(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 397 781 A1**

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

(43) Date of publication:
10.07.2024 Bulletin 2024/28

(21) Application number: **22887587.8**

(22) Date of filing: **26.10.2022**

(51) International Patent Classification (IPC):
C22C 38/50 *(2006.01)* ***C22C 38/48*** *(2006.01)*
C22C 38/42 *(2006.01)* ***C22C 38/00*** *(2006.01)*
C21D 8/02 *(2006.01)* ***C21D 9/46*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C21D 9/46; C22C 38/00; C22C 38/42; C22C 38/48; C22C 38/50

(86) International application number:
PCT/KR2022/016420

(87) International publication number:
WO 2023/075391 (04.05.2023 Gazette 2023/18)

(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:
KH MA MD TN

(30) Priority: **26.10.2021 KR 20210143703**

(71) Applicant: **POSCO Co., Ltd**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

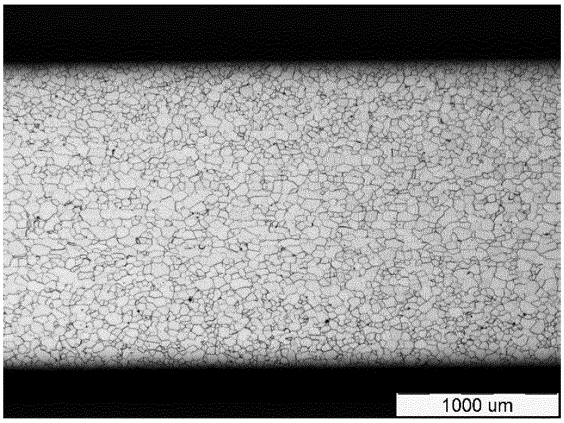
(72) Inventors:
- **KONG, Junghyun**
  Pohang-si, Gyeongsangbuk-do 37680 (KR)
- **KIM, Jinsuk**
  Pohang-si, Gyeongsangbuk-do 37671 (KR)
- **CHU, Nayeon**
  Pohang-si, Gyeongsangbuk-do 37777 (KR)

(74) Representative: **Meissner Bolte Partnerschaft mbB**
Patentanwälte Rechtsanwälte
Postfach 86 06 24
81633 München (DE)

(54) HOT-ROLLED FERRITIC STAINLESS STEEL SHEET HAVING EXCELLENT FORMABILITY AND METHOD FOR MANUFACTURING SAME

(57) The present invention pertains to a hot-rolled ferritic stainless steel sheet having excellent formability, which has an R-bar value of at least 1.08 and satisfies TS/YS ≤ 1.5 representing the ratio of tensile strength (TS) to yield strength (YS) after a steel, containing 0.001-0.1% of C, 10.0-14.0% of Cr, 0.001-0.5% of Ti, 0.001-0.5% of Nb, 0.001-1.5% of Ni, 0.001-1.5% of Mn, 0.001-1.0% of Cu, 0.001-2.0% of Si, 0.001-0.1% of N, and 0.1% or less of Al, with the remainder comprising Fe and inevitable impurities, is hot-rolled and then pre-rolled at a reduction ratio of 30% or more.

FIG.1



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Description

[Technical Field]

[0001] The disclosure relates to a hot-rolled ferritic stainless steel sheet having excellent formability and manufacturing method thereof.

[Background Art]

[0002] Cold-rolled ferritic stainless steel products have excellent high-temperature characteristics such as thermal expansion coefficient and thermal fatigue, are robust to stress corrosion cracking, and also have excellent high-temperature strength. Based on these characteristics, the ferritic stainless steel is applied to vehicle exhaust systems, household tools, structures, home appliances, elevators, etc. To expand the application ranges of the ferritic stainless steel, it is important to secure formability. As the deformation mechanism of the ferritic stainless steel causes transformation according to generation and movement of dislocations unlike an austenitic stainless steel, which has high processability according to plastic induced transformation, the ferritic stainless steel is characterized by having formability changing by increasing an amount of rolling to activate generation and movement of dislocations or controlling impurities that interfere the movement of dislocations. Although many researches have made efforts to increase formability of the ferritic stainless steel, the ferritic stainless steel has problem being vulnerable to stretching forming. Furthermore, hot-rolled materials have a low strain rate, which leads to difficulty in generating dislocations, so even with the same thickness, have difficulty in securing as much formability as a cold-rolled annealed material, and thus, there are limits to applying the hot-rolled material to a product that requires high formability.

[Disclosure]

[Technical Problem]

[0003] To solve the above problem, an objective of the disclosure is to manufacture a hot-rolled stainless steel sheet that exhibits similar formability to cold-rolled materials despite being a hot-rolled material by rolling a hot-rolled steel sheet at a certain reduction rate to control a banded structure formed in the hot-rolled material before annealing the hot-rolled steel sheet, and additionally activating generation of dislocations to refine crystal grains and simultaneously, increase formability after hot annealing.

[Technical Solution]

[0004] According to an embodiment of the disclosure, a hot-rolled ferritic stainless steel sheet with excellent formability satisfies a value of R-bar being 1.08 or more and a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5, after hot rolling a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities and pre-rolling the steel at a reduction rate of 30% or more.

[0005] According to another embodiment of the disclosure, a method of manufacturing a hot-rolled ferritic stainless steel sheet with excellent formability comprises manufacturing a slab by continuously casting a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities; reheating the manufactured slab; hot rolling the reheated slab; performing pre-rolling at a reduction rate of 30% or more to satisfy a value of R-bar being 1.08 or more and a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5; and performing hot annealing.

[Advantageous Effects]

[0006] According to the disclosure, a hot-rolled stainless steel sheet that exhibits similar formability to cold-rolled materials despite being a hot-rolled material by controlling a banded structure formed in the hot-rolled material in a case of rolling the hot-rolled steel sheet at a reduction rate of 30% or more before annealing the hot-rolled steel sheet, and additionally activating generation of dislocations to refine crystal grains and simultaneously, increase formability after hot annealing.

[Brief Description of Drawings]

[0007]

FIG. 1 illustrates a microstructure of embodiment 1 (ferritic stainless steel 35% pre-rolling annealed material).

FIG. 2 illustrates a microstructure of embodiment 2 (ferritic stainless steel 50% pre-rolling annealed material).

FIG. 3 illustrates a microstructure of comparative example 1 (hot-rolled annealed material (2.0t) of ferritic stainless steel).

FIG. 4 illustrates a microstructure of comparative example 2 (ordinary cold annealed material of ferritic stainless steel).

[Best Mode]

[0008] According to an embodiment of the disclosure, a hot-rolled ferritic stainless steel sheet with excellent formability satisfies a value of R-bar being 1.08 or more and a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5, after hot rolling a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities and pre-rolling the steel at a reduction rate of 30% or more.

[Modes]

[0009] Various methods have thus far been examined to enhance formality of ferritic stainless steel. In general, there is a method of facilitating recrystallization by keeping the hot rolling reheating temperature low or rolling at a high reduction rate in a rear stage of rough rolling to activate the introduction of dislocations, but there is a clear limit to actually applying the method because the method makes it difficult to form surface oxidation scales at a low reheating temperature when applied in actual production, causing various surface defects including sticking defects or in severe cases, causing a problem with fracture due to cracks.

[0010] To overcome the shortcomings, the disclosure provides a method of manufacturing a ferritic stainless steel that exhibits similar formability to cold-rolled materials by rolling a hot-rolled steel sheet at a certain reduction rate to control a banded structure formed in the hot-rolled material before annealing the hot-rolled steel sheet, and additionally activating generation of dislocations to refine crystal grains and simultaneously, increase formability after hot annealing.

[Hot-rolled ferritic stainless steel sheet]

[0011] According to an embodiment of the disclosure, a hot-rolled ferritic stainless steel sheet with excellent formability satisfies a value of R-bar being 1.08 or more and a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5, after hot rolling a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities and pre-rolling the steel at a reduction rate of 30% or more, wherein a reduction rate of pre-rolling may be 35% or more.

[0012] Furthermore, according to another embodiment of the disclosure, a hot-rolled ferritic stainless steel sheet with excellent formability may have a ferrite crystal grain size of 60μm or less when the crystal grain size is measured in an electron backscattering diffraction (EBSD) analysis method with intergranular misorientation ranging from 15 ° to 180 °.

[0013] Aunit of wt% will now be used unless otherwise mentioned. The term "include (or including)" or "comprise (or comprising)" is inclusive or open-ended and does not exclude additional, unrecited elements or method steps, unless otherwise mentioned.

(Ranges of Composition)

C: 0.001~0.1%

[0014] When there is a large amount of carbon, strength is enhanced but processability is reduced. In order to obtain sufficient strength, 0.001% or more of carbon needs to be contained, but when the carbon exceeds 0.1%, it leads to reduction in processability.

Cr: 10.0-14.0%

[0015] The amount of chrome is desirably 10.0 to 14.0%. Chrome is an important element to be added to secure corrosion resistance of the stainless steel, and in the disclosure, 10.0% or more of chrome is added to increase corrosion resistance. When chrome C exceeds 14.0%, it causes hot rolling sticking defects, so 14.0% or less is desirable.

Ti: 0.001-0.5%

[0016] The amount of titanium is desirably 0.001 to 0.5%. When the amount of titanium is less than 0.001%, the amount of TiN crystallization decreases, which lowers the equiaxed crystal ratio of the slab, and the dissolved C and N elements increase, causing a decrease in elongation rate, and when it exceeds 0.5%, Ti-based oxides increase, which deteriorates processability.

Nb: 0.001-0.5%

[0017] The amount of niobium is desirably 0.001 to 0.5%. Niobium preferentially combines with carbon and nitrogen to form precipitates that suppress the deterioration of corrosion resistance, but when added in excess, it causes poor appearance and reduced toughness due to the inclusions and increases raw material costs, so the content of the niobium is limited to 0.001 to 0.5%.

Ni: 0.001-1.5%

[0018] The amount of nickel is desirably 0.001 to 1.5%. Nickel is an element that enhances corrosion resistance, but when added in a large amount, it may not only harden but also cause stress corrosion cracking, so it is desirable for nickel to be 1.5% or less.

Mn: 0.001~1.5%

[0019] The amount of manganese is desirably 0.001 to 1.5%. Manganese has an effect of increasing the strength of steel but when contained excessively, generation of Mn-based fume rapidly increases, which deteriorates weldability, and ductility of the steel deteriorates due to excessive formation of MnS precipitates, so manganese is contained at 1.5% or less.

Cu: 0.001-1.0%

[0020] The amount of copper is desirably 1.0% or less. Copper has an effect of enhancing corrosion resistance, but when it is over 1.0%, it deteriorates processability.

Si: 0.001-2.0%

[0021] Silicon is an element that is added for deoxidization of molten steel and ferrite stabilization during steelmaking and is desirably 0.001% or more, but when the content is excessive, it causes hardening of the material and thus, deteriorates ductility of the steel, so the content is limited to 2.0% or less.

N: 0.001-0.1%

[0022] The amount of nitrogen is desirably 0.001 to 0.1%. Like carbon, nitrogen has an effect of increasing the strength of material. When the amount of nitrogen is less than 0.001%, TiN crystallization decreases and thus, the equiaxed crystal ratio of the slab is lowered, and when it exceeds 0.1%, impurities in the material increase, causing a decrease in elongation rate.

Al: 0.1% or less

[0023] The amount of aluminum is desirably 0.1% or less. When the amount of aluminum exceeds 0.1%, impurities in the material increase and the elongation rate is lowered.

[Method of manufacturing hot-rolled ferritic stainless steel sheet]

[0024] According to an embodiment of the disclosure, a method of manufacturing a hot-rolled ferritic stainless steel sheet with excellent formability comprises manufacturing a slab by continuously casting a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities; reheating the manufactured slab; hot rolling the reheated slab; performing pre-rolling at a reduction rate of 30% or more to satisfy a value of R-bar being 1.08 or more and a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5; and
performing hot annealing.

[0025] Reheating temperature of hot rolling ranges from 1100 °C to 1280 °C. When the slab is reheated at a temperature of more than 1280 °C or more, a coarse banded structure is more likely to remain, causing deterioration of formability, and when the slab is reheated at less than 1100 °C, the rolling load increases during hot rolling, which may be likely to reduce productivity.

[0026] Embodiments of the disclosure will now be described in more detail.

[0027] The following embodiments are provided to deliver the idea of the disclosure to those of ordinary skill in the art, but the disclosure is not limited to the embodiments and may be implemented in other forms.

(Embodiments)

[0028] For a hot-rolled ferritic stainless steel sheet obtained by manufacturing a slab by continuously casting, reheating the slab, performing hot rolling, performing pre-rolling with a hot rolling thickness of 2.0 to 5.0t, a thickness of 2.0t after the pre-rolling, and a reduction rate of 0 to 50 %, and performing hot annealing, grain size, R values (R_0, R_{45}, R_{90}, and R-bar), yield strength, tensile strength, TS/YS and an elongation rate were measured.

[Table 1]

section (wt%)	C	Si	Mn	Cr	Ni	Cu	Ti	Nb	N	Al
Example 1	0.007	0.446	0.26	11.12	0.075	0.013	0.19	0.002	0.0077	0.032
Example 2	0.006	0.447	0.26	11.30	0.073	0.010	0.21	0.003	0.0052	0.022
Comparative example 1	0.006	0.472	0.37	11.15	0.067	0.009	0.18	0.002	0.0057	0.023
Comparative example 2	0.008	0.466	0.36	11.17	0.072	0.008	0.22	0.002	0.0079	0.052

[0029] It shows microstructures of a hot-rolled annealed material (2.0t) and a normal cold-rolled annealed material (2.0t) according to reduction rates. Comparative example 1 is a normal 2.0t hot-rolled material that appears to have an average crystal grain size of about 120 μm, which is very coarse. Example 1 shows a microstructure of a material obtained by pre-rolling a hot-rolled steel sheet with a thickness of 3.1t at a reduction rate of about 35% and performing hot annealing, and the crystal grain size appears to be about 60 μm as shown in Table 2, so it may be understood that the crystal grains are refined to a level of 50% as compared to the microstructure of comparative example 1 obtained by annealing the existing hot-rolled 2.0t steel sheet. With this, it may be assumed that crystal grains are refined due to additional generation of dislocations introduced in rolling a hot-rolled material at a reduction rate of 30% or more. Example 2 shows a microstructure of a material obtained by pre-rolling a hot-rolled steel sheet with a thickness of 4.0t at a reduction rate of about 35% and performing hot annealing, and the crystal grain size is refined to a level of about 50 μm, so it may be understood that the higher the pre-rolling reduction rate, the finer the crystal grains. In comparative example 2, a normal cold-rolled annealed material obtained by hot annealing/pickling a 5.0t hot-rolled material and then performing cold rolling at a reduction rate of about 60% appears to have crystal grains of about 55 μm, which is similar to Example 2 in which pre-rolling is performed to a level of about 50%.

[Table 2]

section	Thickness of hot rolling	Thickness after pre-rolling	Pre-rolling reduction rate	Grain size
Example 1	3.1t	2.0t	35%	59.5 μm
Example 2	4.0t	2.0t	50%	50.7 μm
Comparative example 1	2.0t	2.0t	0%	121.5 μm
Comparative example 2	5.0t	2.0t	Cold rolling reduction rate 60%	54.9 μm

[0030] Table 3 shows formality (R values) of a hot-rolled annealed material and formality of a normal cold annealed material with pre-rolling reduction rates. The R-bar value that represents vertical anisotropy of the material has the same properties in the face direction of the sheet and have different properties in the thickness direction, and as most rolled sheets have planar anisotropy whose plasticity changes even in the face direction, an average of R values measured by stretching in directions of 0, 45 and 90 degrees from the rolling direction (R-bar=(R_0 + 2R_{45} + R_{90})/4) is used.

[0031] The R-bar value in comparative 1 (with a normal 2.0t hot-rolled annealed material) is about 1.01, which is very poor, but it may be understood that with a gradual increase in pre-rolling reduction rate, the R-bar value gradually increases. Furthermore, the R-bar value in Example 2 (with a hot-rolled annealed material that goes through 50% pre-rolling) is about 1.21, which is similar to the R-bar value in comparative example 2 (with a normal cold-rolled annealed material).

[Table 3]

section	Thickne ss of hot rolling	Thickne ss after pre-rolling	Pre-rolling reductio n rate	R_0	R_{45}	R_{90}	R-bar
Exampl e 1	3.1t	2.0t	35%	0.77	1.02	1.51	1.08
Exampl e 2	4.0t	2.0t	50%	1.16	0.99	1.7	1.21
Compar ative example 1	2.0t	2.0t	0%	0.54	0.77	1.01	0.77
Compar ative example 2	5.0t	2.0t	Cold rolling reductio n rate 60%	1.22	0.85	2.14	1.27

[0032] Table 4 shows tensile properties of each material, and there is no noticeable difference in tensile strength between Example 2 (with a hot-rolled annealed 2.0t material after about 50% of pre-rolling) and comparative example 2 (with a normal cold-rolled annealed material) but the yield strength appears to be higher by about 10% or more in Example 2. With this, it is determined that the pre-rolled material exhibits higher yield strength than the normal cold-rolled annealed material because the pre-rolled material has additional dislocations introduced thereto and goes through only one hot annealing process while the normal cold-rolled material goes through a total of 2 or more annealing processes comprising hot annealing and cold annealing. It is determined that these characteristics may not only be applied to product groups requiring high-strength of the material, but also help extend the lifespan of the existing products.

[Table 4]

section	Thickness of hot rolling	Thickness after pre-rolling	Pre-rolling reduction rate	YS (MPa)	TS (MPa)	TS/YS	EL (%)
Example 1	3.1t	2.0t	35%	306	415	1.36	33
Example 2	4.0t	2.0t	50%	293	405	1.38	36
Comparat ive example 1	2.0t	2.0t	0%	270	419	1.55	34

(continued)

section	Thickness of hot rolling	Thickness after pre-rolling	Pre-rolling reduction rate	YS (MPa)	TS (MPa)	TS/YS	EL (%)
Comparat ive example 2	5.0t	2.0t	Cold rolling reduction rate 60%	261	397	1.52	35

[Industrial Applicability]

[0033] According to an embodiment of the disclosure, a hot-rolled ferritic stainless steel sheet exhibits similar formality to a cold-rolled material despite being a hot-rolled material, so the industrial applicability is acknowledged.

Claims

1. A hot-rolled ferritic stainless steel sheet with excellent formability having a value of R-bar being 1.08 or more and satisfying a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5, after hot rolling a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities and pre-rolling the steel at a reduction rate of 30% or more.

2. The hot-rolled ferritic stainless steel sheet with excellent formability of claim 1, wherein a ferrite crystal grain size is 60 μm or less when the crystal grain size is measured in an electron backscattering diffraction analysis (EBSD) method with intergranular misorientation ranging from 15 ° to 180 °.

3. A method of manufacturing a hot-rolled ferritic stainless steel sheet with excellent formability, the method comprising:

   manufacturing a slab by continuously casting a steel comprising, in percent by weight (wt%), 0.001 to 0.1% of C, 10.0 to 14.0% of Cr, 0.001 to 0.5% of Ti, 0.001 to 0.5% of Nb, 0.001 to 1.5% of Ni, 0.001 to 1.5% of Mn, 0.001 to 1.0% of Cu, 0.001 to 2.0% of Si, 0.001 to 0.1% of N, 0.1% or less of Al and the remainder having Fe and unavoidable impurities;
   reheating the manufactured slab;
   hot rolling the reheated slab;
   performing pre-rolling at a reduction rate of 30% or more to satisfy a value of R-bar being 1.08 or more and a ratio of yield strength (YS) and tensile strength (TS), TS/YS≤1.5; and
   performing hot annealing.

FIG.1

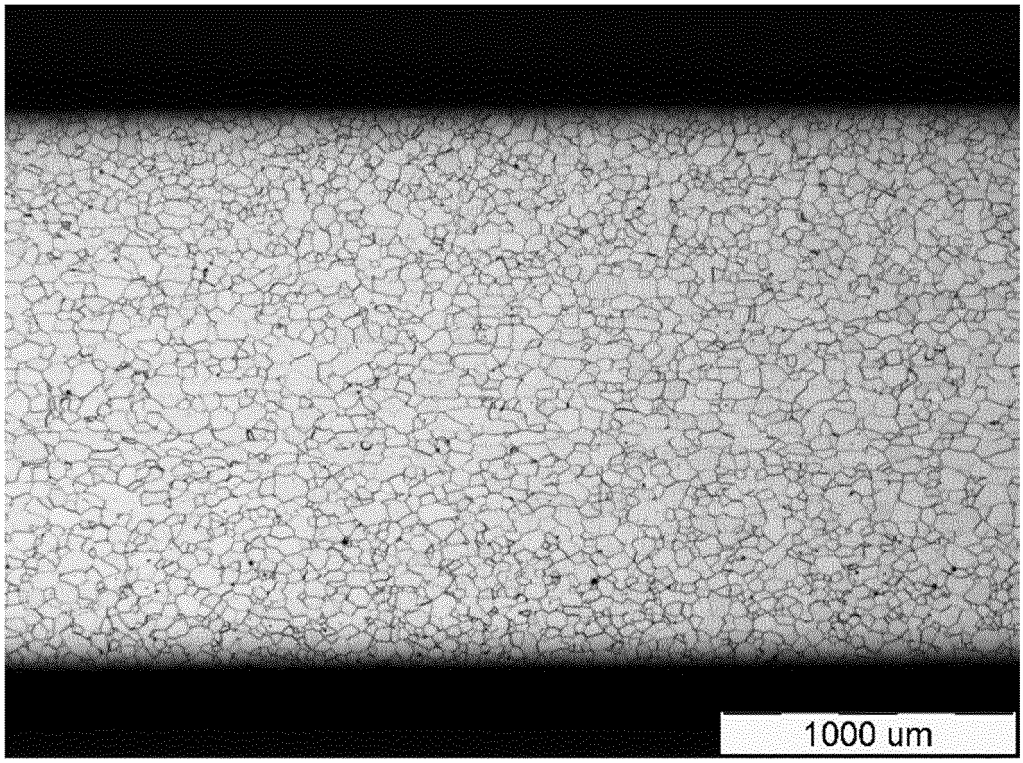


FIG.2

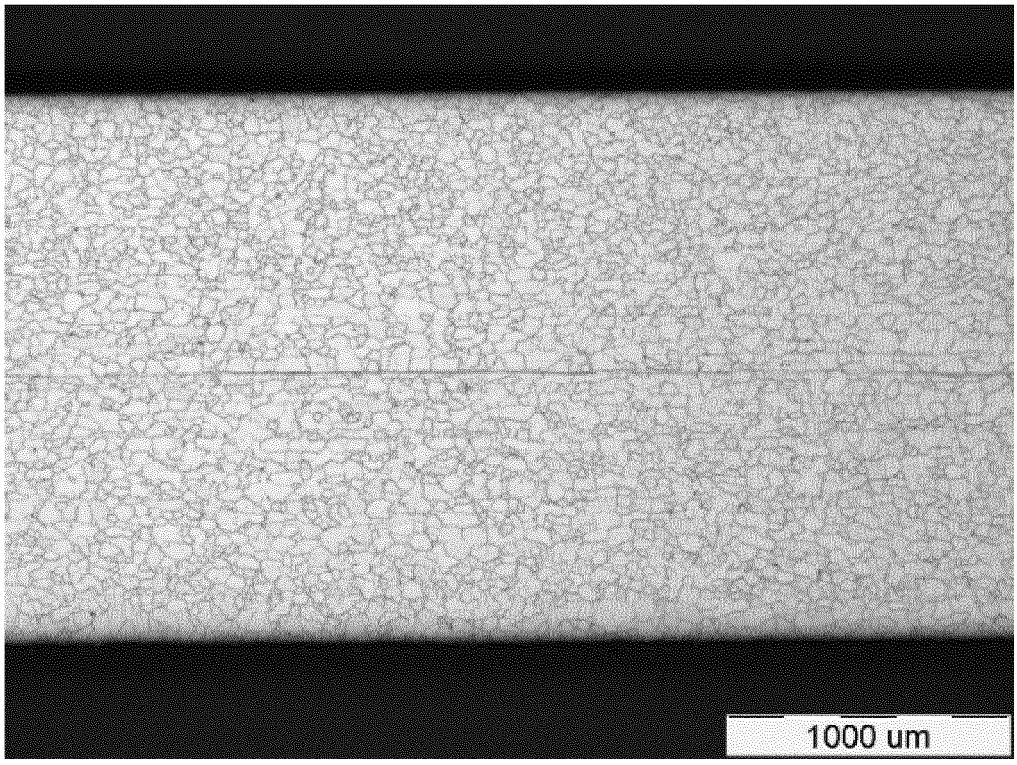


FIG.3

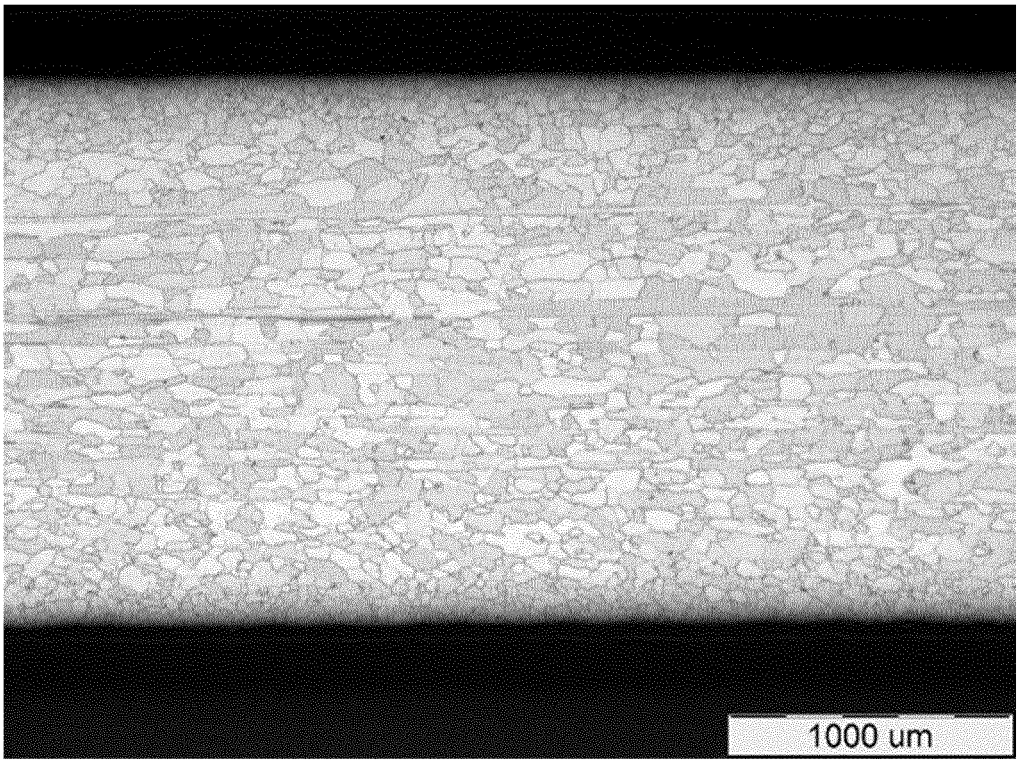
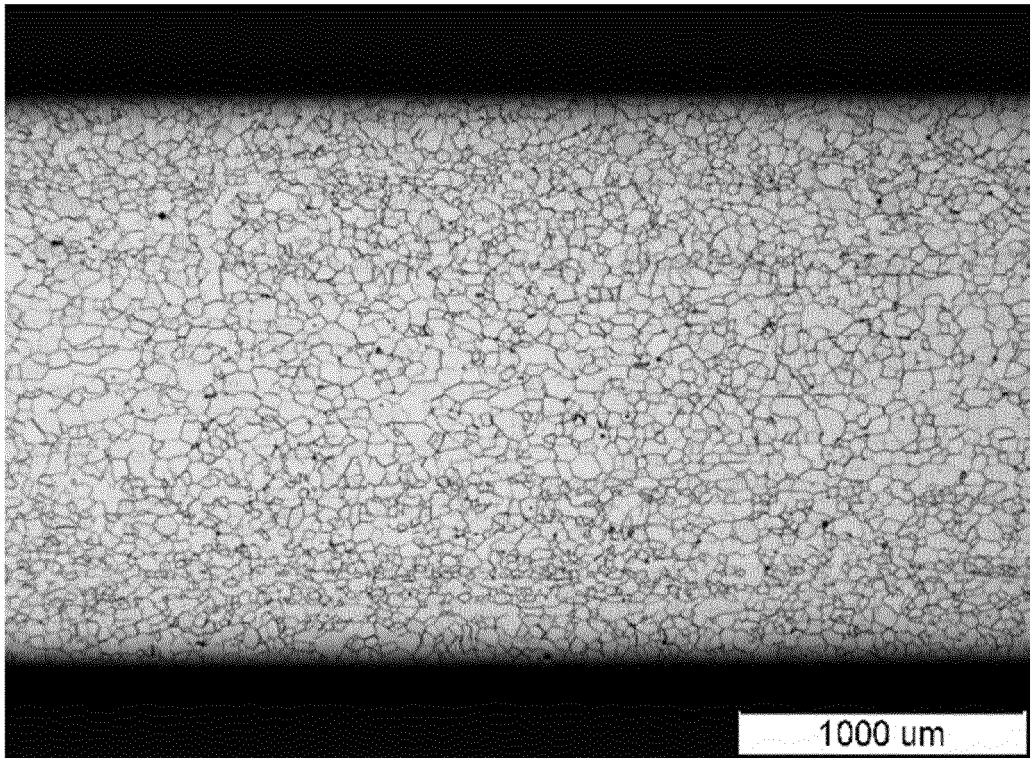


FIG.4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2022/016420

A. CLASSIFICATION OF SUBJECT MATTER

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

C22C 38/50(2006.01); B21B 3/02(2006.01); C21D 8/02(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/34(2006.01); C22C 38/58(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 plate), 페라이트(ferrite), 성형성(formability), 압하율(reduction rate), 열간압연(hot rolled), 스테인리스(stainless)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2001-207244 A (KAWASAKI STEEL CORP.) 31 July 2001 (2001-07-31) See paragraphs [0029], [0041] and [0064] and claims 1-3.	1-3
A	KR 10-2020-0032899 A (POSCO) 27 March 2020 (2020-03-27) See paragraph [0066] and claims 1-2 and 5.	1-3
A	JP 2001-098327 A (KAWASAKI STEEL CORP.) 10 April 2001 (2001-04-10) See paragraphs [0040]-[0041] and claims 1-2.	1-3
A	US 2021-0269890 A1 (JFE STEEL CORPORATION) 02 September 2021 (2021-09-02) See claims 1-3 and 5.	1-3
A	JP 2015-196842 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 09 November 2015 (2015-11-09) See claims 1-4.	1-3

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
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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	Date of mailing of the international search report
13 February 2023	**14 February 2023**
Name and mailing address of the ISA/KR **Korean Intellectual Property Office** **Government Complex-Daejeon Building 4, 189 Cheongsa-ro, Seo-gu, Daejeon 35208** Facsimile No. **+82-42-481-8578**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2022/016420

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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