinc-plated steel sheets under conditions shown in Tables 2-1 and 2-2. An average heating rate during the heating performed before hot stamping was set in a range of 0.1 °C/s to 200 °C/s, and cooling was performed at an average cooling rate in a range of 20 °C/s to 500 °C/s up to a temperature range of 250°C or less after hot stamping.

[0083] An underline in Tables represents that a condition is out of the range of the present invention, a condition is out of a preferred manufacturing condition, or a property value is not preferred.

[0084] The cross-sectional area ratio of voids present in the zinc-plated layer of the hot-stamping formed body was measured from each of the obtained hot-stamping formed bodies using the following method.

[0085] First, a sample was cut out from an arbitrary position away from an end surface of the hot-stamping formed body by a distance of 50 mm or more (a position that avoids an end portion in a case where the sample cannot be taken from this position) so that a cross section (sheet thickness-cross section) perpendicular to the surface could be observed. The size of the sample was set to a size that allows the size to be observed by about 10 mm in a rolling direction.

[0086] Next, after an observation cross section was polished and was imaged using a scanning electron microscope (SEM) with a magnification of 300, the cross-sectional area ratio of voids was calculated using binarization image processing. For the calculation of the cross-sectional area ratio of voids, built-in software of a digital microscope VHX-5000 manufactured by Keyence Corporation was used to determine the voids using luminance and to automatically measure the area of the voids.

[0087] Linear analysis was performed in the sheet thickness direction using an SEM-energy dispersive X-ray spectroscopy (EDS) and the quantitative analysis of the Fe concentration was performed to determine the steel sheet and the zinc-plated layer of the hot-stamping formed body. SEM (NB5000 manufactured by Hitachi High-Tech Corporation), EDS (XFlash(r)6130 manufactured by Bruker AXS Inc.), and EDS analysis software (ESPRIT1.9 manufactured by Bruker AXS Inc.) were used in these examples. In a case where an observation was made using SEM, a region, which is present at the deepest position in the sheet thickness direction and in which the Fe content exceeds 80 mass % excluding measurement noise, was determined as the steel sheet, and other regions were determined as the zinc-plated layer.

[0088] The mechanical properties (tensile strength and spot weldability) of each hot-stamping formed body were evaluated using the following methods.

Tensile strength

[0089] No. 5 test pieces described in JIS Z 2241:2011 were prepared from an arbitrary position of the hot-stamping formed body, and the tensile strength of the hot-stamping formed body was obtained according to a test method described in JIS Z 2241:2011. In a case where the tensile strength was in a range of 1500 MPa to 2500 MPa, the test piece was determined to be acceptable since having strength generally required for a hot-stamping formed body. Further, in a case where the tensile strength was less than 1500 MPa, the test piece was determined to be unacceptable since being insufficient in strength. Furthermore, in a case where the tensile strength exceeded 2500 MPa, the test piece was determined to be unacceptable since being insufficient in toughness and ductility due to excessively high strength.

Spot weldability

[0090] With regard to the hot-stamping formed body, two test pieces having a size of 100 mm × 30 mm were taken from a position excluding a region within 10 mm from an end surface, these test piece overlapped with each other, and spot welding was performed while current was changed under the following conditions.

Electrode force: 400 kgf
Weld time: 15 cycles
Holding time: 9 cycles
Shape of electrode tip: DR type, tip ϕ 6 mm-radius of curvature of R40 mm

[0091] Spot welding was performed while current was increased from a current I_0 at which a nugget diameter was $4\sqrt{t}$ (t denotes the sheet thickness of the test piece) to obtain a current at which electrode sticking occurred (electrode sticking current I_s).

[0092] Further, spot weldability with regard to the obtained electrode sticking current I_s was evaluated on the basis of the following criteria. Here, I_0(kA) is the current at which a nugget diameter was $4\sqrt{t}$ (t denotes the sheet thickness of the test piece), and I_a(kA) is "$I_0 \times 1.4$". Examples evaluated as good and fair were determined to be acceptable since being excellent in spot weldability. On the other hand, an example evaluated as bad was determined to be unacceptable since being insufficient in spot weldability.

Good: $I_s > I_a \times 1.15$
Fair: $I_a \times 1.10 < I_s \leq I_a \times 1.15$
Bad: $I_s \leq I_a \times 1.10$

[Table 1-1]

Steel No.	Chemical composition (mass %) Remainder Fe and impurities									Ac$_3$ (°C)	Note
	C	Si	Mn	Al	Ti	S	P	N	Others		
1	0.19	0.20	2.4	0.030	0.025	0.0020	0.004	0.003		768	Steel of present invention
2	0.49	0.15	2.0	0.030	0.035	0.0020	0.010	0.003		729	Steel of present invention
3	0.31	0.10	1.8	0.040	0.025	0.0020	0.010	0.003		757	Steel of present invention
4	0.31	1.40	1.8	0.040	0.025	0.0020	0.010	0.003		816	Steel of present invention
5	0.33	0.20	0.5	0.040	0.025	0.0020	0.015	0.005		797	Steel of present invention

(continued)

Steel No.	Chemical composition (mass %) Remainder Fe and impurities									Ac$_3$ (°C)	Note
	C	Si	Mn	Al	Ti	S	P	N	Others		
6	0.33	0.20	2.5	0.040	0.025	0.0020	0.015	0.005		737	Steel of present invention
7	0.33	0.15	1.8	0.050	0.050	0.0002	0.090	0.005		766	Steel of present invention
8	0.33	0.15	1.8	0.050	0.050	0.0100	0.090	0.005		766	Steel of present invention
9	0.34	0.18	1.5	0.040	0.010	0.0030	0.010	0.005		759	Steel of present invention
10	0.34	0.18	1.5	0.040	0.100	0.0030	0.010	0.005		795	Steel of present invention
11	0.33	0.15	1.5	0.040	0.025	0.0020	0.090	0.005		765	Steel of present invention
12	0.33	0.15	1.5	0.040	0.025	0.0020	0.001	0.005		765	Steel of present invention
13	0.22	0.20	1.8	0.090	0.025	0.0030	0.010	0.005		780	Steel of present invention
14	0.22	0.20	1.8	0.005	0.025	0.0030	0.010	0.005		780	Steel of present invention
15	0.22	0.18	1.8	0.040	0.030	0.0020	0.010	0.010		781	Steel of present invention
16	0.22	0.18	1.8	0.040	0.030	0.0020	0.010	0.003		781	Steel of present invention
17	0.33	0.20	2.0	0.040	0.024	0.0020	0.010	0.005		752	Steel of present invention

[Table 1-2]

Steel No.	Chemical composition (mass %) Remainder Fe and impurities									Ac$_3$ (°C)	Note
	C	Si	Mn	Al	Ti	S	P	N	Others		
18	0.33	0.21	2.0	0.040	0.024	0.0020	0.010	0.005	Nb: 0.05	752	Steel of present invention
19	0.33	0.20	2.0	0.040	0.025	0.0020	0.010	0.005	V: 0.20	752	Steel of present invention
20	0.33	0.20	2.0	0.040	0.025	0.0020	0.010	0.005	Cr: 0.20	752	Steel of present invention
21	0.33	0.22	1.9	0.040	0.022	0.0020	0.010	0.005	Mo: 0.02	755	Steel of present invention
22	0.34	0.25	1.9	0.040	0.023	0.0020	0.020	0.005	B: 0.003	755	Steel of present invention
23	0.33	0.25	2.0	0.040	0.022	0.0020	0.020	0.005	Ni: 0.04	753	Steel of present invention
24	0.31	0.20	2.1	0.040	0.024	0.0020	0.010	0.005	Mg: 0.001	753	Steel of present invention
25	0.31	0.20	2.1	0.040	0.024	0.0020	0.010	0.005	Ca: 0.001, Mg: 0.001	753	Steel of present invention

(continued)

Steel No.	Chemical composition (mass %)					Remainder Fe and impurities				Ac$_3$ (°C)	Note
	C	Si	Mn	Al	Ti	S	P	N	Others		
26	0.31	0.20	2.0	0.040	0.024	0.0020	0.010	0.005	REM: 0.001, Co: 0.005	756	Steel of present invention
27	0.17	0.20	2.0	0.040	0.022	0.0020	0.010	0.005		784	Comparative steel
28	0.52	0.20	2.0	0.040	0.022	0.0020	0.010	0.005		721	Comparative steel
29	0.23	1.60	1.8	0.050	0.023	0.0020	0.010	0.005		839	Comparative steel
30	0.22	0.20	0.4	0.050	0.025	0.0040	0.009	0.005		822	Comparative steel
31	0.49	0.20	2.6	0.050	0.025	0.0040	0.009	0.005		709	Comparative steel
32	0.22	0.20	2.0	0.040	0.020	0.0130	0.010	0.005		772	Comparative steel
33	0.22	0.20	1.6	0.040	0.008	0.0010	0.010	0.005		779	Comparative steel
34	0.22	0.20	1.6	0.040	0.110	0.0010	0.010	0.005		820	Comparative steel
35	0.22	0.20	2.0	0.040	0.020	0.0010	0.110	0.005		772	Comparative steel
36	0.22	0.20	1.8	0.020	0.030	0.0030	0.020	0.015		782	Comparative steel
37	0.33	1.20	1.9	0.040	0.025	0.0020	0.010	0.005		800	Steel of present invention
38	0.33	1.00	2.0	0.040	0.025	0.0020	0.010	0.005		788	Steel of present invention
An underline represents that a condition is out of the range of the present invention.											

[Table 2-1]

		Finish rolling			Surface layer region		Boundary layer	HS condition		Hot-stamping formed body							Note
												Spot weldability					
Manufacture No.	Steel No.	Before F1 (MPa)	After F1 (between F1 and F2) (MPa)	After F2 (between F2 and F3) (MPa)	Average grain size (μm)	Standard deviation (μm)	Maximum Al concentration (mass %)	Heating temperature (°C)	Heating time (s)	Cross-sectional area ratio of voids (%)	Tensile strength (MPa)	4√t current I_0 (kA)	Continuous spot current I_a (kA)	OK criteria (kA)	Electrode sticking current I_s (kA)	Determination	
1	1	40	2	2	2.9	1.8	0.35	880	120	7.0	1505	5.80	8.12	9.34	10.00	Good	Example of present invention
2	2	40	2	2	2.7	1.7	0.38	820	90	3.0	2480	5.70	7.98	9.18	10.00	Good	Example of present invention
3	3	40	5	5	3.2	1.5	0.36	850	60	5.1	1950	5.80	8.12	9.34	10.00	Good	Example of present invention
4	4	40	5	5	3.1	1.8	0.33	850	60	5.5	1920	5.80	8.12	9.34	9.50	Good	Example of present invention
5	5	35	5	3	3.2	1.4	0.35	900	180	7.1	2010	5.80	8.12	9.34	10.00	Good	Example of present invention
6	6	35	5	3	3.3	1.5	0.42	830	90	4.0	2030	5.70	7.98	9.18	10.00	Good	Example of present invention
7	7	35	5	3	2.9	1.7	0.45	850	60	5.1	1980	5.60	7.84	9.02	10.00	Good	Example of present invention
8	8	35	5	3	3.2	1.9	0.38	850	60	5.0	1975	5.80	8.12	9.34	10.00	Good	Example of present invention
9	9	30	10	5	3.1	1.8	0.32	950	90	12.7	2100	5.80	8.12	9.34	9.50	Good	Example of present invention
10	10	10	10	5	3.9	1.6	0.35	950	90	11.2	2000	6.00	8.40	9.66	10.00	Good	Example of present invention
11	11	30	10	10	3.5	1.8	0.41	880	90	8.3	2025	5.90	8.26	9.50	10.00	Good	Example of present invention
12	12	30	10	10	3.0	1.6	0.42	880	90	7.9	2035	5.80	8.12	9.34	9.50	Good	Example of present invention
13	13	30	10	10	3.3	1.5	0.45	850	120	7.7	1530	5.80	8.12	9.34	10.50	Good	Example of present invention
14	14	30	10	10	3.3	1.1	0.32	850	120	9.0	1550	5.90	8.26	9.50	10.00	Good	Example of present invention
15	15	35	5	3	3.8	1.7	0.35	850	120	10.1	1530	5.70	7.98	9.18	10.00	Good	Example of present invention
16	16	35	5	3	3.1	1.2	0.42	850	120	9.4	1565	6.00	8.40	9.66	10.00	Good	Example of present invention
17	17	35	5	3	3.2	1.5	0.48	850	120	3.9	2045	5.80	8.12	9.34	10.50	Good	Example of present invention
18	18	35	10	5	2.6	1.0	0.46	850	120	3.8	2020	5.80	8.12	9.34	10.00	Good	Example of present invention
19	19	20	10	5	3.7	1.9	0.41	850	120	3.7	2060	5.60	7.84	9.02	10.00	Good	Example of present invention
20	20	20	10	5	3.6	1.7	0.38	850	120	6.1	2055	5.80	8.12	9.34	10.00	Good	Example of present invention
21	21	25	10	5	3.5	1.4	0.35	850	120	8.0	2040	5.90	8.26	9.50	10.00	Good	Example of present invention
22	22	25	10	5	3.7	1.6	0.39	850	120	9.3	2010	5.80	8.12	9.34	9.50	Good	Example of present invention
23	23	25	10	5	3.0	1.4	0.42	850	120	5.5	2100	5.70	7.98	9.18	10.00	Good	Example of present invention
24	24	35	5	5	3.3	1.8	0.41	850	120	9.2	1980	5.90	8.26	9.50	10.00	Good	Example of present invention
25	25	35	5	5	3.1	1.8	0.43	850	150	7.6	2000	5.90	8.26	9.50	10.00	Good	Example of present invention
26	26	35	5	5	3.5	1.4	0.39	850	120	6.4	1940	5.80	8.12	9.34	10.00	Good	Example of present invention

[Table 2-2]

Manufacture No.	Steel No.	Finish rolling			Surface layer region		Boundary layer	HS condition		Hot-stamping formed body							Note
												Spot weldability					
		Before F1 (MPa)	After F1 (between F1 and F2) (MPa)	After F2 (between F2 and F3) (MPa)	Average grain size (μm)	Standard deviation (μm)	Maximum Al concentration (mass %)	Heating temperature (°C)	Heating time (s)	Cross-sectional area ratio of voids (%)	Tensile strength (MPa)	$4\sqrt{t}$ current I_0 (kA)	Continuous spot current I_a (kA)	OK criteria (kA)	Electrode sticking current I_s (kA)	Determination	
27	27	35	10	5	3.4	1.2	0.33	850	120	5.2	1475	6.00	8.40	9.66	10.00	Good	Comparative Example
28	28	35	10	5	3.9	1.8	0.34	850	120	6.1	2550	5.90	8.26	9.50	9.50	Good	Comparative Example
29	29	35	5	5	3.8	1.4	0.36	820	120	3.2	1380	5.90	8.26	9.50	10.50	Good	Comparative Example
30	30	35	5	3	3.6	1.2	0.40	850	60	8.1	1450	5.80	8.12	9.34	10.00	Good	Comparative Example
31	31	35	5	3	3.7	2.0	0.42	900	180	4.9	2550	6.10	8.54	9.82	10.00	Good	Comparative Example
32	32	30	10	5	3.9	1.8	0.32	810	60	10.2	1440	5.90	8.26	9.50	10.00	Good	Comparative Example
33	33	30	10	10	3.3	2.0	0.36	810	60	7.4	1300	5.90	8.26	9.50	10.00	Good	Comparative Example
34	34	30	10	10	3.0	1.3	0.43	810	60	6.2	1120	5.70	7.98	9.18	10.00	Good	Comparative Example
35	35	30	5	3	3.7	1.5	0.31	880	60	7.1	1340	5.90	8.26	9.50	10.00	Good	Comparative Example
36	36	30	5	3	3.4	2.0	0.31	810	60	10.7	1450	5.80	8.12	9.34	9.50	Good	Comparative Example
37	17	None	10	5	5.3	2.3	0.25	850	120	18.4	1920	6.10	8.54	9.82	8.50	Bad	Comparative Example
38	17	5	5	5	4.7	2.1	0.26	850	120	16.2	1950	6.00	8.40	9.66	9.00	Bad	Comparative Example
39	17	50	5	3	3.6	2.6	0.28	850	120	16.0	2020	6.00	8.40	9.66	9.00	Bad	Comparative Example
40	17	40	None	5	3.9	2.7	0.24	850	120	15.9	1975	6.00	8.40	9.66	9.00	Bad	Comparative Example
41	17	40	1	5	3.8	2.2	0.27	850	120	18.3	1980	5.90	8.26	9.50	9.00	Bad	Comparative Example
42	17	40	15	5	3.2	2.6	0.27	850	120	17.5	2030	6.00	8.40	9.66	9.00	Bad	Comparative Example
43	17	40	2	None	3.9	2.0	0.38	850	120	13.2	1985	6.00	8.40	9.66	9.50	Fair	Example of present invention
44	17	40	5	None	3.5	2.0	0.33	850	120	14.5	1980	6.00	8.40	9.66	9.50	Fair	Example of present invention
45	17	40	10	None	3.2	1.9	0.35	850	120	13.3	2025	6.00	8.40	9.66	9.50	Fair	Example of present invention
46	37	40	5	5	3.1	1.8	0.35	850	60	6.9	2000	5.70	7.98	9.18	9.50	Good	Example of present invention
47	38	40	5	5	3.0	1.9	0.39	850	60	5.2	1940	5.80	8.12	9.34	10.00	Good	Example of present invention

An underline represents that a condition is out of the range of the present invention, a manufacturing condition is not preferred, or properties are not preferred.

[0093] Referring to Tables 2-1 and 2-2, with regard to Examples of the present invention, tensile strength is in a range of 1500 MPa to 2500 MPa and the cross-sectional area ratio of voids in the hot-stamping formed body was reduced to 15.0% or less. As a result, it was found that Examples of the present invention were excellent in spot weldability. Particularly, with regard to Manufacture Nos. 1 to 26, the cross-sectional area ratio of voids in the hot-stamping formed body was reduced to 13.0% or less and spot weldability was better. With regard to Examples of the present invention of Tables 2-1 and 2-2, the metallographic structure of the steel sheet of the hot-dip zinc-plated steel sheet consisted of, by area %, 20% to 90% of ferrite, 0% to 100% of bainite and martensite, 10% to 80% of pearlite, and 0% to 5% of residual austenite.

[0094] On the other hand, with regard to Comparative examples of Table 2-2, tensile strength was out of a range of 1500 MPa to 2500 MPa and/or the cross-sectional area ratio of voids exceeded 15.0%. As a result, it was found that Comparative examples were inferior in spot weldability.

[Industrial Applicability]

[0095] According to the aspect of the present invention, it is possible to provide a hot-dip zinc-plated steel sheet from which a hot-stamping formed body excellent in spot weldability and having strength generally required for a hot-stamping formed body can be obtained.

Claims

1. A hot-dip zinc-plated steel sheet comprising:

a steel sheet;
a boundary layer that is provided on a surface of the steel sheet; and
a hot-dip zinc-plated layer that is provided on a surface of the boundary layer,
wherein a chemical composition of the steel sheet contains, by mass %,

C: 0.18% to 0.50%,
Si: 0.10% to 1.50%,
Mn: 0.5% to 2.5%,
sol.Al: 0.001% to 0.100%,
Ti: 0.010% to 0.100%,
S: 0.0100% or less,
P: 0.100% or less,
N: 0.010% or less,
Nb: 0% to 0.05%,
V: 0% to 0.50%,
Cr: 0% to 0.50%,
Mo: 0% to 0.50%,
B: 0% to 0.010%,
Ni: 0% to 2.00%, and
a total of REM, Ca, Co, and Mg: 0% to 0.0300%,
a remainder consisting of Fe and impurities,

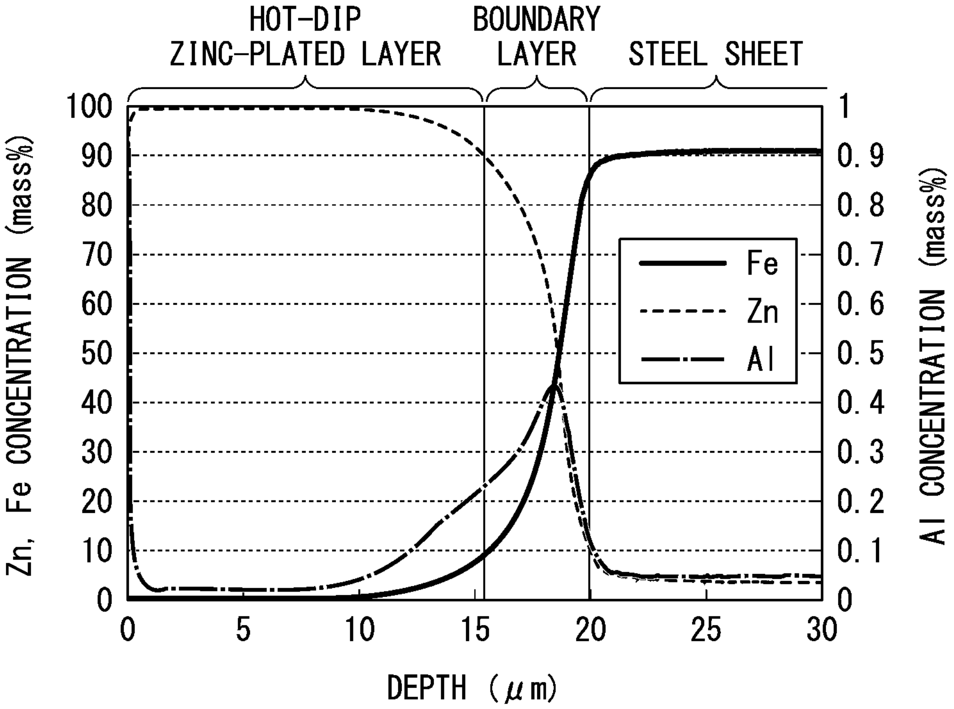
in a surface layer region of the steel sheet, an average grain size is 4.0 μm or less and a standard deviation of grain sizes is 2.0 μm or less, and
in the boundary layer, a maximum Al concentration is 0.30 mass % or more.

2. The hot-dip zinc-plated steel sheet according to claim 1,
wherein the chemical composition contains, by mass %, one or two or more selected from the group consisting of

Nb: 0.02% to 0.05%,
V: 0.005% to 0.50%,
Cr: 0.10% to 0.50%,
Mo: 0.005% to 0.50%,
B: 0.0001% to 0.010%,
Ni: 0.01% to 2.00%, and
a total of REM, Ca, Co, and Mg: 0.0003% to 0.0300%.

3. The hot-dip zinc-plated steel sheet according to claim 1 or 2,
wherein the chemical composition contains, by mass %,
C: 0.24% to 0.50%.

FIG. 1


HOT-DIP
ZINC-PLATED LAYER
BOUNDARY
LAYER
STEEL SHEET
100
90
80
70
60
50
40
30
20
10
0
Zn, Fe CONCENTRATION (mass%)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Al CONCENTRATION (mass%)
Fe
Zn
Al
0
5
10
15
20
25
30
DEPTH (μm)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/011993

A. CLASSIFICATION OF SUBJECT MATTER
C22C 38/00(2006.01)i; C22C 38/58(2006.01)i; C23C 2/06(2006.01)i; C21D 1/18(2006.01)n; C21D 9/00(2006.01)n; C21D 9/46(2006.01)n
FI: C22C38/00 301T; C22C38/58; C23C2/06; C21D9/46 J; C21D9/00 A; C21D1/18 C
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60; C23C2/06; C21D1/18; C21D9/00; C21D9/46

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2019/003447 A1 (JFE STEEL CORPORATION) 03 January 2019 (2019-01-03)	1-3
A	WO 2014/024825 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 13 February 2014 (2014-02-13)	1-3
A	WO 2018/062381 A1 (JFE STEEL CORPORATION) 05 April 2018 (2018-04-05)	1-3
A	WO 2016/031166 A1 (JFE STEEL CORPORATION) 03 March 2016 (2016-03-03)	1-3

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
01 June 2021 (01.06.2021)

Date of mailing of the international search report
15 June 2021 (15.06.2021)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/011993

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WO 2018/062381 A1	05 Apr. 2018	US 2019/0203317 A1 EP 3486346 A1 CN 109642295 A KR 10-2019-0034265 A MX 2019002324 A	
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Form PCT/ISA/210 (patent family annex) (January 2015)

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- WO 2013147228 A **[0007]**