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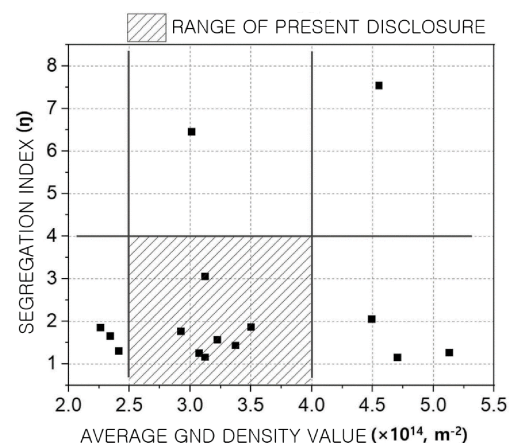
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(54) **HOT-ROLLED STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) The present invention relates to steel suitable for automobile chassis components and, more specifically, to a hot-rolled steel sheet having excellent shear formability and crack propagation resistance, and a manufacturing method therefor.

[FIG. 1]



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Description

Technical Field

5 **[0001]** The present disclosure relates to steel suitable for automotive chassis parts, and more particularly, to a hot-rolled steel sheet having excellent shear formability and crack propagation resistance, and a method for manufacturing the same.

Background Art

10 **[0002]** In the lower arm and upper arm having the highest degree of forming volume among conventional chassis parts, high-burring, high-strength hot-rolled steel sheets with a tensile strength of 590 to 780 MPa have primarily been used. A microstructure of such hot-rolled steel sheets may include a single-phase ferrite structure, a dual-phase composite structure of ferrite and bainite, or a composite structure in which ferrite, bainite, and martensite are mixed.
 15 Hot-rolled steel sheets having such a microstructure have excellent burring formability due to a small difference in hardness between phases.

[0003] As an example, Patent Documents 1 to 3 propose a method of simultaneously securing stretch flangeability and strength by forming a composite structure of polygonal ferrite and bainite by applying three-stage cooling, cooling, air cooling for a certain period of time, cooling again, and then coiling on a hot rolled steel sheet.

20 **[0004]** Stretch flangeability and strength of the hot-rolled steel sheet having such a composite structure are improved by utilizing alloy components, such as Si, Mn, Al, Cr, and Mo. However, excessive addition of the alloy components to achieve higher tensile strength leads to problems, such as segregation of the alloy components and non-uniformity of a microstructure. In addition, as the hardenability of the steel increases, different microstructures are formed depending on the cooling conditions, resulting in inconsistent strength, ductility, and stretch flangeability, and
 25 causing significant deviations.

[0005] In addition, an edge part of the hot-rolled steel sheet has a lower temperature after hot rolling than a center part of the hot-rolled steel sheet and a cooling rate is higher even when the hot-rolled steel sheet is cooled immediately after hot rolling, and therefore, a phase fraction of martensite or bainite increases significantly at the edge part of the hot-rolled steel sheet, resulting in inferiority in ductility, as well as bending workability and stretch flangeability. As
 30 such, when the formability of the edge part of the hot-rolled steel sheet deteriorates, the edge part must be removed, so there is a disadvantage that the productivity decreases due to unnecessary processes and the actual usage of the hot-rolled steel sheet is reduced, which is economically disadvantageous.

[0006] On the other hand, Patent Document 4 may be cited as a technology for a ferrite single-phase structural steel utilizing fine precipitate-forming elements, such as Ti, Nb, Mo, and V, while lowering the content of the aforementioned alloy components. Patent Document 4 discloses a method for securing strength by maximizing fine intragranular precipitation, which limits the formation of a second phase or prevents the formation of hard phases, such as marten-
 35 site, beforehand. However, Patent Document 4 requires that heating furnace conditions be constant, and if a high temperature is not uniformly maintained across the entire length and width of the rolled sheet during the rolling and cooling processes, precipitation behavior becomes non-uniform, failing to secure the intended strength and stretch flangeability. In addition, there is a problem in that fatigue cracks easily occur in a hole or an edge part when components obtained by forming such steel are used.

[0007] Meanwhile, recently, there has been a growing trend of applying an electric arc furnace operation utilizing steel scrap as a measure to minimize carbon emissions in the steelmaking process. However, steel materials utilizing steel scrap are highly likely to contain a large amount of impurity elements, and these impurity elements are likely to
 45 form oxides or be segregated at a surface layer and grain boundaries of steel, which may promote the occurrence and propagation of cracks. In this case, there is a concern that it may adversely affect a hole expansion ratio of the steel, but technical review for this is insufficient.

(Patent Document 1) Japanese Application Publication No. 1994-293910

50 (Patent Document 2) Korean Patent No. 10-1114672

(Patent Document 3) Korean Patent No. 10-1528084

(Patent Document 4) Japanese Application Publication No. 2003-321739

Disclosure of Invention

55 **[0008]** An aspect of the present disclosure is to provide a hot-rolled steel sheet having excellent shear formability

and crack propagation resistance so as to be suitably applied to parts requiring high formability among automobile chassis parts, etc. Another aspect of the present disclosure is to provide a method for manufacturing the hot-rolled steel sheet.

[0009] In addition, the technical problems to be solved by the present disclosure are not limited to those mentioned above, and other technical problems not mentioned herein will be clearly understood by those skilled in the art from the description below.

Solution to Problem

[0010] According to an aspect of the present disclosure, a hot-rolled steel sheet includes, by wt%, at least one selected from the group consisting of 0.030 to 0.080% of carbon (C), 0.01 to 1.00% of silicon (Si), 1.0 to 2.5% of manganese (Mn), 0.005 to 0.500% of chromium (Cr), 0.01 to 0.80% of aluminum (Al), 0.001 to 0.050% of phosphorus (P), 0.001 to 0.010% of sulfur (S), and 0.001 to 0.010% of nitrogen (N); at least one selected from the group consisting of 0.01 to 0.30% of copper (Cu), 0.010 to 0.200% of nickel (Ni), 0.100% or less of antimony (Sb), 0.100% or less of tin (Sn), and 0.100% or less of arsenic (As); and at least one selected from the group consisting of 0.050% or less of niobium (Nb), 0.120% or less of titanium (Ti), 0.300% or less of molybdenum (Mo), and 0.200% or less of vanadium (V), and a remainder of Fe and unavoidable impurities.

[0011] In an embodiment of the present disclosure, in the hot-rolled steel sheet, a T value defined in [Relational Expression 1] may satisfy 30.0 to 60.0, an X-value defined in [Relational Expression 2] may satisfy 0.300 to 0.800, and an A-value defined in [Relational Expression 3] may satisfy 10.000 or less.

$$T = 33.02 \times (1.07([C]/10)^{0.5}) \times (0.7[Si]+1) \times (5[Mn]+1) \times (2.16[Cr]+1) \times (3[Mo]+1) \times (0.36[Ni]+1) \times (0.35[Cu]+1) \quad \text{[Relational Expression 1]}$$

(In Relational Expression 1, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.)

$$X = ((Nb/93) + (Ti^*/48) + (V/51) + (Mo/96))/((C/12) + (N/14)) \quad \text{[Relational Expression 2]}$$

(In Relational Expression 2, Ti^* is calculated as $(Ti-3.42N-1.5S)$, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.)

$$\text{[Relational Expression 3]}$$

$$A = 85([Cu] + 3[Sb] + 2[As] + 3[Sn] - [Ni])^{1.2}$$

(In Relational Expression 3, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.)

[0012] According to an embodiment of the present disclosure, by controlling an alloy composition and alloy component relationship, an excellent hole expansion ratio, as well as high strength of the hot-rolled steel sheet, may be secured.

[0013] In an embodiment of the present disclosure, a microstructure of the hot-rolled steel sheet may satisfy a geometrical necessary dislocation density value in the range of $2.5 \times 10^{14} m^{-2}$ to $4.0 \times 10^{14} m^{-2}$.

[0014] According to an embodiment of the present disclosure, by controlling an average geometrical necessary dislocation (GND) density value of the microstructure, the hole expansion ratio of the hot-rolled steel sheet may be improved, thereby ensuring excellent formability, and particularly, shear formability, during the processing of the steel sheet.

[0015] In an embodiment of the present disclosure, the microstructure of the hot-rolled steel sheet may include 95% or more of a combined area fraction of ferrite and bainite phases, and the remainder of the microstructure may include one or more of martensite and pearlite phases.

[0016] In an embodiment of the present disclosure, the hot-rolled steel sheet may satisfy a segregation index (η) defined by Relational Expression (4) being 4.000 or less.

[Relational Expression 4]

$$[31] \eta = \eta_{\text{grain boundary}} / \eta_{\text{grain}}$$

(In Relational Expression 4, η_{grain} represents the sum of an average concentrations (at%) of segregated elements Cu, Sb, As, and Sn present within grains, and $\eta_{\text{grain boundary}}$ represents the sum of the average concentrations (at%) of segregated elements Cu, Sb, As, and Sn present at grain boundaries.)

[0017] In an embodiment of the present disclosure, the hot-rolled steel sheet may have a yield strength of 650 MPa or higher and may have a hole expansion ratio (HER) of 60% or more.

[0018] According to an aspect of the present disclosure, a method for manufacturing a hot-rolled steel sheet includes: preparing a steel slab; heating the steel slab in a temperature range of 1150 to 1350°C; hot-rolling the heated steel slab in a temperature range of 850 to 1150°C to obtain a hot-rolled steel sheet; and cooling the hot-rolled steel sheet and then coiling the hot-rolled steel sheet in a temperature range of 300 to 500°C.

[0019] In an embodiment of the present disclosure, the cooling may include primary cooling to a temperature range of 550 to 700°C at a cooling rate of 10 to 100°C/s; air cooling after the primary cooling; and secondary cooling to a temperature range of 300 to 500°C at a cooling rate of 10 to 100°C/s after the air cooling.

[0020] In an embodiment of the present disclosure, the coiled hot-rolled steel sheet may be pickled and oiled.

[0021] In an embodiment of the present disclosure, hot-dip galvanizing may be performed on the pickled and oiled hot-rolled steel sheet, and in this case, the galvanizing process may be performed after heating the hot-rolled steel sheet to a temperature range of 450 to 740°C.

[0022] The hot-dip galvanizing may be performed in a plating bath including 0.01 to 30.00 wt% of magnesium (Mg), 0.01 to 50.00 wt% of aluminum (Al), and a remainder of Zn and unavoidable impurities.

Advantageous Effects of Invention

[0023] According to an aspect of the present disclosure, the hot-rolled steel sheet having excellent shear formability and crack propagation resistance may be provided. In addition, the hot-rolled steel sheet according to the present disclosure may have high strength, while having an excellent hole expansion ratio.

[0024] The hot-rolled steel sheet of the present disclosure has the effect of being suitably applicable as a material for automobile chassis parts, in particular, lower arms, upper arms, and link parts, requiring the highest degree of forming.

Brief Description of Drawings

[0025] FIG. 1 is a graph illustrating the relationship between the average geometrical necessary dislocation (GND) density of a microstructure of a hot-rolled steel sheet and a segregation index (η) defined by Relational Expression 4, according to an embodiment of the present disclosure.

Best Mode for the Invention

[0026] The inventors of the present disclosure have conducted in-depth research to solve the problems of hot-rolled steel sheets that have been conventionally applied as materials for automobile chassis parts, while providing a hot-rolled steel sheet having suitable physical properties as materials of lower arms and upper arms having the highest degree of forming among automobile chassis parts.

[0027] Through repeated research, the inventors recognized that, when applying a hot-rolled steel sheet having a yield strength of 650 MPa or higher as the aforementioned materials, there should be no cracks in a hole and edge part of shear- and punched formed parts and it is necessary to suppress the propagation of micro-cracks to prevent fracture during forming or fatigue failure during the use of the parts.

[0028] In particular, the inventors investigated the physical properties (strength, ductility, and hole expansion ratio) of high-strength hot-rolled steel sheets having various alloy compositions and differing microstructures, based on the characteristics of the alloy compositions and microstructures, and noted that crack formation and propagation primarily occur at grain boundaries and their surroundings during the entire process of forming into parts and during the use of the parts.

[0029] Accordingly, the present disclosure has technical significance in terms of proposing a method for removing factors weakening grain boundaries and their surrounding structures when controlling the microstructure of hot-rolled steel sheets. In addition, the present disclosure was completed as a result of examining the dependence on alloy composition and microstructure in securing the strength and formability of the hot-rolled steel sheet.

[0030] The present disclosure will be described in detail below.

[0031] A hot-rolled steel sheet according to an aspect of the present disclosure may include, by wt%, 0.030 to

0.080% of carbon (C), 0.01 to 1.00% of silicon (Si), 1.0 to 2.5% of manganese (Mn), 0.005 to 0.500% of chromium (Cr), 0.01 to 0.80% of aluminum (Al), 0.001 to 0.050% of phosphorus (P), 0.001 to 0.010% of sulfur (S), and 0.001 to 0.010% of nitrogen (N); at least one selected from the group consisting of 0.01 to 0.30% of copper (Cu), 0.010 to 0.200% of nickel (Ni), 0.100% or less of antimony (Sb), 0.100% or less of tin (Sn), and 0.100% or less of arsenic (As); and at least one selected from the group consisting of 0.050% or less of niobium (Nb), 0.120% or less of titanium (Ti), 0.300% or less of molybdenum (Mo), and 0.200% or less of vanadium (V).

[0032] Hereinafter, the reasons for limiting the alloy composition of the hot-rolled steel sheet according to an embodiment of the present disclosure will be described in detail below. Meanwhile, unless otherwise specified, the content of each element is based on weight, and the proportion of the microstructure is based on area.

Carbon (C): 0.030 to 0.080%

[0033] Carbon (C) is the most economical and effective element for strengthening steel and has a significant influence on a hardness value and geometrical necessary dislocation density of each constituent phase, that is, a microstructure. As the content of C increases, the hardenability of the steel increases, leading to an increased phase fraction of hard phases, such as bainite and martensite, in the microstructure, thereby increasing tensile strength and geometrical necessary dislocation density of the steel. In addition, by forming fine precipitates through combination with elements, such as Ti and Nb having a high affinity for C, grain refinement is induced and the precipitation strengthening effect is increased, thereby increasing both yield strength and tensile strength of the steel.

[0034] In an embodiment of the present disclosure, if the content of C is less than 0.030%, the strengthening effect of the steel may not be sufficiently obtained, and during the manufacturing of the steel, ferrite phase transformation occurs rapidly during cooling after hot rolling, making it difficult to obtain a microstructure with high geometrical necessary dislocation density. On the other hand, if the content of C exceeds 0.080%, carbides, fine martensite phases, and MA (a mixed microstructure of martensite and austenite) phases are locally formed at the grain boundaries, causing the grain boundaries to become weak. Moreover, as the fraction of hard phases, such as bainite and martensite increases and the hardness value and geometrical necessary dislocation density of the phases also increase, the strength rises excessively, leading to a problem of reduced ductility and formability.

[0035] Accordingly, in an embodiment of the present disclosure, C may be included in an amount of 0.030 to 0.080%. According to another embodiment of the present disclosure, C may be 0.035% or more, or 0.040% or more. According to yet another embodiment, C may be included in an amount of 0.075% or less, or 0.070% or less.

Silicon (Si): 0.01 to 1.00%

[0036] Silicon (Si) is an element of deoxidizing molten steel, having a solid-solution strengthening effect, and being advantageous in improving the formability of steel by delaying the formation of coarse carbides at grain boundaries.

[0037] In an embodiment of the present disclosure, Si may be included in an amount of 0.01% or more to sufficiently obtain the aforementioned effect. On the other hand, if the content exceeds 1.00%, red scale caused by Si may be formed on the steel surface during hot rolling, resulting in very poor surface quality, and there may be a problem of reduced ductility and weldability of the steel.

[0038] Accordingly, in an embodiment of the present disclosure, Si may be included in an amount of 0.01 to 1.00%. According to another embodiment of the present disclosure, Si may be included in an amount of 0.20% or more, or 0.30% or more. According to yet another embodiment, Si may be included in an amount of 0.70% or less, or 0.60% or less.

Manganese (Mn): 1.0 to 2.5%

[0039] Manganese (Mn) is an effective element for solid solution strengthening of steel. In addition, Mn increases hardenability of steel, facilitating the formation of hard phases, such as bainite and martensite phases, during cooling after hot rolling. In addition, Mn has the effect of suppressing the formation of fine precipitates within grains, thereby preventing the grain boundaries and their surroundings from becoming relatively weakened.

[0040] In an embodiment of the present disclosure, if the content of Mn is less than 1.0%, the effect of adding Mn cannot be obtained. On the other hand, if the content exceeds 2.5%, hardenability of the steel increases significantly, the fraction of hard phases including bainite and martensite phases increases, and a hardness value and geometrical necessary dislocation density of the phases also increase, leading to an excessive increase in strength and a problem of reduced formability. Moreover, during the casting of a slab in a continuous casting process, a segregation zone develops significantly at the center of the thickness of the slab, which leads to the non-uniform formation of microstructures in the thickness direction during cooling after hot rolling, resulting in inferior stretch flangeability. In particular, it may become difficult to uniformly control the geometrical necessary dislocation density across the entire length

and width of the hot-rolled steel sheet during cooling.

[0041] Therefore, in an embodiment of the present disclosure, Mn may be included in an amount of 1.0 to 2.5%. According to another embodiment of the present disclosure, Mn may be included in an amount of 1.3% or more, or 1.5% or more. According to yet another embodiment, Mn may be included in an amount of 2.3% or less, or 2.2% or less.

Chromium (Cr): 0.005 to 0.500%

[0042] Chromium (Cr) strengthens steel through solid solution and delays phase transformation of ferrite during a cooling process, thereby suppressing the formation of polygonal ferrite with low geometrical necessary dislocation density, while inducing the formation of bainite.

[0043] In an embodiment of the present disclosure, if the content of Cr is less than 0.005%, the effect of the addition cannot be sufficiently obtained. On the other hand, if the content of Cr exceeds 0.500%, the ferrite transformation may be excessively delayed, leading to the excessive formation of martensite phases around grain boundaries, which results in inferior formability. In addition, similar to Mn, a segregation zone may develop significantly in the center of the steel in the thickness direction, causing the microstructure to become non-uniform in the thickness direction, which may lead to a risk of inferior stretch flangeability.

[0044] Accordingly, in an embodiment of the present disclosure, Cr may be included in an amount of 0.005 to 0.500%. According to another embodiment of the present disclosure, Cr may be included in an amount of 0.010% or more, or 0.015% or more. According to yet another embodiment, Cr may be included in an amount of 0.450% or less, or 0.400% or less.

Aluminum (Al): 0.01 to 0.80%

[0045] Aluminum (Al) is an element primarily added for deoxidation and has the effect of promoting ferrite transformation. Al refers to soluble aluminum (Sol.Al).

[0046] In an embodiment of the present disclosure, if the content of Al is less than 0.01%, the aforementioned effects cannot be sufficiently obtained. On the other hand, if the content of Al exceeds 0.80%, Al may combine with nitrogen (N) in the steel to form AlN, which may facilitate the occurrence of corner cracks in the slab during continuous casting and there may be a concern that defects due to the formation of inclusions may easily occur.

[0047] Therefore, in an embodiment of the present disclosure, Al may be included in an amount of 0.01 to 0.08%. According to another embodiment of the present disclosure, Al may be included in an amount of 0.02% or more, or 0.03% or more. According to yet another embodiment, Al may be included in an amount of 0.70% or less, or 0.60% or less.

Phosphorus (P): 0.001 to 0.050%

[0048] Phosphorus (P) is an element, similar to Si, having an effect of simultaneously providing solid solution strengthening and promoting ferrite transformation.

[0049] In an embodiment of the present disclosure, manufacturing with the content of P to be less than 0.001% incurs excessive manufacturing costs, which may be economically disadvantageous and may also be disadvantageous for obtaining a target level of strength. On the other hand, if the content of P exceeds 0.050%, there is a concern about brittleness due to grain boundary segregation, and the occurrence of micro-cracks during steel forming may become easier, leading to problems, such as deterioration of ductility, stretch flangeability, and impact resistance.

[0050] Accordingly, in an embodiment of the present disclosure, P may be included in an amount of 0.001 to 0.050%. According to another embodiment of the present disclosure, P may be included in an amount of 0.005% or more, or 0.008% or more. According to yet another embodiment, P may be included in an amount of 0.030% or less, or 0.015% or less.

Sulfur (S): 0.001 to 0.010%

[0051] Sulfur (S) is an impurity inevitably present in steel. In an embodiment of the present disclosure, if the S content exceeds 0.010%, S may combine with Mn, etc. in the steel to form non-metallic inclusions, which makes it prone to micro-cracks during the cutting process of the steel and causes problems that significantly impair stretch flangeability and impact resistance.

[0052] In an embodiment of the present disclosure, the lower limit of the S content is not particularly limited. However, reducing the S content to less than 0.001% requires a significant amount of time during the steelmaking process, which leads to a problem of decreased productivity.

[0053] Therefore, in an embodiment of the present disclosure, S may be included in an amount of 0.001 to 0.010%. According to another embodiment of the present disclosure, S may be included in an amount of 0.002% or more, and according to yet another embodiment, S may be included in an amount of 0.005% or less.

5 Nitrogen (N): 0.001 to 0.010%

[0054] Nitrogen (N) is a representative solid solution strengthening element along with C in the steel. N may combine with Ti, Al, etc. in the steel to form coarse precipitates. Generally, the solid solution strengthening effect of N is similar to that of C; however, since there is a problem in which toughness of the steel decreases significantly as the content of N in the steel increases, the content of N may be limited to 0.010% or less.

[0055] In an embodiment of the present disclosure, reducing the content of N to less than 0.001% requires a significant amount of time during the steelmaking operation, which leads to a problem of decreased productivity.

[0056] Therefore, in an embodiment of the present disclosure, N may be included in an amount of 0.001 to 0.010%. According to another embodiment of the present disclosure, N may be included in an amount of 0.002% or more, and according to yet another embodiment, N may be included in an amount of 0.008% or less.

[0057] The hot-rolled steel sheet according to an embodiment of the present disclosure may further include the following elements in addition to the alloy composition described above.

[0058] As an example, the hot-rolled steel sheet according to an embodiment of the present disclosure may further comprise at least one selected from the group consisting of 0.01 to 0.30% of copper (Cu), 0.010 to 0.200% of nickel (Ni), 0.100% or less of antimony (Sb), 0.100% or less of tin (Sn), and 0.100% or less of arsenic (As), and as another example, the hot-rolled steel sheet according to an embodiment of the present disclosure may further comprise at least one selected from the group consisting of 0.050% or less of niobium (Nb), 0.120% or less of titanium (Ti), 0.300% or less of molybdenum (Mo), and 0.200% or less of vanadium (V).

25 Copper (Cu): 0.01 to 0.30%

[0059] Copper (Cu) has the effect of improving hardenability of steel. When adding Cu to obtain this effect, according to an embodiment of the present disclosure, Cu may be included in an amount of 0.01% or more. However, if the content of Cu is excessive, intergranular cracking may occur in the slab. Therefore, in an embodiment of the present disclosure, Cu may be included in an amount of 0.30% or less.

[0060] In another embodiment of the present disclosure, when Cu is added, Cu may be included in an amount of 0.03% or more, or 0.05% or more, and in yet another embodiment, Cu may be included in an amount of 0.20% or less.

Nickel (Ni): 0.010 to 0.200%

[0061] Nickel (Ni) is an element advantageous for improving hardenability of steel, and when added together with Cu, Ni has the effect of suppressing intergranular cracking in the slab caused by Cu.

[0062] In an embodiment of the present disclosure, Ni may be included in an amount of 0.010% or more in terms of obtaining the effect of adding Ni. Since Ni is an expensive element and an excessive content of Ni may be economically disadvantageous. In consideration of this, Ni may be included in an amount of 0.200% or less.

[0063] Accordingly, in an embodiment of the present disclosure, Ni may be included in an amount of 0.010 to 0.200% when added. According to another embodiment of the present disclosure, Ni may be included in an amount of 0.050% or more, and according to yet another embodiment, Ni may be included in an amount of 0.150% or less.

45 Antimony (Sb): 0.100% or less

[0064] According to an embodiment of the present disclosure, antimony (Sb) may inevitably be included in steel as iron scrap is used. When Sb is included at an appropriate level, it exists in a solid solution state in the steel and causes solid solution strengthening, thereby improving the strength of the steel.

[0065] In an embodiment of the present disclosure, when Sb is added such that the content thereof satisfies Relational Expression 3 described below, the intended effects of adding Sb may be achieved. Thus, the lower limit of the content of Sb is not particularly limited and may be, for example, greater than 0%. However, if the content of Sb exceeds 0.100%, an effect of suppressing the formation of red scale (Fayalite, Fe_2SiO_4) caused by Si may be obtained; however, as this effect acts only locally, defects caused by the red scale may become even more non-uniform and there is a concern that Sb may locally enrich on the steel surface, leading to surface defects.

[0066] Therefore, in an embodiment of the present disclosure, when adding Sb, Sb may be included in an amount greater than 0% to 0.100% or less. According to another embodiment of the present disclosure, Sb may be 0.003% or more, or 0.005% or more, and according to yet another embodiment, Sb may be 0.080% or less.

Tin (Sn): 0.100% or less

[0067] According to an embodiment of the present disclosure, tin (Sn) may inevitably be included in the steel due to the use of iron scrap. Sn has a solid solution strengthening effect similar to that of Sb.

[0068] In an embodiment of the present disclosure, when Sn is added such that the content thereof satisfies Relational Expression 3 described below, the intended effects of adding Sn may be achieved, and thus, the lower limit of the content of Sn is not particularly limited and may be, for example, greater than 0%. However, if Sn is present in an excessive amount, there is a concern that surface defects of the steel may increase due to the characteristics of Sn to enrich on the surface, and therefore, the content of Sn may be limited to 0.100% or less.

[0069] Accordingly, in an embodiment of the present disclosure, Sn may be included in an amount greater than 0% to 0.100% or less. According to another embodiment of the present disclosure, Sn may be 0.001% or more, or 0.003% or more, and according to yet another embodiment, Sn may be 0.080% or less.

Arsenic (As): 0.100% or less

[0070] According to an embodiment of the present disclosure, arsenic (As) may inevitably be included in the steel due to the use of iron scrap. As has a solid solution strengthening effect similar to that of Sb and Sn.

[0071] In an embodiment of the present disclosure, when As is added such that the content thereof satisfies Relational Expression 3 described below, the intended effect of adding As may be achieved, and thus, the lower limit of the content of As is not particularly limited and may be, for example, greater than 0%. On the other hand, As is an element tending to segregate on the steel surface and grain boundaries. If the content of As is excessive, ductility of the steel may become inferior, and there is a concern that surface defects may occur. In consideration of this, the content of As may be limited to 0.100% or less.

[0072] Accordingly, in an embodiment of the present disclosure, when As is added, As may be included in an amount greater than 0% to 0.100% or less. According to another embodiment of the present disclosure, As may be 0.005% or more, or 0.010% or more, and according to yet another embodiment, As may be 0.080% or less.

[0073] In the hot-rolled steel sheet according to an embodiment of the present disclosure, elements, such as tungsten (W), tantalum (Ta), zirconium (Zr), yttrium (Y), lanthanum (La), and cerium (Ce), which are rare-earth metals (REM) other than Sb, Sn, and As, may be further present. If these elements are present in excess within the hot-rolled steel sheet, inclusions may be formed to adversely affect the intended physical properties. Accordingly, in an embodiment of the present disclosure, the above elements may be limited to 0.020% or less based on the sum of the contents of each element.

Niobium (Nb): 0.050% or less

[0074] Niobium (Nb) is a representative precipitation-strengthening element along with titanium (Ti) and vanadium (V) to be described below. Nb precipitates during hot rolling and is effective in improving the strength and impact toughness of steel through the grain refinement effect caused by delayed recrystallization.

[0075] In an embodiment of the present disclosure, if Nb is added such that the content thereof satisfies Relational Expression 2 described below, the intended effect of adding Nb may be achieved, and thus, the lower limit of the Nb content is not particularly limited and may be, for example, greater than 0%. However, if the content exceeds 0.050%, excessive delayed recrystallization may occur during rolling, leading to the formation of elongated grains and the formation of coarse composite precipitates, which may result in a problem of inferior stretch flangeability of the steel.

[0076] Accordingly, in an embodiment of the present disclosure, Nb may be included in an amount greater than 0% to 0.050% or less. According to another embodiment of the present disclosure, Nb may be 0.005% or more, or 0.010% or more, and according to yet another embodiment, Nb may be 0.040% or less.

Titanium (Ti): 0.120% or less

[0077] Titanium (Ti) is a representative precipitation strengthening element along with Nb and V and forms coarse TiN in steel due to its strong affinity for nitrogen (N) in steel. TiN has the effect of inhibiting grain growth during a heating process of steel slabs for hot rolling. In addition, Ti remaining after reacting with nitrogen is dissolved in the steel and combines with carbon to form TiC precipitates, thereby serving as a useful component for improving the strength of the steel.

[0078] In an embodiment of the present disclosure, when Ti is added such that the content thereof satisfies Relational Expression 2 described below, the intended effect of adding Ti may be achieved, and thus, the lower limit of the Ti content is not particularly limited and may be, for example, greater than 0%. However, if the content of Ti exceeds 0.120%, the formation of coarse precipitates may lead to a problem of inferior stretch flangeability of the steel.

[0079] Therefore, in an embodiment of the present disclosure, when Ti is added, Ti may be included in an amount greater than 0% to 0.120% or less. According to another embodiment of the present disclosure, Ti may be 0.005% or more, or 0.010% or more, and according to yet another embodiment, Ti may be 0.115% or less.

5 Molybdenum (Mo): 0.300% or less

[0080] Molybdenum (Mo) increases hardenability of steel and has the effect of helping to form fine precipitates. Mo facilitates the formation of a bainite phase in the structure of the steel, thereby contributing to an improvement in the strength of the steel.

10 **[0081]** In an embodiment of the present disclosure, if Mo is added such that the content thereof satisfies Relational Expression 2 described below, the intended effect of adding Mo may be achieved, and thus, the lower limit of the Mo content is not particularly limited and may be, for example, greater than 0%. However, if the content of Mo exceeds 0.300%, hardenability may become excessive, leading to the formation of an excessive amount of martensite phase, which causes a sharp deterioration in the formability of the steel. In addition, as Mo is an expensive element, an increase in the content thereof may be economically disadvantageous and also adversely affect weldability.

15 **[0082]** Therefore, in an embodiment of the present disclosure, the amount of Mo added may be greater than 0% to 0.300% or less. According to another embodiment of the present disclosure, Mo may be 0.005% or more, or 0.010% or more, and according to yet another embodiment, Mo may be 0.250% or less, or 0.200% or less.

20 Vanadium (V): 0.200% or less

[0083] Vanadium (V) is a representative precipitation strengthening element along with the aforementioned Nb and Ti. Vanadium (V) hardly precipitates during hot rolling, but forms precipitates during a cooling process after coiling to improve the strength of the steel. Therefore, vanadium (V) is advantageous for further improving strength without increasing deformation resistance and rolling load due to delayed recrystallization during hot rolling.

25 **[0084]** In an embodiment of the present disclosure, if V is added such that the content thereof satisfies Relational Expression 2 described below, the intended effect of adding V may be achieved, and thus, the lower limit of the V content is not particularly limited and may be, for example, greater than 0%. However, if the content of V exceeds 0.200%, coarse precipitates may be formed, which leads to inferior stretch flangeability of the steel, and since V is an expensive element, it is also economically disadvantageous.

30 **[0085]** Therefore, in an embodiment of the present disclosure, V may be included in an amount greater than 0% to 0.200% or less. According to another embodiment of the present disclosure, V may be 0.003% or more, or 0.005% or more, and according to yet another embodiment, V may be 0.150% or less.

35 **[0086]** The remainder of the present disclosure is iron (Fe). However, in a normal manufacturing process, unintended impurities from raw materials or the surrounding environment may inevitably be incorporated, and thus cannot be excluded. Since these impurities are well-known to any person skilled in the art of conventional manufacturing processes, specific details thereof are not explicitly mentioned in the present specification.

[0087] The hot-rolled steel sheet according to an embodiment of the present disclosure may include the aforementioned alloy elements, and the relationship between some of the alloy elements may be limited under specific conditions.

40 **[0088]** In an embodiment of the present disclosure, the content relationships of C, Si, Mn, Cr, Mo, Ni, and Cu in the alloy composition may be defined by Relational Expression 1 below. According to an embodiment of the present disclosure, a T value defined by Relational Expression 1 below may be 30.0 to 60.0.

45
$$T = 33.02 \times (1.07/[C]/10)^{0.5} \times (0.7[Si]+1) \times (5[Mn]+1) \times (2.16[Cr]+1) \times (3[Mo]+1) \times (0.36[Ni]+1) \times (0.35[Cu]+1)$$
 [Relational Expression 1]

(In Relational Expression 1, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.)

50 **[0089]** As a result of repeated research by the inventors of the present disclosure, a combination of specific alloy elements has been parameterized as Relational Expression 1 to maintain an appropriate level of geometrical necessary dislocation density in the microstructure of the hot-rolled steel sheet and to prevent localized deviations.

[0090] According to an embodiment of the present disclosure, as the T value of Relational Expression 1 increases, the hardenability of the steel increases and the localized deviation of the microstructure also increases. Specifically, if the T value exceeds 60.0, a martensite phase may be formed in the microstructure, increasing the hardness difference between phases, making it difficult to secure the burring property of the steel and may result in insufficient elongation. Furthermore, the microstructure becomes non-uniform in a position in the width direction of the hot-rolled steel sheet, leading to increased material property deviations. On the other hand, if the T value is less than 30.0, the hardenability

of the steel may be insufficient, and the geometrical necessary dislocation density of the formed microstructure may not be high enough, which may result in low resistance to crack propagation and a decrease in strength.

[0091] Accordingly, in an embodiment of the present disclosure, the T value defined by Relational Expression 1 may be 30.0 to 60.0. According to another embodiment of the present disclosure, the T value may be 35.0 or higher, and according to yet another embodiment, the T value may be 55.0 or lower.

[0092] In an embodiment of the present disclosure, the content relationships between C, N, S, Nb, Ti, V, and Mo in the alloy composition may be defined by Relational Expression 2 below. According to an embodiment of the present disclosure, A-value X defined by Relational Expression 2 below may be 0.300 to 0.800.

$$X = ((\text{Nb}/93) + (\text{Ti}^*/48) + (\text{V}/51) + (\text{Mo}/96))/((\text{C}/12) + (\text{N}/14)) \quad [\text{Relational Expression 2}]$$

(In Relational Expression 2, Ti^* is calculated as $(\text{Ti} - 3.42\text{N} - 1.5\text{S})$, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.)

[0093] Relational Expression 2 according to an embodiment of the present disclosure is a parameterization of the relationship between elements affecting precipitate formation.

[0094] In an embodiment of the present disclosure, if the X-value according to Relational Expression 2 is less than 0.300, grain growth may occur rapidly during slab heating, and recrystallization may become non-uniform during hot rolling, resulting in the formation of locally coarse grains and a non-uniform final microstructure. In addition, the precipitation strengthening effect may be insufficient, leading to inferior strength and formability of the steel. On the other hand, if the X-value exceeds 0.800, the formation of precipitates in the austenite region may increase during hot rolling, causing excessive recrystallization delay during hot rolling, making it easy to form a microstructure elongated in the rolling direction. This reduces the elongation in the vertical direction of rolling, and, although fine precipitates within ferrite grains increase during the phase transformation process upon cooling, regions in which precipitates are not formed relatively exist at the boundaries between grain boundaries and grain interiors, making the grain boundaries and their surroundings vulnerable. In addition, during the cooling of the hot-rolled steel sheet, a shortage of solute carbon (C) and solute nitrogen (N) atoms within the untransformed phase makes it difficult to stably form hard phases. As a result, the quality of the sheared surface during a shearing process of the steel becomes inferior, and the burring formability also deteriorates.

[0095] Accordingly, in an embodiment of the present disclosure, the X-value defined by Relational Expression 2 may be 0.300 to 0.800. According to another embodiment of the present disclosure, the X-value may be 0.350 or higher, and according to yet another embodiment, the X-value may be 0.750 or lower.

[0096] In an embodiment of the present disclosure, the content relationship between Cu, Sb, As, Sn, and Ni in the alloy composition may be defined by Relational Expression 3 below. According to an embodiment of the present disclosure, an A-value defined by Relational Expression 3 below may be 10.000 or lower.

[Relational Expression 3]

$$A = 85 ([\text{Cu}] + 3[\text{Sb}] + 2[\text{As}] + 3[\text{Sn}] - [\text{Ni}])^{1.2}$$

(In Relational Expression 3, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.)

[0097] Relational Expression 3 according to an embodiment of the present disclosure is a parameterization of the relationship between elements that, while increasing the hardenability of steel and providing solid solution strengthening effects, are likely to cause defects during the steel manufacturing process due to their characteristics of segregation in the surface layer or grain boundaries of steel and their low melting point. That is, if the content of these elements is excessive, they weaken the grain boundaries, leading to a problem in which cracks easily occur and propagate in the shear-formed area during the shearing process of steel.

[0098] In an embodiment of the present disclosure, if the A-value defined by Relational Expression 3 exceeds 10.000, the segregation of Cu, Sb, As, and Sn at the grain boundaries becomes excessive. Consequently, the grain boundaries in the microstructure become more vulnerable than the interior of the grains, making it easier for micro-cracks to occur during shear forming of the steel and resulting in inferior resistance to crack propagation.

[0099] Therefore, in an embodiment of the present disclosure, the A-value according to Relational Expression 3 may be 10.000 or less. In an embodiment of the present disclosure, since each element of Relational Expression 3 may inevitably be present or optionally added, the lower limit of the A-value is not particularly limited.

[0100] According to an embodiment of the present disclosure, a hot-rolled steel sheet in which the relationship between segregation elements existing at the grain boundaries and within the grains of the microstructure is controlled may be provided.

[0101] In an embodiment of the present disclosure, the relationship between segregated elements in the microstruc-

ture may be defined by the segregation index (η) of Relational Expression (4) below, which may be expressed as a concentration ratio of elements present at the grain boundaries and elements present within the grains.

[Relational Expression 4]

$$\eta = \eta_{\text{grain boundary}} / \eta_{\text{grain}}$$

(In Relational Expression 4, η_{grain} represents the sum of the average concentrations (at%) of segregated elements Cu, Sb, As, and Sn present within the grains, and $\eta_{\text{grain boundary}}$ represents the sum of the average concentrations (at%) of segregated elements Cu, Sb, As, and Sn present at the grain boundaries.)

[0102] As an embodiment of the present disclosure, the value of the segregation index (η) defined by Relational Expression 4 may be 4.000 or less. The value of η exceeding 4.000 indicates that the segregation of Cu, Sb, As, and Sn at the grain boundaries is excessive, which ultimately leads to the problem of facilitating crack occurrence and propagation in the shear-formed area during the processing of the steel.

[0103] In an embodiment of the present disclosure, the average concentration of segregated elements Cu, Sb, As, and Sn present within the grains and at the grain boundaries may be measured using a 3-dimensional atomic probe. As a non-limiting example, a specimen including both grain interiors and grain boundaries may be taken at a 1/4t point (in which t denotes the thickness (mm) of the hot-rolled steel sheet) in the thickness direction of the hot-rolled steel sheet, and then the concentration of each component may be measured.

[0104] Hereinafter, the microstructure characteristics of the hot-rolled steel sheet according to an embodiment of the present disclosure will be described in detail.

[0105] In an effort to improve the shear formability of the hot-rolled steel sheet according to an embodiment of the present disclosure, the inventors of the present disclosure recognized that, when approaching the issue from the perspective of the microstructure characteristics of the hot-rolled steel sheet, there are limitations in clearly distinguishing excellence in shear formability and stability in punching clearance fluctuations based solely on the ratio of the constituent phases in the microstructure. Accordingly, through repeated research, the inventors discovered that not only the phase composition of the microstructure of the hot-rolled steel sheet but also the geometrically necessary dislocation (GND) density of the microstructure is a critical factor influencing the occurrence of micro-cracks on the sheared surface of the hot-rolled steel sheet.

[0106] Accordingly, the hot-rolled steel sheet according to an embodiment of the present disclosure may satisfy the GND density value in the range of $2.5 \times 10^{14} \text{m}^{-2}$ to $4.0 \times 10^{14} \text{m}^{-2}$. If the GND density value of the microstructure is less than $2.5 \times 10^{14} \text{m}^{-2}$, the strength of the hot-rolled steel sheet is insufficient, making it difficult to secure a target material. On the other hand, if the value exceeds $4.0 \times 10^{14} \text{m}^{-2}$, the strength of the steel increases significantly and a martensite phase is locally formed, increasing the hardness difference between phases, which leads to problems, such as an increase in micro-crack occurrence during steel processing, for example, during punching and shear forming, and a decrease in resistance to crack propagation.

[0107] In an embodiment of the present disclosure, the GND density of the microstructure may be measured using electron backscattered diffraction (EBSD) (JEOL JSM-7001F) based on a cross-section parallel to the rolling direction at a 1/4t point (in which t denotes the thickness (mm) of the hot-rolled steel sheet) in the thickness direction of the hot-rolled steel sheet. As an example, the GND density may be measured using Kernel Average Misorientation (KAM) data based on the results analyzed at a magnification of 1,000 to 3,000. As a non-limiting example, it may be calculated through the [Equation] below, and for convenience, software capable of analyzing EBSD measurement results, such as OIM Analysis™ (EDAX), may be used for this calculation.

[Equation]

$$\text{Average GND density value (m}^{-2}\text{)} = 2\theta/ub$$

(In Equation, θ represents the KAM value, u represents a unit length (step size in the EBED measurement), and b represents a burgers vector.)

[0108] The hot-rolled steel sheet according to an embodiment of the present disclosure may include ferrite and bainite phases as main phases in the microstructure, and the main phases may have an area fraction of 95% or more.

[0109] In an embodiment of the present disclosure, if the main phases are formed with an area fraction of less than 95%, the shear formability and crack propagation resistance of the hot-rolled steel sheet cannot be secured.

[0110] In an embodiment of the present disclosure, the respective area fractions of the ferrite and bainite phases

constituting the main phase are not particularly limited, and an embodiment of the present disclosure may be achieved by satisfying the limitation of the combined fraction of these phases.

[0111] In addition, the main phase may refer to one or more phases of ferrite and bainite, and as an example, the main phase may consist solely of the bainite phase.

[0112] In an embodiment of the present disclosure, the remainder microstructure excluding the main phase may be one or more of a martensite phase and a pearlite phase, and in this case, the pearlite may include coarse carbides. The martensite phase is a harder phase than the bainite phase and, if formed locally, may have an adverse effect on burring formability. Accordingly, the area fraction of the martensite phase may be limited to 5% or less.

[0113] Meanwhile, the hot-rolled steel sheet according to an embodiment of the present disclosure contains almost no MA (martensite and austenite composite phase) phase or residual austenite phase in its microstructure. However, since the MA phase is a harder phase than the bainite phase, if the MA phase is present in the hot-rolled steel sheet, the MA phase may be regarded as a martensite phase.

[0114] The hot-rolled steel sheet according to an embodiment of the present disclosure may have high strength and excellent hole expansion ratio.

[0115] As an example, the hot-rolled steel sheet may have a yield strength of 650 MPa or higher and a hole expansion ratio (HER) of 60% or higher. In this case, hole expansion ratio refers to the average value of result values obtained by applying different punching clearances (cl) of 5%, 10%, and 20%, respectively.

[0116] Hereafter, a method for manufacturing a hot-rolled steel sheet according to another aspect of the present disclosure will be described in detail. It should be noted that the following manufacturing method corresponds to an example for manufacturing a hot-rolled steel sheet according to an embodiment of the present disclosure.

[0117] According to an embodiment of the present disclosure, a hot-rolled steel sheet may be manufactured by subjecting a prepared steel slab to a process of [heating - hot rolling - cooling - coiling], and each process step is described in detail below.

[Heating of Steel Slab]

[0118] After preparing a steel slab according to an embodiment of the present disclosure, the steel slab may be heated. A heating process of the steel slab is a process of facilitating the hot rolling process described below. As an example, the steel slab may have the same alloy composition and alloy component relationship as those of the hot-rolled steel sheet according to an embodiment of the present disclosure, and the descriptions of each alloy element and each component relationship are replaced by the descriptions provided above.

[0119] In an embodiment of the present disclosure, the heating of the steel slab may be performed in a temperature range of 1150 to 1350°C. If the heating temperature is below 1150°C, precipitates are not sufficiently re-dissolved, resulting in reduced formation of precipitates in subsequent processes after the hot rolling process. In addition, due to the presence of coarse TiN, the slab is not sufficiently heated, making it difficult to control the temperature of the steel sheet consistently during subsequent hot rolling. On the other hand, if the temperature exceeds 1350°C, the strength is reduced due to abnormal grain growth of the austenite crystal grains.

[Hot Rolling]

[0120] The heated steel slab may be hot-rolled to obtain a hot-rolled steel sheet.

[0121] In an embodiment of the present disclosure, the hot rolling may be performed in a temperature range of 850 to 1150°C. If the hot rolling is initiated at a temperature exceeding 1150°C, the temperature of the hot-rolled steel sheet increases, causing the grain size to become coarser and potentially degrading the surface quality of the hot-rolled steel sheet. Conversely, if the hot rolling is terminated at a temperature lower than 850°C, excessive recrystallization delay occurs, leading to severe anisotropy due to the development of elongated grains and poor formability. In addition, the shape quality of the rolled sheet deteriorates.

[Cooling]

[0122] The hot-rolled steel sheet obtained by the hot rolling may be cooled.

[0123] In an embodiment of the present disclosure, the cooling may be performed as step-by-step cooling. As an example, the step-by-step cooling may be a process in which the hot-rolled steel sheet is cooled at a constant cooling rate, then air-cooled within a specific temperature range, and then cooled again at a constant cooling rate.

[0124] In an embodiment of the present disclosure, the step-by-step cooling may include an operation of primary cooling a hot-rolled steel sheet to a temperature range of 550 to 700°C at a cooling rate of 10 to 100°C/s; an operation of air cooling after the primary cooling; and an operation of secondary cooling to a temperature range of 300 to 500°C at a cooling rate of 10 to 100°C/s after the air cooling.

[0125] If the cooling rate during the first and secondary cooling is less than 10°C/s, the fraction of polygonal ferrite phases becomes excessive, and the average GND density of the microstructure becomes less than $2.5 \times 10^{14} \text{m}^{-2}$, which is disadvantageous for securing strength. In addition, the length of the cooling equipment must be increased, which is economically disadvantageous. On the other hand, if the cooling rate exceeds 100°C/s, the average GND density of the microstructure exceeds $4.0 \times 10^{14} \text{m}^{-2}$, and the burring formability becomes inferior due to the excessively high strength of the steel.

[0126] If a cooling end temperature during the primary cooling is less than 550°C, there is a concern that the hard phase may be excessively formed in subsequent processes, leading to an excessive increase in strength; conversely, if the temperature exceeds 700°C, there is a concern that the polygonal ferrite phase may be excessively formed.

[0127] After completing the primary cooling, an air cooling process may be performed. According to an embodiment of the present disclosure, the air cooling may be performed for 2 to 8 seconds. Through the air cooling process, fine precipitates and ferrite may be formed within the hot-rolled steel sheet, thereby ensuring a balance between strength, ductility, and hole expansion ratio. If the air cooling time exceeds 8 seconds, the final microstructure consists mainly of ferrite or bainitic ferrite phases, which results in a problem in which the improvement effect on shear formability and crack propagation resistance cannot be obtained and the strength becomes insufficient.

[0128] After completing the air cooling process, secondary cooling may be performed up to a temperature range of a coiling process described below. An end temperature of the secondary cooling is replaced by the description in the coiling process below.

[Coiling]

[0129] The cooled hot-rolled steel sheet may be coiled.

[0130] In an embodiment of the present disclosure, coiling may be performed in a temperature range of 300 to 500°C. If the temperature during the coiling is below 300°C, the martensite phase is excessively formed in the microstructure, causing the strength of the steel to increase excessively. On the other hand, if the temperature exceeds 500°C, the bainite phase is not sufficiently formed in the microstructure, carbides are formed at the grain boundaries, making it impossible to secure the intended physical properties and resulting in inferior shear formability.

[0131] According to an embodiment of the present disclosure, a hot-rolled steel sheet may be manufactured through the aforementioned series of processes, and the hot-rolled steel sheet may have high strength and excellent hole expandability. As a result, the shear formability of the hot-rolled steel sheet is excellent during processing, and excellent resistance to crack propagation may also be secured.

[0132] According to an embodiment of the present disclosure, an operation of pickling and oiling the hot-rolled steel sheet manufactured through the series of processes may be further included.

[0133] In an embodiment of the present disclosure, an operation of hot-dip galvanizing the hot-rolled steel sheet that has undergone the pickling and oiling operation may be further included.

[0134] As a non-limiting example, the hot-dip galvanizing operation may be performed after heating the hot-rolled steel sheet to a temperature range of 450 to 740°C, and a zinc-based plating bath may be used. As an example, it should be noted that the zinc-based plating bath may be a plating bath containing 0.01 to 30.00 wt% of magnesium (Mg), 0.01 to 50.00 wt% of aluminum (Al), and the remainder being Zn and unavoidable impurities, but is not limited thereto.

Mode for the Invention

[0135] Hereinafter, the present disclosure will be described in more detail through examples. However, it should be noted that the following examples are only for illustrating the present disclosure in more detail and are not intended to limit the scope of the present disclosure. This is because the scope of the present disclosure is determined by the matters described in the claims and matters reasonably inferred therefrom.

(Examples)

[0136] Steel slabs having the alloy compositions of Table 1 and the component relational expressions of Table 2 were prepared, heat-treated at 1150 to 1350°C, finished hot-rolled at the temperatures illustrated in Table 3, and then subjected to a series of cooling and coiling processes to manufacture respective hot-rolled steel sheets.

[0137] For each hot-rolled steel sheet, the phase types and fractions of the microstructure and the average GND density values were measured, and mechanical properties were also measured and are illustrated in Table 4 and Table 5.

[0138] At this time, the microstructure was analyzed after collecting specimens from positions corresponding to 1/4t to 1/2t in the thickness direction with respect to the cross-section in the rolling direction of each hot-rolled steel sheet.

To distinguish each phase and measure the area fraction, electron backscattered diffraction (EBSD) (JEOL JSM-7001F) equipment was used for each specimens, and analysis was performed at magnifications of 3,000 to 5,000.

[0139] The average GND for the observed microstructure was determined using OIM analysis™ (EDAX) after the EBSD measurement, based on a cross-section parallel to the rolling direction at the 1/4t position in the thickness direction of each hot-rolled steel sheet.

[0140] In addition, the average concentrations of segregated elements Cu, Sb, As, and Sn present within the grains and at the grain boundaries were measured using a 3-dimensional atomic force microscope (3-dimensional Atom Probe, LA-WATAP, Spatial Resolution: 0.2 nm). In this case as well, specimens were collected at the 1/4t position in the thickness direction of the hot-rolled steel sheet, and the concentrations of each component were measured.

[0141] Meanwhile, the mechanical properties of each hot-rolled steel sheet were evaluated through a tensile test and a hole expansion ratio test.

[0142] In the tensile test, yield strength (off-set yield strength, YS), tensile strength (TS), and fracture elongation (T-EI) were measured, and specimens were collected in a direction perpendicular to the rolling direction according to the JIS No. 5 standard, and then measured using a universal tensile testing machine (UTM-600kN, Zwick)

[0143] In addition, the hole expansion ratio (HER) test was conducted, based on the JFST 1001-1996 standard, by applying different punching clearances (cl) of 5%, 10%, and 20%. Each HER evaluation value was calculated by taking the average of three individual measurements and averaging them.

Steel No .	Alloy composition (wt%)																
	C	Si	Mn	Cr	Mo	Nb	Ti	V	Cu	Ni	Sb	As	Sn	Al	P	S	N
1	0.055	0.30	1.2	0.01	0.05	0.020	0.10	0.003	0.01	0.005	0.006	0.020	0.005	0.03	0.009	0.004	0.006
2	0.060	0.30	2.0	0.03	0.10	0.020	0.10	0.003	0.08	0.110	0.005	0.007	0.050	0.04	0.008	0.002	0.004
3	0.055	0.30	1.9	0.01	0.03	0.003	0.07	0.003	0.10	0.100	0.010	0.020	0.010	0.04	0.008	0.002	0.008
4	0.055	0.30	1.9	0.01	0.15	0.020	0.13	0.050	0.10	0.100	0.010	0.020	0.010	0.04	0.008	0.002	0.008
5	0.060	0.10	1.5	0.01	0.01	0.015	0.07	0.002	0.06	0.080	0.010	0.020	0.010	0.03	0.009	0.002	0.006
6	0.045	0.30	2.0	0.03	0.20	0.020	0.10	0.003	0.09	0.090	0.010	0.008	0.009	0.04	0.010	0.004	0.006
7	0.060	0.30	1.9	0.01	0.01	0.020	0.12	0.003	0.12	0.090	0.050	0.050	0.009	0.04	0.010	0.004	0.006
8	0.055	0.30	2.0	0.40	0.15	0.020	0.12	0.003	0.10	0.080	0.030	0.010	0.060	0.04	0.010	0.004	0.005
9	0.055	0.05	1.9	0.01	0.10	0.020	0.12	0.003	0.10	0.080	0.010	0.010	0.010	0.03	0.010	0.003	0.006
10	0.055	0.30	1.9	0.01	0.01	0.020	0.11	0.050	0.03	0.011	0.012	0.006	0.008	0.03	0.009	0.002	0.006
11	0.050	0.30	2.0	0.01	0.05	0.020	0.10	0.003	0.10	0.120	0.010	0.005	0.020	0.03	0.010	0.004	0.005
12	0.060	0.30	1.7	0.20	0.01	0.020	0.10	0.003	0.03	0.090	0.005	0.010	0.032	0.03	0.011	0.006	0.006
13	0.050	0.30	1.7	0.30	0.01	0.020	0.10	0.003	0.09	0.100	0.004	0.020	0.030	0.03	0.012	0.008	0.005
14	0.050	0.30	1.9	0.01	0.10	0.020	0.11	0.003	0.02	0.050	0.005	0.022	0.041	0.03	0.013	0.010	0.006
15	0.060	0.30	1.7	0.01	0.20	0.020	0.10	0.003	0.10	0.100	0.030	0.004	0.005	0.03	0.014	0.004	0.006

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[Table 2]

	Steel grade	Alloy component relationship			
		T(Relational Expression 1)	Ti*	X (Relational Expression 2)	A (Relational Expression 3)
5	1	26.2	0.073	0.464	3.980
	2	83.4	0.083	0.577	8.655
	3	39.7	0.040	0.239	5.363
10	4	52.9	0.100	0.938	5.363
	5	27.5	0.046	0.235	4.103
	6	88.6	0.073	0.930	3.676
	7	39.4	0.093	0.428	20.606
15	8	95.7	0.097	0.852	20.847
	9	38.4	0.095	0.717	5.363
	10	35.5	0.086	0.619	4.789
20	11	42.2	0.077	0.530	4.103
	12	48.4	0.070	0.340	3.556
	13	52.1	0.071	0.410	7.484
	14	43.2	0.074	0.624	8.864
25	15	55.1	0.073	0.716	6.210

[Table 3]

	Steel grade	Finishing rolling temperature (°C)	Primary cooling		Air-cooling time (Sec.)	Secondary cooling		Classification
			Rate (°C/s)	End temperature(°C)		Rate (°C/s)	End temperature(°C)	
30	1	885	66	634	6	41	443	Comparative Example 1
35	2	890	65	615	6	44	461	Comparative Example 2
	3	882	63	624	6	43	438	Comparative Example 3
40	4	870	55	630	6	38	440	Comparative Example 4
	5	875	70	635	6	45	443	Comparative Example 5
45	6	870	66	627	6	47	445	Comparative Example 6
	7	880	72	628	6	48	439	Comparative Example 7
50	8	876	68	615	6	46	452	Comparative Example 8
	9	870	69	630	6	43	460	Inventive Example 1
55	10	873	72	625	6	41	455	Inventive Example 2

(continued)

Steel grade	Finishing rolling temperature (°C)	Primary cooling		Air-cooling time (Sec.)	Secondary cooling		Classification
		Rate (°C/s)	End temperature(°C)		Rate (°C/s)	End temperature(°C)	
11	888	60	633	6	44	440	Inventive Example 3
12	890	58	617	6	47	447	Inventive Example 4
13	895	56	620	6	50	439	Inventive Example 5
14	887	45	622	6	54	446	Inventive Example 6
15	892	55	609	6	57	452	Inventive Example 7
End temperature during second cooling is the same as coiling temperature (°C).							

[Table 4]

Classification	Microstructure						Relational Expression 4		
	F	B	F+B	P	M	GND($\times 10^{14}$)	η_{GB}	η_G	η
Comparative Example 1	18	79	97	3	0	2.34	0.043	0.026	1.654
Comparative Example 2	2	93	95	0	5	4.49	0.255	0.124	2.057
Comparative Example 3	15	83	98	2	0	2.41	0.167	0.128	1.305
Comparative Example 4	8	90	98	0	2	4.70	0.144	0.125	1.152
Comparative Example 5	22	73	95	4	1	2.26	0.160	0.086	1.861
Comparative Example 6	5	89	94	0	6	5.13	0.133	0.105	1.267
Comparative Example 7	18	81	99	1	0	3.01	1.356	0.210	6.457
Comparative Example 8	4	91	95	0	5	4.55	1.420	0.188	7.553
Inventive Example 1	3	95	98	1	1	3.12	0.135	0.116	1.164
Inventive Example 2	2	96	98	0	2	2.92	0.092	0.052	1.769
Inventive Example 3	3	95	98	0	2	3.07	0.145	0.115	1.261
Inventive Example 4	4	94	98	2	0	3.22	0.105	0.067	1.567
Inventive Example 5	5	93	98	1	1	3.50	0.251	0.134	1.873
Inventive Example 6	4	95	99	1	0	3.12	0.220	0.072	3.056
Inventive Example 7	0	98	98	0	2	3.37	0.194	0.135	1.437
F: Ferrite B: Bainite P: Pearlite (including cases in which coarse carbides are contained) M: Martensite The fraction of each phase refers to the area fraction (%), and the unit of the average geometrically necessary dislocation (GND) density value is m^{-2} .									

[Table 5]

Classification	Tensile test			Hole expansion ratio (HER)
	YS (MPa)	TS (MPa)	T-El (%)	
Comparative Example 1	602	685	21	68.7
Comparative Example 2	706	816	17	56.0
Comparative Example 3	580	670	21	67.7
Comparative Example 4	740	862	16	49.0
Comparative Example 5	565	648	22	59.7
Comparative Example 6	813	905	13	47.7
Comparative Example 7	710	822	17	46.3
Comparative Example 8	802	892	17	45.0
Inventive Example 1	676	767	20	73.3
Inventive Example 2	715	820	17	65.3
Inventive Example 3	721	850	15	65.3
Inventive Example 4	675	778	20	70.7
Inventive Example 5	688	786	19	65.7
Inventive Example 6	704	815	17	64.7
Inventive Example 7	718	845	16	64.0

[0144] As illustrated in Table 1 to Table 5, Inventive Examples 1 to 7 are examples satisfying all of the alloy composition, alloy component relationship, and manufacturing conditions according to an embodiment of the present disclosure, in which the main phase of the microstructure is formed with a combined fraction of ferrite and bainite of 95% or more, and the average GND density value of the microstructure is secured within the intended range. As a result, high strength with a yield strength of 650 MPa or more was achieved, along with a hole expansion ratio of 60% or more, indicating excellent formability.

[0145] Meanwhile, Comparative Examples 1 to 8 are cases in which at least one of the alloy composition, alloy component relationship, and manufacturing conditions according to an embodiment of the present disclosure is not satisfied.

[0146] Among them, Comparative Examples 1 and 2 are cases in which Relational Expression 1 of the alloy component relationship is not satisfied. Comparative Example 1, in which the value of Relational Expression 1 is relatively low, had a yield strength less than 650 MPa, and thus could not secure high strength. Comparative Example 2, in which the value of Relational Expression 1 was excessive, showed an inferior hole expansion ratio, which is attributed to the fact that the fraction of the martensite phase formed around the grain boundaries in the microstructure exceeded 5%.

[0147] Comparative Examples 3 and 4 are cases in which Relational Expression 2 of the alloy component relationship is not satisfied. Comparative Example 3, in which the value of Relational Expression 2 is relatively low, could not secure high strength, with a yield strength less than 650 MPa, because the precipitation strengthening and grain refinement effects were insufficient due to a lack of precipitate-forming elements. On the other hand, Comparative Example 4, in which the value of Relational Expression 2 is excessive, had an excessively high average GND density value in the microstructure due to the excessive addition of alloy components with high hardenability, resulting in an inferior hole expansion ratio.

[0148] Comparative Examples 5 and 6 are cases in which neither Relational Expression 1 nor Relational Expression 2 of the alloy component relationship are satisfied. Among them, Comparative Example 5 not only failed to sufficiently exhibit the precipitation strengthening effect but also had low strength due to insufficient hardenability, and the hole expansion ratio thereof was inferior due to the formation of coarse carbides at the grain boundaries in the microstructure. In the case of Comparative Example 6, the average GND density value of the microstructure was high due to excessive intragranular precipitation and excessive formation of the martensite phase. As a result, the strength increased significantly, resulting in inferior elongation, and the hole expansion ratio was also inferior.

[0149] Comparative Examples 7 and 8 were cases in which Relational Expression 3 of the alloy component relationship was not satisfied; in the case of Comparative Example 7, segregation occurred at the grain boundaries, and as a

result, the hole expansion ratio was inferior. Meanwhile, Comparative Example 8 was a case in which not only Relational Expression 3 but also Relational Expressions 1 and 2 were not satisfied; the average GND density value of the microstructure was high, and the grain boundaries became vulnerable, resulting in an inferior hole expansion ratio.

Claims

1. A hot-rolled steel sheet comprising:

by wt%, at least one selected from the group consisting of 0.030 to 0.080% of carbon (C), 0.01 to 1.00% of silicon (Si), 1.0 to 2.5% of manganese (Mn), 0.005 to 0.500% of chromium (Cr), 0.01 to 0.80% of aluminum (Al), 0.001 to 0.050% of phosphorus (P), 0.001 to 0.010% of sulfur (S), and 0.001 to 0.010% of nitrogen (N); at least one selected from the group consisting of 0.01 to 0.30% of copper (Cu), 0.010 to 0.200% of nickel (Ni), 0.100% or less of antimony (Sb), 0.100% or less of tin (Sn), and 0.100% or less of arsenic (As); and at least one selected from the group consisting of 0.050% or less of niobium (Nb), 0.120% or less of titanium (Ti), 0.300% or less of molybdenum (Mo), and 0.200% or less of vanadium (V), a remainder of Fe and unavoidable impurities,

wherein a T value defined in [Relational Expression 1] satisfies 30.0 to 60.0, an X-value defined in [Relational Expression 2] satisfies 0.300 to 0.800, and an A-value defined in [Relational Expression 3] satisfies 10.000 or less,

$$T = 33.02 \times (1.07([C]/10)^{0.5}) \times (0.7[Si]+1) \times (5[Mn]+1) \times (2.16[Cr]+1) \times (3[Mo]+1) \times (0.36[Ni]+1) \times (0.35[Cu]+1) \quad \text{[Relational Expression 1]}$$

where each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor,

$$X = ((Nb/93) + (Ti^*/48) + (V/51) + (Mo/96))/((C/12) + (N/14)) \quad \text{[Relational Expression 2]}$$

where Ti^* is calculated as $(Ti - 3.42N - 1.5S)$, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor,

$$\text{[Relational Expression 3]}$$

$$A = 85([Cu] + 3[Sb] + 2[As] + 3[Sn] - [Ni])^{1.2}$$

where each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.

2. The hot-rolled steel sheet of claim 1, wherein a microstructure of the hot-rolled steel sheet satisfies a average geometrical necessary dislocation (GND) density value in the range of $2.5 \times 10^{14} m^{-2}$ to $4.0 \times 10^{14} m^{-2}$.

3. The hot-rolled steel sheet of claim 1, wherein a microstructure of the hot-rolled steel sheet includes 95% or more of a combined area fraction of ferrite and bainite phases, and the remainder of the microstructure is one or more of martensite and pearlite phases.

4. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet satisfies a segregation index (η) defined by Relational Expression (4) being 4.000 or less,

$$\text{[Relational Expression 4]}$$

$$\eta = \eta_{\text{grain boundary}} / \eta_{\text{grain}}$$

where η_{grain} represents the sum of an average concentrations (at%) of segregated elements Cu, Sb, As, and Sn present within grains, and $\eta_{\text{grain boundary}}$ represents the sum of the average concentrations (at%) of segregated

elements Cu, Sb, As, and Sn present at grain boundaries.

5. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet has a yield strength of 650 MPa or higher.

6. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet has a hole expansion ratio (HER) of 60% or more.

7. A method for manufacturing a hot-rolled steel sheet, the method comprising:

preparing a steel slab comprising, by wt%, at least one selected from the group consisting of 0.030 to 0.080% of carbon (C), 0.01 to 1.00% of silicon (Si), 1.0 to 2.5% of manganese (Mn), 0.005 to 0.500% of chromium (Cr), 0.01 to 0.80% of aluminum (Al), 0.001 to 0.050% of phosphorus (P), 0.001 to 0.010% of sulfur (S), and 0.001 to 0.010% of nitrogen (N); at least one selected from the group consisting of 0.01 to 0.30% of copper (Cu), 0.010 to 0.200% of nickel (Ni), 0.100% or less of antimony (Sb), 0.100% or less of tin (Sn), and 0.100% or less of arsenic (As); and at least one selected from the group consisting of 0.050% or less of niobium (Nb), 0.120% or less of titanium (Ti), 0.300% or less of molybdenum (Mo), and 0.200% or less of vanadium (V), a remainder of Fe and unavoidable impurities, wherein a T value defined in [Relational Expression 1] satisfies 30 to 60, an X-value defined in [Relational Expression 2] satisfies 0.3 to 0.8, and an A-value defined in [Relational Expression 3] satisfies 10 or less;

heating the steel slab in a temperature range of 1150 to 1350°C;

hot-rolling the heated steel slab in a temperature range of 850 to 1150°C to obtain a hot-rolled steel sheet; and

cooling the hot-rolled steel sheet and then coiling the hot-rolled steel sheet in a temperature range of 300 to 500°C,

$$T = 33.02 \times (1.07([C]/10)^{0.5}) \times (0.7[Si]+1) \times (5[Mn]+1) \times (2.16[Cr]+1) \times (3[Mo]+1) \times (0.36[Ni]+1) \times (0.35[Cu]+1) \quad [\text{Relational Expression 1}]$$

where each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor,

$$X = ((Nb/93) + (Ti^*/48) + (V/51) + (Mo/96))/((C/12) + (N/14)) \quad [\text{Relational Expression 2}]$$

where Ti^* is calculated as $(Ti - 3.42N - 1.5S)$, each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor,

[Relational Expression 3]

$$A = 85([Cu] + 3[Sb] + 2[As] + 3[Sn] - [Ni])^{1.2}$$

where each element represents a weight content thereof, and in a case in which an element is not added, 0 is substituted therefor.

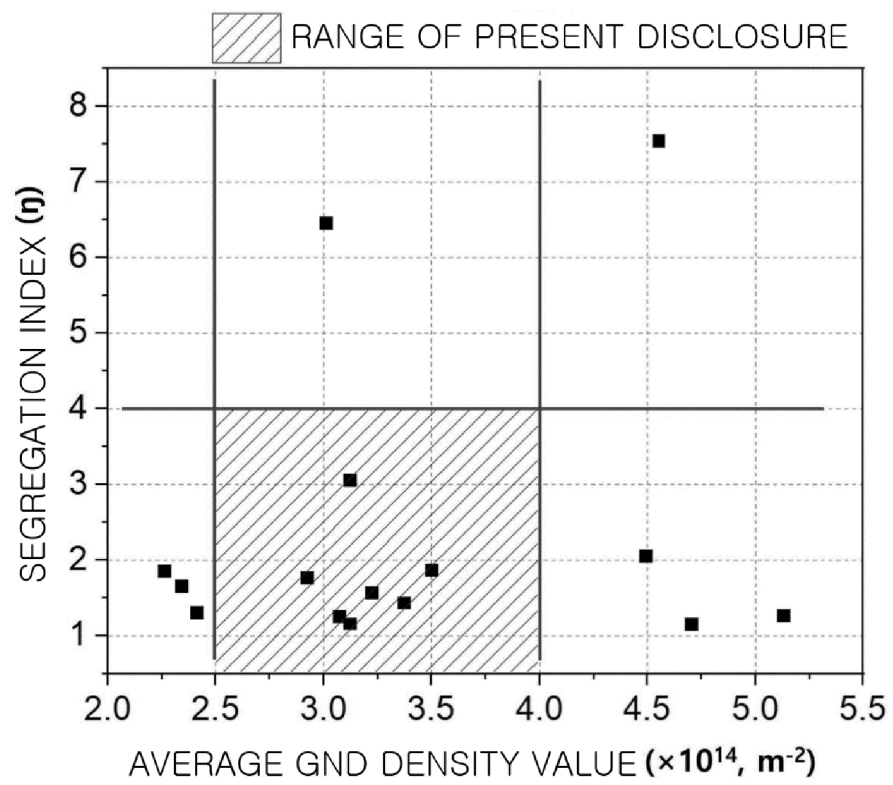
8. The method of claim 7, wherein the cooling is performed by primary cooling to a temperature range of 550 to 700°C at a cooling rate of 10 to 100°C/s; air cooling after the primary cooling; and secondary cooling to a temperature range of 300 to 500°C at a cooling rate of 10 to 100°C/s after the air cooling.

9. The method of claim 7, further comprising pickling and oiling the hot-rolled steel sheet after the coiling.

10. The method of claim 9, further comprising, after the pickling and oiling, heating the hot-rolled steel sheet to a temperature range of 450 to 740°C and then hot-dip galvanizing.

11. The method of claim 10, wherein the hot-dip galvanizing is performed in a plating bath including 0.01 to 30.00 wt% of magnesium (Mg), 0.01 to 50.00 wt% of aluminum (Al), and a remainder of Zn and unavoidable impurities.

[FIG. 1]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020111

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; **C22C 38/42**(2006.01)i; **C22C 38/48**(2006.01)i; **C22C 38/44**(2006.01)i; **C22C 38/50**(2006.01)i;
C22C 38/06(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/46**(2006.01)i; **C21D 8/02**(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)

C22C 38/58(2006.01); B21C 47/02(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01);
 C23C 2/28(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: 열연강판(hot rolled steel sheet), 페라이트(ferrite), 배이나이트(bainite), 가열
 (heating), 냉각(cooling), 강도(strength), 도금(plating), 구리(copper), 니켈(nickel), 니오븀(niobium), 티타늄(titanium), 주석
 (tin)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y		10-11
Y	US 2019-0085427 A1 (JFE STEEL CORPORATION) 21 March 2019 (2019-03-21) See paragraphs [0090] and [0135].	10-11
A	KR 10-2022-0114571 A (TATA STEEL IJMUIDEN B.V.) 17 August 2022 (2022-08-17) See paragraphs [0144]-[0147] and claims 1 and 13.	1-11
A	JP 2013-181208 A (NIPPON STEEL & SUMITOMO METAL CORP.) 12 September 2013 (2013-09-12) See paragraph [0043] and claims 1-2 and 4.	1-11

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

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“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

12 March 2025

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020111

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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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/020111

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