



(11)

EP 4 826 095 A1

(12)

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

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

(21) Application number: **24904111.2**

(22) Date of filing: **29.11.2024**

(51) International Patent Classification (IPC):
C22C 38/58 ^(2006.01) **C22C 38/48** ^(2006.01)
C22C 38/50 ^(2006.01) **C22C 38/00** ^(2006.01)
C21D 8/02 ^(2026.01)

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C22C 38/00; C22C 38/48; C22C 38/50;
C22C 38/58

(86) International application number:
PCT/KR2024/019311

(87) International publication number:
WO 2025/127546 (19.06.2025 Gazette 2025/25)

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

(30) Priority: **15.12.2023 KR 20230183901**

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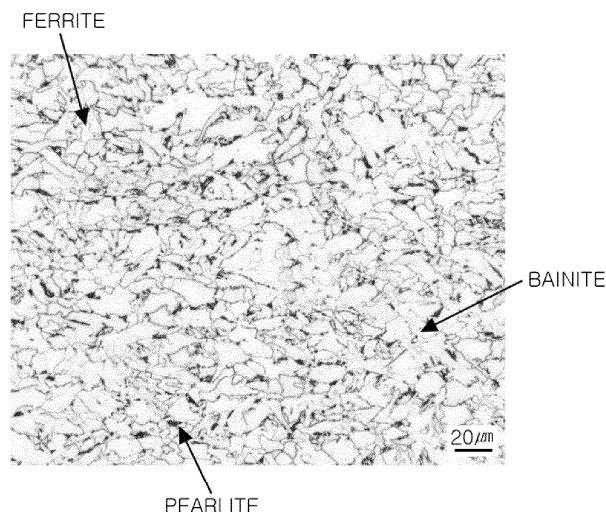
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(54) **STEEL AND METHOD FOR MANUFACTURING SAME**

(57) The present invention relates to: steel that can
be used for a wind power generator having a monopile

or jacket structure; and a method for manufacturing
same.

[FIG. 1]



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Description

Technical Field

- 5 **[0001]** The present disclosure relates to a steel material that can be used in a wind power generator having a monopile or jacket structure and a method for manufacturing the same.

Background Art

- 10 **[0002]** Recently, as a height of a structure used in onshore and offshore wind power generators has gradually increased, demand for an ultra-thick, high-strength steel material with excellent load-resisting capability has increased, and impact toughness at low temperatures and aging impact toughness when deformation such as bending, or the like, is involved, are also required.

- 15 **[0003]** In order to secure excellent low-temperature impact toughness and aging impact toughness along with high strength, a process of refining grains is essential. However, when an ultra-thick steel material is manufactured through a rolling process, there is a disadvantage in that sufficient rolling force is not transmitted to a central portion of a thickness thereof, so there is a limitation in refining grains. In addition, there are many cases in which pores present in a steel slab are not sufficiently compressed during the rolling process, and the internal quality often deteriorates even after a final hot-rolled steel sheet is manufactured due to a segregation zone present in a central portion of a thickness of the steel slab after continuous casting.

[0004] Due to thickening of a steel material used for structures of wind power generators, it is difficult to secure the properties of the central portion of the thickness described above, while a case which requires the strength, low-temperature impact toughness, and excellent internal quality of the central portion of the thickness is rather increasing.

- 25 **[0005]** In order to secure the properties and internal quality of the central portion of the thickness, alloying elements which are advantageous for grain refinement should be appropriately added, and a steel slab with sound interior should be manufactured through optimization in a continuous casting process, and a type and a fraction of a microstructure thereof should be controlled so that both the target strength and low-temperature impact toughness may be satisfied by optimizing rolling accelerating cooling.

- 30 **[0006]** Patent Document 1 has proposed a method for securing the quality of a central portion by increasing a reduction rate per pass to 10% or more during rough rolling so that sufficient rolling force is applied to a central portion of the hot-rolled steel sheet, and by providing sufficient air cooling standby time before finishing rolling, thereby applying additional rolling force to the central portion when a surface portion hardened by the temperature drop is rolled. However, this method has a disadvantage in that there is a limitation in securing the quality of the central portion when segregation defects or large pores are present within the steel slab.

- 35 **[0007]** (Patent Document 1) Korean Patent Publication No. 10-2023-0102791

Summary of Invention

Technical Problem

- 40 **[0008]** An aspect of the present disclosure is to provide a steel material having excellent strength in a central portion thereof, and having excellent impact toughness and internal quality in an ultra-thick steel material, and a method for manufacturing the same.

- 45 **[0009]** An object of the present disclosure is not limited to the above description. The object of the present disclosure will be understood from the entire content of the present specification, and a person skilled in the art to which the present disclosure pertains will understand an additional object of the present disclosure without difficulty.

Solution to Problem

- 50 **[0010]** According to an aspect of the present disclosure, provided is a steel material, the steel material comprising by weight%: 0.03 to 0.08% of carbon (C), 0.1 to 0.5% of silicon (Si), 1.0 to 1.6% of manganese (Mn), 0.01% or less of phosphorus (P), 0.003% or less of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.015 to 0.035% of niobium (Nb), 0.3% or less (excluding 0%) of chromium (Cr), 0.1 to 0.5% of nickel (Ni), 0.01 to 0.02% of titanium (Ti), 0.002 to 0.01% of nitrogen (N), with a remainder of Fe and inevitable impurities,

- 55 wherein a microstructure of the steel material comprises, by area fraction, 60 to 85% of ferrite, 10 to 20% of bainite, and a remainder of pearlite and inevitable structures, and an average effective grain size having a high-angle grain boundary of 15° or more is 20 μm or less.

[0011] The steel material may have the number of remained pores having a size of 100 mm² or more of 1 or less.

[0012] The steel material may have a yield strength of 320 MPa or more at t/4 and t/2 points, where t is a thickness of the steel material.

[0013] The steel material may have a tensile strength of 430 MPa or more and 590 MPa or less at t/4 and t/2 points, where t is a thickness of the steel material.

[0014] The steel material may have a Charpy impact absorption energy of 100J or more at -50°C.

[0015] According to another aspect of the present disclosure, provided is a method for manufacturing a steel material, the method comprising: preparing a steel slab including by weight, 0.03 to 0.08% of carbon (C), 0.1 to 0.5% of silicon (Si), 1.0 to 1.6% of manganese (Mn), 0.01% or less of phosphorus (P), 0.003% or less of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.015 to 0.035% of niobium (Nb), 0.3% or less (excluding 0%) of chromium (Cr), 0.1 to 0.5% of nickel (Ni), 0.01 to 0.02% of titanium (Ti), 0.002 to 0.01% of nitrogen (N), with a remainder of Fe and inevitable impurities;

heating the steel slab at a temperature within a range of 1000 to 1080°C;

rough rolling the heated steel slab at a temperature within a range of 900 to 1000°C;

finishing rolling at a temperature within a range of Ar3 or higher and T_{nr} or lower after the rough rolling; and

cooling at a cooling rate of 2 to 5°C/s to a temperature within a range of 350 to 500°C.

[0016] The steel slab is manufactured by continuous casting of molten steel, and during the continuous casting, slab reduction (unit: mm) of 3 mm or more and 6 mm or less is applied, and additional reduction of 3 mm or more and 10 mm or less is applied after solidification, thereby manufacturing a steel slab having a thickness of 290 mm or more and 397 mm or less.

[0017] A hydrogen concentration in the molten steel may be 1.5 ppm or less.

[0018] When the steel slab is manufactured, a molten steel degassing process (RH process) may be performed before continuous casting, and the RH process may be performed for 15 minutes or more under conditions of 2 torr or less.

Advantageous Effects of Invention

[0019] As set forth above, according to an aspect of the present disclosure, it is possible to provide an ultra-thick steel material for wind power structures having excellent low-temperature impact and aging impact toughness in addition to the strength of the central portion.

[0020] The various and beneficial advantages and effects of the present disclosure are not limited to the above-described content, and may be more easily understood through description of specific embodiments of the present disclosure.

Brief Description of Drawings

[0021]

FIG. 1 is an optical microscope photograph of a microstructure at a t/2 point, where t is a thickness of the steel material having a component of Inventive Example 1 and a thickness of 120 mm.

FIG. 2 is an EBSD result observing a microstructure at a t/2 point, where t is a thickness of the steel material having a component of Inventive Example 1 and a thickness of 120 mm.

Best Mode for Invention

[0022] The terms used in this specification are used to describe the present disclosure and are not intended to limit the present disclosure. In addition, as used herein, singular forms include plural forms unless the relevant definition clearly indicates the contrary.

[0023] The meaning of "including" or "comprising" used in the specification specifies a configuration and does not exclude the presence or addition of another configuration.

[0024] Unless otherwise defined, all terms, including technical terms and scientific terms used in this specification, have the same meaning as that which could be commonly understood by those skilled in the art in the technical field to which the present disclosure pertains. Terms defined in the dictionary are interpreted as having meanings consistent with related technical literature and current disclosure.

[0025] As a steel material used for a structure of wind power generators such as monopiles and jackets is becoming larger and strict internal quality is required, the inventors of the present disclosure have recognized the need for a

method for securing the physical properties required for the steel material. In particular, in a steel material for wind power generators having a certain thickness or more, the inventors of the present disclosure have conducted in-depth research on a method for securing low-temperature impact toughness and aging impact toughness in addition to the strength of the central portion. As a result, it was confirmed that a steel material for wind power generators having target properties could be provided by controlling a composition of components and a relationship between some components in alloy design, and at the same time, optimizing manufacturing conditions, and thus the present disclosure was provided. As an example, it can be manufactured using a Thermo Mechanical Controlled Process (TMCP) method by utilizing a steel slab with excellent internal soundness.

[0026] First, an example of a steel material of the present disclosure will be described in detail. Hereinafter, an alloy composition and a range of the steel material will be described. A content of the alloy composition described below means a weight % unless specifically specified.

[0027] The steel material comprises by weight %, 0.03 to 0.08% of carbon (C), 0.1 to 0.5% of silicon (Si), 1.0 to 1.6% of manganese (Mn), 0.01% or less of phosphorus (P), 0.003% or less of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.015 to 0.035% of niobium (Nb), 0.3% or less (excluding 0%) of chromium (Cr), 0.1 to 0.5% of nickel (Ni), 0.01 to 0.02% of titanium (Ti), and 0.002 to 0.01% of nitrogen (N).

Carbon (C): 0.03 to 0.08%

[0028] Carbon (C) is an effective element for improving the strength by increasing the hardenability of steel. In order to sufficiently obtain such an effect, C may be included in an amount of 0.03% or more. However, when a content of C exceeds 0.08%, a high fraction of bainite and coarse carbides are present therein due to high hardenability, which can significantly reduce impact toughness, and when the content of C is less than 0.03%, it is not sufficient to secure strength. Therefore, C may be included in an amount of 0.03 to 0.08%, and more advantageously, C may be included in an amount of 0.03 to 0.05%.

Silicon (Si): 0.1 to 0.5%

[0029] Silicon (Si) is not only used as a deoxidizer, but is also an element which is advantageous in improving the strength and toughness of steel. In order to sufficiently obtain the effect described above, Si may be included in an amount of 0.1% or more. However, when a content of Si exceeds 0.5%, there is a concern that excessive formation of martensite (MA) may occur, resulting in poor low-temperature impact toughness. Therefore, Si may be included in an amount of 0.1 to 0.5%.

Manganese (Mn): 1.0 to 1.6%

[0030] Manganese (Mn) is an element which is advantageous in improving the strength of steel due to a solid solution strengthening effect. In order to sufficiently obtain the effect, Mn may be included in an amount of 1.0% or more. However, when a content of Mn exceeds 1.6%, Mn combines with sulfur (S) in steel to form MnS, causing a problem in that low-temperature impact toughness and aging impact toughness of a central portion are significantly reduced. Therefore, Mn may be included in an amount of 1.0 to 1.6%, and more advantageously, Mn may be included in an amount of 1.4 to 1.6%.

Phosphorus (P): 0.01% or less

[0031] Phosphorus (P) is an element which is advantageous in improving the strength of steel and securing corrosion resistance, but P can significantly reduce the impact toughness of steel, so it is preferable to limit a content of P to be as low as possible. In the present disclosure, even when a maximum content of P is 0.01%, there is no problem in securing target properties, so the content of P may be limited to be 0.01% or less. However, considering the level that is inevitably added, 0% can be excluded.

Sulfur (S): 0.003% or less

[0032] Sulfur (S) is an element which combines with Mn in steel to form MnS, or the like, thereby significantly reducing hydrogen-induced crack resistance and impact toughness of steel. Therefore, it is advantageous to limit a content of S to be as low as possible. In the present disclosure, even when a maximum content of S is 0.003%, there is no problem in securing target properties, so the content can be limited to be 0.003% or less. However, considering the level that is inevitably added, 0% can be excluded.

Aluminum (Al): 0.01 to 0.05%

[0033] Aluminum (Al) is an element which can deoxidize molten steel inexpensively. In order to sufficiently obtain the above-described effect, Al may be included in an amount of 0.01% or more. However, when a content of Al is excessive and exceeds 0.05%, not only may nozzle clogging occur during continuous casting, but also a significant decrease in impact toughness may be caused due to the formation of Al-based oxidizing inclusions, which is not preferable.

Niobium (Nb): 0.015 to 0.035%

[0034] Niobium (Nb) is precipitated in the form of NbC or Nb(C,N), which significantly improves the strength of a base material, and when reheated at a high temperature, dissolved Nb suppresses the recrystallization of austenite and the transformation into ferrite or bainite, thereby obtaining a microstructural refinement effect. However, when a content of Nb becomes excessive, undissolved Nb is formed in the form of TiNb(C,N), which causes UT defects and to inhibit low-temperature impact toughness, so it is preferable to limit an upper limit of a content of Nb to 0.035%. Therefore, in the present disclosure, Nb may be included in an amount of 0.015 to 0.035%, and more advantageously, in an amount of 0.025 to 0.03%.

Nickel (Ni): 0.1 to 0.5%

[0035] Nickel (Ni) is an element which can simultaneously improve the strength and low-temperature impact toughness of a base material, but as an expensive element, if a content of Ni exceeds 0.5%, there is a problem that the economic feasibility is greatly reduced. Therefore, Ni can be included in an amount of 0.5% or less. However, in order to exert the effect of Ni, it is preferable to add at least 0.1% or more of Ni.

Titanium (Ti): 0.01 to 0.02%

[0036] Titanium (Ti) is added together with N to form TiN, thereby reducing the occurrence of surface cracks due to the formation of AlN precipitates, so it is preferable to add at least 0.01% or more of Ti. However, when a content of Ti exceeds 0.02%, coarse TiN is formed during reheating of a steel slab, which acts as a factor inhibiting low-temperature impact toughness. Therefore, the content of Ti is preferably 0.01 to 0.02%, and more preferably 0.01 to 0.015%.

Nitrogen (N): 0.002 to 0.01%

[0037] Nitrogen (N) is an element which is advantageous in suppressing grain growth due to heat affect during welding by forming TiN, when added together with Ti. In order to sufficiently obtain the above-described effect when adding N, N may be included in an amount of 0.002% or more. However, when a content of N exceeds 0.01%, coarse TiN is formed, which inhibits the low-temperature impact toughness, so it is not preferable. Therefore, the content of N is preferably 0.002 to 0.01%.

Chromium (Cr): 0.3% or less (excluding 0%)

[0038] Chromium (Cr) is an effective element that can not only increase the hardenability of steel, increase a fraction of a low-temperature phase such as bainite, but also improve strength by forming fine Cr-based carbides. However, when a content of Cr exceeds 0.3%, the low-temperature impact toughness or aging impact toughness may be significantly reduced due to coarse bainite and carbides present therein, so it is preferable that the content of Cr is 0.3% or less.

[0039] The remaining component of the present disclosure is iron (Fe). However, since in the common manufacturing process, unintended impurities may be inevitably incorporated from raw materials or the surrounding environment, the component may not be excluded. Since these impurities are known to any person skilled in the common manufacturing process, the entire contents thereof.

[0040] The steel material may include by area %, 60 to 85% of ferrite, 10 to 20% of bainite, with a remainder of pearlite and inevitable structures.

[0041] It is preferable that the steel material have an average effective grain size having a high-angle grain boundary of 15° or more is 20 μm or less.

[0042] When a fraction of ferrite is less than 60%, and a fraction of bainite exceeds 20%, the impact toughness may be significantly reduced due to excessively high strength, and conversely, when the fraction of ferrite exceeds 85% and the fraction of bainite is too low, less than 10%, the strength may be insufficient.

[0043] Meanwhile, when the average effective grain size having the high-angle grain boundary exceeds 20 μm , the impact toughness may be significantly reduced. As an example of measuring the effective grains having the high-angle grain boundary of 15° or more, it can be confirmed through EBSD (Electron Backscatter Diffraction).

[0044] Meanwhile, it is preferable that the steel material has the number of remained pores having a size of 100 mm^2 or more of 1 or less. The remained pores affect the internal quality. The steel material may be measured through ultrasonic inspection. The remained pores are pores that usually present in a central portion of the slab and remains since sufficient rolling force is not transmitted to the central portion during rolling, so it is common that the remained pores are present at a 1/4t point of the hot-rolled steel sheet to the central portion of the hot-rolled steel sheet.

[0045] When the number of remained pores having a size of 100 mm^2 or more exceeds 1, an accident such as fracture due to internal defects may occur when the hot-rolled steel sheet is used as a structure. Therefore, it is preferable that there be no remained pores having a size of 100 mm^2 or more, and therefore, the number of remained pores having a size of 100 mm^2 or more is preferably 1 or less.

[0046] Meanwhile, it is preferable that the remained pores present within the steel material be 30 mm or less based on a major axis.

[0047] A thickness of the steel material may be 100 mm or more and 150 mm or less.

[0048] The steel material may have excellent strength and low-temperature impact toughness having a yield strength of 320 MPa or more, a tensile strength of 430 MPa or more and 590 MPa or less, evaluated perpendicularly to a rolling direction at t/4 and t/2 points in the thickness direction, where t is a thickness of the steel material (mm), and a Charpy impact absorption energy (CVN) value of 100 J or more evaluated in the rolling direction at -50°C.

[0049] The steel material may have excellent aging impact toughness having a Charpy impact absorption energy (CVN) value of 50 J or more at -50°C for a specimen which was subjected to tensile strain of 8% perpendicularly to the rolling direction at t/4 and t/2 points in the thickness direction, which t is a thickness of the steel material (mm) and was then subjected to aging heat treatment at 250°C for 60 minutes.

[0050] Next, an example of a method for manufacturing a steel material of the present disclosure will be described in detail.

[0051] The method for manufacturing a steel material may include manufacturing a steel slab including the above-described alloy composition, heating the steel slab, rolling the heated steel slab, and cooling the heated steel slab. This will be described in detail below.

Steel slab manufacturing

[0052] In the present disclosure, in order to secure a strength of a central portion, low-temperature impact toughness, aging impact toughness, and internal quality of the final steel material, it is preferable to secure a steel slab having excellent internal quality. As an example of a method for manufacturing the steel slab, a steel slab may be manufactured by continuously casting molten steel having performed a steelmaking process.

[0053] As a preferable example, during the steelmaking process, it is preferable to perform a vacuum degassing process (RH process) in which the interior of a vessel is made vacuum after a molten steel ladle is lifted, and then a reflux gas is introduced into the vessel through a dipping tube to reflux the molten steel to perform degassing or decarburization, or the like, so that a hydrogen concentration in the molten steel is 1.5 ppm or less. It is preferable to perform the RH process for 15 minutes or more under conditions of 2 torr or less. When operating for less than 15 minutes under conditions of 2 torr or less, sufficient degassing is not performed, resulting in an excessively high concentration of hydrogen, so that there may be a concern that coarse pores may remain inside the final steel material, which may adversely affect the internal quality. Meanwhile, although an upper limit thereof is not particularly limited and when it exceeds 30 minutes, a load may occur in the manufacturing process, so an RH operation is preferably performed within 30 minutes.

[0054] A steel slab may be manufactured by continuously casting molten steel having a hydrogen concentration of 1.5 ppm or less. During the continuous casting process, 3 mm or more and 6 mm or less of slab reduction of may be performed in a solid/liquid coexistence region. The slab reduction may be applied to minimize segregation in the central portion of the steel slab. In this case, it is possible to selectively perform a process of suppressing the growth of dendrites and inducing the formation of equiaxed crystals by applying EMS (Electro Magnetic Stirring) to suppress segregation in the central portion. When an amount of slab reduction is less than 3 mm, a problem in which an Mn segregation zone existing in the central portion of the steel slab is not sufficiently pushed out in a liquid phase and the segregation zone remains, may occur. On the other hand, when the amount of slab reduction is excessive, exceeding 6 mm, cracks may occur during slab manufacturing.

[0055] Meanwhile, after the slab reduction and solidification are completed, the size of the pores present inside the steel slab may be minimized through additional reduction of 3 mm to 10 mm. Thereby, the remained pores in a final steel material are preferably 100 mm^2 or less, based on area. In addition, the remained pores should not exceed 30 mm based on a major axis, the number of remained pores having a size exceeding 30 mm is preferably 1 or less.

When additional reduction after the solidification is less than 3 mm, the size of the pores inside the steel slab may not be sufficiently reduced, which may adversely affect the internal quality of a final steel material. When additional reduction of more than 10 mm is applied, it is effective in reducing the pores, but excessive rolling force may cause surface cracks.

Steel slab heating

[0056] It is preferable to perform a process of heating and homogenizing the steel slab, and it is preferable to heat the steel slab in a temperature within a range of 1000 to 1080°C. When a heating temperature of the steel slab is lower than 1000°C, the precipitates (carbide and nitride) formed within the slab are not sufficiently re-dissolved, so the formation of precipitates decreases in a process after hot rolling. Ultimately, it becomes difficult to satisfy the yield strength and tensile strength suggested in the present disclosure. On the other hand, when the heating temperature of the steel slab exceeds 1080°C, there is a concern that the austenite grains will be coarsened, which may deteriorate the properties of steel.

[0057] Meanwhile, it is preferable that the heating time be 2 hours or longer. When the heating time of the steel slab is less than 2 hours, there is insufficient time for a central portion of the slab to be sufficiently heated. Although an upper limit thereof is not limited, the heating time is preferably less than 6 hours at most considering the load in the manufacturing process.

Hot rolling

[0058] The heated steel slab may be hot rolled to manufacture a hot-rolled steel sheet. After the heated steel slab is rough rolled in a temperature within a range of 900 to 1000°C, and is then finishing rolled at a temperature of T_{nr} or less and finishing hot rolled at a temperature of Ar_3 or more.

[0059] The T_{nr} and Ar_3 can be defined as follows.

$$T_{nr} (^{\circ}C) = 887 + (464 \times C) + ((6445 \times Nb) - (644 \times Nb^{0.5})) + (890 \times Ti) + (363 \times Al) - (357 \times Si)$$

$$Ar_3 (^{\circ}C) = 910 - 310 \times C - 80 \times Mn - 55 \times Ni + 124 \times Ti - 18 \times Nb + 179 \times Al$$

where each element refers to a weight content.

[0060] When a temperature during the rough rolling is lower than 900°C, there is a problem that a temperature during a subsequent finishing hot rolling becomes too low. When the finishing hot rolling is started at a temperature exceeding the T_{nr} temperature, even if a subsequent hot rolling end temperature is the T_{nr} temperature or lower, there is a disadvantage in that coarse grains and fine grains coexist, which may intermittently reduce the individual values of impact toughness. When the finishing hot rolling temperature is lower than Ar_3 , a rolling load may increase, which may cause quality defects such as surface cracks.

Cooling

[0061] After hot rolling, cooling may be performed to a temperature within a range of 350 to 500°C at a cooling rate of 2 to 5°C/s. When the cooling end temperature is lower than 350°C, it may be advantageous for securing strength, but due to the characteristics of extremely thick materials, excessive oscillation operations may be performed, which may cause serious loads in the manufacturing process. On the other hand, when the cooling end temperature exceeds 500°C, it is difficult to secure strength. When the cooling speed is less than 2°C/s during the cooling, a fraction of polygonal ferrite increases excessively, making it difficult to secure strength. When the cooling speed exceeds 5°C/s, it may be advantageous to secure strength, but the increased flow rate during water cooling may cause severe overload in the manufacturing process, making it difficult to apply to mass production. The cooling speed may be preferably 2.0 to 5.0°C/s.

Mode for Invention

[0062] Hereinafter, the present disclosure will be specifically described through the following Examples. However, it should be noted that the following examples are only for describing the present disclosure by illustration, and not intended to limit the scope of rights of the present disclosure. The reason is that the scope of rights of the present

disclosure is determined by the matters described in the claims and reasonably inferred therefrom.

(Example)

[0063] A steel slab was manufactured by continuous casting molten steel having an alloy composition (weight %, a remainder of Fe and inevitable impurities) and a hydrogen concentration in the molten steel in Table 1 below. A unit of each component is weight %, a remainder of Fe and inevitable impurities, and T_{nr} and Ar₃ are derived from the following Equations.

$$T_{nr} (^{\circ}\text{C}) = 887 + (464 \times \text{C}) + ((6445 \times \text{Nb}) -$$

$$(644 \times \text{Nb}^{0.5})) + (890 \times \text{Ti}) + (363 \times \text{Al}) - (357 \times \text{Si})$$

$$\text{Ar}_3 (^{\circ}\text{C}) = 910 - 310 \times \text{C} - 80 \times \text{Mn} - 55 \times \text{Ni} + 124 \times \text{Ti} - 18 \times \text{Nb} + 179 \times \text{Al}$$

where each element refers to a content (weight %).

[0064] When the steel slab was manufactured, pressure of 4.5 mm was applied, and additional reduction after solidification was disclosed under the conditions of Table 2 below. In Inventive Examples 1 and 2 and Comparative Examples 1 to 3, rough rolling was performed at a temperature within a range of 900 to 1000°C, and in Comparative Example 4, rough rolling was performed at a temperature of more than 1000°C. The manufactured steel slab was heated, hot rolled, and cooled under the conditions disclosed in Table 2 to manufacture a steel material.

[Table 1]

Steel type	C	Si	Mn	P	S	Al	Nb	Cr	Ni	Ti	N	H	T _{nr}	Ar ₃
1	0.040	0.15	1.55	0.008	0.002	0.025	0.030	0.150	0.450	0.012	0.0035	1.1	954	754
2	0.035	0.20	1.55	0.008	0.002	0.025	0.025	0.100	0.400	0.012	0.0035	1.2	911	759
3	0.065	0.20	1.55	0.008	0.002	0.030	0.025	0.100	0.000	0.012	0.0035	1.1	927	772
4	0.085	0.15	1.45	0.008	0.002	0.025	0.035	0.150	0.300	0.012	0.0035	1.3	998	756

[Table 2]

Division	Steel type	Slab thickness (mm)	Additional reduction after solidification (mm)	Slab heating temperature (°C)	Cumulative reduction ratio (%)	Finishing rolling start temperature (°C)	Finishing rolling end temperature (°C)	Cooling start temperature (°C)	Cooling end temperature (°C)	Cooling rate (°C/s)
Inventive Example 1	1	295	5	1050	40	807	791	780	430	2.7
		395	5	1080	30	810	795	790	450	2.5
Inventive Example 2	2	295	5	1050	40	800	790	788	450	2.7
		395	5	1080	30	805	792	790	450	2.5
Comparative Example 1	3	295	5	1050	40	810	790	780	430	2.7
		395	5	1080	30	804	789	785	450	2.5
Comparative Example 2	4	295	5	1050	40	800	790	785	430	2.7
		395	5	1080	30	805	795	785	450	2.5
Comparative Example 3	1	300	0	1050	40	810	790	780	430	2.7
		400	0	1080	30	804	789	785	450	2.5
Comparative Example 4	1	295	5	1110	40	1020	920	900	430	3.2
		395	5	1100	30	1025	940	920	450	2.8

[0065] Thereafter, a microstructure of the manufactured steel material was observed, and mechanical properties of the steel material was evaluated. The microstructure was observed using EBSD and an optical microscope, and then observed using an image analysis program. Thereby, an average effective grain size having a high-angle grain with a grain boundary angle of 15° or more was measured, and a phase with a misorientation of 5° or less within the high-angle grain was classified as ferrite, and a phase with irregular subboundaries within the high-angle grains was classified as bainite. Pearlite was defined as a black portion which appears in optical microscope photographs.

[0066] In this case, the microstructure was measured at a $t/2$ point, where t is a thickness (mm) of each steel material in the thickness direction, and the results are shown in Table 3 below. Then, the mechanical properties of each steel material were evaluated, and the results are shown in Table 4. In this case, a tensile test specimen was collected at a $t/2$ point, where t is a thickness (mm) of each steel material in the thickness direction, in a direction perpendicular to a rolling direction, and the tensile strength (TS), yield strength (YS), and elongation (EI) were measured at room temperature. The impact test specimen was taken from a JIS No. 4 standard test specimen at the $t/2$ point in the thickness direction in the rolling direction, and the impact toughness (Charpy impact toughness energy, CVN) at -50°C was measured three times, and an average value and minimum and maximum ranges thereof were indicated in parentheses. In addition, impact toughness (aging impact toughness) at -50°C was evaluated using impact specimens of JIS No. 4 standard for specimens which were heat treated at 250°C for 60 minutes after applying 8% of tensile strain perpendicular to the rolling direction, and the results are also shown in Table 4 below.

[0067] In addition, remained pores were measured through ultrasonic testing at the $t/2$ point, where t is the thickness (mm) in the thickness direction, and the number of remained pores with a size exceeding 100 μm^2 is shown in Table 4.

[Table 3]

Division	Steel l type	Steel sheet thickness (mm)	Ferrite (%)	Bainite (%)	Pearlite (%)	Average effective grain size(μm)
Inventive Example 1	1	120	70	20	10	14
		150	75	15	10	16
Inventive Example 2	2	120	70	20	10	15
		150	75	15	10	16
Comparative Example 1	3	120	70	20	10	21
		150	75	15	10	24
Comparative Example 2	4	120	55	35	10	22
		150	55	30	15	23
Comparative Example 3	1	120	70	20	10	14
		150	75	15	10	16
Comparative Example 4	1	120	55	40	5	22
		150	55	40	5	24

[0068] As shown in Table 3 above, Inventive Examples 1 and 2 manufactured by the alloy composition, component relationship, and manufacturing conditions suggested in the present disclosure satisfy the fractions of ferrite, bainite, and pearlite and the effective grain size suggested in the present disclosure. On the other hand, Comparative Examples 1 to 3 satisfy the fractions of ferrite, bainite, and pearlite, but do not satisfy the effective grain size, and it can be confirmed that Comparative Example 4 deviates from the values suggested in the present disclosure in not only the fractions of ferrite and bainite but also the effective grain size.

[Table 4]

Division	Steel type	Steel sheet thickness (mm)	YS (MPa)	TS (MPa)	El. (%)	Low-temperature impact toughness (J@-50°C)	Aging impact toughness (J@-50°C)	Number of remained pores
Inventive Example 1	1	120	415	512	33	345 (319~362)	315 (297~334)	0
		150	398	501	35	322 (289~355)	295 (284~308)	0
Inventive Example 2	2	120	401	508	34	355 (323~372)	309 (288~324)	0
		150	392	497	36	330 (291~360)	282 (272~299)	0
Comparative Example 1	3	120	423	524	32	124 (14~209)	89 (10~124)	0
		150	419	519	33	112 (7~165)	100 (13~145)	0
Comparative Example 2	4	120	437	555	28	142 (12~212)	121 (9~156)	0
		150	430	546	30	145 (11~184)	84 (10~126)	0
Comparative Example 3	1	120	415	512	33	215 (17~342)	188 (10~312)	4
		150	398	501	35	322 (289~355)	295 (284~308)	7
Comparative Example 4	1	120	442	533	27	154 (11~269)	114 (8~209)	0
		150	435	530	29	146 (15~195)	98 (10~184)	0

[0069] Table 4 showed the yield strength, tensile strength, elongation, low-temperature impact toughness, aging impact toughness, and the number of remained pores with an area exceeding 100mm² inside the hot-rolled steel sheet for Inventive Examples 1 and 2 and Comparative Examples 1 to 4. In the case of both Inventive Examples 1 and 2 and Comparative Examples 1 to 4, it can be confirmed that the tensile properties suggested in the present disclosure were satisfied without difficulty. Specifically, in the case of Inventive Examples 1 and 2, not only the tensile properties but also the average and individual values of the low-temperature impact toughness and the aging impact toughness were all excellent, and it was confirmed that excellent internal quality could be secured because no remained pores existed due to the additional reduction process after solidification.

[0070] On the other hand, in the case of Comparative Example 1, it can be confirmed that a minimum value of impact toughness is inferior according to a size of coarse effective grains, as a steel material to which Ni, which is useful for reducing the effective grain size, is added, and in particular, it can be confirmed that the aging impact toughness is greatly reduced. In the case of Comparative Example 2, due to excessive addition of C content, the yield/tensile strength may satisfy the values suggested in the present disclosure, but it can be confirmed that the minimum values of the impact toughness and the aging impact toughness do not satisfy the values suggested in the present disclosure. In the case of Comparative Example 3, all of the components and rolling/cooling conditions suggested in the present disclosure are satisfied, but additional reduction is not applied after solidification during the steel slab manufacturing process. It can be confirmed that the tensile properties are satisfied but the minimum values of impact toughness and aging impact toughness are inferior, and it can be confirmed that the remained pores are not sufficiently compressed and remain in a coarse form. In the case of Comparative Example 4, the components satisfy the range suggested in the present disclosure, but due to a high slab heating temperature, the austenite grains are coarsened and the hardenability is increased, so the fraction of bainite increases, and since the finishing rolling start temperature is applied above the T_{nr} temperature, the grains may not be refined to a sufficient level, so the strength is improved, but it can be confirmed that the minimum values of the impact toughness and the aging impact toughness are greatly reduced.

[0071] FIG. 1 is an optical microscope photograph of the microstructure at a t/2 point in the thickness direction of the steel material having a thickness of 120 mm and a component of Inventive Example 1, and it can be confirmed that it has a structure in which ferrite, bainite, and some pearlite are mixed.

[0072] FIG. 2 is a photograph illustrating an EBSD microstructure at a t/2 point in the thickness direction of the steel material having a thickness of 120 mm and a composition of Inventive Example 1, where (a) shows ferrite and (b) shows bainite.

Claims

1. A steel material, comprising by weight%:

0.03 to 0.08% of carbon (C), 0.1 to 0.5% of silicon (Si), 1.0 to 1.6% of manganese (Mn), 0.01% or less of phosphorus (P), 0.003% or less of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.015 to 0.035% of niobium (Nb), 0.3% or less (excluding 0%) of chromium (Cr), 0.1 to 0.5% of nickel (Ni), 0.01 to 0.02% of titanium (Ti), 0.002 to 0.01% of nitrogen (N), with a remainder of Fe and inevitable impurities, wherein a microstructure of the steel material comprises, by area fraction, 60 to 85% of ferrite, 10 to 20% of bainite, and a remainder of pearlite and inevitable structures, and an average size of effective grains having a high-angle grain boundary of 15° or more is 20 μm or less.

2. The steel material of claim 1, wherein the steel material has the number of remained pores having a size of 100 mm² or more of 1 or less.

3. The steel material of claim 1, wherein the steel material has a yield strength of 320 MPa or more at t/4 and t/2 points, where t is a thickness of the steel material.

4. The steel material of claim 1, wherein the steel material has a tensile strength of 430 MPa or more and 590 MPa or less at t/4 and t/2 points, where t is a thickness of the steel material.

5. The steel material of claim 1, wherein the steel material has a has a Charpy impact absorption energy of 100J or more at -50°C.

6. A method for manufacturing a steel material, comprising:

preparing a steel slab comprising by weight, 0.03 to 0.08% of carbon (C), 0.1 to 0.5% of silicon (Si), 1.0 to 1.6% of manganese (Mn), 0.01% or less of phosphorus (P), 0.003% or less of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.015 to 0.035% of niobium (Nb), 0.3% or less (excluding 0%) of chromium (Cr), 0.1 to 0.5% of nickel (Ni), 0.01 to 0.02% of titanium (Ti), 0.002 to 0.01% of nitrogen (N), with a remainder of Fe and inevitable impurities;

heating the steel slab at a temperature within a range of 1000 to 1080°C;

rough rolling the heated steel slab at a temperature within a range of 900 to 1000°C;

finishing rolling at a temperature within a range of Ar₃ or higher and T_{nr} or lower after the rough rolling; and

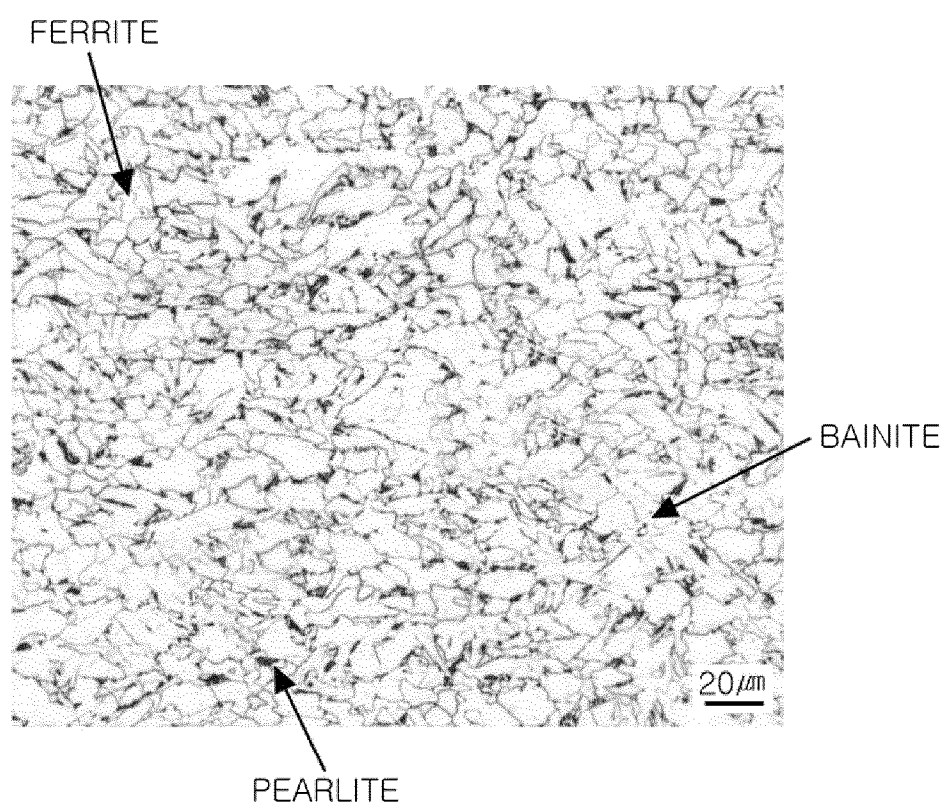
cooling at a cooling rate of 2 to 5°C/s to a temperature within a range of 350 to 500°C.

7. The method for manufacturing a steel material of claim 6, wherein the steel slab is manufactured by continuous casting of molten steel, and during the continuous casting, slab reduction (unit: mm) of 3 mm or more and 6 mm or less is applied, and after solidification, additional reduction of 3 mm or more and 10 mm or less is performed, thereby manufacturing a steel slab having a thickness of 290 mm or more and 397 mm or less.

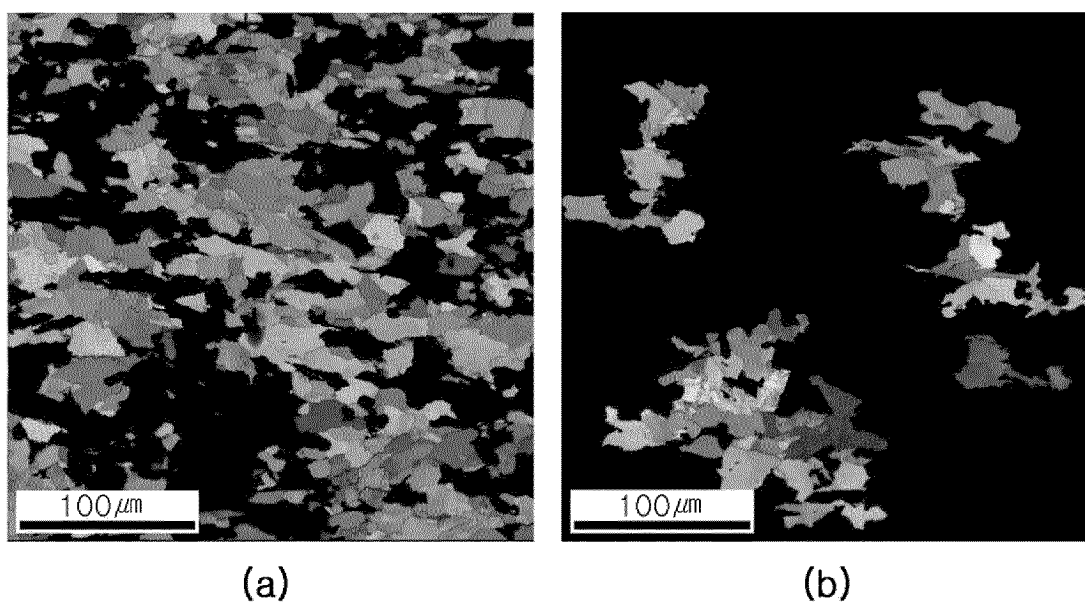
8. The method for manufacturing a steel material of claim 7, wherein a hydrogen concentration in the molten steel is 1.5 ppm or less.

9. The method for manufacturing a steel material of claim 7, wherein when the steel slab is manufactured, a molten steel degassing process (RH process) is performed before continuous casting, and the RH process is performed for 15 minutes or more under conditions of 2 torr or less.

[FIG. 1]



[FIG. 2]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019311

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; C22C 38/48(2006.01)i; C22C 38/50(2006.01)i; C22C 38/00(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); B21B 3/00(2006.01); C21D 8/02(2006.01); C22C 38/02(2006.01); C22C 38/04(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: 페라이트(ferrite), 베이나이트(bainite), 니오븀(niobium), 니켈(nickel), 티타늄(titanium), 크롬(chromium), 연속 주조(continuous casting), 조압연(rough rolling), 냉각(cooling)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2019-0104077 A (NIPPON STEEL CORPORATION) 05 September 2019 (2019-09-05) See paragraphs [0072], [0167], [0184] and [0198], claims 1-2 and table 3.	1-9
A	KR 10-2022-0133985 A (NIPPON STEEL CORPORATION) 05 October 2022 (2022-10-05) See paragraphs [0110]-[0111] and claims 1-2 and 4.	1-9
A	CN 114058942 A (BAOSHAN IRON & STEEL CO., LTD.) 18 February 2022 (2022-02-18) See claims 1, 4 and 7.	1-9
A	KR 10-2021-0126995 A (POSCO) 21 October 2021 (2021-10-21) See paragraph [0138] and claims 1 and 6.	1-9
A	WO 2022-067961 A1 (NANJING IRON & STEEL CO., LTD.) 07 April 2022 (2022-04-07) See claims 1 and 7.	1-9

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

* Special categories of cited documents:

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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

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

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Date of the actual completion of the international search

21 February 2025

Date of mailing of the international search report

21 February 2025

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/019311

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