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(54) PLATED STEEL MATERIAL AND METHOD FOR MANUFACTURING PLATED STEEL MATERIAL

(57) Provided are: a coated steel material including a base steel and a coating layer including a Zn-Al-Mg alloy layer provided on a surface of the base steel and a Mg enrichment layer provided on a surface of the Zn-Al-Mg alloy layer in which a thickness of the Mg enrichment layer is 0.8 μm or more and (thickness of coating layer × 1/2) or less; and a method for manufacturing the coated steel material.

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Description

Technical Field

[0001] The present disclosure relates to a coated steel material and a method for manufacturing a coated steel material.

Background Art

[0002] A wide variety of coated steel materials are used, for example, in the field of construction materials. Many of them are Zn-coated steel materials. Due to the need for having a long life for construction materials, research on improving the corrosion resistance of Zn-coated steel materials has been conducted over a long time, and various coated steel materials have been developed. The first high corrosion resistant coated steel material for construction materials was a Zn-5% Al coated steel material (Galfan coated steel material), in which Al was added to a Zn-based coating layer to improve the corrosion resistance. It is a well-known fact that the corrosion resistance is improved by addition of Al into a coating layer, and by addition of 5% of Al, Al phase are formed in the coating layer (specifically Zn phase) and the corrosion resistance is improved. A Zn-55% Al-1.6% Si coated steel material (Galvalume steel product) is also a coated steel material, in which corrosion resistance is basically improved for the same reason.

[0003] The attractive feature of a Zn-based coated steel material is the sacrificial corrosion protection effect on a base steel. In other words, in a cut edge of a coated steel material, a cracked portion of a coating layer generated at the time of forming, and an exposed portion of a base steel which appears, for example, by exfoliation of a coating layer, the coating layer in the vicinity of such portions dissolves out before corrosion of the base steel, and the dissolved coating component forms a protective film. This makes it possible to prevent rusting in the base steel to some extent.

[0004] In general, such effects are preferable in a case of a lower Al concentration and a higher Zn concentration. Accordingly, a high corrosion-resistant coated steel material in which the Al concentration is reduced to a relatively low concentration of about from 5% to 25% has been available for practical use in recent years. In particular, a coated steel material, in which the Al concentration is suppressed at a low level and Mg is contained at about from 1% to 3%, has superior corrosion resistance with respect to the Galfan coated steel material. Therefore, this has become a market trend in coated steel materials, and widely known in the market at present.

[0005] As such a coated steel material containing a certain amount of Al and Mg, for example, a coated steel material disclosed in Patent Literature 1 has been also developed.

[0006] Specifically, Patent Literature 1 discloses "a hot dip Zn-Al-Mg-Si coated steel material in which 200 or more Al phases exist per 1 mm^2 on the surface of a coated steel material having a coating layer composed of from 5% to 18% by mass of Al, from 1% to 10% by mass of Mg, from 0.01% to 2% by mass of Si, and the balance of Zn and unavoidable impurities".

[0007] In addition, Patent Literature 2 discloses "a coated steel material including a steel product, and a coating layer including a Zn-Al-Mg alloy layer provided on a surface of the steel product, in which the coatcoating layer has a chemical composition composed of Zn at more than 65.0%, Al at more than 5.0% and less than 25.0%, Mg at more than 3.0% and less than 12.5%, and Sn at from 0.1% to 20.0%, and in a backscattered electron image of the Zn-Al-Mg alloy layer, obtained by polishing a surface of the Zn-Al-Mg alloy layer to 1/2 of a layer thickness, and observing the surface at a magnification of 100 x with a scanning electron microscope, Al phase are present, and an average value of a cumulative circumferential length of the Al phase is from 88 to 195 mm/mm^2".

Citation List

Patent Literature

[0008]

Patent Literature 1: Japanese Patent Application Laid-Open (JP-A) No. 2001-355053
Patent Literature 2: WO 2019/221193

SUMMARY OF INVENTION

Technical Problem

[0009] In a Zn-Al-Mg-based alloy coated steel material having a high Al concentration and a high Mg concentration, corrosion resistance is superior to that of a Zn-based coated steel material in a heavy salt damage region in which the amount of airborne chlorides is large and the corrosion environment is severe, but white rust tends to be generated soon after construction. In addition, since coating with a high Mg concentration is likely to cause oxidative discoloration and the coating is hard, formability may be poor.

[0010] Therefore, an object of the disclosure is to provide a coated steel material which is excellent in corrosion resistance even in a heavy salt damage region and can achieve both formability and discoloration resistance, and a method for manufacturing the coated steel material.

Solution to Problem

[0011] The above object is achieved by the following means.

<1> A coated steel material including a base steel and a coating layer including a Zn-Al-Mg alloy layer provided on a surface of the base steel and a Mg enrichment layer provided on a surface of the Zn-Al-Mg alloy layer,
in which the coating layer has a chemical composition composed of, in terms of % by mass:

Zn at more than 65.00%,
Al at more than 5.00% and less than 25.00%,
Mg at more than 3.00% and less than 12.50%,
Sn at from 0% to 3.0%,
Bi at from 0% to less than 5.00%,
In at from 0% to less than 2.00%,
Ca at from 0% to 3.00%,
Y at from 0% to 0.50%,
La at from 0% to less than 0.50%,
Ce at from 0% to less than 0.50%,
Si at from 0% to less than 2.5%,
Cr at from 0% to less than 0.25%,
Ti at from 0% to less than 0.25%,
Zr at from 0% to less than 0.25%,
Mo at from 0% to less than 0.25%,
W at from 0% to less than 0.25%,
Ag at from 0% to less than 0.25%,
P at from 0% to less than 0.25%,
Ni at from 0% to less than 0.25%,
Co at from 0% to less than 0.25%
V at from 0% to less than 0.25%,
Nb at from 0% to less than 0.25%,
Cu at from 0% to less than 0.25%,
Mn at from 0% to less than 0.25%,
Li at from 0% to less than 0.25%,
Na at from 0% to less than 0.25%,
K at from 0% to less than 0.25%,
Fe at from 0% to 5.0%,
Sr at from 0% to less than 0.5%
Sb at from 0% to less than 0.5%
Pb at from 0% to less than 0.5%,
B at from 0% to less than 0.5%, and
impurities,
in the Zn-Al-Mg alloy layer, a total area ratio of Al phase, $MgZn_2$, phase, and Zn/Al/$MgZn_2$ ternary eutectics is 90% or more, and
a thickness of the Mg enrichment layer is 0.8 μm or more and (thickness of coating layer × 1/2) or less.

<2> The coated steel material according to <1>, in which the coating layer has an Al-Fe alloy layer between the base steel and the Zn-Al-Mg alloy layer.
<3> A method for manufacturing the coated steel material according to <1> or <2>,

in which a base steel is immersed in a hot-dip coating bath and pulled up from the hot-dip coating bath, and then cooled down in a temperature range of from 450°C to 395°C at an average cooling rate of 15°C/s or less, cooled down in a temperature range of from 395°C to 340°C at an average cooling rate of 3°C/s or less, and cooled down in a temperature range of from 340°C to 280°C at an average cooling rate of from 10 to 20°C/s or more, and after the cooling, subjected to skin pass rolling under conditions that a surface roughness Ra of a skin pass roll is from 1 to 5 μm and a skin pass rolling force is from 100 to 500 ton.

Advantageous Effects of Invention

[0012] Therefore, according to the disclosure, it is possible to provide a coated steel material which is excellent in corrosion resistance even in a heavy salt damage region and can achieve both formability and discoloration resistance, and a method for manufacturing the coated steel material.

BRIEF DESCRIPTION OF DRAWINGS

[0013] Fig. 1 is a graph for explaining a method for measuring a thickness of a Mg enrichment layer.

DESCRIPTION OF EMBODIMENTS

[0014] An example of the disclosure will be described below.
[0015] In the disclosure, the expression of "%" with respect to the content of each element of a chemical composition means "% by mass".
[0016] A numerical range expressed using "to" means a range including the numerical values stated before and after "to" as the upper limit and lower limit.
[0017] In a case where the numerical values stated before and after "to" are denoted with the term "more than" or "less than", the numerical range means a range not including the numerical value as the upper limit or lower limit.
[0018] The content of an element of a chemical composition may be expressed as an element concentration (for example, Zn concentration and Mg concentration).
[0019] A coated steel material according to the disclosure includes a base steel and a coating layer including a Zn-Al-Mg alloy layer provided on a surface of the base steel and a Mg enrichment layer provided on a surface of the Zn-Al-Mg alloy layer.
[0020] In the Zn-Al-Mg alloy layer, a total area ratio of Al phase, $MgZn_2$ phase, and Zn/Al/$MgZn_2$ ternary eutectics is 90% or more.
[0021] Also, a thickness of the Mg enrichment layer is 0.8 μm or more and (thickness of coating layer × 1/2) or less.
[0022] Since the coated steel material of the disclosure has the Mg enrichment layer of the Zn-Al-Mg alloy layer on the surface of the Zn-Al-Mg alloy layer, a dense corrosion product film containing Mg is formed soon in the early stage of corrosion. The dense corrosion product film reduces a corrosion rate. Therefore, corrosion resistance is excellent even in a heavy salt damage region in which the amount of airborne chlorides is large and the corrosion environment is severe. When setting a chemical composition of a coating layer and a range of the Mg enrichment layer to appropriate ranges, both formability and discoloration resistance can be achieved.
[0023] In addition, when the Zn-Al-Mg alloy layer having the above structure is present below the Mg enrichment layer, Mg ions and Al ions are supplied to the corrosion environment from the middle to the late stage of corrosion while securing formability. Accordingly, a dense corrosion product film is maintained, and therefore corrosion resistance is improved.
[0024] The coated steel material of the disclosure will be described in detail below.

(Base Steel)

[0025] There is no particular restriction on the shape of the base steel. Examples of the base steel include besides a steel sheet, shape formed base steel, such as a steel pipe, a civil engineering and building material (such as fence conduit, corrugated pipe, drain ditch cover, wind-blown sand preventing coate, bolt, wire mesh, guardrail, and cut-off wall), a home electrical appliance component (such as housing for an air conditioner outdoor unit), and an automobile part (such as a suspension system component). For shape forming, for example, various plastic working methods, such as press working, roll forming, and bending, can be used.
[0026] There is no particular restriction on the material of the base steel. As the base steel, there are various applicable base steels, and examples thereof include general steel, precoated steel, Al killed steel, ultra-low carbon steel, high carbon steel, various high tensile strength steels, and some high alloy steels (for example, steel containing a strengthening element such as Ni and Cr).
[0027] With respect to the base steel, there is also no particular restriction on the method for manufacturing a base steel, or the conditions of a method for manufacturing a base steel sheet (such as a hot rolling method, a pickling method, and a cold rolling method).
[0028] In addition, as the base steel, a hot-rolled steel sheet, a hot-rolled steel strip, a cold rolled steel sheet, and a cold

rolled steel strip described in JIS G 3302 (2010) are also applicable.

[0029] The base steel may be a precoated steel material which has been precoated. A precoated steel material is obtained, for example, by an electrolytic treatment method or a displacement coating method. In the electrolytic treatment method, a base steel is immersed in a sulfate bath or chloride bath containing various metal ions corresponding to precoating components, and an electrolytic treatment is performed to obtain a precoated steel material. In the displacement coating method, a base steel is immersed in an aqueous solution, which contains various metal ions corresponding to precoating components, and of which a pH has been adjusted with sulfuric acid, for causing displacement deposition of a metal to obtain a precoated steel material.

[0030] Typical examples of a precoated steel material include a Ni precoated steel material.

(Coating Layer)

[0031] The coating layer includes a Zn-Al-Mg alloy layer and a Mg enrichment layer provided on a surface of the Zn-Al-Mg alloy layer. The coating layer may include an Al-Fe alloy layer in addition to the Zn-Al-Mg alloy layer and the Mg enrichment layer. The Al-Fe alloy layer is provided between the base steel and the Zn-Al-Mg alloy layer.

[0032] That is, the coating layer may have a laminated structure including the Zn-Al-Mg alloy layer, the Mg enrichment layer, and the Al-Fe alloy layer.

[0033] Although there are some cases where an oxide film of a constituent element of the coating layer is formed on the surface of the coating layer in a thickness of about 50 nm, a thickness thereof is thin relative to the thickness of the entire coating layer (about from 8 to 60 μm) such that the oxide film is deemed not to constitute a main part of the coating layer.

[0034] A deposited amount of the coating layer is preferably from 40 to 300 g/m^2 per one surface.

[0035] When the deposited amount of the coating layer is 40 g/m^2 or more, corrosion resistance can be ensured more reliably. Also, when the deposited amount of the coating layer is 300 g/m^2 or less, appearance defects such as sagging patterns of the coating layer can be suppressed.

[0036] Next, the chemical composition of the coating layer will be described.

[0037] The chemical composition of the coating layer is a chemical composition composed of, in terms of % by mass:

Zn at more than 65.00%,
Al at more than 5.00% and less than 25.00%,
Mg at more than 3.00% and less than 12.50%,
Sn at from 0% to 3.00%,
Bi at from 0% to less than 5.00%,
In at from 0% to less than 2.00%,
Ca at from 0% to 3.00%,
Y at from 0% to 0.50%,
La at from 0% to less than 0.50%,
Ce at from 0% to less than 0.50%,
Si at from 0% to less than 2.5%,
Cr at from 0% to less than 0.25%,
Ti at from 0% to less than 0.25%,
Zr at from 0% to less than 0.25%,
Mo at from 0% to less than 0.25%,
W at from 0% to less than 0.25%,
Ag at from 0% to less than 0.25%,
P at from 0% to less than 0.25%,
Ni at from 0% to less than 0.25%,
Co at from 0% to less than 0.25%
V at from 0% to less than 0.25%,
Nb at from 0% to less than 0.25%,
Cu at from 0% to less than 0.25%,
Mn at from 0% to less than 0.25%,
Li at from 0% to less than 0.25%,
Na at from 0% to less than 0.25%,
K at from 0% to less than 0.25%,
Fe at from 0% to 5.00%,
Sr at from 0% to less than 0.50%
Sb at from 0% to less than 0.50%
Pb at from 0% to less than 0.50%,

B at from 0% to less than 0.50%, and
impurities.

[0038] In the chemical composition of the coating layer, Sn, Bi, In, Ca, Y, La, Ce, Si, Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na, K, Fe, Sr, Sb, Pb, and B are optional components. In other words, these elements need not be contained in the coating layer. When any of these optional components is contained, the content of each optional element is preferably in the range described below.
[0039] Here, the chemical composition of the coating layer is an average chemical composition of the entire coating layer (an average chemical composition of all of the Zn-Al-Mg alloy layer and the Mg enrichment layer or an average chemical composition of all of the Al-Fe alloy layer, the Zn-Al-Mg alloy layer, and the Mg enrichment layer).
[0040] Each element of a coating layer will be described below.

Zn at More Than 65.00%

[0041] Zn is an element necessary for obtaining corrosion resistance. As for Zn concentration in terms of the atomic composition ratio, since the coating layer is composed together with elements having a low specific gravity such as Al and Mg, Zn is required to occupy the main portion also in the atomic composition ratio.
[0042] Therefore, the Zn concentration is set above 65.00%. The Zn concentration is preferably 70.00% or more. In this regard, the upper limit of the Zn concentration is a remnant concentration excluding elements other than Zn, and impurities.

Al at More Than 5.00% and Less Than 25.00%

[0043] Al is an essential element for forming Al phase and ensuring corrosion resistance. Also, Al is an essential element for enhancing the adhesion of a coating layer and ensuring the formability. Therefore, the lower limit of the Al concentration is set above 5.00% (preferably at 10.00% or more).
[0044] Meanwhile, when the Al concentration increases too much, the corrosion resistance tends to deteriorate. Therefore, the upper limit of the Al concentration is set below 25.00% (preferably at 23.00% or less).

Mg at More Than 3.00% and Less Than 12.50%

[0045] Mg is an essential element for ensuring corrosion resistance. Therefore, the lower limit of the Mg concentration is set above 3.00% (preferably above 4.00%).
[0046] Meanwhile, when the Mg concentration increases too much, the formability tends to deteriorate. Therefore, the upper limit of the Mg concentration is set at lower than 12.50% (preferably at 10.00% or less).

Sn at from 0% to 3.00%

[0047] Sn is an element that contributes to corrosion resistance and initial discoloration resistance. Therefore, the lower limit of the Sn concentration is preferably more than 0.00% (preferably 0.05% or more, and more preferably 0.10% or more).
[0048] Meanwhile, when the Sn concentration increases too much, corrosion resistance and initial discoloration resistance tend to deteriorate. Therefore, the upper limit of the Sn concentration is set at 3.00% or less.

Bi at from 0% to Less Than 5.00%

[0049] Bi is an element that contributes to corrosion resistance. Therefore, the lower limit of the Bi concentration is preferably more than 0.00% (preferably 0.10% or more, and more preferably 3.00% or more).
[0050] Meanwhile, when the Bi concentration increases too much, the corrosion resistance tends to deteriorate. Therefore, the upper limit of the Bi concentration is set below 5.00% (preferably at 4.80% or less).

In at from 0% to Less Than 2.00%

[0051] In is an element that contributes to corrosion resistance. Therefore, the lower limit of the In concentration is preferably more than 0.00% (preferably 0.10% or more, and more preferably 1.00% or more).
[0052] Meanwhile, when the In concentration increases too much, the corrosion resistance tends to deteriorate. Therefore, the upper limit of the In concentration is set below 2.00% (preferably at 1.80% or less).

Ca at from 0% to 3.00%

[0053] Ca is an element capable of adjusting the dissolution amount of Mg to a level optimal for imparting corrosion resistance. Therefore, the lower limit of the Ca concentration is preferably more than 0.00% (preferably 0.05% or more).
[0054] Meanwhile, when the Ca concentration increases too much, the corrosion resistance and formability tend to deteriorate. Therefore, the upper limit of the Ca concentration is set at 3.00% or less (preferably at 1.00% or less).

Y at from 0% to 0.50%

[0055] Y is an element that contributes to corrosion resistance. Therefore, the lower limit of the Y concentration is preferably more than 0.00% (preferably 0.10% or more).
[0056] Meanwhile, when the Y concentration increases too much, the corrosion resistance tends to deteriorate. Therefore, the upper limit of the Y concentration is set at 0.50% or less (preferably at 0.30% or less).

La And Ce at from 0% to Less Than 0.50%

[0057] La and Ce are elements that contribute to corrosion resistance. Therefore, the lower limit of each of the La concentration and Ce concentration is preferably more than 0.00% (preferably 0.10% or more).
[0058] Meanwhile, when the La concentration or the Ce concentration increases too much, the corrosion resistance tends to deteriorate. Therefore, the upper limit of each of the La concentration and the Ce concentration is set below 0.50% (preferably at 0.40% or less).

Si at from 0% to Less Than 2.50%

[0059] Si is an element that contributes to improvement of the corrosion resistance by suppressing growth of an Al-Fe alloy layer. Therefore, the Si concentration is preferably more than 0.00% (preferably 0.05% or more, and more preferably 0.10% or more). In particular, when Sn is not contained (that is, when the Sn concentration is 0%), the Si concentration is preferably 0.10% or more (preferably 0.20% or more) from the viewpoint of ensuring corrosion resistance.
[0060] Meanwhile, when the Si concentration increases too much, the corrosion resistance and formability tend to deteriorate. Therefore, the upper limit of the Si concentration is set below 2.50%. In particular, from the viewpoint of corrosion resistance, the Si concentration is preferably 2.40% or less, more preferably 1.80% or less, and further preferably 1.20% or less.
[0061] Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na, and K at from 0% to Less Than 0.25%
[0062] Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na, and K are elements that contribute to corrosion resistance. Therefore, the lower limit of the concentration of each of Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na and K is preferably more than 0% (preferably 0.05% or more, and more preferably 0.10% or more).
[0063] Meanwhile, when the concentration of Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na, or K increases too much, corrosion resistance tends to deteriorate. Therefore, the upper limit of the concentration of each of Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na, and K is set below 0.25%. The upper limit of the concentration of Cr, Ti, Zr, Mo, W, Ag, P, Ni, Co, V, Nb, Cu, Mn, Li, Na, or K is preferably 0.22% or less.

Fe at from 0% to 5.00%

[0064] When a coating layer is formed by a hot dip metal coating method, Fe is contained in a Zn-Al-Mg alloy layer and an Al-Fe alloy layer at certain concentrations.
[0065] It has been confirmed that there is no adverse effect on the performance, even when Fe is contained in a coating layer (particularly a Zn-Al-Mg alloy layer), up to a concentration of 5.00%. Since most of the Fe is contained in an Al-Fe alloy layer in many cases, when the thickness of this layer is large, the Fe concentration generally increases.

Sr, Sb, Pb, and B at from 0% to Less Than 0.50%

[0066] Sr, Sb, Pb, and B are elements that contribute to corrosion resistance. Therefore, the lower limit of the concentration of each of Sr, Sb, Pb, and B is preferably more than 0% (preferably 0.05% or more, and more preferably 0.10% or more).
[0067] Meanwhile, when the concentration of Sr, Sb, Pb, or B increases too much, the corrosion resistance tends to deteriorate. Therefore, the upper limit of the concentration of each of Sr, Sb, Pb, and B is set below 0.50%.

Impurities

[0068] Impurities refer to components contained in raw materials, or components to be mixed in in the manufacturing process, which are not intentionally added. For example, in a coating layer, trace amounts of components other than Fe may be mixed in as impurities in a coating layer by mutual atomic diffusion between a base steel and a hot-dip coating bath.

[0069] The chemical components of a coating layer are measured by the following method.

[0070] First, an acid solution in which a coating layer is separated and dissolved with an acid containing an inhibitor that inhibits the corrosion of a base steel is prepared. Next, the chemical composition of the coating layer can be obtained by measuring the obtained acid solution by ICP analysis. There is no particular restriction on the acid species, insofar as it is an acid capable of dissolving the coating layer. The chemical composition is measured as an average chemical composition. In the ICP analysis, the Zn concentration is determined from "Formula: Zn concentration = 100% - Concentration (%) of other elements".

[0071] Here, when a precoated steel material is used as a base steel, a component of the precoating is also detected.

[0072] For example, when a Ni precoated steel material is used, not only Ni in the coating layer but also Ni in the Ni precoating is detected in the ICP analysis. Specifically, for example, when a precoated steel material having a Ni deposited amount of from 1 g/m^2 to 3 g/m^2 (thickness of about 0.1 to 0.3 μm) is used as a base steel, even if the concentration of Ni contained in the coating layer is 0%, the Ni concentration is detected as from 0.1% to 15% when measured by the ICP analysis.

[0073] Here, a method for determining whether a base steel is a Ni precoated steel material is as follows.

[0074] A sample in which a cross section cut along the thickness direction of the coating layer serves as a measurement surface is collected from a target steel product.

[0075] The vicinity of the interface between the coating layer and the base steel in the steel product is linearly analyzed by an electron probe microanalyzer (FE-EPMA) on the measurement surface of the sample to measure the Ni concentration. The measurement conditions are an acceleration voltage of 15 kV, a beam diameter of about 100 nm, irradiation time per point of 1000 ms, and a measurement pitch of 60 nm. A measurement distance may be any distance insofar as it is possible to confirm whether or not the Ni concentration is concentrated at the interface between a coating layer and a base steel in a steel product.

[0076] When the Ni concentration is concentrated at the interface between a coating layer and a base steel in the steel product, the base steel is discriminated as a Ni precoated steel material.

[0077] When a Ni precoated steel material is used as a base steel, the Ni concentration of the coating layer is defined as a value measured as follows.

[0078] First, with a high frequency glow discharge emission surface analyzer (GDS: manufactured by HORIBA, Ltd., model number: GD-Profiler2), the emission intensity of Ni is measured for three or more kinds of standard samples (Zn alloy standard samples IMN ZH1, ZH2, and ZH4 manufactured by BAS) having different Ni concentrations. A calibration curve is prepared from the relationship between the obtained emission intensity of Ni and the Ni concentration in the standard test.

[0079] Next, the surface of the coating layer of the sample is polished in the thickness direction of the coating layer (hereinafter also referred to as "Z-axis direction").

[0080] Specifically, the surface of the coating layer is dry-polished with a #1200 abrasive sheet, and then finish-polishing is carried out successively using a finishing liquid containing alumina having an average particle diameter of 3 μm, a finishing liquid containing alumina having an average particle diameter of 1 μm, and a finishing liquid containing colloidal silica in the mentioned order.

[0081] In doing so, the Zn intensity in the surface of the coating layer is measured by XRF (X-ray fluorescence analysis) before and after the polishing, and when the Zn intensity after the polishing reduces to 1/2 the Zn intensity before the polishing, the then thickness of the coating layer is deemed as the 1/2 layer thickness.

[0082] Next, the emission intensity of Ni at a position where a film thickness of a coating layer of a coated steel material to be measured is 1/2 is measured by the high frequency glow discharge emission surface analyzer (GDS: manufactured by HORIBA, model number: GD-Profiler2). The Ni concentration at the position of 1/2 of the coating layer is determined from the obtained emission intensity of Ni and the prepared calibration curve.

[0083] When a Ni precoated steel material is used as a base steel, the Zn concentration of the coating layer is defined as a Zn concentration calculated from the following formula.

Zn concentration = 100 - (Concentration of elements other than Zn and Ni determined by ICP analysis + Ni concentration determined by GDS)   Formula:

[0084] Measurement conditions of the high frequency glow discharge emission surface analyzer are as follows.

- H.V.: 630 V
- Anode diameter: φ 4 mm
- Gas: Ar
- Gas pressure: 600 Pa
- Output: 35 W

[0085] Next, the structure of the Zn-Al-Mg alloy layer will be described.
[0086] In the Zn-Al-Mg alloy layer, a total area ratio of Al phase, $MgZn_2$ phase, and Zn/Al/$MgZn_2$ ternary eutectics is 90% or more.
[0087] From the viewpoint of improving corrosion resistance, the lower limit of the area ratio is preferably 92%, 95%, or 98%. Ideally, the area ratio is particularly preferably 100%.
[0088] In addition, the area ratio of the structure excluding the Al phase, the $MgZn_2$ phase, and the Zn/Al/$MgZn_2$ ternary eutectics, as that of Zn phase is preferably from 0% to 10%, more preferably from 0% to 8% or from 0% to 5%, and still more preferably from 0% to 2%. Ideally, the area ratio of Zn phase is particularly preferably 0% (that is, it is particularly preferable not to contain Zn phase.).
[0089] Here, the Al crystal and the Zn crystal each mean phase crystallized independently.
[0090] The structure of the Zn-Al-Mg alloy layer is measured as follows.
[0091] First, a sample is taken from a coated steel material to be measured. In this regard, the sample is taken from a portion which is not in the vicinity (within 2 mm from the end face) of the punched end face of the coated steel material, and is free from a defect of the coating layer.
[0092] Next, the surface of the coating layer of the sample is polished in the thickness direction of the coating layer (hereinafter also referred to as "Z-axis direction").
[0093] Specifically, the surface of the coating layer is dry-polished with a #1200 abrasive sheet, and then finish-polishing is carried out successively using a finishing liquid containing alumina having an average particle diameter of 3 μm, a finishing liquid containing alumina having an average particle diameter of 1 μm, and a finishing liquid containing colloidal silica in the mentioned order.
[0094] In doing so, the Zn intensity in the surface of the coating layer is measured by XRF (X-ray fluorescence analysis) before and after the polishing, and when the Zn intensity after the polishing reduces to 1/2 the Zn intensity before the polishing, the then thickness of the coating layer is deemed as the 1/2 layer thickness. Since the Zn-Al-Mg alloy layer occupies 1/2 or more of the layer thickness of the coating layer, the polished surface obtained by polishing the surface of the coating layer to 1/2 of the layer thickness is the polished surface of the Zn-Al-Mg alloy layer. Therefore, the metal structure contained in the Zn-Al-Mg alloy layer can be grasped by analyzing the polished surface.
[0095] Next, the polished surface is observed with a scanning electron microscope (SEM) at a magnification of 500 x to obtain a backscattered electron image (hereinafter also referred to as "SEM backscattered electron image"). The SEM observation conditions are: acceleration voltage at 15 kV, probe-current at 10 nA, and visual field size of 244 μm × 198 μm.
[0096] Further, using an electron probe microanalyzer (FE-EPMA), mapping analysis is performed at a magnification of 500 x at an acceleration voltage of 15 kV, an irradiation current of 30 nA, a beam diameter of about 100 nm, an irradiation time per point of 5 ms, and a measurement pitch of 300 nm. Then, regions can be roughly divided into a region in which the detection points of Mg and Zn overlap, a region in which the detection points of Al and Zn overlap, and a region in which Zn is detected alone. In this case, the region in which the detection points of Mg and Zn overlap is defined as $MgZn_2$, and a region in which the detection points of Al and Zn overlap is defined as Al phase. Further, in the region in which Zn is detected alone, FE-EPMA line analysis is performed at a magnification of 2000 x for a length of 10 μm. In this case, in the measurement region, a region in which Mg or Al is detected by 1% or more can be discriminated as Zn/Al/$MgZn_2$ ternary eutectics, and a region in which both Mg and Al are detected by less than 1% can be discriminated as Zn phase.
[0097] Computer image processing is performed on these regions to obtain the area ratio (area (pixel) of each phase in the visual field is calculated).
[0098] Next, the Mg enrichment layer will be described.
[0099] The Mg enrichment layer is a layer in which a Mg-containing phase such as a Zn/Al/$MgZn_2$ ternary eutectics existing in a surface layer of the Zn-Al-Mg alloy layer is densified and a Mg concentration is enriched.
[0100] When the Mg enrichment layer is thin, corrosion resistance becomes poor. On the other hand, when the Mg enrichment layer is too thick, discoloration resistance deteriorates.
[0101] Therefore, a thickness of the Mg enrichment layer is set to 0.8 μm or more and (thickness of coating layer × 1/2) or less. The thickness of the Mg enrichment layer is preferably 0.9 μm or more and 25 μm or less, and more preferably 1.0 μm or more and 22.5 μm or less.
[0102] The thickness of the coating layer is preferably 5 μm or more and 50 μm or less, and more preferably 10 μm or more and 45 μm or less.
[0103] The Mg enrichment layer is a layer defined as follows.
[0104] First, sputtering is performed in a depth direction from a surface side of the coating layer by glow discharge optical

emission spectrometry (quantitative GDS), and the depth direction distribution of the intensity of each element (such as Zn, Al, Mg, or Fe) contained in the coating layer is measured (see Fig. 1) (measurement device: manufactured by HORIBA, Ltd., model number: GD-Profiler2, measurement conditions: DC mode, voltage: 900 V, current: 20 mA). In this case, in a case where a chemical conversion film or the like is present on the coating layer, the depth direction distribution of the intensity of an element as a main component of a film (for example, carbon (C) in the case of an organic film, and an element as a main component of a film in the case of an inorganic film) is also measured. In the case of the inorganic film, the element as a main component is, for example, zirconium (Zr) in a case of a zirconium oxide film, and silicon (Si) in a case of a film containing a silane coupling agent.

[0105] The measurement is performed to a depth at which the coating layer disappears and a base iron is sufficiently exposed. In this case, the depth [μm] of a hole after the measurement is measured, and the sputtering rate [μm/s] is obtained by dividing the measured value by the GDS measurement time [s]. By multiplying this sputtering rate by the elapsed time from the start of measurement at the target measurement position, the depth [μm] from the surface of the target measurement position is obtained.

[0106] Here, a point at which the amount of increase in intensity of Fe per 0.1 μm exceeds 0.003 when the change in intensity of Fe is viewed from the coating surface direction is defined as (A). The intensity of Mg at the point (A) is defined as 1, and a point (B) at which the relative intensity of Mg is 1.03 when the Mg intensity is viewed from the base iron (that is, the base steel) side to the coating layer surface side is defined as an interface between the Mg enrichment layer and the Zn-Al-Mg alloy layer. A point (C) at which the intensity of Mg and the intensity of carbon (C) become the same when the coating layer surface side is viewed from the point (B) is defined as the top of the Mg enrichment layer. The intensity of carbon (C) that determines the point (C) (the intensity of the carbon (C) in a case where no chemical conversion film or the like is present on the coating layer) is the intensity of the carbon (C) derived from dust or oil attached to the surface of the coating layer.

[0107] However, in a case where a chemical conversion film or the like is present on the coating layer, the point at which the intensity of the chemical conversion film or the like is the same as the intensity of the element as the main component of the film is defined as the point (C), and the point (C) is defined as the top of the Mg enrichment layer.

[0108] The Mg enrichment layer is defined as a layer between the point (B) and the point (C), and the thickness of the Mg enrichment layer is defined as an average value of differences in depth between the point (B) and the point (C) measured at three points.

[0109] Next, the Al-Fe alloy layer will be described.

[0110] The Al-Fe alloy layer is a layer that is formed on the surface of a base steel (specifically, between a base steel and a Zn-Al-Mg alloy layer), and has a structure constituted mainly with an Al_5Fe phase. The Al-Fe alloy layer is formed by mutual atomic diffusion of a base steel and a hot-dip coating bath. Since, in the steel product of the disclosure, a coating layer is formed by using a hot dip metal coating method, an Al-Fe alloy layer is easily formed in a coating layer containing an Al element. Since Al is contained in a hot-dip coating bath at a certain concentration or higher, an Al_5Fe phase is formed at the highest content. However, it takes time for atomic diffusion, and there is a portion where the Fe concentration is high in the vicinity of the base steel. Therefore, the Al-Fe alloy layer may partially contain a small amount of an AlFe phase, an Al_3Fe phase, an Al_5Fe_2 phase, or the like. Also, since Zn is also contained in the hot-dip coating bath at a certain concentration, the Al-Fe alloy layer also contains a small amount of Zn.

[0111] Regarding the corrosion resistance, there is no significant difference among any of an Al_5Fe phase, an Al_3Fe phase, an AlFe phase, and an Al_5Fe_2 phase. The referred corrosion resistance is the corrosion resistance at a portion not affected by welding.

[0112] When Si is contained in a coating layer, Si is particularly apt to be incorporated into an Al-Fe alloy layer and an Al-Fe-Si intermetallic compound phase may be formed. The intermetallic compound phase to be identified includes an AlFeSi phase, and there are α, β, q1, q2-AlFeSi phases, or the like as isomers. Therefore, these AlFeSi phases or the like may be detected in the Al-Fe alloy layer in some cases. Such an Al-Fe alloy layer including the AlFeSi phases or the like is also referred to as an Al-Fe-Si alloy layer.

[0113] Since the thickness of the Al-Fe-Si alloy layer is also small relative to the Zn-Al-Mg alloy layer, the effect on the corrosion resistance of the entire coating layer is small.

[0114] Also, when various precoated steel materials are used for a base steel, the structure of the Al-Fe alloy layer may be changed in some cases depending on the deposited amount of the precoating. Specifically, there are a case where a layer of a pure metal used for precoating remains in the vicinity of the Al-Fe alloy layer, a case where an intermetallic compound phase (for example, an Al_3Ni phase), in which a constituent component of the Zn-Al-Mg alloy layer is bonded to a precoating component, constitutes an alloy layer, a case where some of Al atoms and Fe atoms are displaced to form an Al-Fe alloy layer, a case where some of Al atoms, Fe atoms, and Si atoms are displaced to form an Al-Fe-Si alloy layer, and the like.

[0115] That is, the Al-Fe alloy layer means a layer that includes the above various modes of alloy layers in addition to the alloy layer mainly composed of the Al_5Fe phase.

[0116] When a coating layer is formed on a Ni precoated steel material among various precoated steel materials, an Al-

Ni-Fe alloy layer is formed as the Al-Fe alloy layer.

[0117] The thickness of the Al-Fe alloy layer is, for example, 0 μm or more and 7 μm or less.

[0118] The thickness of the Al-Fe alloy layer is preferably 0.05 μm or more and 5 μm or less from the viewpoints of increasing the adhesion of the coating layer (specifically, Zn-Al-Mg alloy layer), and ensuring the corrosion resistance and formability.

[0119] Since the thickness of a Zn-Al-Mg alloy layer is normally larger than that of an Al-Fe alloy layer, the contribution of an Al-Fe alloy layer as a coated steel material to the corrosion resistance is small as compared with a Zn-Al-Mg alloy layer. However, an Al-Fe alloy layer contains Al and Zn, which are corrosion-resistant elements, at a certain concentration or more, as inferred from the results of a component analysis. Therefore, the Al-Fe alloy layer has a certain degree of corrosion resistance for a base steel.

[0120] Also, when a coating layer having the chemical composition specified in the disclosure is formed by a hot dip metal coating method, an Al-Fe alloy layer having a thickness of 100 nm or more is apt to be formed between the base steel and the Zn-Al-Mg alloy layer.

[0121] From the viewpoint of corrosion resistance, it is more preferable that the Al-Fe alloy layer is thicker. Therefore, the thickness of the Al-Fe alloy layer is preferably 0.05 μm or more. However, since a thick Al-Fe alloy layer causes significant deterioration in formability, the thickness of the Al-Fe alloy layer is preferably 7 μm or less. When the thickness of the Al-Fe alloy layer is 7 μm or less, cracks generated from the Al-Fe alloy layer and the amount of powdering are reduced and the formability is improved. The thickness of the Al-Fe alloy layer is more preferably 5 μm or less and still more preferably 2 μm or less.

[0122] The thickness of the Al-Fe alloy layer is measured as follows.

[0123] The thickness of an identified Al-Fe alloy layer is measured at optional 5 positions in an SEM backscattered electron image (magnification: 10000 x, visual field size: 50 μm in width × 200 μm in length, provided that an Al-Fe alloy layer is visible in the visual field) of a cross section of a coating layer (a cross section cut along the coate thickness direction of the coating layer) prepared by embedding a sample in a resin and then polishing the same. The arithmetic average of the five positions is defined as the thickness of the Al-Fe alloy layer.

[0124] Regarding the thickness of the coating layer, the thickness thereof is also measured at optional five positions in the SEM backscattered electron image (magnification: 500 x, visual field size: 198 μm in width × 244 μm in length, provided that the entire coating layer is visible in the visual field) of the cross section. The arithmetic average of the five positions is defined as the thickness of the coating layer.

(method for Manufacturing coated steel material)

[0125] Hereinafter, an example of a method for manufacturing a coated steel material according to the disclosure will be described.

[0126] A coated steel material of the disclosure is obtained by forming a coating layer having the above-specified chemical composition and metal structure on the surface(s) (namely, on one side, or both sides) of a base steel (such as a base steel sheet) by a hot dip metal coating method.

[0127] Specifically, for example, hot dip metal coating is performed under the following conditions. Hereinafter, a method for manufacturing a coated steel sheet will be described as an example of the method for manufacturing a coated steel material of the disclosure.

[0128] First, a base steel sheet as the base steel is immersed in a hot-dip coating bath and pulled up from the hot-dip coating bath, and then cooled down in a temperature range of from 450°C to 395°C at an average cooling rate of 15°C/s or less.

[0129] Next, cooling down is performed in a temperature range of from 395°C to 340°C at an average cooling rate of 3°C/s or less.

[0130] Next, cooling down is performed in a temperature range of from 340°C to 280°C at an average cooling rate of from 10°C/s to 20°C/s or more.

[0131] Here, for coating, for example, a continuous hot dip metal coating method such as a Sendzimir method is carried out.

[0132] Then, after cooling, skin pass rolling is performed under conditions that a surface roughness Ra of a skin pass roll is from 1 to 5 μm and a skin pass rolling force is from 100 to 500 ton.

[0133] Here, the coating layer solidifies in the order of Al phase, a $MgZn_2$ phase crystallized around Al phase, and a Zn/Al/$MgZn_2$ ternary eutectic.

[0134] Therefore, Al phase are grown by performing cooling down in a temperature range of from 450°C to 395°C at an average cooling rate of 15°C/s or less. When cooling down is performed in the temperature range of from 395°C to 340°C at an average cooling rate of 3°C/s or less, $MgZn_2$ phase are reliably crystallized around the Al phase. By doing so, the Zn/Al/$MgZn_2$ ternary eutectics can be refined.

[0135] The upper limit of the average cooling rate in the temperature range of from 450°C to 395°C is 15°C/s, preferably

13°C/s, and more preferably 11°C/s.

[0136] The lower limit is not particularly limited, and is preferably 1°C/s, more preferably 2°C/s or more from the viewpoint of productivity.

[0137] When the average cooling rate in the temperature range of from 450°C to 395°C is more than 15°C/s, the Al phase are excessively finely crystallized, and the Zn/Al/$MgZn_2$ ternary eutectics are also excessively refined. This makes it difficult to form a Mg enrichment layer by skin pass rolling described below.

[0138] The upper limit of the average cooling rate in the temperature range of from 395°C to 340°C is 3°C/s, and preferably 2.5°C/s.

[0139] The lower limit is not particularly limited, and is preferably 0.5°C/s, more preferably 1°C/s or more from the viewpoint of productivity.

[0140] When the average cooling rate in the temperature range of 395°C to 340°C is more than 3°C/s, $MgZn_2$ phase around the Al crystal cannot be sufficiently grown, and the refinement of the Zn/Al/$MgZn_2$ ternary eutectics becomes insufficient.

[0141] As a result, it is difficult to form a Mg enrichment layer by skin pass rolling described below.

[0142] Next, when cooling down is performed in the temperature range of from 340°C to 280°C at an average cooling rate of 10°C/s or more, the Zn/Al/$MgZn_2$ ternary eutectics are refined. This makes it easier to form a Mg enrichment layer by skin pass rolling described below.

[0143] However, when the average cooling rate in the temperature range of from 340°C to 280°C is more than 20°C/s, the Zn/Al/$MgZn_2$ ternary eutectics is excessively refined, and it is difficult to form a Mg enrichment layer by skin pass rolling described below.

[0144] The average cooling rate in the temperature range of lower than 280°C is not limited. For example, furnace cooling may be used, or heat retention may be performed by adjusting the properties of a steel material. In addition, water cooling may be performed by mist cooling or the like. The average cooling rate in the method as exemplified here is, for example, 50°C/sec or less.

[0145] Next, after cooling, when skin pass rolling is performed under the conditions that the surface roughness Ra of the skin pass roll is 1 μm or more and the skin pass rolling force is 100 ton or more, soft Mg-containing phase (such as Zn/Al/$MgZn_2$ ternary eutectics) present on a surface layer of the Zn-Al-Mg alloy layer are extended, and the Mg enrichment layer is formed.

[0146] However, when the surface roughness Ra of the skin pass roll is more than 5 μm, a surface area of the coating layer surface increases, and therefore, the Mg enrichment layer is excessively thickened, and discoloration resistance deteriorates. Meanwhile, when the surface roughness Ra of the skin pass roll is less than 1 μm, the base steel sheet slips during the skin pass rolling, and uniform rolling cannot be performed, and corrosion resistance and discoloration resistance cannot be secured.

[0147] In addition, when the skin pass rolling force is more than 500 ton, soft Mg-containing phase (such as Zn/Al/$MgZn_2$ ternary eutectics) excessively extend, and therefore, the Mg enrichment layer is difficult to be thickened, and corrosion resistance deteriorates. However, even when the skin pass rolling force is less than 100 ton, the Mg enrichment layer is difficult to be thickened, and corrosion resistance deteriorates.

[0148] When the surface roughness Ra of the skin pass roll increases within an appropriate range of the skin pass rolling force, the point (B) in Fig. 1 tends to move to the right side, and the thickness of the Mg enrichment layer increases.

[0149] The surface roughness Ra of the skin pass roll is measured as follows. Roughness is measured at three positions on the surface of the skin pass roll in the width direction of the roll with a stylus-type portable roughness meter, and an average value thereof is obtained.

[0150] A post-treatment applicable to a coated steel material of this disclosure will be described below.

[0151] A film may be formed on the coating layer of a coated steel material of this disclosure. The film may be constituted with a single layer, or two or more layers. Examples of the kind of the film directly on the coating layer include a chromate film, a phosphate film, and a chromate-free film. A chromate treatment, a phosphate treatment, or a chromate-free treatment for forming the film may be performed by a known method.

[0152] The chromate treatment includes an electrolytic chromate treatment, by which a chromate film is formed by electrolysis; a reactive chromate treatment, by which a film is formed utilizing a reaction with a material, and then an excess treatment solution is washed out; and a painting type chromate treatment, by which a treatment solution is applied to an object, and then dried without washing with water to form a film. Any treatment may be adopted.

[0153] Examples of the electrolytic chromate treatment include those using chromic acid, silica sol, a resin (such as an acrylic resin, a vinyl ester resin, a vinyl acetate/acrylic emulsion, a carboxylated styrene butadiene latex, a diisopropanolamine-modified epoxy resin), or hard silica.

[0154] Examples of the phosphate treatment include a zinc phosphate treatment, a zinc calcium phosphate treatment, and a manganese phosphate treatment.

[0155] The chromate-free treatment is particularly preferable because it does not impose a burden on an environment. The chromate-free treatment includes an electrolytic chromate-free treatment, by which a chromate-free film is formed by electrolysis; a reactive chromate-free treatment, by which a film is formed utilizing a reaction with a material, and then an excess treatment solution is washed out; and a painting type chromate-free treatment, by which a treatment solution is applied to an object, and then dried without washing with water to form a film. Any treatment may be adopted.

[0156] Furthermore, one layer, or two or more layers of an organic resin film may be provided on the film directly on the coating layer. There is no particular restriction on the kind of the organic resin, and examples thereof include a polyester resin, a polyurethane resin, an epoxy resin, an acrylic resin, and a polyolefin resin, as well as modified products of these resins. In this regard, the modified product refers to a resin in which a reactive functional group included in the structure of these resins is reacted with another compound (such as a monomer, or a crosslinking agent) having in its structure a functional group capable of reacting with the former functional group.

[0157] As such an organic resin, one kind, or a mixture of two or more kinds of (unmodified) organic resins may be used; or one kind, or a mixture of two or more kinds of organic resins obtained by modifying at least one kind of organic resin in the presence of at least one kind of another organic resin may be used. Further, the organic resin film may contain an optional color pigment or rust preventive pigment. A water-based form prepared through dissolution or dispersion in water may also be used.

Examples

(Examples)

[0158] In order to obtain a coating layer having a chemical composition shown in Tables 1 and 2, an ingot was melted in a vacuum melting furnace using a predetermined amount of pure metal ingot, and then a hot-dip coating bath was prepared in the air. A hot dip metal coating simulator was used for preparing the coated steel sheet.

[0159] As the base steel material, a general hot-rolled steel sheet (C concentration < 0.1%) having a sheet thickness of 2.3 mm was used. After a surface to be coated of the base steel was brush-polished, degreasing and pickling were performed immediately before a coating step.

[0160] In addition, in some examples, as the base steel, a Ni precoated steel material prepared by applying Ni precoating to general hot-rolled steel sheet having a sheet thickness of 2.3 mm was used. The deposited amount of Ni was set at from 1 g/m^2 to 3 g/m^2. In this regard, with respect to an example in which a Ni precoated steel material was used as the base steel, a remark of "Ni precoated" was entered in the column of "Base steel" in the Tables.

[0161] A contact type K thermocouple was attached to a back surface of the surface to be coated of the base steel in order to monitor the temperature of the steel product in a coated steel sheet preparing process.

[0162] In any sample preparation, the same reduction treatment method was applied to the base steel up to a step of immersion in the hot-dip coating bath. In other words, the base steel was heated from room temperature to 800°C by electric heating in a N_2-H_2 (5%) environment (dew point of -40°C or less, oxygen concentration of less than 25 ppm), retained there for 60 sec, cooled to the hot-dip coating bath temperature +10°C by N_2 gas blow, and then immediately immersed in the hot-dip coating bath.

[0163] In any of the coated steel sheets, the immersion time in the hot-dip coating bath was set to the time in the table. The N_2 gas wiping pressure was adjusted and a coated steel sheet was prepared such that a coating thickness was 30 μm (±1 μm).

[0164] The hot-dip coating bath temperature was 500°C. The immersion time in the hot-dip coating bath was 2 seconds.

[0165] The base steel was pulled up from the hot-dip coating bath, and then subjected to a cooling process under the conditions set forth in Table 1 or 2 with respect to the following average cooling rates at the first to third stages as itemized in Table 1 or 2 to obtain a coating layer.

· Average cooling rate at first stage: Average cooling rate in the temperature range of from 450°C to 395°C
· Average cooling rate at second stage: Average cooling rate in the temperature range of from 395°C to 340°C
· Average cooling rate at third stage: Average cooling rate in the temperature range of from 340°C to 280°C

In the cooling process, the steel product was cooled down by spraying N_2 gas onto the steel product after being coated. In this case, cooling was performed while adjusting a spraying amount of the N_2 gas so as to achieve a predetermined cooling rate in the above temperature range.

-Various Measurements-

[0166] A sample was cut out from an obtained coated steel sheet. The following items were measured according to the method described above.

· Thickness of coating layer
· Thickness of Mg enrichment layer

· Thickness of Al-Fe alloy layer (thickness of Al-Ni-Fe alloy layer, in an example in which a Ni precoated steel sheet was used as the base steel)
· A total area ratio of Al phase, $MgZn_2$ phase, and Zn/Al/$MgZn_2$ ternary eutectics in Zn-Al-Mg alloy layer (in Tables, referred to as specific structure area ratio)

-Corrosion Resistance-

[0167] A sample was cut out from an obtained coated steel sheet. Then, the samples were placed vertically, and 21 cycles of a combined cycle corrosion test (CCT) in accordance with the corrosion acceleration test (JASO M609-91) were conducted. After performing the corrosion test, the case where the corrosion loss was 20 g/m^2 or less was evaluated as "A", and the case where the corrosion loss was more than 20 g/m^2 was evaluated as "NG".

-Formability -

[0168] A sample was cut out from an obtained coated steel sheet. After bending the sample by 1 T, tape was exfoliated from the processed portion, and an area ratio of the coating layer attached to the tape was evaluated. An area ratio of the deposited coating layer of 5% or less was evaluated as "A", and an area ratio of more than 5% was evaluated as "NG".

-Discoloration Resistance -

[0169] A sample was cut out from an obtained coated steel sheet. Then, the sample was placed at an angle of 60° with respect to the horizontal direction on a constant temperature and humidity tester (KCL-2000 manufactured by EYELA) at 50°C and 80%RH, and a color difference ΔE after 3 days was evaluated. With respect to the color difference, before and after the test, the L value, a* value, and b* value of the sample in a SCE (specular light removal) method were measured with a colorimeter (CR-400 manufactured by Konica Minolta Optics), and the color difference ΔE was investigated at 4 points to determine an average value thereof.
[0170] A case where the average value of the color differences ΔE after three days was 10 or less was evaluated as "A", and a case where the average value was more than 10 was evaluated as "NG".
[0171] Examples are listed in Tables 1 and 2.

[Table 1-1]

[0172]

Table 1-1

No.	Class	Base steel	Coating cooling			Skin pass rolling	
			Average cooling rate at first stage	Average cooling rate at second stage	Average cooling rate at third stage	Roll surface roughness Ra	Rolling force
		-	(°C/s)	(°C/s)	(°C/s)	(μm)	(ton)
1	Example	-	9	2	15	3	300
2	Example	-	9	2	15	3	300
3	Example	-	9	2	15	3	300
4	Example	-	9	2	15	3	300
5	Example	-	9	2	15	3	300
6	Example	-	9	2	15	3	300
7	Example	-	9	2	15	3	300
8	Example	-	9	2	15	3	300
9	Example	-	9	2	15	3	300
10	Example	-	9	2	15	3	300
11	Example	-	9	2	15	3	300
12	Example	-	9	2	15	3	300

(continued)

No.	Class	Base steel	Coating cooling			Skin pass rolling	
			Average cooling rate at first stage	Average cooling rate at second stage	Average cooling rate at third stage	Roll surface roughness Ra	Rolling force
		-	(°C/s)	(°C/s)	(°C/s)	(μm)	(ton)
13	Example	-	9	2	15	3	300
14	Example	-	9	2	15	3	300
15	Example	-	9	2	15	3	300
16	Example	-	9	2	15	3	300
17	Example	-	9	2	15	3	300
18	Example	-	9	2	15	3	300
19	Example	-	9	2	15	3	300
20	Example	-	9	2	15	3	300
21	Example	-	9	2	15	3	300
22	Example	-	9	2	15	3	300
23	Example	-	9	2	15	3	300
24	Example	-	9	2	15	3	300
25	Example	-	9	2	15	3	300
26	Example	-	9	2	15	3	300
27	Example	-	9	2	15	3	300
28	Example	-	9	2	15	3	300
29	Example	-	9	2	15	3	300
30	Example	-	9	2	15	3	300
31	Example	-	9	2	15	3	300
32	Example	-	9	2	15	3	300
33	Example	-	9	2	15	3	300
34	Example	-	9	2	15	3	300
35	Example	-	9	2	15	3	300
36	Example	-	9	2	15	3	300
37	Example	-	9	2	15	3	300
38	Example	-	9	2	15	3	300
39	Example	-	9	2	15	3	300
40	Example	-	9	2	15	3	300
41	Example	-	9	2	15	3	300
42	Example	-	9	2	15	3	300
43	Example	-	9	2	15	3	300
44	Example	-	9	2	15	3	300
45	Example	-	9	2	15	3	300
46	Example	-	9	2	15	3	300
47	Example	-	9	2	15	3	300
48	Example	-	9	2	15	3	300

(continued)

No.	Class	Base steel	Coating cooling			Skin pass rolling	
			Average cooling rate at first stage	Average cooling rate at second stage	Average cooling rate at third stage	Roll surface roughness Ra	Rolling force
		-	(°C/s)	(°C/s)	(°C/s)	(μm)	(ton)
49	Example	-	9	2	15	3	300
50	Example	-	9	2	15	3	300
51	Example	-	15	2	15	3	300
52	Example	-	9	3	15	3	300
53	Example	-	9	2	10	3	300
54	Example	-	9	2	20	3	300
55	Example	-	9	2	15	1	300
56	Example	-	9	2	15	5	300
57	Example	-	9	2	15	3	100
58	Example	-	9	2	15	3	500
59	Example	-	9	2	15	3	300
60	Example	-	9	2	15	3	300
61	Example	Pre-Ni	9	2	15	3	300
62	Example	Pre-Ni	9	2	15	3	300
63	Example	Pre-Ni	9	2	15	3	300
64	Example	Pre-Ni	9	2	15	3	300

[Table 1-2]

[0173]

Table 1-2

No.	Class	Composition of coating layer (mass%)																	
		Zn	Al	Mg	Sn	Bi	In	Ca	Y	La	Ce	Si	Cr	Ti	Zr	Mo	W	Ag	P
1	Example	88.40	5.50	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Example	88.32	5.50	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Example	69.32	24.50	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Example	76.32	20.00	3.50	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Example	67.82	20.00	12.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Example	73.50	20.00	6.00	0.10	0.00	0.00	0.20	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Example	73.70	20.00	6.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Example	73.50	20.00	6.00	0.20	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Example	73.50	20.00	6.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Example	73.40	20.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Example	72.87	20.00	6.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Example	72.04	20.00	6.00	0.06	0.00	0.00	0.30	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Example	73.75	20.00	6.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Example	73.62	20.00	6.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Example	73.30	20.00	6.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Example	72.90	20.00	6.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Example	83.93	10.00	4.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Example	69.30	20.00	6.00	0.10	4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Example	72.30	20.00	6.00	0.10	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	Example	73.70	20.00	6.00	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	Example	73.30	20.00	6.00	0.10	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Example	72.80	20.00	6.00	0.10	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Example	70.80	20.00	6.00	0.10	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(continued)

No.	Class	Composition of coating layer (mass%)																	
		Zn	Al	Mg	Sn	Bi	In	Ca	Y	La	Ce	Si	Cr	Ti	Zr	Mo	W	Ag	P
25	Example	73.30	20.00	6.00	0.10	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Example	73.40	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Example	73.40	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Example	71.50	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
30	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
31	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
32	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
33	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00
34	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00
35	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
36	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	Example	73.60	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	Example	68.90	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	Example	68.90	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	Example	73.40	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	Example	73.40	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	Example	73.40	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(continued)

No.	Class	Composition of coating layer (mass%)																	
		Zn	Al	Mg	Sn	Bi	In	Ca	Y	La	Ce	Si	Cr	Ti	Zr	Mo	W	Ag	P
50	Example	73.40	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
51	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	Example	73.80	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	Example	73.76	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	Example	73.77	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	Example	73.76	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	Example	73.77	20.00	6.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[Table 1-3]

[0174]

Table 1-3

No.	Class	Composition of coating layer (mass%)													
		Ni	Co	v	Nb	Cu	Mn	Li	Na	K	Fe	Sr	Sb	Pb	B
1	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
2	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
3	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
4	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
5	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
6	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
7	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
8	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
9	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
10	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
11	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
12	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
13	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
14	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
15	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
16	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
17	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
18	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
19	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
20	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
21	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
22	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
23	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
24	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
25	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
26	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
27	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
28	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
29	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
30	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
31	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
32	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
33	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
34	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
35	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00

(continued)

No.	Class	Composition of coating layer (mass%)													
		Ni	Co	v	Nb	Cu	Mn	Li	Na	K	Fe	Sr	Sb	Pb	B
36	Example	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
37	Example	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
38	Example	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
39	Example	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
40	Example	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
41	Example	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
42	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.10	0.00	0.00	0.00	0.00
43	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.00	0.00	0.00	0.00
44	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.10	0.00	0.00	0.00	0.00
45	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00
46	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00
47	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.40	0.00	0.00	0.00
48	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.40	0.00	0.00
49	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.40	0.00
50	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.40
51	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
52	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
53	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
54	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
55	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
56	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
57	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
58	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
59	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
60	Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
61	Example	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
62	Example	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
63	Example	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
64	Example	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00

[Table 1-4]

[0175]

Table 1-4

No.	Class	Thickness of coating layer (μm)	Thickness of Mg enrichment layer (μm)	Thickness of Al-Fe alloy layer (μm)	Specific structure area ratio (%)	Corrosion resistance	formability	Discoloration resistance
1	Example	20	5	1	99	A	A	A
2	Example	20	5	1	97	A	A	A
3	Example	20	5	1	97	A	A	A
4	Example	20	5	1	97	A	A	A
5	Example	20	5	1	98	A	A	A
6	Example	20	5	1	97	A	A	A
7	Example	20	5	1	95	A	A	A
8	Example	20	5	1	97	A	A	A
9	Example	20	5	1	96	A	A	A
10	Example	20	5	1	95	A	A	A
11	Example	20	5	1	94	A	A	A
12	Example	20	5	1	92	A	A	A
13	Example	20	5	1	93	A	A	A
14	Example	20	5	1	96	A	A	A
15	Example	20	5	1	96	A	A	A
16	Example	20	5	1	95	A	A	A
17	Example	20	5	1	94	A	A	A
18	Example	20	5	1	94	A	A	A
19	Example	20	5	1	92	A	A	A
20	Example	20	5	1	93	A	A	A
21	Example	20	5	1	95	A	A	A
22	Example	20	5	1	93	A	A	A
23	Example	20	5	1	92	A	A	A
24	Example	20	5	1	90	A	A	A
25	Example	20	5	1	96	A	A	A
26	Example	20	5	1	96	A	A	A
27	Example	20	5	1	95	A	A	A
28	Example	20	5	1	91	A	A	A
29	Example	20	5	1	96	A	A	A
30	Example	20	5	1	96	A	A	A
31	Example	20	5	1	96	A	A	A
32	Example	20	5	1	96	A	A	A
33	Example	20	5	1	96	A	A	A
34	Example	20	5	1	96	A	A	A
35	Example	20	5	1	96	A	A	A
36	Example	20	5	1	96	A	A	A

(continued)

No.	Class	Thickness of coating layer (μm)	Thickness of Mg enrichment layer (μm)	Thickness of Al-Fe alloy layer (μm)	Specific structure area ratio (%)	Corrosion resistance	formability	Discoloration resistance
37	Example	20	5	1	96	A	A	A
38	Example	20	5	1	96	A	A	A
39	Example	20	5	1	96	A	A	A
40	Example	20	5	1	96	A	A	A
41	Example	20	5	1	96	A	A	A
42	Example	20	5	1	96	A	A	A
43	Example	20	5	1	96	A	A	A
44	Example	20	5	1	96	A	A	A
45	Example	20	5	5	97	A	A	A
46	Example	20	5	4	97	A	A	A
47	Example	20	5	1	96	A	A	A
48	Example	20	5	1	96	A	A	A
49	Example	20	5	1	96	A	A	A
50	Example	20	5	1	96	A	A	A
51	Example	20	0.8	1	97	A	A	A
52	Example	20	4	1	97	A	A	A
53	Example	20	4	1	97	A	A	A
54	Example	20	2	1	97	A	A	A
55	Example	20	1.5	1	97	A	A	A
56	Example	20	6	1	97	A	A	A
57	Example	20	6	1	97	A	A	A
58	Example	20	2	1	97	A	A	A
59	Example	50	5	1	97	A	A	A
60	Example	10	5	1	97	A	A	A
61	Example	30	5	1	97	A	A	A
62	Example	10	5	1	97	A	A	A
63	Example	20	5	1	97	A	A	A
64	Example	20	5	1	97	A	A	A

[Table 2-1]

[0176]

Table 2-1

No.	Class	Base steel	Coating cooling			Skin pass rolling	
			Average cooling rate at first stage	Average cooling rate at second stage	Average cooling rate at third stage	Roll surface roughness Ra	Rolling force
		-	(°C/s)	(°C/s)	(°C/s)	(μm)	(ton)
65	Comparative Example	-	9	2	15	3	300
66	Comparative Example	-	9	2	15	3	300
67	Comparative Example	-	9	2	15	3	300
68	Comparative Example	-	9	2	15	3	300
69	Comparative Example	-	9	2	15	3	300
70	Comparative Example	-	9	2	15	3	300
71	Comparative Example	-	9	2	15	3	300
72	Comparative Example	-	9	2	15	3	300
73	Comparative Example	-	9	2	15	3	300
74	Comparative Example	-	9	2	15	3	300
75	Comparative Example	-	9	2	15	3	300
76	Comparative Example	-	9	2	15	3	300
77	Comparative Example	-	9	2	15	3	300
78	Comparative Example	-	9	2	15	3	300
79	Comparative Example	-	9	2	15	3	300
80	Comparative Example	-	9	2	15	3	300
81	Comparative Example	-	9	2	15	3	300
82	Comparative Example	-	9	2	15	3	300
83	Comparative Example	-	9	2	15	3	300
84	Comparative Example	-	9	2	15	3	300
85	Comparative Example	-	9	2	15	3	300
86	Comparative Example	-	9	2	15	3	300
87	Comparative Example	-	9	2	15	3	300
88	Comparative Example	-	9	2	15	3	300
89	Comparative Example	-	9	2	15	3	300
90	Comparative Example	-	9	2	15	3	300
91	Comparative Example	-	9	2	15	3	300
92	Comparative Example	-	9	2	15	3	300
93	Comparative Example	-	9	2	15	3	300
94	Comparative Example	-	9	2	15	3	300
95	Comparative Example	-	9	2	15	3	300
96	Comparative Example	-	9	2	15	3	300
97	Comparative Example	-	9	2	15	3	300
98	Comparative Example	-	9	2	15	3	300
99	Comparative Example	-	<u>**18**</u>	2	15	3	300

(continued)

No.	Class	Base steel	Coating cooling			Skin pass rolling	
			Average cooling rate at first stage	Average cooling rate at second stage	Average cooling rate at third stage	Roll surface roughness Ra	Rolling force
		-	(°C/s)	(°C/s)	(°C/s)	(μm)	(ton)
100	Comparative Example	-	9	**5**	15	3	300
101	Comparative Example	-	9	2	**25**	3	300
102	Comparative Example	-	9	2	15	**8**	300
103	Comparative Example	-	9	2	15	**0.5**	300
104	Comparative Example	-	9	2	15	3	**50**
105	Comparative Example	-	9	2	15	3	**700**
106	Comparative Example	-	9	2	**7**	3	300
107	Comparative Example	-	9	2	15	3	300

[Table 2-2]

Table 2-2

No.	Class	Composition of coating layer (mass%)																	
		Zn	Al	Mg	Sn	Bi	In	Ca	Y	La	Ce	Si	Cr	Ti	Zr	Mo	W	Ag	P
65	Comparative Example	**63.90**	24.00	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	Comparative Example	89.40	**4.50**	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67	Comparative Example	67.90	**26.00**	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
68	Comparative Example	77.40	20.00	**2.50**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
69	Comparative Example	66.90	20.00	**13.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	Comparative Example	70.40	20.00	6.00	**3.50**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	Comparative Example	68.82	20.00	6.00	0.08	**5.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72	Comparative Example	71.82	20.00	6.00	0.08	0.00	**2.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
73	Comparative Example	70.32	20.00	6.00	0.08	0.00	0.00	**3.50**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74	Comparative Example	73.22	20.00	6.00	0.08	0.00	0.00	0.00	**0.60**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	Comparative Example	73.22	20.00	6.00	0.08	0.00	0.00	0.00	0.00	**0.60**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
76	Comparative Example	73.22	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	**0.60**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	Comparative Example	71.12	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	**2.70**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00	0.00	0.00	0.00
79	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00	0.00	0.00
80	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00	0.00
81	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00
82	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00
83	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00
84	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**
85	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
86	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
89	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(continued)

No.	Class	Composition of coating layer (mass%)																	
		Zn	Al	Mg	Sn	Bi	In	Ca	Y	La	Ce	Si	Cr	Ti	Zr	Mo	W	Ag	P
90	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
91	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
92	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	Comparative Example	73.52	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94	Comparative Example	66.92	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	Comparative Example	73.32	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	Comparative Example	73.32	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
97	Comparative Example	73.32	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	Comparative Example	73.22	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
101	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
102	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
103	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	Comparative Example	73.82	20.00	6.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
107	Comparative Example	95.00	**2.00**	**2.90**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[Table 2-3]

[0178]

Table 2-3

No.	Class	Composition of coating layer (mass%)													
		Ni	Co	v	Nb	Cu	Mn	Li	Na	K	Fe	Sr	Sb	Pb	B
65	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
66	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
67	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
68	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
69	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
70	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
71	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
72	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
73	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
74	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
75	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
76	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
77	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
78	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
79	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
80	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
81	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
82	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
83	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
84	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
85	Comparative Example	**0.30**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
86	Comparative Example	0.00	**0.30**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
87	Comparative Example	0.00	0.00	**0.30**	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
88	Comparative Example	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00

(continued)

No.	Class	Composition of coating layer (mass%)													
		Ni	Co	v	Nb	Cu	Mn	Li	Na	K	Fe	Sr	Sb	Pb	B
89	Comparative Example	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
90	Comparative Example	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
91	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.00	0.10	0.00	0.00	0.00	0.00
92	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.00	0.10	0.00	0.00	0.00	0.00
93	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.30**	0.10	0.00	0.00	0.00	0.00
94	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**7.00**	0.00	0.00	0.00	0.00
95	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.60**	0.00	0.00	0.00
96	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.60**	0.00	0.00
97	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.60**	0.00
98	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	**0.60**
99	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
100	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
101	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
102	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
103	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
104	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
105	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
106	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
107	Comparative Example	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00

[Table 2-4]

[0179]

Table 2-4

No.	Class	Thickness of coating layer (μm)	Thickness of Mg enrichment layer (μm)	Thickness of Al-Fe alloy layer (μm)	Specific structure area ratio (%)	Corrosion resistance	Formability	Discoloration resistance
65	Comparative Example	20	5	1	92	NG	A	A
66	Comparative Example	20	5	1	60	NG	NG	A
67	Comparative Example	20	5	1	97	NG	A	A
68	Comparative Example	20	0	1	91	NG	A	A
69	Comparative Example	20	5	1	96	A	NG	A
70	Comparative Example	20	5	1	89	NG	A	NG
71	Comparative Example	20	5	1	88	NG	A	A
72	Comparative Example	20	5	1	92	NG	A	A
73	Comparative Example	20	5	1	89	NG	NG	A
74	Comparative Example	20	5	1	94	NG	A	A
75	Comparative Example	20	5	1	94	NG	A	A
76	Comparative Example	20	5	1	94	NG	A	A
77	Comparative Example	20	5	1	87	NG	NG	A
78	Comparative Example	20	5	1	94	NG	A	A
79	Comparative Example	20	5	1	94	NG	A	A
80	Comparative Example	20	5	1	94	NG	A	A
81	Comparative Example	20	5	1	94	NG	A	A
82	Comparative Example	20	5	1	94	NG	A	A
83	Comparative Example	20	5	1	94	NG	A	A

(continued)

No.	Class	Thickness of coating layer	Thickness of Mg enrichment layer	Thickness of Al-Fe alloy layer	Specific structure area ratio	Corrosion resistance	Formability	Discoloration resistance
		(μm)	(μm)	(μm)	(%)			
84	Comparative Example	20	5	1	94	NG	A	A
85	Comparative Example	20	5	1	94	NG	A	A
86	Comparative Example	20	5	1	94	NG	A	A
87	Comparative Example	20	5	1	94	NG	A	A
88	Comparative Example	20	5	1	94	NG	A	A
89	Comparative Example	20	5	1	94	NG	A	A
90	Comparative Example	20	5	1	94	NG	A	A
91	Comparative Example	20	5	1	94	NG	A	A
92	Comparative Example	20	5	1	94	NG	A	A
93	Comparative Example	20	5	1	94	NG	A	A
94	Comparative Example	20	5	8	94	NG	NG	A
95	Comparative Example	20	5	1	94	NG	A	A
96	Comparative Example	20	5	1	94	NG	A	A
97	Comparative Example	20	5	1	94	NG	A	A
98	Comparative Example	20	5	1	94	NG	A	A
99	Comparative Example	20	0	1	97	NG	A	A
100	Comparative Example	20	0.5	1	97	NG	A	A
101	Comparative Example	20	0	1	97	NG	A	A
102	Comparative Example	20	11	1	97	A	A	NG
103	Comparative Example	-	-	-	97	NG	A	NG
104	Comparative Example	20	0.3	1	97	NG	A	A

(continued)

No.	Class	Thickness of coating layer (μm)	Thickness of Mg enrichment layer (μm)	Thickness of Al-Fe alloy layer (μm)	Specific structure area ratio (%)	Corrosion resistance	Formability	Discoloration resistance
105	Comparative Example	20	0.6	1	97	NG	A	A
106	Comparative Example	20	0.6	1	97	NG	A	A
107	Comparative Example	20	0.8	1	55	NG	A	A

[0180] From the above results, Examples corresponding to a coated steel material of the disclosure exhibit more excellent corrosion resistance as compared to Comparative Examples, even in a coastal region in which the amount of airborne chlorides is large and the corrosion environment is severe. In addition, it can also be seen that formability and discoloration resistance are excellent.

[0181] In Test No. 103, since uniform rolling could not be performed and the variation in appearance was large, the thickness of various coating layers was not measured.

[0182] The preferred embodiments of the disclosure have been described in detail with reference to the accompanying drawings, but the disclosure is not limited to such examples. It is obvious that those skilled in the art to which this disclosure belongs can conceive of various changes or modifications within the scope of the technical concept described in the claims. It is obviously understood that these changes or modifications also fall within the technical scope of the disclosure.

[0183] The entire disclosure of Japanese Patent Application No. 2022-138732 is incorporated herein by reference.

[0184] All the literature, patent application, and technical standards cited herein are also herein incorporated to the same extent as provided for specifically and severally with respect to an individual literature, patent application, and technical standard to the effect that the same should be so incorporated by reference.

Claims

1. A coated steel material comprising a base steel and a coating layer including a Zn-Al-Mg alloy layer provided on a surface of the base steel and a Mg enrichment layer provided on a surface of the Zn-Al-Mg alloy layer, wherein the coating layer has a chemical composition composed of, in terms of % by mass:

Zn at more than 65.00%,
Al at more than 5.00% and less than 25.00%,
Mg at more than 3.00% and less than 12.50%,
Sn at from 0% to 3.00%,
Bi at from 0% to less than 5.00%,
In at from 0% to less than 2.00%,
Ca at from 0% to 3.00%,
Y at from 0% to 0.50%,
La at from 0% to less than 0.50%,
Ce at from 0% to less than 0.50%,
Si at from 0% to less than 2.5%,
Cr at from 0% to less than 0.25%,
Ti at from 0% to less than 0.25%,
Zr at from 0% to less than 0.25%,
Mo at from 0% to less than 0.25%,
W at from 0% to less than 0.25%,
Ag at from 0% to less than 0.25%,
P at from 0% to less than 0.25%,
Ni at from 0% to less than 0.25%,
Co at from 0% to less than 0.25%

V at from 0% to less than 0.25%,
Nb at from 0% to less than 0.25%,
Cu at from 0% to less than 0.25%,
Mn at from 0% to less than 0.25%,
Li at from 0% to less than 0.25%,
Na at from 0% to less than 0.25%,
K at from 0% to less than 0.25%,
Fe at from 0% to 5.00%,
Sr at from 0% to less than 0.50%
Sb at from 0% to less than 0.50%
Pb at from 0% to less than 0.50%,
B at from 0% to less than 0.50%, and
impurities,
in the Zn-Al-Mg alloy layer, a total area ratio of Al phase, $MgZn_2$ phase, and Zn/Al/$MgZn_2$ ternary eutectics is 90% or more, and
a thickness of the Mg enrichment layer is 0.8 μm or more and (thickness of coating layer × 1/2) or less.

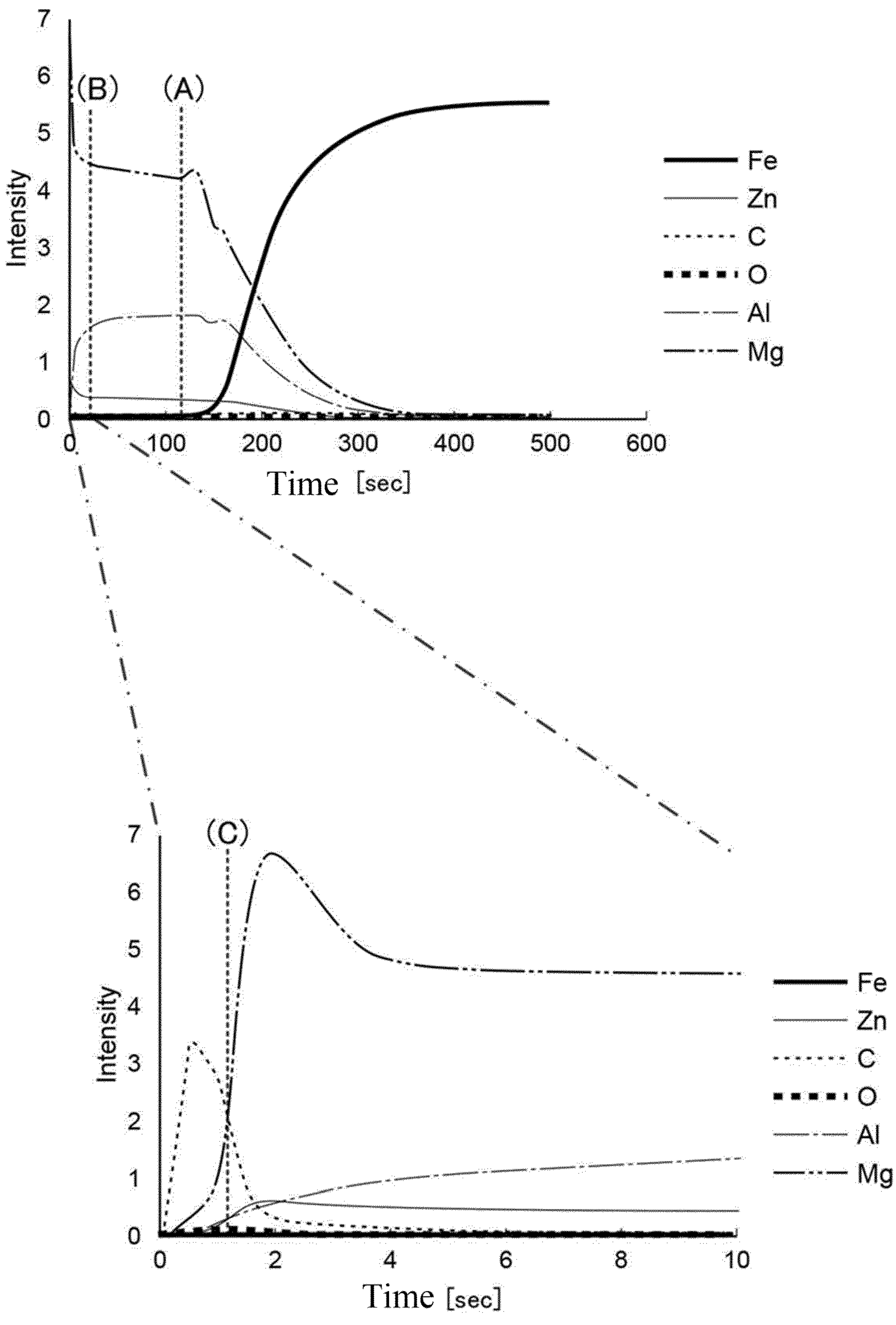
2. The coated steel material according to claim 1, wherein the coating layer has an Al-Fe alloy layer between the base steel and the Zn-Al-Mg alloy layer.

3. A method for manufacturing the coated steel material according to claim 1 or 2,

wherein a base steel is immersed in a hot-dip coating bath and pulled up from the hot-dip coating bath, and then cooled down in a temperature range of from 450°C to 395°C at an average cooling rate of 15°C/s or less, cooled down in a temperature range of from 395°C to 340°C at an average cooling rate of 3°C/s or less, and cooled down in a temperature range of from 340°C to 280°C at an average cooling rate of from 10 to 20°C/s or more, and after the cooling, subjected to skin pass rolling under conditions that a surface roughness Ra of a skin pass roll is from 1 to 5 μm and a skin pass rolling force is from 100 to 500 ton.

[Fig. 1]

FIG. 1


7
6
5
4
3
2
1
0
Intensity
(B)
(A)
0
100
200
300
400
500
600
Time [sec]
Fe
Zn
C
O
Al
Mg
(C)
0
2
4
6
8
10
Time [sec]

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/046531

A. CLASSIFICATION OF SUBJECT MATTER

C23C 2/06(2006.01)i; ***C22C 18/00***(2006.01)i; ***C22C 18/04***(2006.01)i; ***C23C 2/26***(2006.01)i
FI: C23C2/06; C22C18/04; C22C18/00; C23C2/26

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)

C23C2/06; C22C18/00; C22C18/04; C23C2/26

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 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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.
Y A	JP 2019-501296 A (POSCO) 17 January 2019 (2019-01-17) paragraphs [0006], [0016], [0025], [0030]-[0060], fig. 1	1-2 3
Y A	WO 2022/085386 A1 (NIPPON STEEL CORP) 28 April 2022 (2022-04-28) paragraphs [0025], [0035], [0047]-[0053], tables 1-1, 1-4	1-2 3
A	WO 2018/131171 A1 (NIPPON STEEL & SUMITOMO METAL CORP) 19 July 2018 (2018-07-19) table 1	1-3

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"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
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"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	Date of mailing of the international search report
17 February 2023	**07 March 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/046531

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2019-501296 A	17 January 2019	EP 3396004 A1 paragraphs [0006], [0017], [0027], [0033]-[0063], fig. 1A US 2019/0010595 A1 WO 2017/111400 A1 KR 10-2017-0076924 A CN 108474093 A ES 2893003 T	
WO 2022/085386 A1	28 April 2022	TW 202223117 A	
WO 2018/131171 A1	19 July 2018	US 2019/0368007 A1 table 1 JP 6176424 B1 EP 3569729 A1 AU 2017392662 A CN 110191973 A SG 11201906466X A KR 10-2019-0102239 A MX 2019008300 A BR 112019014494 A	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2001355053 A **[0008]**
- WO 2019221193 A **[0008]**
- JP 2022138732 A **[0183]**