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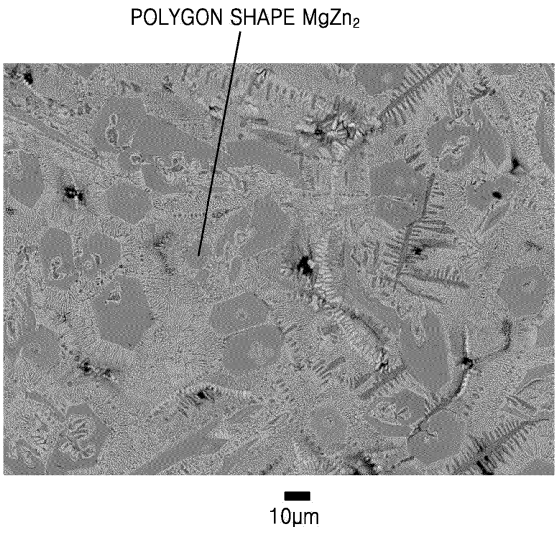
(54) METHOD FOR MANUFACTURING PLATED STEEL HAVING EXCELLENT PROCESSABILITY AND CORROSION RESISTANCE

(57) A method for manufacturing a plated steel having excellent processability and corrosion resistance according to one embodiment of the present invention comprises: a step for immersing an iron substrate in a molten alloy plating bath; and a step for forming a molten alloy plating layer on the iron substrate by withdrawing the immersed iron substrate from the molten alloy plating bath and performing a cooling process, wherein in the cooling process, a first average cooling rate varies depending on the difference between a first temperature, which is the temperature of the molten alloy plating bath, and a second temperature, which is the solidification initiation temperature of MgZn2 phases constituting the molten alloy plating layer.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a steel material, and more specifically, to a method of manufacturing a plated steel material having excellent workability and corrosion resistance.

BACKGROUND ART

[0002] Hot-dip zinc-plated steel sheets have excellent sacrificial corrosion resistance, and when exposed to a corrosive environment, zinc with a low potential is preferentially eluted to prevent corrosion of a steel material. Due to such excellent corrosion characteristics, the hot-dip zinc-plated steel sheets have been used as steel sheets for home appliances, construction materials, and automobiles. However, as the expectation and demand for corrosion resistance increase due to technological development and improvement in quality level, the need for development of products having better corrosion resistance than the hot-dip zinc-plated steel sheets of the related art has been increasing. In order to solve the above problem, since the early 2000s, highly corrosion-resistant plated steel sheets that improve corrosion resistance by adding aluminum (Al) and magnesium (Mg) to a zinc (Zn) plating bath have been produced in Europe and Japan. In addition to the sacrificial corrosion resistance of Zn, the highly corrosion-resistant plated steel sheet forms dense corrosion products in a corrosive environment as a result of the addition of Mg and Al to shield the steel material from an oxidizing atmosphere, thereby improving corrosion resistance. However, the Zn-Al-Mg plated steel sheet has excellent corrosion resistance, compared with the zinc-plated steel sheet, but has a disadvantage in that workability is deteriorated. The intermetallic compound of Zn-Al-Mg has high hardness and low crack resistance, and cracks cause problems of degrading appearance in a processing process or exposing the base steel material to lower corrosion resistance.

[0003] As the related prior art, there is Japanese Patent Application Publication No. 2005-105367

DETAILED DESCRIPTION

Technical Problem

[0004] A technical problem to be achieved by the present disclosure is to provide a method of manufacturing a plated steel material having excellent workability and corrosion resistance.

Technical Solution

[0005] A method of manufacturing a plated steel material having excellent workability and corrosion resistance according to an aspect of the present disclosure for addressing the above problems includes the steps of immersing a base steel in a hot-dip alloy plating bath; and forming a hot-dip alloy-plated layer on the base steel by drawing the immersed base steel from the hot-dip alloy plating bath and performing a cooling process. A first average cooling rate in the cooling process varies depending on a difference between a first temperature that is a temperature of the hot-dip alloy plating bath and a second temperature that is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer.

[0006] In the method as described herein, when the difference between the first temperature and the second temperature is less than 50 °C, the first average cooling rate may be 10 to 20 °C/s, when the difference between the first temperature and the second temperature is 50 °C or greater and less than 100 °C, the first average cooling rate may be 15 to 35 °C/s, and when the difference between the first temperature and the second temperature is 100 °C or greater, the first average cooling rate may be 20 to 50 °C/s.

[0007] In the method as described herein, the first average cooling rate may be an average cooling rate from a time point at which the immersed base steel is drawn from the hot-dip alloy plating bath to a time point at which the $MgZn_2$ phase starts to solidify.

[0008] In the method as described herein, a second average cooling rate in the cooling process from a time point at which the $MgZn_2$ phase starts to solidify to a time point at which the solidification is completed may satisfy a relationship of Formula 1 below.

<Formula 1>

$0.0114 \times T - 0.2841 \leq$ second average cooling rate $\leq 0.025 \times T + 10$ (T: solidification start temperature of $MgZn_2$ phase)

[0009] In the method as described herein, the hot-dip alloy plating bath may be a Zn plating bath including, by wt.%, 6 to 23% of Al, 3 to 7% of Mg, and inevitable impurities.

[0010] In the method as described herein, an area fraction of a $MgZn_2$ phase where a ratio of an average minor axis length (a) to an average major axis length (b) is 0.5 or less in the entire $MgZn_2$ phase on a surface of the hot-dip alloy-plated layer formed on the base steel may be 70% or less.

Advantageous Effects

[0011] According to the exemplary embodiment of the present disclosure, a method of manufacturing a plated steel material having excellent workability and corrosion resistance may be provided.

[0012] It should be noted that the scope of the present disclosure is not limited by these effects.

BRIEF DESCRIPTION OF DRAWINGS

[0013]

FIG. 1 is a photograph of a surface of a hot-dip alloy-plated layer according to Example 6 in Experimental Example.

FIG. 2 is a photograph of a surface of a hot-dip alloy-plated layer according to Comparative Example 1 in Experimental Example.

FIG. 3 is a 200-times magnified FE-SEM photograph of a processed part after evaluating 3T bending workability for the hot-dip alloy-plated layer according to Example 6 in Experimental Example.

FIG. 4 is a 200-times magnified FE-SEM photograph of a processed part after evaluating 3T bending workability for a hot-dip alloy-plated layer according to Comparative Example 4 in Experimental Example.

FIG. 5 is a 1000-times magnified FE-SEM photograph of a section of a hot-dip alloy-plated layer according to Example 3 in Experimental Example.

FIG. 6 is a 1000-times magnified FE-SEM photograph of a section of the hot-dip alloy-plated layer according to Comparative Example 4 in Experimental Example.

BEST MODE

[0014] A method of manufacturing a plated steel material having excellent workability and corrosion resistance according to an exemplary embodiment of the present invention will be described in detail. The terms used herein are terms appropriately selected in consideration of the functions in the present invention. Accordingly, the definitions of the terms should be made based on the contents throughout the present specification. Hereinafter, specific details of an ultra-high-strength, high-corrosion-resistant plated steel sheet having excellent elongation and a manufacturing method thereof will be provided.

[0015] A Zn-Al-Mg plated steel sheet has excellent corrosion resistance, compared with a zinc-plated steel sheet, but has a disadvantage in that workability is deteriorated. The intermetallic compound of Zn-Al-Mg has high hardness and low crack resistance, and cracks cause problems of degrading appearance during processing or exposing the base steel material to lower corrosion resistance during processing. $MgZn_2$ of intermetallic compounds has the highest hardness, and therefore, the technology of controlling a shape, a distribution and a size of the $MgZn_2$ phase is important.

[0016] The present disclosure aims to provide a method of manufacturing a Zn-Al-Mg-based high corrosion-resistant plated steel material including, by wt.%, 6 to 23% of Al, 3 to 7% of Mg, a balance of Zn and inevitable impurities, and to control the microstructure of the $MgZn_2$ phase with high hardness for improving workability and processing corrosion resistance.

[0017] A method of manufacturing a plated steel material having excellent workability and corrosion resistance according to an exemplary embodiment of the present disclosure includes the steps of immersing a base steel in a hot-dip alloy plating bath (S10); and forming a hot-dip alloy-plated layer on the base steel by drawing the immersed base steel from the hot-dip alloy plating bath and performing a cooling process (S20).

[0018] In the step of immersing the base steel (S10), the hot-dip alloy plating bath may be, for example, a Zn plating bath including, by wt.%, 6 to 23% of Al, 3 to 7% of Mg, and inevitable impurities. Furthermore, the hot-dip alloy plating bath may

further include, by wt.%, 0.05 to 10% of Fe, and greater than 0 and less than 1% of Si.

[0019] Mg and Al in the hot-dip alloy plating bath are ones of elements that improve corrosion resistance of the plated layer, and improve corrosion resistance by forming a corrosion product more densely. If Mg in the plating bath is less than 1.0 wt.%, the contribution to corrosion resistance is insignificant, and in the related art, Mg is used in an amount of less than 2.0 wt.% because of difficulty in production due to Mg oxide dross when the amount is greater than 2.0 wt.%. However, in the present disclosure, Mg in the plating bath is added in an amount of 3.0 wt.% or greater in order to achieve better corrosion resistance. As described above, when Mg is added in an amount greater than 3.0 wt.%, there is difficulty in production due to oxide dross. However, when Al is added in an amount of 6.0 wt.% or greater, dross caused by Mg oxidation in the hot-dip metal can be reduced. In addition, when Al is added, it can play a role of improving corrosion resistance by forming primary crystal Al and a ternary eutectic phase of Zn-Al-Mg. On the other hand, if Mg in the plating bath is added in an amount greater than 7.0 wt.%, the rod-shaped and acicular $MgZn_2$ or Al-including $MgZn_2$ phase in the plated layer grows in excess of 70% of an area fraction of the whole $MgZn_2$, and therefore, the workability of the plated layer is deteriorated, and cracks are generated in the plated layer during processing, thereby exposing the steel material or the Fe-Al-Zn interface alloying layer to lower the corrosion resistance. On the other hand, if Al in the plating bath is added in an amount greater than 23 wt.%, the discontinuous Fe-Al-Zn interface alloy layer between the steel material and the plated layer grows excessively due to rising melting point of the plating bath, resulting in poor interface adhesiveness during processing.

[0020] A shape and a fraction of the $MgZn_2$ phase can be closely controlled through cooling. In the method of manufacturing a plated steel material having excellent workability and corrosion resistance according to the exemplary embodiment of the present disclosure, in the step of forming a hot-dip alloy-plated layer (S20), a first average cooling rate in the cooling process varies depending on a difference between a first temperature that is a temperature of the hot-dip alloy plating bath and a second temperature that is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer. The first average cooling rate may be an average cooling rate from a time point at which the immersed base steel is drawn from the hot-dip alloy plating bath to a time point at which the $MgZn_2$ phase starts to solidify.

[0021] Specifically, when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is less than 50 °C, the first average cooling rate may be 10 to 20 °C/s. In this case, if the first average cooling rate is less than 10 °C/s, an Al phase, a Zn phase, etc., which are constituent phases other than the $MgZn_2$ phase, are coarsely crystallized to make it difficult to favorably control a fraction of a $MgZn_2$ area, and the plated layer in a liquid state may react with oxygen to act as a factor that impairs the appearance of the plated surface. On the other hand, if the first average cooling rate is greater than 20 °C/s, it may be difficult to form a coarse region of $MgZn_2$.

[0022] Meanwhile, when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is 50 °C or greater and less than 100 °C, the first average cooling rate may be 15 to 35 °C/s. In this case, if the first average cooling rate is less than 15 °C/s, an Al phase, a Zn phase, etc., which are constituent phases other than the $MgZn_2$ phase, are coarsely crystallized to make it difficult to favorably control a fraction of a $MgZn_2$ area, and the plated layer in a liquid state may react with oxygen to act as a factor that impairs the appearance of the plated surface. On the other hand, if the first average cooling rate is greater than 35 °C/s, it may be difficult to form a coarse region of $MgZn_2$.

[0023] In addition, when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is 100 °C or greater, the first average cooling rate may be 20 to 50 °C/s. In this case, if the first average cooling rate is less than 20 °C/s, an Al phase, a Zn phase, etc., which are constituent phases other than the $MgZn_2$ phase, are coarsely crystallized to make it difficult to favorably control a fraction of a $MgZn_2$ area, and the plated layer in a liquid state may react with oxygen to act as a factor that impairs the appearance of the plated surface. On the other hand, if the first average cooling rate is greater than 50 °C/s, it may be difficult to form a coarse region of $MgZn_2$.

[0024] Furthermore, in the method of manufacturing a plated steel material having excellent workability and corrosion resistance according to the exemplary embodiment of the present disclosure, a second average cooling rate in the cooling process from a time point at which the $MgZn_2$ phase starts to solidify to a time point at which the solidification is completed may satisfy a relationship of Formula 1 below.

<Formula 1>

$$0.0114\times T-0.2841 \leq \text{second average cooling rate} \leq 0.025\times T+10$$ (T: solidification start temperature of $MgZn_2$ phase)

[0025] If the cooling process is performed under conditions that do not satisfy Formula 1, it is difficult to control growth of a

rod-shaped $MgZn_2$ precipitated phase during cooling, resulting in poor workability and reduced productivity due to vibration of the sheet.

[0026] An area fraction of a $MgZn_2$ phase whose ratio of an average minor axis length (a) to an average major axis length (b) is 0.5 or less in a whole $MgZn_2$ phase on a surface of a hot-dip alloy-plated layer implemented by the method of manufacturing a plated steel material having excellent workability and corrosion resistance may be 70% or less. That is, an area fraction of a rod-shaped or acicular $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the implemented plated layer may be 70% or less. In this case, an area fraction of a polygon-shaped $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the implemented plated layer may be 30% or greater.

[0027] A zinc alloy-plated layer of the present disclosure may be configured by a primary crystal Al phase (Al single-phase structure with Zn solid-solution), an Al-Zn eutectoid phase, a Zn solid-solution phase, $MgZn_2$ (including Al-including $MgZn_2$ phase, and Mg_2Zn_{11} phase), and an Al/Zn/Mg eutectic structure or a combination thereof. The $MgZn_2$ phase and the Al-including $MgZn_2$ phase on a surface of the Zn-Al-Mg-based plated layer may have a polygonal shape, and a rod and acicular shape, in terms of microstructure for improving workability and processing corrosion resistance.

[0028] A ratio of an average minor axis length (a) and an average major axis length (b) of the rod and acicular shape is $1:10 \leq a:b \leq 1:2$. The rod-shaped and acicular $MgZn_2$ phase of the whole $MgZn_2$ phase is distributed on the surface in an area fraction of less than 70%, and more preferably, in an area fraction of less than 50%, and the remainder $MgZn_2$ is distributed in the polygonal shape.

[0029] An exemplary process of forming a hot-dip alloy-plated layer on the base steel in the present disclosure is as follows.

[0030] For example, the base steel annealed at 680 to 850 °C is immersed in a plating bath of 440 to 530 °C and is passed through an air knife to satisfy 30 to 300 g/m^2 based on one side of the base steel. However, an entry temperature of the base steel after annealing is controlled so that there is no difference of $\pm$20°C or greater from the plating bath temperature.

[0031] In a plated steel material according to an exemplary embodiment of the present disclosure, an area fraction of a $MgZn_2$ phase in a section (for example, longitudinal section) of the hot-dip alloy-plated layer is 20 to 70%, and a ratio of an area fraction of an Al-containing phase to the area fraction of the $MgZn_2$ phase in the section (for example, longitudinal section) of the hot-dip alloy-plated layer is 1 to 70%. Here, the Al-containing phase may be present apart from the $MgZn_2$ phase or within the $MgZn_2$ phase in the section in the hot-dip alloy-plated layer. In addition, in the present exemplary embodiment, the Al-containing phase means i) an Al single phase, and ii) a phase that contains 20% or greater of Al, but includes less than 2% of inevitable impurities and a balance of Zn.

[0032] The hot-dip alloy-plated layer may include, by area fraction, 20 to 70% of the $MgZn_2$ phase in the section. That is, a ratio of a cross-sectional area (A2) occupied by the $MgZn_2$ phase in a total cross-sectional area (A1) of the hot-dip alloy-plated layer is 20 to 70%, and a value of $(A2/A1)\times100$ may satisfy a range of 20 to 70. On the other hand, in the section of the hot-dip alloy-plated layer, a sum of a cross-sectional area (B1) of the Al-containing phase present apart from the $MgZn_2$ phase and a cross-sectional areas (B2) of the Al-containing phase present within the $MgZn_2$ phase may have a ratio of 1 to 70%, compared to a cross-sectional area (B3) of the whole $MgZn_2$ phase. That is, a value of $[(B1+B2)/B3]\times100$ may satisfy a range of 1 to 70. Based on this structure, crack resistance is excellent, and specifically, in bending evaluation (3T bending evaluation, 1T bending evaluation), an average crack width may be 30 μm or less.

[0033] On the surface of the hot-dip alloy-plated layer of the plated steel material of the present disclosure, the area fraction of the $MgZn_2$ phase may be 10 to 70%, and if the area fraction is less than 10%, the formation thereof is impossible, and if the area fraction is greater than 70%, crack resistance is reduced. Here, the surface of the hot-dip alloy-plated layer may mean an upper surface in contact with an outside.

[0034] In the plated steel material according to an exemplary embodiment of the present disclosure, an area fraction of a $MgZn_2$ phase where a ratio of an average minor axis length (a) to an average major axis length (b) is 0.5 or less in the entire $MgZn_2$ phase on the surface of the hot-dip alloy-plated layer may be 70% or less. For example, 70% or less of the $MgZn_2$ phase of the whole $MgZn_2$ phase on the surface of the hot-dip alloy-plated layer may have a ratio of the average minor axis length (a) to the average major axis length (b) of 1:2 to 1:10, i.e., a value of 0.5 or less. In this case, the $MgZn_2$ phase whose ratio of the average minor axis length (a) to the average major axis length (b) is 0.5 or less may have the ratio of the average minor axis length (a) to the average major axis length (b) of 1/10 or greater and 1/2 or less. If the ratio of the average minor axis length (a) to the average major axis length (b) is less than 0.5, crack resistance is reduced. The average minor axis length (a) may be 1 to 20 μm, and the average major axis length (b) may be 2 to 200 μm. An average minor axis length (a) of less than 1 μm and an average major axis length (b) of less than 2 μm cannot be formed, and if the average minor axis length (a) is greater than 20 μm or the average major axis length (b) exceeds 200 μm, crack resistance is reduced.

[0035] Meanwhile, on the surface of the hot-dip alloy-plated layer of the plated steel material according to another aspect of the present disclosure, an area fraction of Al-Zn dendrites configured by an Al phase and a Zn phase may be 30% or less. Al-Zn dendrites preferably have a low area fraction because they do not favorably affect chemical conversion treatment properties or liquid metal embrittlement (LME) resistance. Therefore, in the plated layer according to the present exemplary embodiment, the area fraction of Al-Zn dendrites is set to 30% or less.

[0036] As described above, in the plated steel material having excellent workability and corrosion resistance according

to an exemplary embodiment of the present disclosure, the $MgZn_2$ phase and the Al-including $MgZn_2$ phase on the surface of the Zn-Al-Mg-based plated layer have the polygonal shape, and the rod and acicular shape, and a ratio of an average minor axis length (a) to an average major axis length (b) of the rod- and acicular shape is $1:2 \leq a:b \leq 1:10$. The rod-shaped and acicular $MgZn_2$ phase of the whole $MgZn_2$ is distributed on the surface in an area fraction of 70% or less, and more preferably, in an area fraction of less than 50%, and the remainder $MgZn_2$ is distributed in the polygonal shape.

[0037] An area fraction of a $MgZn_2$ phase whose ratio of the average minor axis length (a) to the average major axis length (b) is greater than 0.5 in the entire $MgZn_2$ phase on the surface of the hot-dip alloy-plated layer is 30% or greater. For example, 30% or greater of the $MgZn_2$ phase in the whole $MgZn_2$ phase on the surface of the hot-dip alloy-plated layer has a ratio of the average minor axis length (a) to the average major axis length (b) greater than 0.5, such as 1:1.5 or 1:1.2. A diameter (average diameter) of an imaginary circle having the same area as a cross-sectional area of the $MgZn_2$ phase where the ratio of the average minor axis length (a) to the average major axis length (b) is greater than 0.5 may be 1 to 50 μm. If the average diameter is less than 1 μm, the formation thereof is impossible, and if the average diameter is greater than 50 μm, crack resistance is reduced.

[0038] Hereinafter, preferred Experimental Examples are presented for better understanding of the present disclosure. However, the following Experimental Examples are only for helping understanding of the present disclosure, and the present disclosure is not limited by the following Experimental Examples.

Experimental Example

1. Specimen Composition and Processing Conditions

[0039] A 1.2 mm cold-rolled material was prepared as a base steel sheet, and had the components (composition) of 0.15 wt.% of carbon (C), 0.01 wt.% of silicon (Si), 0.6 wt.% of manganese (Mn), 0.05 wt.% of phosphorus (P), 0.05 wt.% of sulfur (S) and the remainder of iron (Fe). After annealing within a range of 680 to 850 °C, specifically, at a temperature of 760 °C in a nitrogen-5 to 10% hydrogen atmosphere gas, the annealed specimen was cooled to a temperature that was not different greater than 20 °C from the plating bath, and then immersed in the plating bath for 1 to 5 seconds. After immersion in the plating bath within a range of 440 to 530 °C, specifically, a temperature of 485 °C, the plating thickness was adjusted by nitrogen wiping, and cooled at the first average cooling rate and the second average cooling rate to obtain a Zn-Al-Mg-based plated steel sheet.

2. Plated Layer Composition and Microstructure Evaluation

[0040] Table 1 shows the composition of the hot-dip alloy-plated layer in the plated steel material according to Experimental Example of the present disclosure (unit: wt.%), and microstructures and bending workability evaluation results according to the eutectic structures.

[Table 1]

Classification	Zn (wt%)	Al (wt%)	Mg (wt%)	Temperature difference (°C)	First average cooling rate (°C/s)	Second average cooling rate (°C/s)	$MgZn_2$ Area fraction (area %)	Bending Workability
Example 1	Bal.	10	3.2	70	20	13	45	◦
Example 2	Bal.	10	3	100	22	13	44	◦
Example 3	Bal.	10	3.1	90	30	13	40	◦
Example 4	Bal.	10	3.2	70	20	13	42	◦
Example 5	Bal.	10.2	5	40	15	13	55	◦
Example 6	Bal.	10.1	5.3	30	13	13	52	◦
Example 7	Bal.	10.3	5.4	10	12	13	51	◦
Example 8	Bal.	15	5	100	35	15	54	◦
Example 9	Bal.	10	7	70	30	15	62	◦
Example 10	Bal.	15	5.3	95	34	13	53	◦
Example 11	Bal.	15	5.1	100	45	11	55	◦

(continued)

Classification	Zn (wt%)	Al (wt%)	Mg (wt%)	Temperature difference (°C)	First average cooling rate (°C/s)	Second average cooling rate (°C/s)	$MgZn_2$ Area fraction (area %)	Bending Workability
Comparative Example 1	Bal.	10.2	7	50	10	13	71	X
Comparative Example 2	Bal.	10.3	7	70	7	13	73	X
Comparative Example 3	Bal.	15	5.3	120	10	3	71	X
Comparative Example 4	Bal.	23.5	7	60	25	13	75	X
Comparative Example 5	Bal.	24	7.5	60	26	15	72	X
Comparative Example 6	Bal.	24	7.3	40	15	11	80	X

[0041] In Table 1, 'Temperature difference' means a temperature difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer formed on the base steel immersed in the hot-dip alloy plating bath, 'First average cooling rate' means an average cooling rate in the cooling process from a time point at which the immersed base steel is drawn from the hot-dip alloy plating bath to a time point at which the $MgZn_2$ phase starts to solidify, and 'Second average cooling rate' means an average cooling rate in the cooling process from a time point at which the $MgZn_2$ phase starts to solidify to a time point at which the solidification is completed. In this Experimental Example, the solidification start temperature of the $MgZn_2$ phase was derived using a thermodynamic calculation program (FactSage 7.1). The temperature difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer formed on the base steel immersed in the hot-dip alloy plating bath varied depending on the plating components, but for the same plating components, was adjusted by adjusting the plating bath temperature, and the first average cooling rate was controlled by adjusting a height of the air knife. The $MgZn_2$ area fraction was measured using an image program after observing the surface of each manufactured plated steel sheet at 500 times with a FE-SEM. The area fraction shown in Table 1 is a fraction of the rod-shaped or acicular $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the plated layer, as an area ratio.

[0042] In the bending workability evaluation, after 1T and 3T bending, the bending processed part was observed at 200 times and 500 times with a Field Emission Scanning Electron Microscope (FE-SEM), and then, the widths of the bending cracks were measured and averaged for evaluation. 'O' means that the average crack width in the bending evaluation was greater than 0 and 30 μm or less, and 'X' means that the average crack width in the bending evaluation was greater than 30 μm.

[0043] Referring to Table 1, in Examples 1 to 11, i) the composition of the hot-dip alloy plating bath satisfied the range of, by wt.%, 6 to 23% of Al, 3 to 7% of Mg, and a balance of Zn, ii) it was satisfied that when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is less than 50 °C, the first average cooling rate is 10 to 20 °C/s (Examples 5, 6, and 7), it was satisfied that when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is 50 °C or higher and less than 100 °C, the first average cooling rate is 15 to 35 °C/s (Examples 1, 3, 4, 9, 10), and it was satisfied that when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is 100 °C or greater, the first average cooling rate is 20 to 50 °C/s (Examples 2, 8, and 11), and iii) the second average cooling rate in the cooling process from a time point at which the $MgZn_2$ phase starts to solidify to a time point at which the solidification is completed satisfied the relationship of Formula 1 below.

<Formula 1>

$0.0114 \times T - 0.2841 \leq$ second average cooling rate $\leq 0.025 \times T + 10$ (T: solidification start temperature of $MgZn_2$ phase)

[0044] In this case, it can be confirmed that, in Examples 1 to 11, the area fraction of the rod-shaped or acicular $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the implemented plated layer was 70% or less, and the average crack width in the bending evaluation was 30 μm or less (refer to FIGS. 1 and 3). Furthermore, it can be confirmed that the growth of the Fe-Al interface alloy layer could be controlled to be less than 10 μm in the section of the plated layer (refer to FIG. 5).

[0045] In contrast, it can be confirmed that, in Comparative Examples 1 and 2, it was not satisfied that when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is 50 °C or greater and less than 100 °C, the first average cooling rate is 15 to 35 °C/s, and accordingly, the area fraction of the rod-shaped or acicular $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the implemented plated layer was greater than 70%, and the average crack width in the bending evaluation was greater than 30 μm.

[0046] It can be confirmed that, in Comparative Example 3, it was not satisfied that when the difference between the first temperature, which is a temperature of the hot-dip alloy plating bath, and the second temperature, which is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer, is 50 °C or greater and less than 100 °C, the first average cooling rate is 15 to 35 °C/s, the second average cooling rate in the cooling process from a time point at which the $MgZn_2$ phase starts to solidify to a time point at which the solidification is completed did not satisfy the relationship of Formula 1, and accordingly, the area fraction of the rod-shaped or acicular $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the implemented plated layer was greater than 70%, and the average crack width in the bending evaluation was greater than 30 μm.

[0047] It can be confirmed that, in Comparative Examples 4 to 6, it was not satisfied that the composition of the hot-dip alloy plating bath includes, by wt.%, 6 to 23% of Al, and in Comparative Examples 5 and 6, it was not satisfied that the composition of the hot-dip alloy plating bath includes, by wt.%, 3 to 7% of Mg, and that the area fraction of the rod-shaped or acicular $MgZn_2$ phase in the whole $MgZn_2$ phase distributed on the surface of the implemented plated layer was greater than 70%, and the average crack width in the bending evaluation was greater than 30 μm (refer to FIGS. 2 and 4).

[0048] For example, in Examples 1 to 3, the formation of rod-shaped and acicular $MgZn_2$ phase was relatively less developed, and the widths of the cracks were measured less than 15 μm or 30 μm. On the other hand, in Comparative Example 1 and Comparative Example 2, the first average cooling rate range of the present disclosure was not satisfied, and when the area fraction of the rod-shaped and acicular $MgZn_2$ phase was greater than 70%, cracks progressed within $MgZn_2$ phase having high hardness and along the grain boundaries and the widths of the cracks were greater than 30 μm on average.

[0049] Comparative Example 3 indicates that the bending workability is not good when the ranges of the first average cooling rate and the second average cooling rate disclosed in Examples of the present disclosure are not satisfied.

[0050] It can be confirmed that, in Comparative Example 4, the Al content range of the hot-dip alloy-plated layer of the present disclosure was not satisfied, and in Comparative Examples 5 and 6, the Al and Mg contents of the hot-dip alloy-plated layer were not satisfied, and that the Fe-Al alloy layer was excessively generated and the area fraction of $MgZn_2$ was greater than 70%, and therefore, the bending workability was deteriorated. It can be confirmed that, in Comparative Example 4, the Fe-Al interface alloy layer grew thicker such as 10 μm or greater (refer to FIG. 6), and there was no directionality of the cracks and the average crack width and the area were deteriorated due to the excessive formation of the rod-shaped and acicular $MgZn_2$ phase and the growth of the Fe-Al alloy layer (refer to FIG. 4).

[0051] According to the technical aspects of the present disclosure described above, even when the $MgZn_2$ phase with high hardness, which is unfavorable to workability, is formed, a plated steel sheet having excellent workability can be implemented by suppressing the growth of the rod-shaped and acicular $MgZn_2$ phase and controlling the area fraction thereof.

[0052] While the exemplary embodiments of the present disclosure have been described, various changes or modifications can be made by one skilled in the art. Such changes and modifications fall within the present disclosure as long as they do not depart from the scope of the present disclosure. Therefore, the scope of the present disclosure should be determined by the claims described below.

Claims

1. A method of manufacturing a plated steel material having excellent workability and corrosion resistance, the method comprising:

   immersing a base steel in a hot-dip alloy plating bath; and
   forming a hot-dip alloy-plated layer on the base steel by drawing the immersed base steel from the hot-dip alloy plating bath and performing a cooling process,
   wherein a first average cooling rate in the cooling process varies depending on a difference between a first temperature that is a temperature of the hot-dip alloy plating bath and a second temperature that is a solidification start temperature of a $MgZn_2$ phase constituting the hot-dip alloy-plated layer.

2. The method according to Claim 1,

   wherein when the difference between the first temperature and the second temperature is less than 50 °C, the first average cooling rate is 10 to 20 °C/s,
   wherein when the difference between the first temperature and the second temperature is 50 °C or greater and less than 100 °C, the first average cooling rate is 15 to 35 °C/s, and
   wherein when the difference between the first temperature and the second temperature is 100 °C or greater, the first average cooling rate is 20 to 50 °C/s.

3. The method according to Claim 1, wherein the first average cooling rate is an average cooling rate from a time point at which the immersed base steel is drawn from the hot-dip alloy plating bath to a time point at which the $MgZn_2$ phase starts to solidify.

4. The method according to Claim 1, wherein a second average cooling rate in the cooling process from a time point at which the $MgZn_2$ phase starts to solidify to a time point at which the solidification is completed satisfies a relationship of Formula 1 below.

   <Formula 1>

   $$0.0114 \times T - 0.2841 \leq \text{second average cooling rate} \leq 0.025 \times T + 10$$ (T: solidification start temperature of $MgZn_2$ phase).

5. The method according to Claim 1, wherein the hot-dip alloy plating bath is a Zn plating bath comprising, by wt.%, 6 to 23% of Al, 3 to 7% of Mg, and inevitable impurities.

6. The method according to Claim 1, wherein an area fraction of a $MgZn_2$ phase where a ratio of an average minor axis length (a) to an average major axis length (b) is 0.5 or less in the entire $MgZn_2$ phase on a surface of the hot-dip alloy-plated layer formed on the base steel is 70% or less.

FIG. 1

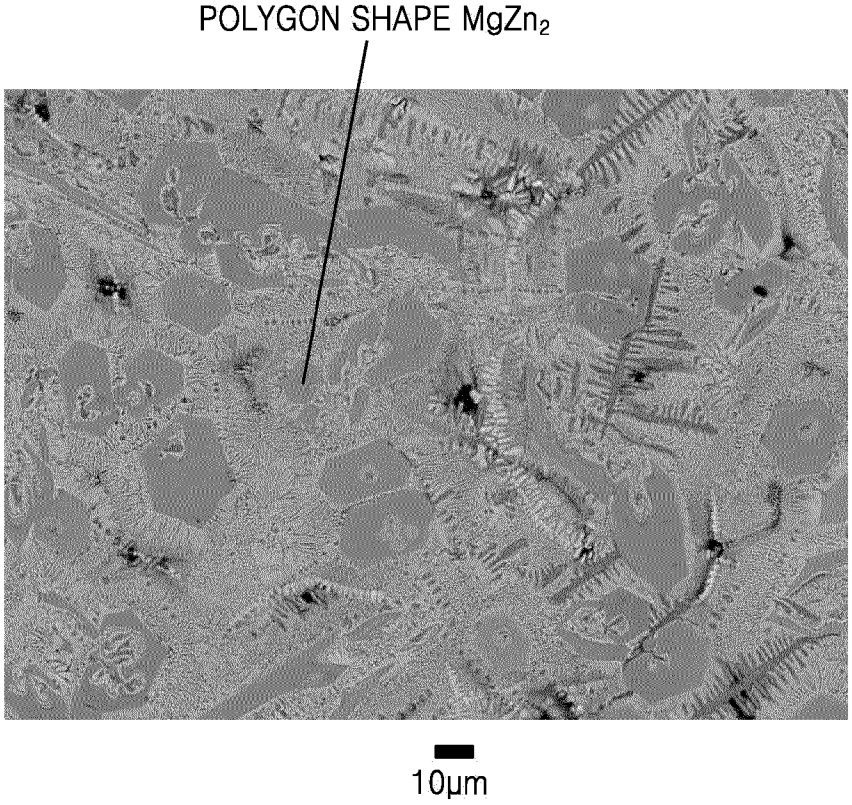


FIG. 2

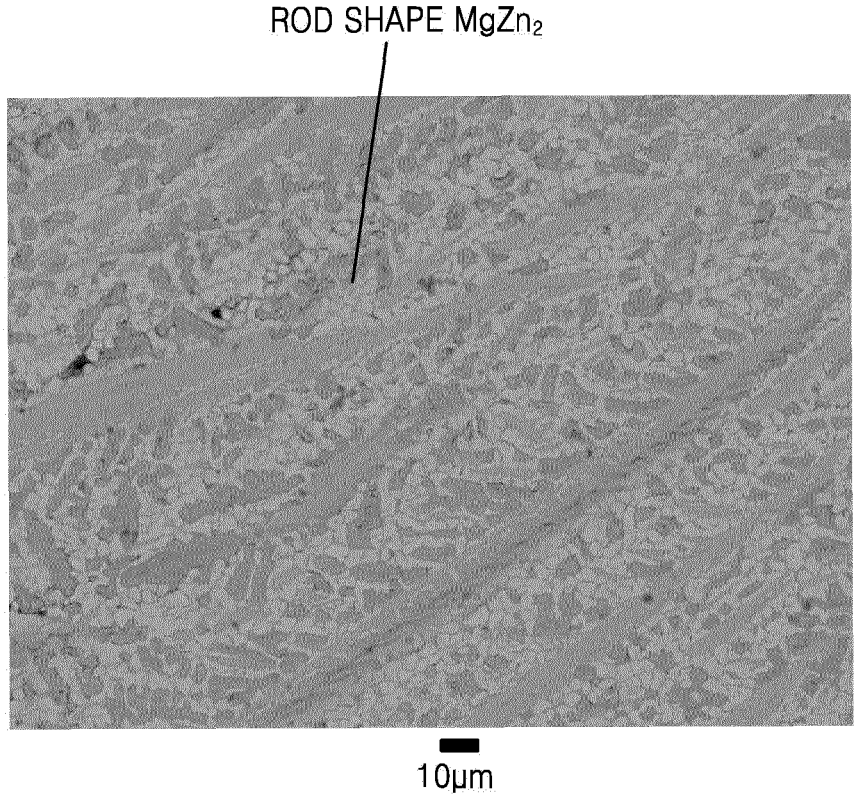


FIG. 3

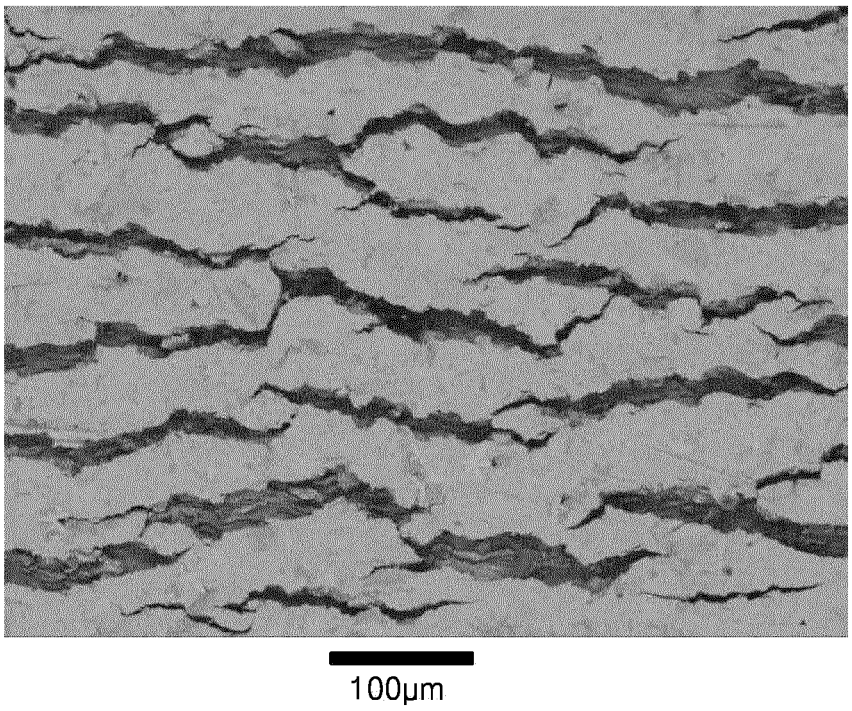


FIG. 4

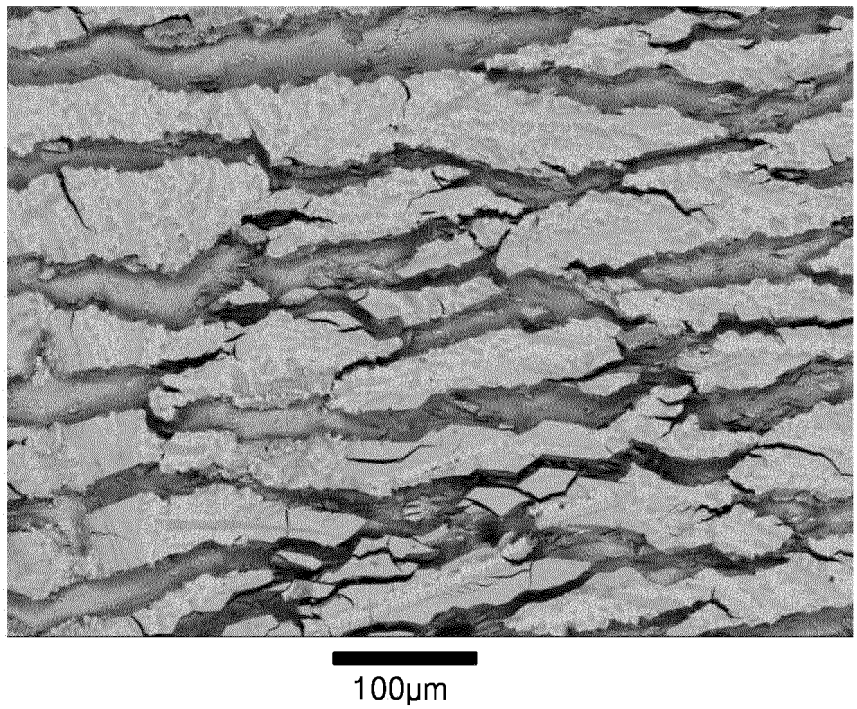


FIG. 5

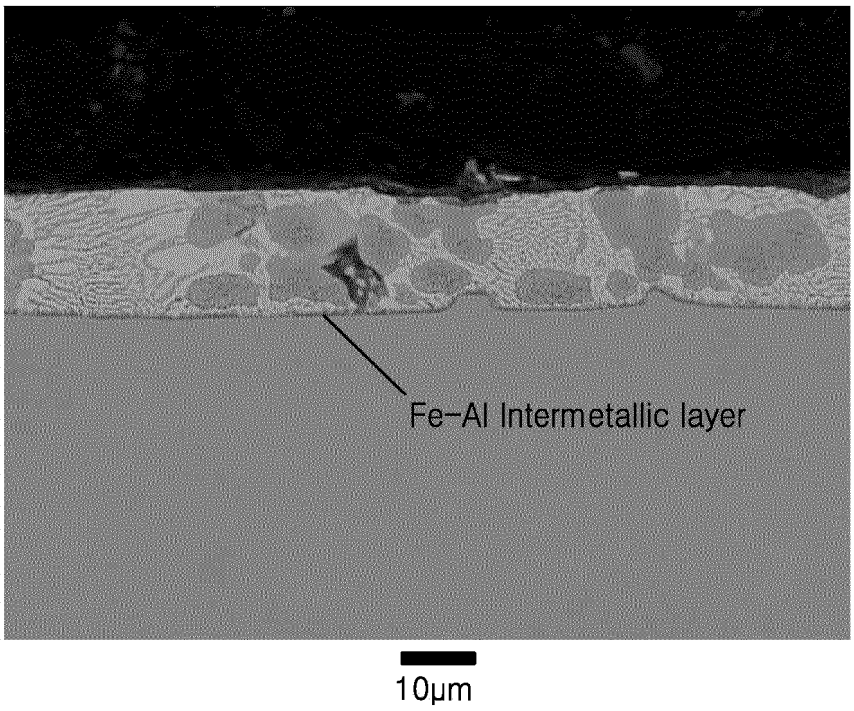
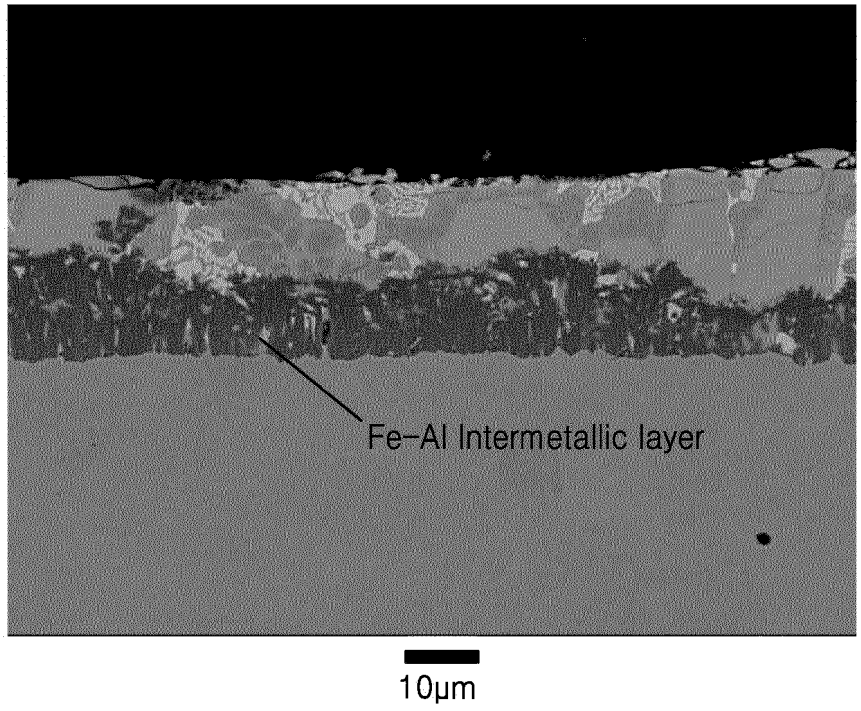


FIG. 6



147243774.1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2022/020448

A. CLASSIFICATION OF SUBJECT MATTER

C23C 2/26(2006.01)i; **C23C 2/40**(2006.01)i; **C23C 2/06**(2006.01)i; **C22C 18/04**(2006.01)i

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)

C23C 2/26(2006.01); C21D 8/02(2006.01); C22C 18/04(2006.01); C22C 38/04(2006.01); C23C 18/00(2006.01); C23C 2/06(2006.01); C23C 2/14(2006.01); C23C 2/40(2006.01); C23C 22/17(2006.01)

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

Korean utility models and applications for utility models: IPC as above
Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 내식성(corrosion resistance), 도금강판(plated steel sheet), 냉각속도(cooling rate), 도금욕(plating bath), 온도(temperature)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	KR 10-2021-0035722 A (POSCO et al.) 01 April 2021 (2021-04-01) See claim 9.	1-6
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A	CN 104419867 B (ANGANG STEEL COMPANY LIMITED) 07 September 2016 (2016-09-07) See claim 4.	1-6

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

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 August 2023	**02 August 2023**

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Information on patent family members

International application No.
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