



(11)

EP 4 826 110 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
21.10.2026 Bulletin 2026/43

(21) Application number: **24904391.0**

(22) Date of filing: **12.12.2024**

(51) International Patent Classification (IPC):
C23C 2/06 ^(2006.01) **C23C 2/40** ^(2006.01)
C23C 2/28 ^(2006.01) **C23C 2/00** ^(2006.01)
C22C 18/04 ^(2006.01) **C21D 9/46** ^(2006.01)

(52) Cooperative Patent Classification (CPC):
C21D 9/46; C22C 18/04; C23C 2/00; C23C 2/06;
C23C 2/28; C23C 2/40

(86) International application number:
PCT/KR2024/096803

(87) International publication number:
WO 2025/127826 (19.06.2025 Gazette 2025/25)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

(30) Priority: **14.12.2023 KR 20230181816**

(71) Applicant: **Hyundai Steel Company**
Incheon 22525 (KR)

(72) Inventors:
• **LEE, Jae Min**
Incheon 22525 (KR)
• **SO, Seong Min**
Incheon 22525 (KR)
• **JEONG, Chang U**
Incheon 22525 (KR)

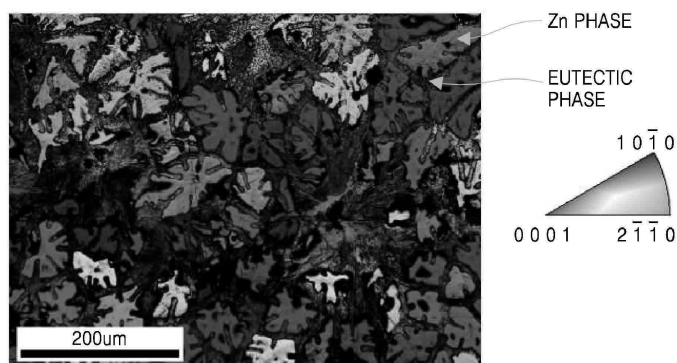
(74) Representative: **Viering, Jentschura & Partner**
mbB
Patent- und Rechtsanwälte
Am Brauhaus 8
01099 Dresden (DE)

(54) **PLATED STEEL AND MANUFACTURING METHOD THEREOF**

(57) A plated steel according to the present invention comprises: a base steel; and a plating layer formed on the base steel, the plating layer containing 1 to 4 wt% of aluminum (Al) and 1 to 3 wt% of magnesium (Mg), with the remainder comprising zinc (Zn) and inevitable impurities, wherein the weight ratio between aluminum and magnesium in the plating layer is 1.0 or

more and 4.0 or less, the plating layer includes a eutectic phase structure containing a Zn phase and a primary Zn phase structure, and the area fraction of the primary Zn phase structure and the Zn phase in the eutectic phase structure having matching crystal orientations is at least 30% on a cross section and the surface of the plating layer.

FIG. 3



EP 4 826 110 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a plated steel and a method for manufacturing the same, and more particularly, to a plated steel with excellent corrosion resistance in a worked section, and a method for manufacturing the same.

BACKGROUND ART

[0002] Existing hot-dip galvanized steel products are widely used in construction materials, home appliances, and other applications due to their excellent sacrificial protection properties. When exposed to corrosive environments, zinc (Zn) acts as a sacrificial anode for iron (Fe) exposed at uncoated areas, resulting in the depletion of zinc from the plating layer. While this sacrificial anode action of zinc plays a significant role in suppressing the formation of rust on the base steel in corrosive environments, the sacrificial anode efficiency of zinc is relatively low. To address this issue, high-corrosion-resistant plated products have been produced in Japan and Europe by adding magnesium (Mg) to a zinc (Zn) plating bath, which generates dense corrosion products in corrosive environments and improves sacrificial anode efficiency, thereby achieving excellent corrosion resistance.

[0003] However, a plating process using a plating bath in which magnesium (Mg) is added to zinc (Zn) has a problem in that, as the magnesium (Mg) content increases, Mg reacts with oxygen in the air to form oxides, which degrades the surface quality. To address this problem, the amount of plating is controlled using an inert gas (nitrogen) in a wiping process that controls the amount of plating. In addition, a non-oxidizing chamber is used to minimize contact with oxygen in order to minimize oxygen concentration in the wiping process zone.

[0004] Furthermore, while an increase in magnesium (Mg) content has the advantage of improving corrosion resistance, the increase in the fraction of a Mg-rich phase or a eutectic phase having a lamellar structure, which are generated by the addition of magnesium (Mg), may act as crack initiation sites in the plating layer during working, thereby deteriorating the corrosion resistance of the worked section. Moreover, when the plated steel is worked after coating, cracks in the plating layer may be transferred to the coating layer on top, thereby degrading the working quality.

[0005] The related art includes Japanese Patent Publication No. 2005-105367.

DETAILED DESCRIPTION OF THE INVENTION

TECHNICAL PROBLEM

[0006] A technical object of the present invention is to provide a highly corrosion-resistant plated steel having crack resistance in a worked section and excellent corrosion resistance, and a method for manufacturing the same.

[0007] However, the above-described object is merely illustrative, and the technical concept of the present invention is not limited thereto.

TECHNICAL SOLUTION

[0008] According to an aspect of the present invention for achieving the above object, a plated steel comprises: a base steel; and a plating layer formed on the base steel, the plating layer comprising 1 to 4 wt% of aluminum (Al), 1 to 3 wt% of magnesium (Mg), and a balance of zinc (Zn) and inevitable impurities, wherein a weight ratio of aluminum to magnesium in the plating layer is 1.0 or more and 4.0 or less, wherein the plating layer comprises a eutectic phase structure containing a Zn phase, and a primary Zn phase structure, and wherein an area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, is 30% or more on a cross section and a surface of the plating layer.

[0009] In the plated steel, a thickness of the plating layer may be 5 μm or more and less than 30 μm .

[0010] In the plated steel, the eutectic phase structure containing the Zn phase may comprise a binary eutectic phase in which a Zn phase and an MgZn_2 phase form a lamellar structure, or a ternary eutectic phase in which an MgZn_2 phase containing Al and a Zn phase form a lamellar structure.

[0011] According to another aspect of the present invention for achieving the above object, a method for manufacturing a plated steel comprises: (a) providing a base steel; (b) passing the base steel through a plating bath containing aluminum (Al), magnesium (Mg), and zinc (Zn) to form a plating layer on the base steel, the plating layer comprising 1 to 4 wt% of aluminum (Al), 1 to 3 wt% of magnesium (Mg), and a balance of zinc (Zn) and inevitable impurities, and having a weight ratio of aluminum to magnesium of 1.0 or more and 4.0 or less; and (c) cooling the plating layer at a

cooling rate of 5 to 15°C/sec, wherein the plating layer obtained after performing step (c) comprises a eutectic phase structure containing a Zn phase, and a primary Zn phase structure, and wherein an area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, is 30% or more on a cross section and a surface of the plating layer.

[0012] In the method for manufacturing the plated steel, the plating bath may have a temperature of 420°C to 470°C.

[0013] In the method for manufacturing the plated steel, when the plating bath has a temperature of 420°C to 470°C, an area fraction (A) of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, on a cross section and a surface of the plating layer, may satisfy the following Formula 1.

$$\text{Formula 1: } A = 57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$$

(wherein [Cooling Rate] is the cooling rate in cooling step (c) in units of °C/sec, [Mg] is the content of magnesium in the plating layer in units of wt%, and [Al] is the content of aluminum in the plating layer in units of wt%)

[0014] In the method for manufacturing the plated steel, the area fraction (A, unit: %) may be 30% or more.

[0015] In the method for manufacturing the plated steel, a thickness of the plating layer may be 5 μm or more and less than 30 μm.

[0016] In the method for manufacturing the plated steel, the eutectic phase structure containing the Zn phase may comprise a binary eutectic phase in which a Zn phase and an MgZn₂ phase form a lamellar structure, or a ternary eutectic phase in which an MgZn₂ phase containing Al and a Zn phase form a lamellar structure.

ADVANTAGEOUS EFFECTS

[0017] According to an embodiment of the present invention, a plated steel having excellent corrosion resistance in a worked section and a method for manufacturing the same can be implemented.

[0018] However, the scope of the present invention is not limited to the above effects.

DESCRIPTION OF THE DRAWINGS

[0019]

FIG. 1 is a flowchart illustrating a method for manufacturing a plated steel according to an embodiment of the present invention.

FIG. 2 is a view showing EBSD analysis results for a zinc (Zn) component on a cross section of a plating layer of a plated steel according to Example 3 among the test examples of the present invention.

FIG. 3 is a view showing EBSD analysis results for a zinc (Zn) component on a surface of a plating layer of a plated steel according to Example 3 among the test examples of the present invention.

FIG. 4 is a view showing EBSD analysis results for a zinc (Zn) component on a cross section of a plating layer of a plated steel according to Comparative Example 6 among the test examples of the present invention.

FIG. 5 is a view showing EBSD analysis results for a zinc (Zn) component on a surface of a plating layer of a plated steel according to Comparative Example 6 among the test examples of the present invention.

MODE OF THE INVENTION

[0020] Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. The embodiments of the present invention are provided to more fully explain the technical concept of the present invention to those skilled in the art, and the following embodiments may be modified into various other forms. The scope of the technical concept of the present invention is not limited to the following embodiments. Rather, these embodiments are provided so that this disclosure will be thorough and complete and will fully convey the technical concept of the present invention to those skilled in the art.

[0021] A plated steel with excellent corrosion resistance in a worked section and a method for manufacturing the same, according to an embodiment of the present invention, will now be described in detail. The terms used herein are appropriately selected in consideration of their functions in the present invention, and the definitions of such terms should be made based on the content of the entire specification.

[0022] FIG. 1 is a flowchart illustrating a method for manufacturing a plated steel according to an embodiment of the present invention.

[0023] Referring to FIG. 1, the method for manufacturing a plated steel according to an embodiment of the present

invention comprises: (a) providing a base steel (S10); (b) passing the base steel through a plating bath containing aluminum (Al), magnesium (Mg), and zinc (Zn) to form, on the base steel, a plating layer comprising 1 to 4 wt% of aluminum (Al), 1 to 3 wt% of magnesium (Mg), and a balance of zinc (Zn) and inevitable impurities, and having a weight ratio of aluminum to magnesium of 1.0 or more and 4.0 or less (S20); and (c) cooling the plating layer at a cooling rate of 5 to 15°C/sec (S30).

[0024] The plating layer obtained after performing step (c) (S30) comprises a eutectic phase structure containing a Zn phase, and a primary Zn phase structure, wherein an area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, is 30% or more on a cross section and a surface of the plating layer.

[0025] A thickness of the plating layer may be 5 μm or more and less than 30 μm.

[0026] In the method for manufacturing the plated steel, when the plating bath has a temperature of 420°C to 470°C, the area fraction (A) of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, on a cross section and a surface of the plating layer, may satisfy Formula 1 below, and the area fraction (A, unit: %) may be 30% or more.

$$\text{Formula 1: } A = 57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$$

wherein [Cooling Rate] is the cooling rate in cooling step (c) (S30) in units of °C/sec, [Mg] is the content of magnesium in the plating layer in units of wt%, and [Al] is the content of aluminum in the plating layer in units of wt%.

[0027] In general, in a high-corrosion-resistant plated steel, while an increase in magnesium (Mg) content has the advantage of improving corrosion resistance, the increase in the fraction of an Mg-rich phase or a eutectic phase having a lamellar structure, which are generated by the addition of magnesium (Mg), may act as crack initiation sites in the plating layer during working, thereby deteriorating the corrosion resistance of the worked section. As used herein, the eutectic phase may comprise a binary eutectic phase in which a Zn phase and an MgZn₂ phase form a lamellar structure, or a ternary eutectic phase in which an MgZn₂ phase containing Al and a Zn phase form a lamellar structure. Additionally, when working is performed after coating, cracks in the plating layer may be transferred to the coating layer on top, thereby degrading the working quality. Furthermore, when the Mg content is high, the amount of Mg dross adhesion increases, which may deteriorate corrosion resistance.

[0028] On the other hand, when the Mg content is reduced such that the fraction of the primary Zn phase in the plating microstructure increases, the workability of the plating layer may be improved. However, when the Mg content is excessively low, the primary Zn phase formed during solidification of the plating layer is produced in a relatively coarse form, and regions where coarse primary Zn phase is formed develop into areas with poor corrosion resistance in corrosive environments. In addition, when the Mg content decreases, the amount of eutectic phase containing Mg decreases, making it difficult to achieve high corrosion resistance.

[0029] The fractions of the primary Zn phase and the eutectic phase can be controlled by adjusting the aluminum (Al) and magnesium (Mg) contents, and additionally by adjusting the cooling rate during the solidification of the plating layer after plating. However, to ensure both corrosion resistance and workability of the plating layer simultaneously, the concentrations of aluminum (Al) and magnesium (Mg) added to the zinc plating bath must be limited. It has been confirmed that a plated steel with excellent workability can be achieved by controlling the fraction of phases in which the crystal grain orientation of the primary Zn phase and the crystal grain orientation of the Zn phase in the eutectic phase (which is adjacent to the primary Zn phase) are the same.

[0030] Depending on the contents of aluminum (Al) and magnesium (Mg) added to the zinc plating solution to improve corrosion resistance, the fractions of the microstructures formed during solidification of the plating layer differ: a primary Zn phase, an Mg-rich phase, a binary eutectic phase in which a Zn phase and an MgZn₂ phase form a lamellar structure, and a ternary eutectic phase in which an MgZn₂ phase containing Al and a Zn phase form a lamellar structure.

[0031] The primary Zn phase has a Zn content of 90% or more by composition and has lower hardness than the eutectic phase, thereby contributing to crack resistance of the plating layer. The eutectic phase formed in the plating layer acts as a crack initiation site during working due to its high hardness. However, when the crystal grain orientation of the primary Zn phase and the crystal grain orientation of the eutectic phase (more specifically, the crystal grain orientation of the Zn phase present in the eutectic phase) are aligned, the occurrence of cracks in the eutectic phase can be minimized.

[0032] In the technical concept of the present invention, in order to increase the probability that the crystal grain orientations of the Zn phase in the primary Zn phase and the eutectic phase coincide, the solidification process is critical: solidification begins from the primary Zn phase during cooling, and at the end of solidification, the eutectic phase solidifies from the interface of the primary Zn phase. If rapid cooling is performed during the eutectic phase solidification zone after the primary Zn phase has solidified, the eutectic phase solidification does not occur from the

interface of the primary Zn phase. Under rapid cooling in the eutectic phase solidification zone, solidification of the eutectic phase begins from within the liquid phase, so the probability that the crystal grain orientation of the primary Zn phase and the crystal grain orientation of the Zn phase in the eutectic phase coincide decreases.

[0033] To implement the technical concept of the present invention, the cooling rate during the process of cooling the plating layer after controlling the plating amount in the production process must satisfy a range of 5 to 15°C/sec. More preferably, the cooling rate may be set at 7 to 13°C/sec.

[0034] When the fraction of the primary Zn phase structure and the Zn phase in the eutectic phase structure, in which the crystal grain orientations coincide on the cross section and surface of the plating layer produced under these process conditions, is 30% or more, excellent crack resistance of the plating layer is achieved.

[0035] When the cooling rate exceeds 15°C/sec, the fraction of phases in which the crystal grain orientations of the primary Zn phase and the eutectic phase coincide is formed at less than 30%, resulting in a negligible contribution to workability. In addition, when the cooling rate is less than 5°C/sec, the plating layer does not solidify and flows down, causing flow marks.

[0036] To implement the technical concept of the present invention, the contents of aluminum (Al) and magnesium (Mg) added to the zinc bath can be limited.

[0037] An appropriate range of aluminum (Al) concentration is 1 to 4 wt%, and more strictly 1 to 3.5 wt%. An appropriate range of magnesium (Mg) concentration is 1 to 3 wt%. Furthermore, to minimize Mg oxidation, the weight ratio of aluminum (Al) to magnesium (Mg) must be 1.0 or more and 4.0 or less.

[0038] When the aluminum (Al) concentration is less than 1 wt%, considering the Al-to-Mg addition ratio, a Mg content of less than 1 wt% is insufficient to achieve corrosion resistance. When the aluminum (Al) concentration exceeds 4 wt%, the amount of iron (Fe) eluted from the base steel increases, raising the likelihood of Fe dross formation. When the weight ratio of aluminum (Al) to magnesium (Mg) exceeds 4.0, the iron (Fe) content eluted from the base steel increases, leading to Fe dross formation and reduced surface quality. When the magnesium (Mg) concentration exceeds 3.0 wt%, a rapid increase in the eutectic phase reduces the fraction of the primary Zn phase to less than 30%, resulting in a sharp decrease in workability.

[0039] In the method for manufacturing the plated steel, the plating bath preferably has a temperature of 420°C to 470°C. When the plating bath temperature is less than 420°C, cooling occurs in the plated steel during the process of controlling the plating amount, which causes supercooling down to the temperature at which the eutectic phase solidifies, making it difficult to achieve a phase fraction of 30% or more in which the crystal grain orientations of the primary Zn phase and the Zn phase in the eutectic phase coincide. When the plating bath temperature exceeds 470°C, an excessive temperature rise increases the amount of zinc (Zn) vaporization on the plating layer surface, causing an increase in ash defects.

[0040] In the method for manufacturing the plated steel, when the plating bath has a temperature of 420°C to 470°C, the area fraction (A) of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, on a cross section and a surface of the plating layer, may satisfy Formula 1 below, and the area fraction (A, unit: %) may be 30% or more.

$$\text{Formula 1: } A = 57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$$

wherein [Cooling Rate] is the cooling rate in cooling step (c) (S30) in units of °C/sec, [Mg] is the content of magnesium in the plating layer in units of wt%, and [Al] is the content of aluminum in the plating layer in units of wt%.

[0041] The plated steel manufactured by the above-described method comprises: a base steel; and a plating layer formed on the base steel, the plating layer comprising 1 to 4 wt% of aluminum (Al), 1 to 3 wt% of magnesium (Mg), and a balance of zinc (Zn) and inevitable impurities, wherein a weight ratio of aluminum to magnesium in the plating layer is 1.0 or more and 4.0 or less, wherein the plating layer comprises a eutectic phase structure containing a Zn phase, and a primary Zn phase structure, and wherein an area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, is 30% or more on a cross section and a surface of the plating layer.

[0042] A thickness of the plating layer may be 5 μm or more and less than 30 μm.

[0043] Hereinafter, preferred test examples are presented to facilitate understanding of the present invention. However, the following test examples are provided only for the purpose of facilitating understanding of the present invention, and the present invention is not limited to the following test examples.

Test Examples

[0044] A base steel having a thickness of 0.7 mm is immersed in an alkaline solution at 50°C for 30 minutes, and then washed with water to remove foreign substances and oil from the surface, thereby preparing a specimen. The

specimen is annealed and then plated. The annealing is performed in a reducing atmosphere consisting of 5 to 20% hydrogen and 80 to 95% nitrogen at an annealing heat treatment temperature of 700°C to 850°C.

[0045] The plating is performed by cooling the annealed specimen to the plating bath temperature, immersing the specimen in the plating bath for 2 seconds, withdrawing the specimen, and adjusting the plating thickness to approximately 10 μm by nitrogen wiping.

[0046] The cold-rolled steel sheet constituting the base steel has a composition comprising carbon (C): 0.15 wt%, manganese (Mn): 0.6 wt%, phosphorus (P): 0.05 wt%, sulfur (S): 0.05 wt%, and the balance of iron (Fe).

[0047] Table 1 shows the compositions and process conditions of the plated steels according to the test examples of the present invention, and Table 2 shows the evaluation results for plating layer workability, corrosion resistance of the worked section, and surface appearance quality of the plating layer according to the compositions and process conditions in Table 1.

[Table 1]

Category	Zn	Al (wt%)	Mg (wt%)	Al:Mg	Area Fraction (%)	Cooling Rate (°C/s)	Plating Bath Temp. (°C)	Formula Satisfied
Comparative Example 1	Bal.	0.5	0.5	1:1	51	7	450	○
Comparative Example 2	Bal.	1	0.5	2:1	49	7	450	○
Comparative Example 3	Bal.	1	1.8	1:1.8	39	7	450	○
Comparative Example 4	Bal.	1.2	2	0.6:1	38	7	450	○
Comparative Example 5	Bal.	1.2	2	0.6:1	40	4	450	○
Comparative Example 6	Bal.	1.5	2	0.75:1	25	17	450	×
Comparative Example 7	Bal.	2	1.5	1.3:1	24	17	450	×
Comparative Example 8	Bal.	2	1.5	1.3:1	27	7	410	○
Comparative Example 9	Bal.	1.5	1.5	1:1	42	3	450	○
Comparative Example 10	Bal.	6	1.2	5:1	35	7	450	○
Comparative Example 11	Bal.	4	4	1:1	33	7	450	×
Comparative Example 12	Bal.	5	1	5:1	37	7	450	○
Comparative Example 13	Bal.	2	1.2	1.6:1	30	12	480	○
Example 1	Bal.	1.5	1	1.5:1	44	5	450	○
Example 2	Bal.	1.5	1.5	1:1	32	15	450	○
Example 3	Bal.	2	1	2:1	41	7	450	○
Example 4	Bal.	2	1.2	1.6:1	32	12	450	○
Example 5	Bal.	2.5	1.5	1.6:1	36	10	450	○
Example 6	Bal.	3	1.8	1.6:1	37	6	450	○
Example 7	Bal.	2.5	1.2	1.6:1	34	10	460	○
Example 8	Bal.	2.5	1.2	1.6:1	36	10	470	○

[0048] In Table 1, Zn, Al, and Mg indicate the plating bath composition (unit: wt%) in the plating process. The cooling rate refers to the cooling rate in the cooling step (S30) shown in FIG. 1, and the plating bath temperature refers to the plating bath temperature in the plating layer forming step (S20) shown in FIG. 1. The area fraction column refers to the area fraction of the primary Zn phase structure and the Zn phase in the eutectic phase structure, in which the crystal grain orientations coincide with each other, as measured on the cross section and surface of the plating layer. In the "Formula Satisfied" column, the result is indicated as ○ when the calculated value of: $57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$ is 30 or more, and as × when the calculated value is less than 30. In the formula, [Cooling Rate] is the numerical value of the cooling rate (unit: °C/s) in the cooling step (S30), [Mg] is the numerical value of the Mg content (unit: wt%) in the plating layer, and [Al] is the numerical value of the Al content (unit: wt%) in the plating layer.

[0049] FIG. 2 is a view showing EBSD analysis results for a Zn component on a cross section of the plating layer of Example 3, FIG. 3 is a view showing EBSD analysis results for a Zn component on a surface of the plating layer of Example 3, FIG. 4 is a view showing EBSD analysis results for a Zn component on a cross section of the plating layer of Comparative Example 6, and FIG. 5 is a view showing EBSD analysis results for a Zn component on a surface of the plating layer of Comparative Example 6. In FIGS. 2 to 5, regions labeled as "Zn PHASE" correspond to the primary Zn phase structure, and regions labeled as "EUTECTIC PHASE" correspond to the Zn phase in the eutectic phase structure.

[Table 2]

Category	Surface Quality Grade	Flow Mark	Fe dross adhesion	Mg dross adhesion	Workability	Corrosion Resistance (Worked Section)
Comparative Example 1	○	Good	Good	Good	⊙	△
Comparative Example 2	○	Good	Good	Good	⊙	△
Comparative Example 3	△	Good	Good	Observed	○	○
Comparative Example 4	△	Good	Good	Observed	○	○
Comparative Example 5	×	Observed	Good	Observed	○	○
Comparative Example 6	△	Good	Good	Observed	△	○
Comparative Example 7	○	Good	Good	Good	△	○
Comparative Example 8	○	Good	Good	Good	△	○
Comparative Example 9	△	Observed	Good	Good	○	○
Comparative Example 10	△	Good	Observed	Good	○	⊙
Comparative Example 11	○	Good	Good	Good	×	⊙
Comparative Example 12	△	Good	Observed	Good	○	⊙
Comparative Example 13	○	Good	Good	Poor	○	○
Example 1	○	Good	Good	Good	⊙	○
Example 2	○	Good	Good	Good	○	○
Example 3	○	Good	Good	Good	⊙	○
Example 4	○	Good	Good	Good	○	○
Example 5	○	Good	Good	Good	○	○
Example 6	○	Good	Good	Good	○	⊙
Example 7	○	Good	Good	Good	○	○
Example 8	○	Good	Good	Good	○	○

[0050] In the workability evaluation of the plating layer in Table 2, for plated steel sheets having a plating layer thickness of 10 μm , 3T bending was performed and observation was made at 50 $\times$ magnification using an electron microscope. The number of cracks passing through a line drawn perpendicularly to the bending direction of the worked section was measured, and the degree of crack formation in the worked section was evaluated based on the following criteria: ⊙ indicates no cracks observed; ○ indicates an average of fewer than 20 cracks observed; △ indicates an average of 20 to 25 cracks observed; and × indicates an average of 26 or more cracks observed.

[0051] In the corrosion resistance evaluation of the worked section, after 3T bending, the time to red rust formation on the worked section was evaluated by a salt spray test using a 5% NaCl solution at 35°C. ⊙ indicates a time to red rust formation of 1200 hours or more; ○ indicates a time to red rust formation of approximately 1000 hours; △ indicates a time to red rust formation of approximately 800 hours; and × indicates a time to red rust formation of approximately 600 hours.

[0052] In the surface appearance quality evaluation of the plating layer, ○ indicates no flow mark, no Fe dross adhesion, and no Mg dross adhesion observed visually; △ indicates that any one of flow mark, Fe dross adhesion, or

Mg dross adhesion is observed visually; and × indicates that two or more of flow mark, Fe dross adhesion, or Mg dross adhesion are observed visually.

[0053] Referring to Tables 1 and 2, Examples 1 to 8 satisfy the composition ranges of aluminum (Al): 1 to 4 wt%, magnesium (Mg): 1 to 3 wt%, and the balance zinc (Zn), with a weight ratio of aluminum to magnesium of 1.0 or more and 4.0 or less, and were produced by immersing a base steel in a plating bath at a temperature of 420°C to 470°C, forming a plating layer having a thickness of 5 μm or more and less than 30 μm by nitrogen wiping, and cooling at a cooling rate of 5 to 15°C/sec. It is confirmed that, on the cross section and surface of the resulting plating layer, the area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which the crystal grain orientations coincide with each other, is 30% or more (see FIGS. 2 and 3).

[0054] Furthermore, in Examples 1 to 8, when the plating bath temperature is 420°C to 470°C, the area fraction (A) of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which the crystal grain orientations coincide with each other, on the cross section and surface of the plating layer, satisfies Formula 1, and the area fraction (A) is confirmed to be 30% or more.

$$\text{Formula 1: } A = 57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$$

(wherein [Cooling Rate] is the cooling rate in cooling step (c) in units of °C/sec, [Mg] is the content of magnesium in the plating layer in units of wt%, and [Al] is the content of aluminum in the plating layer in units of wt%)

[0055] Additionally, in Examples 1 to 8, it is confirmed that no visible cracks are observed in the worked section after 3T bending, indicating excellent workability of the plating layer; the time to red rust formation evaluated by a salt spray test using a 5% NaCl solution at 35°C on the worked section after 3T bending is 1000 hours or more, indicating excellent corrosion resistance of the worked section; and the surface appearance quality of the plating layer is good.

[0056] In contrast, Comparative Example 1 is a plated steel in which the content of aluminum (Al) is below the range of 1 to 4 wt% and the content of magnesium (Mg) is below the range of 1 to 3 wt%. Evaluation of the time to red rust formation by a salt spray test using a 5% NaCl solution at 35°C on the worked section after 3T bending yielded a result of approximately 800 hours, confirming that the corrosion resistance of the worked section is not satisfactory.

[0057] Comparative Example 2 is a plated steel in which the content of magnesium (Mg) is below the range of 1 to 3 wt%. Evaluation of the time to red rust formation on the worked section after 3T bending yielded a result of approximately 800 hours, confirming that the corrosion resistance of the worked section is not satisfactory.

[0058] Comparative Examples 3 and 4 are plated steels in which the weight ratio of aluminum to magnesium is below the range of 1.0 or more and 4.0 or less. Mg dross adhesion occurs in both cases, confirming that the surface appearance quality of the plating layer is not satisfactory.

[0059] Comparative Example 5 is a plated steel in which the weight ratio of aluminum to magnesium is below the range of 1.0 or more and 4.0 or less and the cooling rate is below the range of 5 to 15°C/sec. Mg dross adhesion occurs and flow marks are generated, confirming that the surface appearance quality of the plating layer is not satisfactory.

[0060] Comparative Example 6 is a plated steel in which the weight ratio of aluminum to magnesium is below the range of 1.0 or more and 4.0 or less, the cooling rate exceeds the range of 5 to 15°C/sec, and the area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, does not satisfy and falls below the range of 30% or more (see FIGS. 4 and 5). It is confirmed that Mg dross adhesion occurs such that the surface appearance quality is not satisfactory, and that 20 to 25 cracks on average are observed in the worked section after 3T bending, indicating that workability is not satisfactory.

[0061] Comparative Example 7 is a plated steel in which the cooling rate exceeds the range of 5 to 15°C/sec and the area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, does not satisfy and falls below the range of 30% or more. It is confirmed that 20 to 25 cracks on average are observed in the worked section after 3T bending, indicating that workability is not satisfactory.

[0062] Comparative Example 8 is a plated steel in which the plating bath temperature is below the range of 420°C to 470°C and the area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, does not satisfy and falls below the range of 30% or more. It is confirmed that 20 to 25 cracks on average are observed in the worked section after 3T bending, indicating that workability is not satisfactory.

[0063] Comparative Example 9 is a plated steel in which the cooling rate is below the range of 5 to 15°C/sec. Flow marks are generated, confirming that the surface appearance quality of the plating layer is not satisfactory.

[0064] Comparative Examples 10 and 12 are plated steels in which the aluminum (Al) content and the weight ratio of aluminum to magnesium exceed the ranges of 1 to 4 wt% and 1.0 or more and 4.0 or less, respectively. Fe dross adhesion occurs in both cases, confirming that the surface appearance quality of the plating layer is not satisfactory.

[0065] Comparative Example 11 is a plated steel in which the magnesium (Mg) content exceeds the range of 1 to 3 wt%. It is confirmed that 26 or more cracks on average are observed in the worked section after 3T bending, indicating that workability is not satisfactory.

[0066] Comparative Example 13 is a plated steel in which the plating bath temperature exceeds the range of 420°C to 470°C. Mg dross adhesion occurs, confirming that the surface appearance quality of the plating layer is not satisfactory.

[0067] Meanwhile, referring to Comparative Examples 6, 7, and 11, although the plating bath temperature falls within the range of 420°C to 470°C, when the calculated value of $57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$ falls below 30, workability is confirmed to be unsatisfactory. Conversely, referring to Comparative Example 8 or 13, it is confirmed that even when the calculated value of $57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$ exceeds 30, if the plating bath temperature does not fall within the range of 420°C to 470°C, workability is not satisfactory or surface appearance quality is not satisfactory. Here, [Cooling Rate] is the cooling rate in cooling step (c) (S30) in units of °C/sec, [Mg] is the content of magnesium in the plating layer in units of wt%, and [Al] is the content of aluminum in the plating layer in units of wt%.

[0068] While the present invention has been described with reference to the embodiments above, various changes and modifications can be made by those skilled in the art within the scope of the technical concept of the present invention. Such changes and modifications fall within the scope of the present invention. Accordingly, the scope of rights of the present invention shall be determined by the following claims.

Claims

1. A plated steel comprising:

a base steel; and
a plating layer formed on the base steel, the plating layer comprising 1 to 4 wt% of aluminum (Al), 1 to 3 wt% of magnesium (Mg), and a balance of zinc (Zn) and inevitable impurities,
wherein a weight ratio of aluminum to magnesium in the plating layer is 1.0 or more and 4.0 or less,
wherein the plating layer comprises a eutectic phase structure containing a Zn phase, and a primary Zn phase structure, and
wherein an area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, is 30% or more on a cross section and a surface of the plating layer.

2. The plated steel of claim 1, wherein a thickness of the plating layer is 5 μm or more and less than 30 μm.

3. The plated steel of claim 1, wherein the eutectic phase structure containing the Zn phase comprises a binary eutectic phase in which a Zn phase and an MgZn₂ phase form a lamellar structure, or a ternary eutectic phase in which an MgZn₂ phase containing Al and a Zn phase form a lamellar structure.

4. A method for manufacturing a plated steel, the method comprising:

(a) providing a base steel;
(b) passing the base steel through a plating bath containing aluminum (Al), magnesium (Mg), and zinc (Zn) to form a plating layer on the base steel, the plating layer comprising 1 to 4 wt% of aluminum (Al), 1 to 3 wt% of magnesium (Mg), and a balance of zinc (Zn) and inevitable impurities, and having a weight ratio of aluminum to magnesium of 1.0 or more and 4.0 or less; and
(c) cooling the plating layer at a cooling rate of 5 to 15°C/sec,
wherein the plating layer obtained after performing step (c) comprises a eutectic phase structure containing a Zn phase, and a primary Zn phase structure, and
wherein an area fraction of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, is 30% or more on a cross section and a surface of the plating layer.

5. The method of claim 4, wherein the plating bath has a temperature of 420°C to 470°C.

6. The method of claim 5, wherein the area fraction (A) of the primary Zn phase structure and the Zn phase within the eutectic phase structure, in which crystal grain orientations coincide with each other, on a cross section and a

surface of the plating layer, satisfies the following Formula 1:

$$\text{Formula 1: } A = 57 - 1.30 \times [\text{Cooling Rate}] - 3.47 \times [\text{Mg}] - 1.40 \times [\text{Al}]$$

wherein [Cooling Rate] is the cooling rate in cooling step (c) in units of °C/sec, [Mg] is the content of magnesium in the plating layer in units of wt%, and [Al] is the content of aluminum in the plating layer in units of wt%.

7. The method of claim 6, wherein the area fraction (A) is 30% or more.
8. The method of claim 4, wherein a thickness of the plating layer is 5 μm or more and less than 30 μm.
9. The method of claim 4, wherein the eutectic phase structure containing the Zn phase comprises a binary eutectic phase in which a Zn phase and an MgZn₂ phase form a lamellar structure, or a ternary eutectic phase in which an MgZn₂ phase containing Al and a Zn phase form a lamellar structure.

FIG. 1

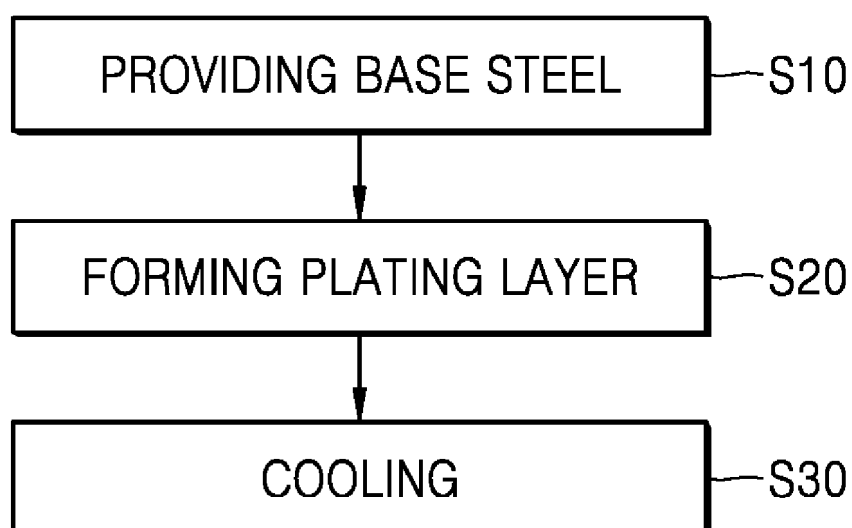


FIG. 2

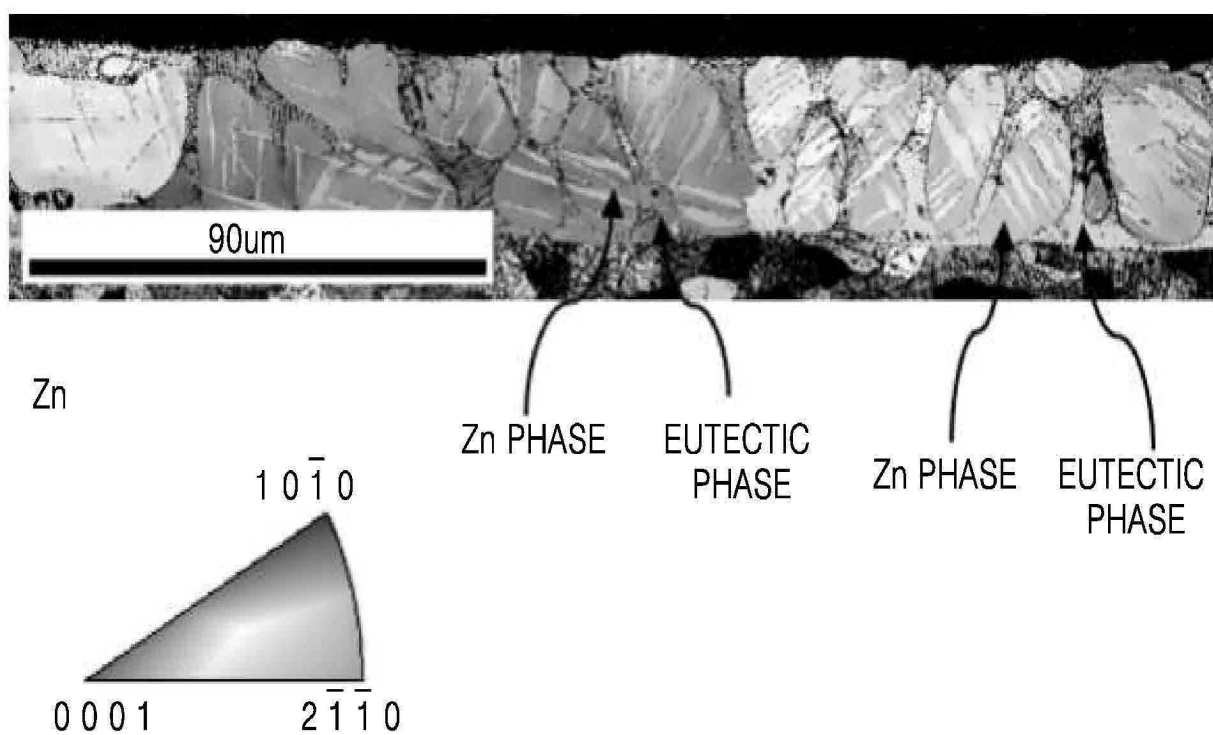


FIG. 3

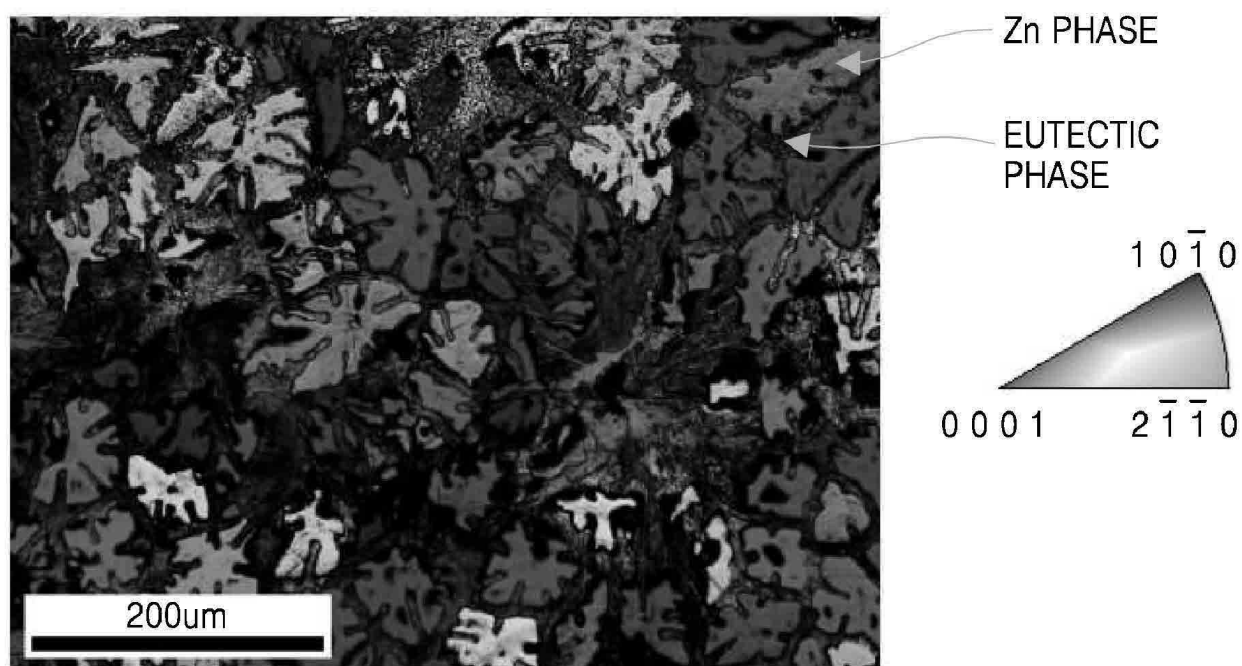


FIG. 4

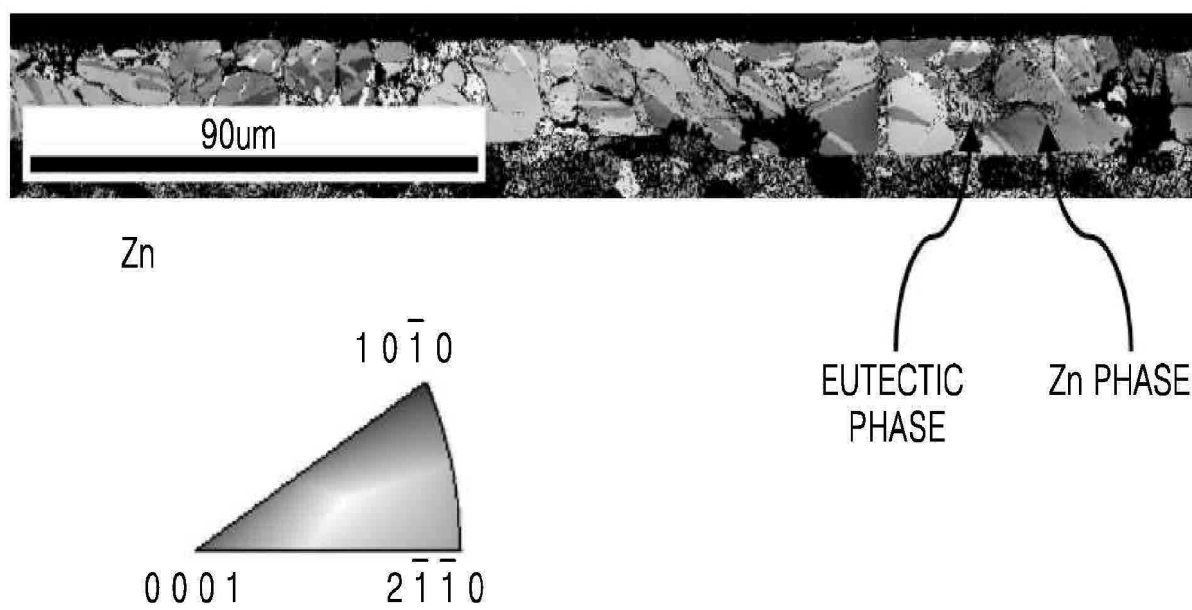
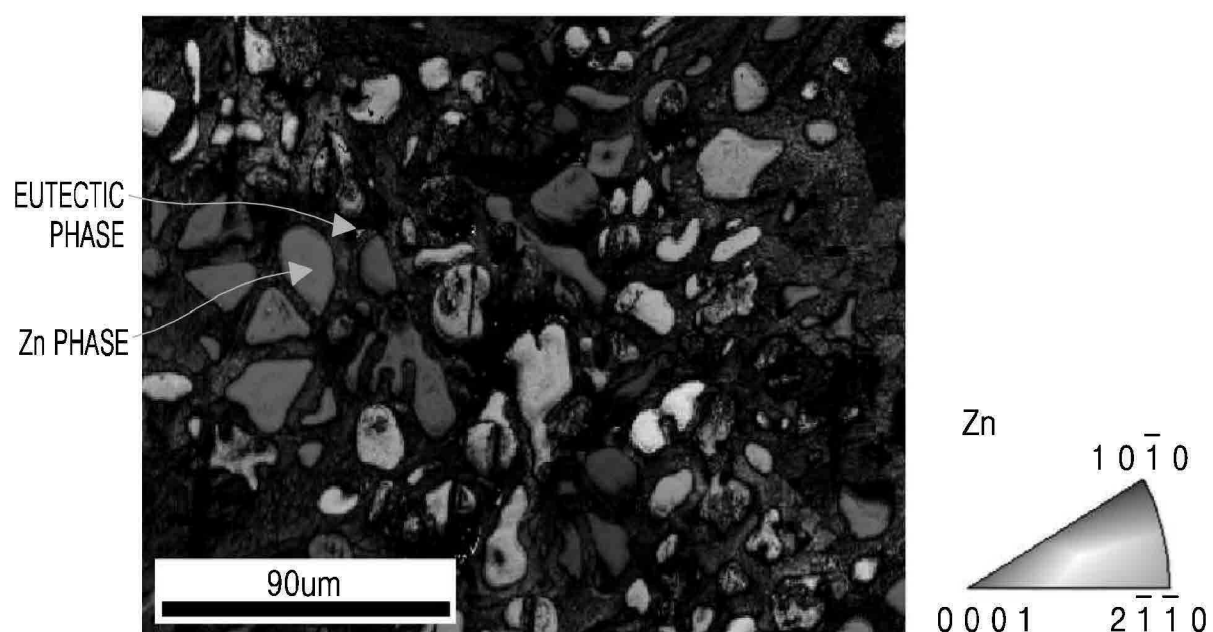


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/096803

A. CLASSIFICATION OF SUBJECT MATTER

C23C 2/06(2006.01)i; C23C 2/40(2006.01)i; C23C 2/28(2006.01)i; C23C 2/00(2006.01)i; C22C 18/04(2006.01)i;
C21D 9/46(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 2/06(2006.01); C22C 18/00(2006.01); C22C 18/04(2006.01); C23C 2/02(2006.01); C23C 2/04(2006.01);
C23C 2/14(2006.01); C23C 2/18(2006.01); C23C 2/26(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: 도금층(plating layer), 알루미늄(aluminum), 아연(zinc), 마그네슘(magnesium), 냉각(cooling), 두께(thickness)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	KR 10-2022-0089293 A (POSCO) 28 June 2022 (2022-06-28) See paragraphs [0062]-[0063] and claims 1 and 6-8.	1-5,7-9 6
Y	KR 10-2022-0089027 A (POSCO) 28 June 2022 (2022-06-28) See claim 1.	1-5,7-9
A	KR 10-2021-0077953 A (POSCO) 28 June 2021 (2021-06-28) See paragraphs [0028]-[0057].	1-9
A	KR 10-2019-0078434 A (POSCO) 04 July 2019 (2019-07-04) See paragraphs [0037]-[0052].	1-9
A	KR 10-2012-0041619 A (POSCO) 02 May 2012 (2012-05-02) See claims 1-4.	1-9



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

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“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

18 March 2025

Date of mailing of the international search report

19 March 2025

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208

Facsimile No. +82-42-481-8578

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/096803

5

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
KR 10-2022-0089293 A	28 June 2022	CN 116670317 A	29 August 2023
		EP 4265812 A1	25 October 2023
		JP 2024-500435 A	09 January 2024
		KR 10-2453011 B1	12 October 2022
		US 2024-0052471 A1	15 February 2024
		WO 2022-139367 A1	30 June 2022
KR 10-2022-0089027 A	28 June 2022	KR 10-2453009 B1	12 October 2022
KR 10-2021-0077953 A	28 June 2021	CN 114901853 A	12 August 2022
		CN 114901853 B	02 January 2024
		EP 4079924 A1	26 October 2022
		JP 2023-507962 A	28 February 2023
		JP 7496876 B2	12 June 2024
		KR 10-2305753 B1	27 September 2021
		US 2023-0021399 A1	26 January 2023
		WO 2021-125630 A1	24 June 2021
KR 10-2019-0078434 A	04 July 2019	CN 111527232 A	11 August 2020
		EP 3733918 A1	04 November 2020
		EP 3733918 B1	31 August 2022
		JP 2021-508771 A	11 March 2021
		JP 2023-025076 A	21 February 2023
		JP 7244722 B2	23 March 2023
		KR 10-2031465 B1	11 October 2019
		MX 2020006698 A	20 August 2020
		US 11566314 B2	31 January 2023
		US 2021-0002751 A1	07 January 2021
		WO 2019-132336 A1	04 July 2019
KR 10-2012-0041619 A	02 May 2012	None	

Form PCT/ISA/210 (patent family annex) (July 2022)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2005105367 A [0005]