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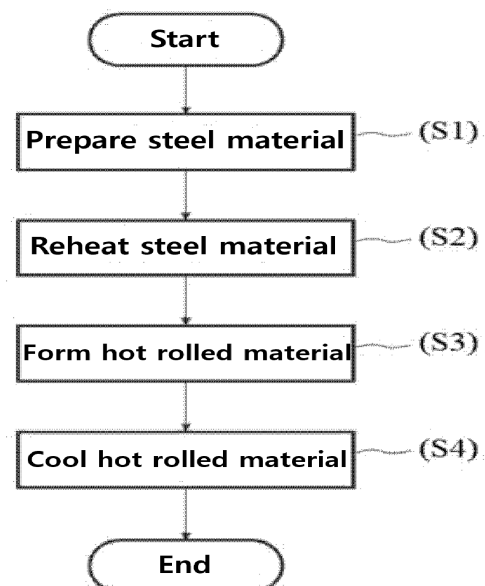
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(54) **HIGH-PERFORMANCE STEEL BAR, AND METHOD FOR MANUFACTURING HIGH-PERFORMANCE STEEL BAR**

(57) A high-performance steel bar according to one embodiment of the present disclosure includes 0.03-0.17 wt% of carbon (C), 0.50 wt% or less (excluding 0) of silicon (Si), 0.50-2.50 wt% of manganese (Mn), 0.02 wt% or less (excluding 0) of phosphorus (P), 0.02 wt% or less (excluding 0) of sulfur (S), 0.30-1.00 wt% of nickel (Ni), 0.002-0.500 wt% of chromium (Cr), 0.20 wt% or less (excluding 0) of copper (Cu), 0.003-0.150 wt% of molybdenum (Mo), 0.040 wt% or less (excluding 0) of aluminum (Al), 0.015 wt% or less (excluding 0) of nitrogen (N), and the balance of iron (Fe) and inevitable impurities, in which the room-temperature yield strength (YS) is at least 600 MPa and the cryogenic yield strength (YS) is at least 820 MPa.

【Fig. 1】



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Description**[Technical Field]**

[0001] The present disclosure relates to a high-performance steel bar and a manufacturing method therefor.

[Background Art]

[0002] Deformed steel bars or reinforcing bars are elongated steel materials used for concrete reinforcement, and have been widely used in construction and civil engineering sites due to an advantage of reducing the crack width when concrete cracks occur by compensating for concrete having large adhesion to concrete and being vulnerable to tension. For example, the deformed steel bars or reinforcing bars are used as pivotal materials of construction, such as bridges, massive offshore structures, underground structures, and storage facilities.

[0003] Recently, interest in natural gas has increased as part of environmental issues and the shift in domestic energy policy. The natural gas is liquefied below -170°C and transported in the form of liquefied natural gas (LNG), and the transported LNG is stored in LNG tanks. The LNG tank for storing liquefied LNG at a temperature below -170°C requires a special structure and materials capable of withstanding temperatures around -170°C .

[0004] The structure of the LNG tank is largely composed of an inner shell and an outer shell, and the inner shell, which comes into contact with the LNG, is made of 9% Ni steel plates capable of withstanding a -170°C environment, and the outer shell is made of reinforced concrete. For deformed steel bars used in LNG storage tanks, reinforcing bars capable of withstanding -170°C are required to maintain the structure without brittle fracture even during a rapid temperature drop.

[0005] Therefore, there is a need to develop a high-performance steel bar having excellent strength even in environments with temperatures of -170°C or lower without brittle fracture, and a method for manufacturing the same.

[Disclosure]**[Technical Problem]**

[0006] In order to solve the problems in the related art, an object of the present disclosure is to provide a high-performance steel bar capable of securing yield strength and tensile strength not only in a room-temperature environment, but also in a low-temperature environment, and a method for manufacturing the steel bar.

[0007] The objects of the present disclosure are not limited to the aforementioned objects, and other objects, which are not mentioned above, will be apparent to those skilled in the art from the following description.

[Technical Solution]

[0008] According to an embodiment of the present disclosure, a high-performance steel bar includes 0.08 to 0.17 wt% of carbon (C), 0.50 wt% or less (excluding 0) of silicon (Si), 0.50 to 2.50 wt% of manganese (Mn), 0.02 wt% or less (excluding 0) of phosphorus (P), 0.02 wt% or less (excluding 0) of sulfur (S), 0.30 to 1.00 wt% of nickel (Ni), 0.002 to 0.500 wt% of chromium (Cr), 0.20 wt% or less (excluding 0) of copper (Cu), 0.003 to 0.150 wt% of molybdenum (Mo), 0.040 wt% or less (excluding 0) of aluminum (Al), 0.015 wt% or less (excluding 0) of nitrogen (N), and the balance of iron (Fe) and inevitable impurities, in which the room-temperature yield strength (YS) is at least 600 MPa and the low-temperature yield strength ($\text{YS}_{-170^{\circ}\text{C}}$) is at least 800 MPa.

[0009] The high-performance steel bar may further include at least any one of 0.1 wt% or less of tin (Sn) and 0.05 wt% or less of calcium (Ca).

[0010] The room-temperature tensile strength (TS) may be at least 690 MPa

[0011] The room-temperature elongation (EL) may be at least 13%.

[0012] The uniform elongation (UE) may be at least 3%.

[0013] The low-temperature notch tensile strength (TS_n) may be at least 800 MPa.

[0014] The notch sensitivity ratio (NSR) may be at least 1.00.

[0015] The high-performance steel bar may include a surface layer and a core, in which the surface layer may include at least any one of tempered martensite and bainite, and the core may include at least any one of bainite, acicular ferrite, and pearlite.

[0016] According to another embodiment of the present disclosure, a method for manufacturing a high-performance steel bar includes: steps of (S1) preparing a steel material; (S2) reheating the steel material; (S3) forming a hot rolled material by hot rolling the steel material; and (S4) cooling the hot rolled material to form a final product, in which the final product includes 0.08 to 0.17 wt% of carbon (C), 0.50 wt% or less (excluding 0) of silicon (Si), 0.50 to 2.50 wt% of

manganese (Mn), 0.02 wt% or less (excluding 0) of phosphorus (P), 0.02 wt% or less (excluding 0) of sulfur (S), 0.30 to 1.00 wt% of nickel (Ni), 0.002 to 0.500 wt% of chromium (Cr), 0.20 wt% or less (excluding 0) of copper (Cu), 0.003 to 0.150 wt% of molybdenum (Mo), 0.040 wt% or less (excluding 0) of aluminum (Al), 0.015 wt% or less (excluding 0) of nitrogen (N), and the balance of iron (Fe) and inevitable impurities, the room-temperature yield strength (YS) of the final product is at least 600 MPa, and the cryogenic yield strength (YS_{-170°C}) is at least 800 MPa.

[0017] The reheating temperature of step (S2) may be 1030 to 1200°C.

[0018] The rolling ratio of step (S3) may be 14 to 40%.

[0019] The rolling end temperature of step (S3) may be 900 to 1,000°C.

[0020] The cooling rate of step (S4) may be 30 to 400°C/s.

[0021] The cooling end temperature of step (S4) may be 540 to 700°C.

[Advantageous Effects]

[0022] According to an embodiment of the present disclosure, it is possible to implement a high-performance steel bar and a method for manufacturing the steel bar capable of securing yield strength and tensile strength not only in a room-temperature environment, but also in a low-temperature environment.

[0023] The effects of the present disclosure are not limited to the aforementioned effect, and other effects not mentioned above will be clearly understood to those skilled in the art from the description of the appended claims.

[Description of Drawings]

[0024]

FIG. 1 is a flowchart illustrating a method for manufacturing a high-performance steel bar according to an embodiment of the present disclosure.

FIG. 2 is a photograph showing results of observing a surface layer and a core of a high-performance steel bar according to an embodiment of the present disclosure using an optical microscope.

[Best Mode]

[0025] Hereinafter, embodiments of the present disclosure will be described in detail so as to be easily implemented by those skilled in the art, with reference to the accompanying drawings. However, the present disclosure is not limited or restricted to the following embodiments.

[0026] In addition, when a component (or region, layer, part, etc.) is described as being "on", "connected to" or "coupled to" the other component, it means that the component may be directly displaced/connected/coupled on the other component, or a third component may also be displaced therebetween.

[0027] It should be understood that term "including" or "having" indicates that a feature, a number, a step, an operation, a component, a part or a combination thereof described in the specification is present, but does not exclude the possibility of presence or addition of one or more other features, numbers, steps, operations, components, parts or combinations thereof, in advance.

[0028] In order to clearly explain the present disclosure, detailed descriptions of known related arts that are irrelevant to the explanation or may unnecessarily obscure the gist of the present disclosure have been omitted, and in adding reference numerals to components of each drawing in this specification, like or similar reference numerals are designated to like or similar components throughout the specification.

[0029] Terms and words used in the present specification and claims should not be interpreted as being limited to typical or dictionary meanings, but should be interpreted as meanings and concepts which comply with the technical spirit of the present disclosure, based on the principle that the present inventor can appropriately define the concepts of the terms to describe his/her own invention in the best manner.

[0030] Unless otherwise specified, the expression 'A ~ B' for numerical values A and B means 'A or more and B or less'. In such expression, if a unit is attached only to numerical value B, the corresponding unit is also applied to numerical value A.

[0031] Hereinafter, embodiments of the present disclosure will be described with reference to the accompanying drawings.

High-performance steel bar

[0032] A high-performance steel bar according to an embodiment of the present disclosure may be manufactured by a steel material including 0.08 to 0.17 wt% of carbon (C), 0.50 wt% or less (excluding 0) of silicon (Si), 0.50 to 2.50

wt% of manganese (Mn), 0.02 wt% or less (excluding 0) of phosphorus (P), 0.02 wt% or less (excluding 0) of sulfur (S), 0.30 to 1.00 wt% of nickel (Ni), 0.002 to 0.500 wt% of chromium (Cr), 0.20 wt% or less (excluding 0) of copper (Cu), 0.003 to 0.150 wt% of molybdenum (Mo), 0.040 wt% or less (excluding 0) of aluminum (Al), 0.015 wt% or less (excluding 0) of nitrogen (N), and the balance of iron (Fe) and inevitable impurities, and the steel bar as a final product may include the same alloy components.

[0033] In addition, the high-performance steel bar according to an embodiment of the present disclosure may further include at least any one of 0.1 wt% or less of tin (Sn) and 0.05 wt% or less of calcium (Ca) instead of the balance of iron (Fe).

[0034] Hereinafter, the roles and contents of each alloy element included in the high-performance steel bar according to an embodiment of the present disclosure will be described in detail.

Carbon (C)

[0035] Carbon (C) is the most effective and important element for increasing the strength of steel.

[0036] The carbon dissolves into austenite, and may form a low-temperature structure with excellent strength, such as martensite and bainite structures during rapid cooling. In addition, the hardness may be improved as the carbon content increases.

[0037] If the carbon content is insufficient, the aforementioned effect is lacking, making it difficult to secure sufficient strength. In contrast, if the carbon content is excessive, the carbon may cause deformation during cooling or a decrease in elongation and low-temperature toughness of a steel material.

[0038] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.08 to 0.17 wt%, preferably 0.10 to 0.17 wt%, and more preferably 0.13 to 0.17 wt% of carbon (C).

Silicon (Si)

[0039] Silicon (Si) is added as a deoxidizer to remove oxygen from steel in a steelmaking process together with aluminum, and is a ferrite stabilizing element with a solid solution strengthening effect to induce ferrite formation and improve the hardenability and softening resistance of steel.

[0040] If the silicon content exceeds 0.50 wt%, toughness may decrease and plastic workability may be impaired.

[0041] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.50 wt% or less (excluding 0) of silicon (Si).

Manganese (Mn)

[0042] Manganese (Mn) is a solid solution strengthening element and may not only contribute to securing the strength but also improve the hardenability of steel. In addition, as the manganese content increases, pearlite becomes finer and ferrite is solid-solution strengthened, thereby improving the yield strength.

[0043] If the manganese content is insufficient, the aforementioned effect may be negligible. On the other hand, if the manganese content is excessive, an austenite structure may remain, which may actually lower strength and toughness.

[0044] At this time, the high-performance steel bar according to an embodiment of the present disclosure may include 0.50 to 2.50 wt% of manganese (Mn).

Phosphorus (P)

[0045] Phosphorus (P) is an element that partially contributes to strength enhancement. However, if included excessively, the phosphorus deteriorates the ductility of steel and causes deviation in the final material due to billet centerline segregation. If the phosphorus content exceeds 0.02 wt%, the phosphorus may form centerline segregation and microsegregation, which may reduce the ductility of the steel and lower the impact value due to precipitation behavior.

[0046] In consideration of this, the high-performance steel bar according to an embodiment of the present disclosure may include 0.02 wt% or less (excluding 0) of phosphorus (P).

Sulfur (S)

[0047] Sulfur (S) combines with manganese, zinc, titanium, molybdenum, etc., to improve the machinability of steel and combines with manganese to form fine precipitates (e.g., MnS), thereby improving processability. However, if the amount of manganese in steel is insufficient, the sulfur combines with iron to form sulfides (e.g., FeS), which may cause cracks during hot and cold working. If the sulfur content exceeds 0.02 wt%, the ductility of the steel may

decrease, and the toughness and weldability may be reduced.

[0048] To this end, the high-performance steel bar according to an embodiment of the present disclosure may include 0.02 wt% or less (excluding 0) of sulfur (S).

5 Nickel (Ni)

[0049] Nickel is an important and common alloying element for low-temperature toughness. The nickel (Ni) refines the structure of steel and dissolves well into austenite and ferrite, which is used for solid solution strengthening.

10 **[0050]** If the nickel content is insufficient, the aforementioned effect may be negligible. On the other hand, if the nickel content is excessive, the manufacturing cost of steel increases, and the weldability and toughness may decrease.

[0051] At this time, the high-performance steel bar according to an embodiment of the present disclosure may include 0.30 to 1.00 wt% of nickel (Ni).

15 Chromium (Cr)

[0052] Chromium (Cr) is a ferrite stabilizing element, and delays carbon diffusion due to a solute interference effect when added to C-Mn steel, thereby affecting grain size refinement. In addition, the chromium may improve the hardenability of steel, thereby improving quenchability. However, if the chromium content is excessive, coarse carbides
20 may be formed at the grain boundaries, which may reduce the room-temperature and low-temperature ductility of the steel.

[0053] At this time, the high-performance steel bar according to an embodiment of the present disclosure may include 0.002 to 0.500 wt% of chromium (Cr).

25 Copper (Cu)

[0054] Copper (Cu) is usually contained in steel at about 0.1 to 0.3 wt%. The copper dissolves into ferrite up to 0.35 wt% at room temperature and exhibits a solid solution strengthening effect, thereby improving the strength and hard-
30 ness. In addition, corrosion resistance may be increased in the atmosphere or seawater. However, if the copper content is excessive, the elongation may decrease.

[0055] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.20 wt% or less (excluding 0) of copper (Cu).

35 Molybdenum (Mo)

[0056] Molybdenum (Mo) may improve hardenability up to 10 times greater than nickel (Ni) even with the addition of a small amount, and prevents temper brittleness, thereby providing resistance to temper brittleness. In addition, since the molybdenum forms carbides, the molybdenum also has an excellent effect as an alloy element for high-quality cutting tools and raises a crystal grain coarsening temperature. The molybdenum is more effective when used in
40 combination with chromium rather than alone to improve hardenability.

[0057] If the molybdenum content is insufficient, the aforementioned effect may be negligible. On the other hand, if the molybdenum content is excessive, the manufacturing cost of steel increases, and the weldability may decrease.

[0058] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.003 to 0.150 wt% of molybdenum (Mo).

45

Aluminum (Al)

[0059] Aluminum (Al) is added to a steelmaking process as a deoxidizer to remove oxygen from steel. In addition, the aluminum may contribute to crystal grain refinement through the formation of precipitates (e.g., AlN).

50 **[0060]** If the aluminum content is insufficient, the deoxidizing effect may be negligible. On the other hand, if the aluminum content is excessive, the ductility and toughness may be decreased.

[0061] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.040 wt% or less (excluding 0) of aluminum (Al).

55 Nitrogen (N)

[0062] Nitrogen (N) has a significant effect on the mechanical properties of steel even in extremely small amounts, and as the nitrogen content increases, the tensile strength and yield strength increase, whereas the elongation

decreases. In particular, a decrease in impact value and an increase in transition temperature are significant.

[0063] When the nitrogen is added, austenite crystal grains are refined, making it possible to manufacture fine-grained steel, and nitrides are formed with titanium, zirconium, vanadium, niobium, etc. to refine the crystal grains, but if the nitrogen content is excessive, high-temperature toughness may decrease, and intergranular brittleness may occur due to the precipitation of nitrides at the austenite grain boundaries.

[0064] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.015 wt% or less (excluding 0) of nitrogen (N).

Tin (Sn)

[0065] Tin (Sn) may improve the corrosion resistance and strength of steel.

[0066] If the tin is added in an amount of more than 0.1 wt%, it may induce a large amount of defects such as scale swelling or blistering on the surface of the steel, rather than contributing to improved corrosion resistance. In addition, if the tin content is excessive, the elongation and low-temperature impact toughness may decrease.

[0067] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.1 wt% or less (excluding 0) of tin (Sn).

Calcium (Ca)

[0068] Calcium (Ca) is added to a steelmaking process as a deoxidizer to remove oxygen from steel. In addition, it is possible to prevent a decrease in elongation and improve low-temperature toughness by suppressing the formation of non-metallic inclusions such as MnS.

[0069] If the calcium content is excessive, the calcium reacts with oxygen contained in the steel to form coarse oxide (CaO), which may reduce elongation.

[0070] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may include 0.05 wt% or less (excluding 0) of calcium (Ca).

[0071] In addition to the aforementioned components of the steel, the balance may contain Fe and inevitable impurities. The inevitable impurities are impurities to be mixed during the steelmaking step and the manufacturing process of the steel bar, and since the inevitable impurities are well known in the art, a detailed description thereof will be omitted.

[0072] In an embodiment of the present disclosure, the addition of elements other than the above-described alloy components is not excluded, but may be variously included within a range without impairing the technical spirit of the present disclosure. If additional elements are included, the additional elements may be included instead of the balance of iron (Fe).

[0073] The high-performance steel bar according to an embodiment of the present disclosure may have the room-temperature yield strength (YS) of at least 600 MPa and room-temperature tensile strength (TS) of at least 690 MPa.

[0074] The high-performance steel bar according to an embodiment of the present disclosure may have the room-temperature elongation (EL) of at least 13%.

[0075] The high-performance steel bar according to an embodiment of the present disclosure may have the low-temperature yield strength (YS_{-170°C}) of at least 800 MPa. Here, the low-temperature yield strength (YS_{-170°C}) refers to the yield strength measured on a specimen at -170°C.

[0076] If the low-temperature yield strength (YS_{-170°C}) is at least 800 MPa, it is possible to suppress or prevent deformation of the steel bar due to low-temperature brittleness even when an external force is applied in a low-temperature (-170°C) environment.

[0077] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may have the low-temperature yield strength (YS_{-170°C}) of at least 800 MPa, preferably the low-temperature yield strength (YS_{-170°C}) of at least 820 MPa, and more preferably the low-temperature yield strength (YS_{-170°C}) of at least 823 MPa.

[0078] The high-performance steel bar according to an embodiment of the present disclosure may have the low-temperature notch tensile strength (TS_n) of at least 800 MPa. Here, the low-temperature notch tensile strength (TS_n) refers to tensile strength measured in a notched specimen at -170°C.

[0079] If the low-temperature notch tensile strength (TS_n) is at least 800 MPa, it is possible to suppress or prevent fatigue failure from occurring by the notch in a low-temperature (-170°C) environment.

[0080] The high-performance steel bar according to an embodiment of the present disclosure may have the uniform elongation (UE) of at least 3%. Here, the uniform elongation (UE) refers to the elongation measured on a specimen at -170°C.

[0081] If the uniform elongation is at least 3%, it is possible to suppress or prevent fracture of the steel bar from occurring due to low-temperature brittleness even when an external force is applied in a low-temperature (-170°C) environment.

[0082] Accordingly, the high-performance steel bar according to an embodiment of the present disclosure may have the uniform elongation (UE) of at least 3%, preferably at least 6%.

[0083] The high-performance steel bar according to an embodiment of the present disclosure may have the notch sensitivity ratio (NSR) of at least 1.00. Here, the notch sensitivity ratio (NSR) refers to a ratio of low-temperature notch tensile strength (TS_n) and low-temperature yield strength ($YS_{-170^\circ\text{C}}$).

[0084] The low-temperature notch sensitivity ratio (NSR) may be improved to suppress or prevent the fatigue failure from occurring by the notch in a low-temperature (-170°C) environment. Accordingly, the low-temperature notch sensitivity ratio (NSR) may be at least 1.0.

[0085] Hereinafter, a method for manufacturing a high-performance steel bar according to an embodiment of the present disclosure will be described in detail.

Manufacturing method of high-performance steel bar

[0086] Hereinafter, a manufacturing method of a high-performance steel bar according to an embodiment of the present disclosure will be described with reference to FIG. 1.

[0087] FIG. 1 is a flowchart illustrating a manufacturing method of a high-performance steel bar according to an embodiment of the present disclosure.

[0088] The manufacturing method of the high-performance steel bar according to an embodiment of the present disclosure includes the steps of preparing a steel material as a semi-finished product (S1), reheating the steel material (S2), forming a hot rolled material by hot rolling the steel material (S3), and cooling the formed hot rolled material (S4).

[0089] Hereinafter, respective steps of the manufacturing method of the high-performance steel bar according to an embodiment of the present disclosure will be described in detail.

[0090] According to an embodiment of the present disclosure, the step (S1) of preparing the steel material as the semi-finished product is a step of preparing a steel material having the alloy composition range described above, in order to manufacture the high-performance steel bar as a final product.

[0091] Specifically, the step (S1) of preparing the steel material may be a step of preparing a semi-finished product by designing the alloy components in the alloy composition range described above. The semi-finished product may be a billet or a bloom, but is not limited thereto. In addition, the manufacturing of the semi-finished product may be performed through processes known in the art, such as steelmaking and continuous casting processes.

[0092] According to an embodiment of the present disclosure, after the step (S1) of preparing the steel material, the step (S2) of reheating the steel material may be performed.

[0093] The step (S2) of reheating the steel material is a pretreatment process of the rolling step, and may be a step of charging the steel material into a heating furnace and heating the steel material uniformly to facilitate plastic deformation, thereby re-dissolving segregated components during casting of the steel material.

[0094] In the step (S2) of reheating the steel material, the steel material may be reheated at 1030 to 1200°C . If the reheating temperature is less than 1030°C , the rolling load may increase. On the other hand, if the reheating temperature exceeds 1200°C , the austenite crystal grains may be coarsened or decarburized, which may impair the strength. In addition, increased heating costs and time may cause problems such as increased manufacturing costs and decreased productivity.

[0095] Therefore, in the present disclosure, the steel material may be reheated at a temperature of 1030 to 1200°C .

[0096] According to an embodiment of the present disclosure, after the step (S2) of reheating the steel material, the step (S3) of forming the hot rolled material by hot rolling the steel material may be performed.

[0097] In the step (S3) of forming the hot rolled material, the temperature of the reheated steel material may drop slightly due to reasons such as transport, and hot rolling may start in a temperature range of 1020 to 1180°C .

[0098] The hot rolling may include rough rolling and finishing rolling processes. Here, the rough rolling process may be a process of making the steel material into a rolled material with a suitable shape, thickness, and width, and the finishing rolling process may be a process of adjusting the steel material to a predetermined size and rolling the steel material with a good surface and shape at a finishing temperature suitable for the application.

[0099] In the step (S3) of forming the hot rolled material, the rolling ratio may be 14 to 40%.

[0100] When the rolling ratio is less than 14%, it is difficult to obtain a uniform and fine structure, which may cause severe variations in strength and impact toughness. On the other hand, if the rolling ratio exceeds 40%, cracks may occur in the hot rolled material during working.

[0101] In the step (S3) of forming the hot rolled material, the finishing rolling temperature may be 900 to 1000°C . If the finishing rolling temperature is less than 900°C , the rolling load increases, which lowers productivity and may reduce a heat treatment effect. On the other hand, if the temperature exceeds 1000°C , a pearlite structure may be coarsely formed and the strength may decrease rapidly.

[0102] Therefore, the finishing rolling temperature can be 900 to 1000°C .

[0103] By performing the finishing rolling temperature in the aforementioned range, dynamic recrystallization may

continuously occur within the steel material. As a result, the austenite structure may be refined, and furthermore, the structure of the high-performance steel bar as a final product after cooling is also refined, which may improve low-temperature properties.

[0104] According to an embodiment of the present disclosure, after performing the step (S3) of forming the hot rolled material, the step (S4) of cooling the formed hot rolled material may be performed.

[0105] The step (S4) of cooling the hot rolled material may be performed through cooling equipment.

[0106] The cooling equipment may be Temp-core equipment. In other words, the hot rolled material may be recuperated using residual heat after being rapidly cooled by a refrigerant. For example, the refrigerant may be water.

[0107] In other words, the step (S4) of cooling the hot rolled material may rapidly cool the hot rolled material at a cooling rate of 30 to 400°C/sec using cooling water. The aforementioned temperature range refers to the surface temperature of the hot rolled material.

[0108] After rapid cooling, the surface of the hot rolled material may be recuperated in a temperature range of 540 to 700°C through internal residual heat and then air-cooled back to room temperature.

[0109] After the step (S4) of cooling the hot rolled material is performed, the high-performance steel bar, which is the final product, may be formed.

[0110] The high-performance steel bar manufactured by the method for manufacturing the high-performance steel bar according to an embodiment of the present disclosure may satisfy all values of the aforementioned room-temperature yield strength (YS), room-temperature tensile strength (TS), low-temperature yield strength (YS_{-170°C}), low-temperature notch tensile strength (TS_n), uniform elongation (UE), and notch sensitivity ratio (NSR).

[0111] In addition, the high-performance steel bar manufactured by the method for manufacturing the high-performance steel bar according to an embodiment of the present disclosure may include a surface layer and a core.

[0112] In a cross-section of the steel bar cut in a direction perpendicular to the rolling direction, the core is defined as an area of 65 to 75% of the entire area, and the surface layer is defined as the remaining area (i.e., 25 to 35% of the entire area) surrounding the core.

[0113] The surface layer is formed of a structure including at least any one of tempered martensite and bainite, and the core may be formed of a structure including at least any one of bainite, acicular ferrite, and pearlite.

[0114] A detailed description thereof will be further described with reference to FIG. 2.

[0115] FIG. 2 is a photograph showing results of observing a surface layer and a core of a high-performance steel bar according to an embodiment of the present disclosure using an optical microscope. In FIG. 2, (a) shows a photograph observing a microstructure of the surface layer of the steel bar, and (b) shows a photograph observing a microstructure of the core of the steel bar.

[0116] Referring to (a) of FIG. 2, it can be seen that a composite structure of tempered martensite and bainite is formed on the surface layer of the steel bar, and referring to (b) of FIG. 2, it can be seen that a composite structure of bainite, acicular ferrite, and pearlite is formed in the core of the steel bar.

[0117] According to an embodiment of the present disclosure, room-temperature and low-temperature strengths may be improved through the composite structure of tempered martensite and bainite formed on the surface layer of the steel bar.

[0118] In addition, the room-temperature elongation, uniform elongation, and notch sensitivity ratio of the steel bar may be improved through the composite structure of bainite, acicular ferrite, and pearlite formed in the core of the steel bar.

Examples and Comparative Examples

[0119] Hereinafter, preferred Comparative Examples and Examples will be presented in order to assist the understanding of the present disclosure. However, the following Comparative Examples and Examples are intended only to aid in understanding the present disclosure, and the present disclosure is not limited by the following Examples.

[0120] Table 1 shows alloy element compositions of Comparative Examples and Examples, and Table 2 shows operating conditions and physical property values of Comparative Examples and Examples.

[0121] Comparative Examples and Examples were manufactured using semi-finished products having the alloy compositions shown in Table 1 below, respectively, and hot rolling and cooling were performed under the operating conditions shown in Table 2.

[0122] In the case of the cooling rate, the steel bar was cooled through accelerated controlled cooling, and started at a cooling rate of 30°C/sec and ended at a cooling rate of 400°C/sec.

[0123] Except for the conditions described above, the manufacturing processes of Comparative Examples and Examples of the present disclosure, as control variables, were controlled under the same conditions within the range described in the method for manufacturing the high-performance steel bar according to an embodiment of the present disclosure.

[0124] In addition, the room-temperature properties of Comparative Examples and Examples were measured in an

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environment of 20°C, and the low-temperature properties were measured in an environment of -170°C.

[0125] In Table 1 below, the composition unit of alloy elements was wt%, and in Table 2 below, the unit of rolling start temperature, rolling end temperature, and recuperative temperature was °C, the unit of room-temperature yield strength (YS), room-temperature tensile strength (TS), low-temperature yield strength (YS_{-170°C}) and low-temperature notch tensile strength (TS_n) was MPa, and the unit of room-temperature elongation (EL) and uniform elongation (UE) was %.

[Table 1]

Classification	C	Si	Mn	P	S	Cu	Cr	Mo	Ni	Sn	Al	Ca	N
Comp. Ex. 1	0.070	0.12	1.55	0.010	0.012	0.23	0.11	0.02	0.59	0.007	0.015	0.002	0.009
Comp. Ex. 2	0.070	0.12	1.55	0.010	0.012	0.23	0.11	0.02	0.59	0.007	0.015	0.002	0.009
Comp. Ex. 3	0.035	0.12	1.62	0.010	0.010	0.13	0.11	0.06	0.56	0.007	0.015	0.002	0.009
Comp. Ex. 4	0.046	0.17	1.53	0.008	0.010	0.15	0.05	0.02	0.53	0.008	0.030	0.002	0.010
Comp. Ex. 5	0.070	0.15	1.55	0.010	0.008	0.11	0.08	0.12	0.47	0.007	0.020	0.010	0.008
Comp. Ex. 6	0.070	0.15	1.55	0.010	0.008	0.11	0.08	0.12	0.47	0.007	0.020	0.010	0.008
Ex. 1	0.134	0.12	1.78	0.010	0.010	0.20	0.11	0.04	0.59	0.007	0.015	0.002	0.009
Ex. 2	0.162	0.25	1.83	0.009	0.008	0.13	0.08	0.10	0.58	0.010	0.025	0.002	0.009

[Table 2]

Classification	Operating condition				Room-temperature property (20°C)			Low-temperature property (-170°C)			
	Rolling start temperature (°C)	Rolling end temperature (°C)	Cooling rate (°C/sec)	Recuperative temperature (°C)	YS (MPa)	TS (MPa)	EL (%)	YS. 170°C (MPa)	UE (%)	TS _n (MPa)	NSR
Comp. Ex. 1	1,180	1,000	30 to 400	670	573	680	16.6	762	8.5	770	1.01
Comp. Ex. 2	1,020	910		580	607	706	12.9	782	8.3	798	1.02
Comp. Ex. 3	1,100	960		535	553	677	13.4	783	9.4	806	1.03
Comp. Ex. 4	1,100	960		535	589	683	15.9	781	11.0	812	1.04
Comp. Ex. 5	1,180	1005		670	563	691	20.5	748	10.5	778	1.04
Comp. Ex. 6	1,020	920		580	616	706	16.5	774	9.6	813	1.05
Ex. 1	1,100	960		573	604	699	13.8	823	6.2	826	1.00
Ex. 2	1,100	995		577	636	714	16.0	829	9.0	846	1.02

[0126] Referring to Tables 1 and 2 above, Comparative Example 1 is a Comparative Example in which the carbon (C) content is 0.070 wt%.

[0127] In the case of Comparative Example 1, it can be confirmed that the room-temperature elongation (EL), uniform elongation (UE), and notch sensitivity ratio (NSR) satisfy the range according to an embodiment of the present disclosure, but the room-temperature yield strength (YS) is 573 MPa, the room-temperature tensile strength (TS) is 680 MPa, the low-temperature yield strength (YS_{-170°C}) is 762 MPa, and the low-temperature notch tensile strength (TS_n) is 770 MPa.

[0128] In other words, in the case of Comparative Example 1, it can be confirmed that the aforementioned physical properties do not satisfy the range according to an embodiment of the present disclosure of room-temperature yield strength (YS) of at least 600 MPa, room-temperature tensile strength (TS) of at least 690 MPa, low-temperature yield strength (YS_{-170°C}) of at least 800 MPa, and low-temperature notch tensile strength (TS_n) of 800 MPa.

[0129] Comparative Example 2 is Comparative Example that has the same alloy element composition as Comparative Example 1, but different operating conditions. Specifically, it can be confirmed that the rolling start temperature is 1020°C, the rolling end temperature is 910°C, and the recuperative temperature is 580°C, which is lower than those of Comparative Example 1.

[0130] In the case of Comparative Example 2, it can be confirmed that the room-temperature yield strength (YS), room-temperature tensile strength (TS), room-temperature elongation (EL), uniform elongation (UE), and notch sensitivity ratio (NSR) satisfy the range according to an embodiment of the present disclosure, and the low-temperature yield strength (YS_{-170°C}) is 782 MPa, and the low-temperature notch tensile strength (TS_n) is 798 MPa.

[0131] In the case of Comparative Example 2, it can be confirmed that the strengths were improved compared to Comparative Example 1, but the low-temperature yield strength (YS_{-170°C}) and low-temperature notch tensile strength (TS_n) do not satisfy the range according to an embodiment of the present disclosure of the low-temperature yield strength (YS_{-170°C}) of at least 800 MPa and low-temperature notch tensile strength (TS_n) of at least 800 MPa.

[0132] Comparative Example 3 is Comparative Example in which the carbon (C) content is 0.035 wt%.

[0133] In the case of Comparative Example 3, it can be confirmed that the room-temperature elongation (EL), uniform elongation (UE), and notch sensitivity ratio (NSR) satisfy the range according to an embodiment of the present disclosure, but the room-temperature yield strength (YS) is 553 MPa, the room-temperature tensile strength (TS) is 677 MPa, and the low-temperature yield strength (YS_{-170°C}) is 783 MPa.

[0134] In other words, in the case of Comparative Example 3, it can be confirmed that the aforementioned physical properties do not satisfy the range according to an embodiment of the present disclosure of the room-temperature yield strength (YS) of at least 600 MPa, room-temperature tensile strength (TS) of at least 690 MPa, and low-temperature yield strength (YS_{-170°C}) of at least 800 MPa.

[0135] Comparative Example 4 is Comparative Example in which the carbon (C) content is 0.046 wt%.

[0136] In the case of Comparative Example 4, it can be confirmed that the room-temperature elongation (EL), uniform elongation (UE), and notch sensitivity ratio (NSR) satisfy the range according to an embodiment of the present disclosure, but the room-temperature yield strength (YS) is 589 MPa, the room-temperature tensile strength (TS) is 683 MPa, and the low-temperature yield strength (YS_{-170°C}) is 781 MPa.

[0137] In other words, in the case of Comparative Example 4, it can be confirmed that the aforementioned physical properties do not satisfy the range according to an embodiment of the present disclosure of the room-temperature yield strength (YS) of at least 600 MPa, room-temperature tensile strength (TS) of at least 690 MPa, and low-temperature yield strength (YS_{-170°C}) of at least 800 MPa.

[0138] Comparative Example 5 is Comparative Example in which the carbon (C) content is 0.070 wt%, but the alloy composition is different from those of Comparative Examples 1 and 2.

[0139] In the case of Comparative Example 5, it can be confirmed that the room-temperature tensile strength (TS), room-temperature elongation (EL), uniform elongation (UE), and notch sensitivity ratio (NSR) satisfy the range according to an embodiment of the present disclosure, but the room-temperature yield strength (YS) is 563 MPa, the low-temperature yield strength (YS_{-170°C}) is 748 MPa, and the low-temperature notch tensile strength (TS_n) is 778 MPa.

[0140] In other words, in the case of Comparative Example 5, it can be confirmed that the aforementioned physical properties do not satisfy the range according to an embodiment of the present disclosure of the room-temperature yield strength (YS) of at least 600 MPa, low-temperature yield strength (YS_{-170°C}) of at least 800 MPa, and low-temperature notch tensile strength (TS_n) of 800 MPa.

[0141] Comparative Example 6 is Comparative Example that has the same alloy element composition as Comparative Example 5, but different operating conditions. Specifically, it can be confirmed that the rolling start temperature is 1020°C, the rolling end temperature is 920°C, and the recuperative temperature is 580°C, which is lower than those of Comparative Example 5.

[0142] In the case of Comparative Example 6, it can be confirmed that the room-temperature yield strength (YS), room-temperature tensile strength (TS), room-temperature elongation (EL), low-temperature notch tensile strength (TS_n), uniform elongation (UE), and notch sensitivity ratio (NSR) satisfy the range according to an embodiment of the

present disclosure, and the low-temperature yield strength ($YS_{-170^{\circ}\text{C}}$) is 774 MPa.

[0143] In the case of Comparative Example 6, it can be confirmed that the strengths were improved compared to Comparative Example 5, but the low-temperature yield strength ($YS_{-170^{\circ}\text{C}}$) does not satisfy at least 800 MPa which is the range according to an embodiment of the present disclosure.

[0144] As a result, in the case of Comparative Examples 1 to 6, it can be confirmed that the carbon (C) content does not satisfy at least 0.08 wt% which is the range according to an embodiment of the present disclosure, so that at least any one of the room-temperature properties and low-temperature properties is not satisfied.

[0145] On the other hand, in the case of Examples 1 and 2, it can be confirmed that the alloy composition range satisfies all of the embodiments of the present disclosure.

[0146] Through this, it can be confirmed that the values of room-temperature yield strength (YS), room-temperature tensile strength (TS), room-temperature elongation (EL), low-temperature yield strength ($YS_{-170^{\circ}\text{C}}$), low-temperature notch tensile strength (TS_n), uniform elongation (UE), and notch sensitivity ratio (NSR) all satisfy a target range of the present disclosure.

[0147] As described above, the prepared embodiments of the present disclosure have been described and it will be apparent to those skilled in the art that the present disclosure can be materialized in other specific forms without departing from the gist or scope in addition to the above-described embodiments. Therefore, the aforementioned embodiments are not limited but should be considered to be illustrative, and accordingly, the present disclosure is not limited to the above description and may be modified within the scope of the appended claims and a range equivalent thereto.

Claims

1. A high-performance steel bar comprising:

0.08 to 0.17 wt% of carbon (C), 0.50 wt% or less (excluding 0) of silicon (Si), 0.50 to 2.50 wt% of manganese (Mn), 0.02 wt% or less (excluding 0) of phosphorus (P), 0.02 wt% or less (excluding 0) of sulfur (S), 0.30 to 1.00 wt% of nickel (Ni), 0.002 to 0.500 wt% of chromium (Cr), 0.20 wt% or less (excluding 0) of copper (Cu), 0.003 to 0.150 wt% of molybdenum (Mo), 0.040 wt% or less (excluding 0) of aluminum (Al), 0.015 wt% or less (excluding 0) of nitrogen (N), and a balance of iron (Fe) and inevitable impurities, wherein a room-temperature yield strength (YS) is at least 600 MPa and a low-temperature yield strength ($YS_{-170^{\circ}\text{C}}$) is at least 800 MPa.

2. The high-performance steel bar of claim 1, further comprising:

at least any one of 0.1 wt% or less of tin (Sn) and 0.05 wt% or less of calcium (Ca).

3. The high-performance steel bar of claim 1, wherein a room-temperature tensile strength (TS) is at least 690 MPa.

4. The high-performance steel bar of claim 1, wherein a room-temperature elongation (EL) is at least 13%.

5. The high-performance steel bar of claim 1, wherein a uniform elongation (UE) is at least 3%.

6. The high-performance steel bar of claim 1, wherein a low-temperature notch tensile strength (TS_n) is at least 800 MPa.

7. The high-performance steel bar of claim 1, wherein a notch sensitivity ratio (NSR) is at least 1.00.

8. The high-performance steel bar of claim 1, wherein the high-performance steel bar includes a surface layer and a core,

wherein the surface layer includes at least any one of tempered martensite and bainite, and the core includes at least any one of bainite, acicular ferrite, and pearlite.

9. A method for manufacturing a high-performance steel bar comprising steps of:

(S1) preparing a steel material;

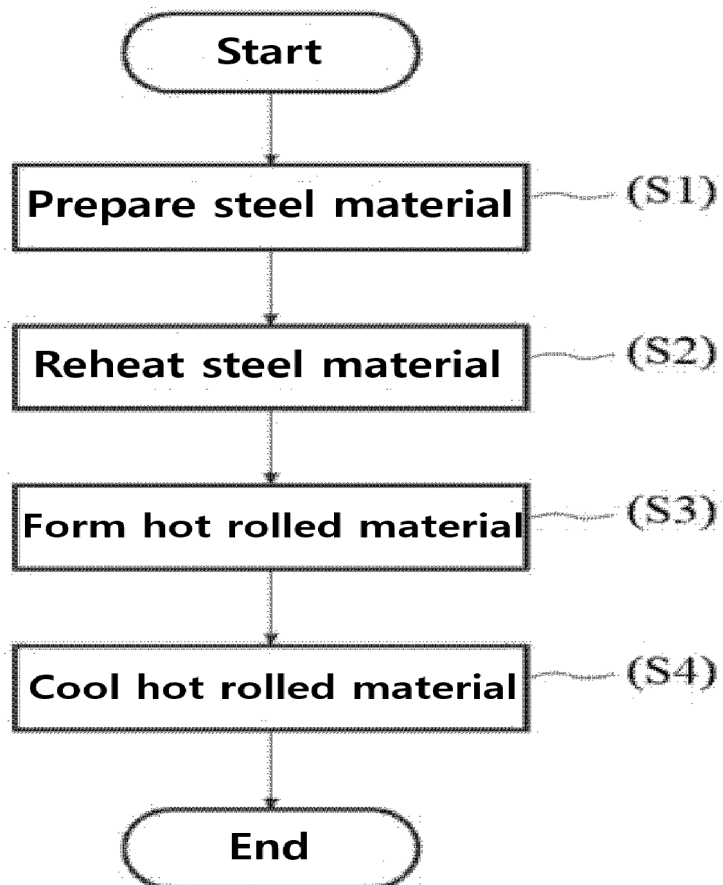
(S2) reheating the steel material;

(S3) forming a hot rolled material by hot rolling the steel material; and

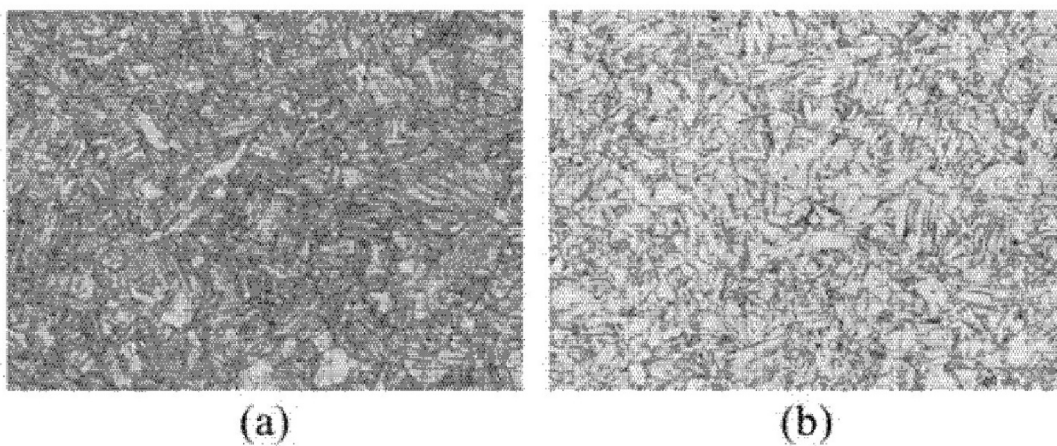
(S4) cooling the hot rolled material to form a final product,
 wherein the final product includes 0.08 to 0.17 wt% of carbon (C), 0.50 wt% or less (excluding 0) of silicon (Si), 0.50 to 2.50 wt% of manganese (Mn), 0.02 wt% or less (excluding 0) of phosphorus (P), 0.02 wt% or less (excluding 0) of sulfur (S), 0.30 to 1.00 wt% of nickel (Ni), 0.002 to 0.500 wt% of chromium (Cr), 0.20 wt% or less (excluding 0) of copper (Cu), 0.003 to 0.150 wt% of molybdenum (Mo), 0.040 wt% or less (excluding 0) of aluminum (Al), 0.015 wt% or less (excluding 0) of nitrogen (N), and a balance of iron (Fe) and inevitable impurities,
 a room-temperature yield strength (YS) of the final product is at least 600 MPa, and
 a cryogenic yield strength (YS_{-170°C}) is at least 800 MPa.

10. The method for manufacturing the high-performance steel bar of claim 9, wherein a reheating temperature of step (S2) is 1030 to 1200°C.
11. The method for manufacturing the high-performance steel bar of claim 9, wherein a rolling ratio of step (S3) is 14 to 40%.
12. The method for manufacturing the high-performance steel bar of claim 9, wherein a rolling end temperature of step (S3) is 900 to 1,000°C.
13. The method for manufacturing the high-performance steel bar of claim 9, wherein a cooling rate of step (S4) is 30 to 400°C/s.
14. The method for manufacturing the high-performance steel bar of claim 9, wherein a cooling end temperature of step (S4) is 540 to 700°C.

【Fig. 1】



【Fig. 2】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019125

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; **C22C 38/42**(2006.01)i; **C22C 38/44**(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/00**(2006.01)i;
C21D 8/06(2006.01)i; **C21D 9/28**(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); C21D 8/02(2006.01); C21D 9/08(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01);
C22C 38/32(2006.01); C22C 38/48(2006.01); C22C 38/60(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: 봉강(steel bar), 고강도(high strength), 표층부(surface layer), 중심부
(core), 항복강도(yield strength)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2057765 B1 (HYUNDAI STEEL COMPANY) 19 December 2019 (2019-12-19) See paragraphs [0007], [0091] and [0125], table 6, and claims 1-3 and 6.	1,3-12,14
Y		2,13
Y	JP 6874913 B2 (JFE STEEL CORPORATION) 19 May 2021 (2021-05-19) See claims 1 and 3-4.	2,13
A	JP 2010-229528 A (JFE STEEL CORP.) 14 October 2010 (2010-10-14) See claims 1-3.	1-14
A	JP 5751012 B2 (JFE STEEL CORPORATION) 22 July 2015 (2015-07-22) See claim 1.	1-14

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

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“A” document defining the general state of the art which is not considered to be of particular relevance

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“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

“&” document member of the same patent family

Date of the actual completion of the international search 05 March 2025	Date of mailing of the international search report 05 March 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019125

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015-0044086 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 12 February 2015 (2015-02-12) See paragraphs [0131]-[0135] and claim 14.	1-14

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