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(54) **PRECIPITATION-HARDENING HOT ROLLED STEEL SHEET HAVING EXCELLENT MATERIAL UNIFORMITY AND HOLE EXPANDABILITY, AND MANUFACTURING METHOD THEREFOR**

(57) One aspect of the present invention relates to a precipitation-hardening hot rolled steel sheet having excellent material uniformity and hole expandability, comprising, by wt%, 0.02-0.05% of C, 0.01-0.3% of Si, 1.0-1.6% of Mn, 0.04-0.1% of Ti, 0.01-0.05% of Nb, 0.008% or less of N and the balance of Fe and other inevitable impurities, wherein the following formula (1) is satisfied, the microstructure comprises 95 area% or more of ferrite and (Ti, Nb)C composite precipitates, and the (Ti, Nb)C composite precipitates are formed such that the number of (Ti, Nb)C composite precipitates having a diameter of 10 nm or less is five times or more the number of (Ti, Nb)C composite precipitates having a diameter of more than 10 nm.

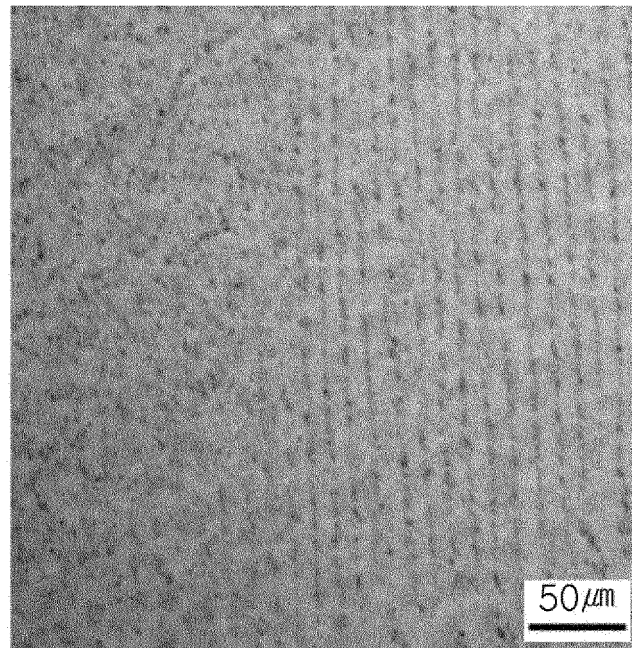
$$\text{Formula (1): } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

Formula (1):

(In formula (1), each element symbol means the at.% of each element and the element, which is not contained in steel, is calculated as zero.)

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Fig.1



Description

[Technical Field]

5 **[0001]** The present disclosure relates to a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, and a manufacturing method therefor.

[Background Art]

10 **[0002]** As known in the related art, in order to improve hole expandability, it is necessary to suppress the occurrence of fine cracks during a machining operation. In addition, when a difference in hardness between a hard phase and a soft phase is relatively high, deformation may be concentrated on, and fine cracks may occur at, grain boundaries of two phases.

15 **[0003]** Patent Document 1 discloses a transformation-strengthening steel in which a relatively large amount of bainite is formed to prevent the occurrence of fine cracks, and to ensure hole expandability.

[0004] Further, research has been carried out on the development of precipitation-hardening steel materials capable of securing high strength by precipitation-hardening effects using Ti, Nb, Mo, V, C, and the like, on a ferrite main phase, to maximize hole expandability and to secure high strength at the same time.

20 **[0005]** Patent Document 2 discloses a technique for securing strength by realizing a ferrite-based soft main phase matrix structure to prevent the occurrence of fine cracks due to a difference in hardness between a soft phase and a hard phase in advance, and by inducing a fine precipitation phenomenon in a crystal grain during transformation from austenite to ferrite, under conditions matching an Ar₃ nose and a precipitation nose after a strip mill rolling operation.

25 **[0006]** In the case of the precipitation-hardening steel material of Patent Document 2, it can be confirmed that burring properties were further improved while ensuring similar levels of strength in materials, as compared to the transformation-strengthening steel material. However, Patent Document 2 relates to a conventional mill-process-based manufacturing method comprising: cooling a slab to room temperature; and then reheating and rolling the cooled slab again, but has a problem in which deviation in a material is present in view of strength, elongation, hole expandability, or the like, due to heterogeneity of the precipitation behavior by deviation in a temperature in width and length directions after a rolling operation, and conditions of a heating furnace.

30 **[0007]** Meanwhile, a Continuous Endless Mill (CEM) method, a new process for milling steel that has gained attention recently and which produces steel sheets by a so-called high-speed continuous casting process and an endless rolling process, is known as a process for obtaining a steel material having good deviation in a material, because it has small deviation in a temperature in width and longitudinal directions of the strip due to a characteristic features of process.

35 **[0008]** As disclosed in Patent Documents 3 and 4, most of research and development focuses on transformation-strengthening hot rolled steel sheets such as DP steel and TRIP steel. However, the above-described transformation-strengthening hot rolled steel sheets may have a problem in ensuring excellent burring properties, because a combination of a soft phase and a hard phase in steel is inevitable.

40 **[0009]** Further, in the case of the solid solution strengthening hot rolled steel sheet, the steel sheet may have a problem of increasing manufacturing costs, because a large amount of solid solution strengthening elements such as Si, Mn and Cr should be added during the manufacturing operation of high strength steel having a tensile strength of 590 MPa or more.

45 **[0010]** Meanwhile, there may be advantages, in that precipitation-hardening steel materials have low manufacturing costs and excellent burring properties. However, when precipitation-hardening steel materials are manufactured by applying a CEM method using a high-speed continuous casting process and an endless rolling process, problems such as the occurrence of casting cracks, the occurrence of edge cracks due to precipitation elements such as Ti, Nb, N, or the like, and relatively low strip mill rolling temperatures, deterioration of a passing ability due to change in a deformation resistant behavior of the material by Nb, or the like, may occur.

[0011] Accordingly, there is a need for development of a precipitation-hardening hot rolled steel sheet which may address the above-described problems to be applicable to the CEM method and has excellent material uniformity and hole expandability, and a manufacturing method therefor.

50 (Prior Art Document)

[0012]

55 Patent Document 1: Japanese Laid-Open Patent Publication No. 1994-200351
 Patent Document 2: Japanese Laid-Open Patent Publication No. 2003-321739
 Patent Document 3: Korean Patent Publication No. 2012-0049993
 Patent Document 4: Korean Patent Publication No. 2012-0052022

[Disclosure]

[Technical Problem]

[0013] An aspect of the present disclosure is to provide a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, and a manufacturing method therefor.

[0014] Meanwhile, the object of the present disclosure is not limited to the above description. It will be understood by those of ordinary skill in the art that there would be no difficulty in understanding the additional problems of the present disclosure.

[Technical Solution]

[0015] According to an aspect of the present disclosure, a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, includes, by weight, 0.02% to 0.05% of C, 0.01% to 0.3% of Si, 1.0% to 1.6% of Mn, 0.04% to 0.1% of Ti, 0.01% to 0.05% of Nb, 0.008% or less of N, and a remainder of Fe and inevitable impurities, satisfying Relationship 1, wherein a microstructure of the precipitation-hardening hot rolled steel sheet comprises 95 area% or more of ferrite and (Ti, Nb)C complex precipitates, the number of (Ti, Nb)C complex precipitates having a diameter of 10 nm or less is five or more times the number of (Ti, Nb)C complex precipitates having a diameter greater than 10 nm.

$$\text{Relationship 1: } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

[0016] (In Relationship 1, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

[0017] According to another aspect of the present disclosure, a production method for a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, includes:

continuous casting ingot steel satisfying the above-described alloy composition to produce a thin slab;
rough rolling the thin slab to obtain a bar;
heating or concurrently heating the bar;
finish rolling the heated bar to obtain a hot rolled steel sheet;
cooling and air cooling the hot rolled steel sheet at a cooling rate of 30 °C/s or higher to a temperature within a range of 600°C to 700°C in a run-out table; and
coiling the cooled hot rolled steel sheet at a temperature within a range of 450°C to 600°C.

[Advantageous Effects]

[0018] According to an aspect of the present disclosure, a precipitation-hardening hot rolled steel sheet and a production method therefor, having a tensile strength of 590 MPa or more and material deviation in a width/length direction within $\pm 5\%$ with respect to an average value, and having excellent material uniformity and hole expandability, may be provided.

[Description of Drawings]

[0019]

FIG. 1 is an image of a microstructure of Inventive Example 1 captured by a scanning electron microscope;
FIG. 2 is an image of a microstructure of Comparative Example 1 captured by a scanning electron microscope; and
FIG. 3 is an image of a microstructure of Comparative Example 7 captured by a scanning electron microscope.

[Best Mode for Invention]

[0020] Hereinafter, preferred embodiments of the present disclosure will be described. However, the embodiments of the present disclosure can be modified into various other forms, and the scope of the present disclosure is not limited to the embodiments described below. Further, the embodiments of the present disclosure are provided to more fully explain the present disclosure to those skilled in the art.

[0021] The present inventors have recognized that when precipitation-hardening steel materials are manufactured by

applying the CEM method using a high-speed continuous casting process and an endless rolling process, problems such as the occurrence of casting cracks, the occurrence of edge cracks due to precipitation elements such as Ti, Nb, N, or the like, and relatively low strip mill rolling temperature, deterioration of a passing ability due to change in a deformation resistant behavior of the material by Nb, or the like, may occur, and have conducted a deep investigation into solving these problems.

[0022] As a result, it has been confirmed that a precipitation-hardening hot rolled steel sheet, applying the CEM method using a high-speed continuous casting process and an endless rolling process to have excellent material uniformity and hole expandability, may be provided by precisely controlling the alloy composition and manufacturing method, thereby completing the present disclosure.

[0023] Hereinafter, a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, according to an aspect of the present disclosure will be described in detail.

[0024] The precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, according to an aspect of the present disclosure, includes, by weight, 0.02% to 0.05% of C, 0.01% to 0.3% of Si, 1.0% to 1.6% of Mn, 0.04% to 0.1% of Ti, 0.01% to 0.05% of Nb, 0.008% or less of N, and a remainder of Fe and inevitable impurities, satisfying Relationship 1, wherein a microstructure of the precipitation-hardening hot rolled steel sheet comprises 95 area% or more of ferrite and (Ti, Nb)C complex precipitates, the number of (Ti, Nb)C complex precipitates having a diameter of 10 nm or less is five or more times the number of (Ti, Nb)C complex precipitates having a diameter greater than 10 nm.

$$\text{Relationship 1: } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

[0025] (In Relationship 1, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

[0026] First, an alloy composition of the precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, according to an aspect of the present disclosure will be described in detail. Hereinafter, the unit of each element content is % by weight.

C: 0.02% to 0.05%

[0027] C may be the most economical and effective element to strengthen steel. Meanwhile, C may cause a volume shrinkage phenomenon during transformation of liquid + ferrite → austenite in a solidification operation of a high-speed casting process, and may promote occurrence of surface cracks, when the content thereof is present in the hypoperitectic composition.

[0028] When the content of C exceeds 0.05%, surface cracks may occur during a high-speed continuous casting process. Meanwhile, when the content of C is lower than 0.02%, strength and weldability may significantly deteriorate.

Si: 0.01% to 0.3%

[0029] Si may be an element stabilizing ferrite by removing oxygen from ingot steel. Si may promote ferrite transformation during a cooling operation after a hot rolling operation. Therefore, Si may help to form a uniform ferrite structure, and to secure high strength material by a solid solution strengthening effect.

[0030] When the content of Si is lower than 0.01%, the above-mentioned effects may be insufficient. Meanwhile, when the content of Si is higher than 0.3%, the solid solution strengthening effect may be greater than the precipitation hardening effect. In addition, a red color scale due to Si may be formed on a surface of the steel sheet during a hot rolling operation. Therefore, a more preferable upper limit of the Si content is 0.2%, and a still more preferable upper limit of the Si content is 0.1%.

Mn: 1.0% to 1.6%

[0031] Mn, in a similar manner as Si, may be an effective element for solid solution strengthening steel.

[0032] When the content of Mn is lower than 1.0%, sufficient strength of the welded portion may be difficult to be secured by a scheme adding the above-mentioned low content of C. Meanwhile, when the content of Mn exceeds 1.6%, the ferrite transformation may be delayed excessively, a sufficient precipitation effect may not be realized, and carbide or pearlite may be formed in the structure to lower the burring property. Therefore, the content of Mn according to the present disclosure is preferably limited to be 1.0% to 1.6%.

Ti: 0.04% to 0.1%

[0033] Ti may be an element capable of maximizing an increase in strength due to a fine precipitation effect at an interphase (Ti, Nb)C upon transformation from austenite to ferrite.

[0034] When the content of Ti is lower than 0.04%, a sufficient fine precipitation effect may be not easy to be secured due to N that is inevitably included in the steelmaking process. Meanwhile, when the content of Ti exceeds 0.1%, a fine precipitation effect may be saturated, and surplus Ti may be present after the formation of fine precipitates, which is economically undesirable.

Nb: 0.01% to 0.05%

[0035] Nb may be an important element for the formation of (Ti, Nb)C fine precipitates together with Ti, and may be an element useful for forming a fine ferrite grain size.

[0036] When the content of Nb is lower than 0.01%, the above-described effect may be difficult to be realized. Meanwhile, when the content of Nb exceeds 0.05%, a temperature of the non-recrystallized zone of the material may rise, which may cause a load problem during a rolling operation.

N: 0.008% or less

[0037] N may have a great effect on mechanical properties of steel even in an extremely small amount. N may increase tensile strength and yield strength. N may be a main factor of strain aging, which lowers an elongation rate, causes blue brittleness, deteriorates the impact characteristics of the material, and particularly wrinkles on a surface during a thin sheet processing. Further, since nitrogen, together with other alloying elements, forms a nitride, the (Ti, Nb)C fine precipitation effect which is important in the present disclosure may be reduced.

[0038] Therefore, in the present disclosure, N may be considered as an impurity, and the content thereof is preferable to be strictly controlled to be 0.008% or less.

[0039] The remainder of the present disclosure may be iron (Fe). In the ordinary manufacturing process, impurities that are not intended from the raw material or the surrounding environment may be inevitably incorporated. Therefore, the impurities may not be excluded. The impurities are not specifically mentioned in this specification, as are known to any person skilled in the art of steel manufacturing. For example, P, S, Cu, V, Ni, Al, Cr, and the like, may be inevitably incorporated.

[0040] In the present disclosure, not only the above-described content of each element should be satisfied, but also, Relationship 1 should be satisfied.

$$\text{Relationship 1: } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

[0041] (In Relationship 1, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

[0042] The metallurgical significance of Relationship 1 is to take into account the optimum atomic ratio in consideration of loss of Ti, Nb, V, and Mo due to initial coarse precipitation by C and N, to maximize the fine precipitation behavior. Considering this equivalence ratio in advance, steels having excellent burring property with relatively low alloying iron costs may be manufactured by minimizing the content of elements such as Si, Cr, and the like.

[0043] When the value of Relationship 1 is lower than 0.35, sufficient (Ti, Nb)C precipitates may be difficult to secure in the ferrite, and strength of the material may be insufficient. Meanwhile, when the value of Relationship 1 is higher than 0.70, the effect of the surplus Ti, Nb, V, Mo remaining after the formation of the complex precipitate by chemical bonding with C on the basis of the equivalence ratio may be relatively small, and may have a negative impact on securing economic efficiency.

[0044] In addition, not only the content of each of the above elements and the value of Relationship 1 should be satisfied, but also the value of Relationship 2 should be satisfied.

$$\text{Relationship 2: } 0.04 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{Mn} + \text{Si} + \text{Cr})$$

[0045] (In Relationship 2, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

[0046] Relationship 2 is based on the atomic ratio of precipitation elements (Ti, Nb, Mo, and V) and solid solution elements (C, Si, Mn, and Cr), and is to secure a desired tensile strength by the precipitation hardening.

[0047] When the value of Relationship 2 is lower than 0.04, an effect of solid solution strengthening is greater than an effect of precipitation hardening. To satisfy tensile strength of 590 MPa or more, a large amount of solid solution strengthening elements such as Si, Mn, Cr, and the like, should be added. Therefore, there is a problem in that the manufacturing costs thereof may be increased.

[0048] A microstructure of the precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, according to an aspect of the present disclosure may include 95 area% or more of ferrite and (Ti, Nb)C complex precipitates. In addition, the number of (Ti, Nb)C complex precipitates having a diameter of 10 nm or less may be formed to be five or more times the number of (Ti, Nb)C complex precipitates having a diameter greater than 10 nm. In the present disclosure, the (Ti, Nb)C complex precipitate may be a concept including TiC, NbC, and (Ti, Nb)C complex carbide, and the diameter refers to a circle equivalent diameter.

[0049] When the content of ferrite is lower than 95 area%, a relatively large amount of a structure having a relatively large difference between the phases in hardness may be present, as compared to pearlite and ferrite such as low-temperature transformation phase.

[0050] When the number of (Ti, Nb)C complex precipitates having a diameter of 10 nm or less is lower than five times the number of (Ti, Nb)C complex precipitates having a diameter greater than 10 nm, the precipitation hardening effect may be insufficient and the tensile strength may be deteriorated.

[0051] The fact that the number of (Ti, Nb)C complex precipitates having a diameter of 10 nm or less is formed at five or more times the number of (Ti, Nb)C complex precipitates having a diameter greater than 10 nm means that the value of Relationship 3:

$$\text{Relationship 3: } \phi = \sum_{d=0}^{10} PN \times \left(\sum_{d=10}^{20} PN + \sum_{d=20}^{50} PN + \sum_{d=50}^{100} PN \right)^{-1}$$

[0052] In Relationship 3, PN is the number of (Ti, Nb)C complex precipitates in a structure of the hot rolled steel sheet, and d is a diameter of the complex precipitate captured by a transmission microscope (TEM), and the unit thereof is nm.

[0053] $\sum_{d=0}^{10} PN$, $\sum_{d=10}^{20} PN$, $\sum_{d=20}^{50} PN$, $\sum_{d=50}^{100} PN$ refer to the number of precipitates having diameters of greater than 0 nm to 10 nm, greater than 10 nm to 20 nm, greater than 20 nm to 50 nm, and greater than 50 nm to 100 nm, respectively. In addition, precipitates exceeding 100 nm are almost not present, and may thus be excluded.

[0054] At this time, a distance between the (Ti, Nb)C complex precipitates may be 30 nm or less.

[0055] More specifically, the distance refers to a line-spacing (LS) of interphase precipitation, present in a curved or straight form in series, when observed by Transmission Electron Microscopy (TEM) analysis based on [001] or [110] zone axis, may be 30 nm or less.

[0056] When a distance between the (Ti, Nb)C complex precipitates is greater than 30 nm, a problem in which the effect of fine precipitation on strength is remarkably reduced, may occur. The lower limit thereof is not particularly limited, but may be 5 nm or more.

[0057] In addition, the (Ti, Nb)C complex precipitate may be present in a frequency of 15,000/ μm^2 or more.

[0058] Even in the case that a distance between the (Ti, Nb)C complex precipitates is 30 nm or less, when the (Ti, Nb)C complex precipitate is lower than 15,000/ μm^2 , distribution of uniform and fine precipitates may be not realized over the entire area within the crystal grain, and the burring workabilities may not be easy to be secured.

[0059] Meanwhile, the hot rolled steel sheet according to the present disclosure may have a tensile strength of 590 MPa or more and material deviation in a width/length direction within $\pm 5\%$ with respect to an average value. Not only material deviation in view of strength and elongation, but also material deviation in view of hole expandability, may be secured in a good level.

[0060] Hereinafter, a production method for a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, which is another aspect of the present disclosure, will be described in detail.

[0061] The precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, which is another aspect of the present disclosure, includes:

continuous casting ingot steel satisfying the above-described alloy composition to produce a thin slab;
rough rolling the thin slab to obtain a bar;
heating or concurrently heating the bar;
finish rolling the heated bar to obtain a hot rolled steel sheet;

cooling and air cooling the hot rolled steel sheet at a cooling rate of 30 °C/s or higher to a temperature within a range of 600°C to 700°C in a run-out table; and
coiling the cooled hot rolled steel sheet at a temperature within a range of 450°C to 600°C.

Continuous Casting Operation

[0062] A thin slab may be prepared by continuously casting ingot steel satisfying the above-described alloy composition.

[0063] At this time, a thickness of the thin slab may be 30 mm to 150 mm. The thin slab may be compared to slabs of 200 mm or more produced from continuous casting machines of conventional mills. Since the slabs of 200 mm or more produced in the prior art are completely cooled in a yard, etc., it is necessary to sufficiently reheat the steel sheet to a surface temperature of 1100°C or more in a reheating furnace before performing a hot rolling operation. Meanwhile, since the thin slab may be transported directly to a rough rolling mill without going through the reheating furnace, heat in the continuous casting operation may be used as it is. Therefore, energy may be saved, and productivity may be greatly improved.

Rough Rolling Operation

[0064] The thin slab may be rough rolled to obtain a bar. At this time, the rough rolling operation may be performed at a temperature within a range of 850°C to 1,150°C. When the rough rolling temperature is lower than 850°C, cracks may easily occur at an edge portion. When the rough rolling temperature is higher than 1,150°C, cracks may easily occur on a surface of the thin slab during a rolling operation.

Heating Operation

[0065] The bar may be heated or concurrently heated. At this time, the heating or concurrent heating may be a temperature within a range of 850°C to 1,150°C. When the temperature is lower than 850°C, a rolling load may be considerably increased during a finish rolling operation. When the temperature exceeds 1,150°C, energy costs for temperature rise may increase, and the tendency of surface scale defects occurring may increase.

[0066] At this time, an operation of coiling the heated bar after the above heating operation and before the subsequent finish rolling operation may be further included.

Finish Rolling Operation

[0067] The heated bar may be subjected to a finish rolling operation to obtain a hot rolled steel sheet. At this time, the finish rolling operation may be performed in a temperature within a range of 770°C to 1,000°C. When the finish rolling temperature is lower than 770°C, the effect of the rolling operation in a two-phase region may be strengthened, and the desired material due to a severe anisotropy of the structure may be difficult to secure. Meanwhile, it is necessary to heat the steel sheet at a high temperature of 1,150°C or more in the heating operation, to control the finish rolling temperature to exceed 1,000°C. Therefore, surface scale defects may result, and high costs may be required economically.

Cooling Operation

[0068] The hot rolled steel sheet may be cooled and air cooled in a run-out table to a temperature within a range of 600°C to 700°C at a cooling rate of 30 °C/s or higher. When the cooling end temperature is out of the temperature range of 600°C to 700°C, the fine precipitation behavior which occurs upon ferrite transformation in the austenite may not be sufficiently realized. When the cooling rate is lower than 30 °C/s, even if the cooling end temperature is satisfied, the ferrite transformation of a substantial fraction prior to the air cooling operation may be carried out, a fraction of ferrite to secure micro precipitates may be remarkably reduced, and, thus, a material having a desired strength may be not secured.

[0069] At this time, a mass-flow velocity of the hot rolled steel sheet in the run-out table may be 100 mpm to 200 mpm, and a difference in velocity may be 10% or less.

Coiling Operation

[0070] The cooled hot rolled steel sheet may be coiled at a temperature within a range of 450°C to 600°C. When the cooled hot rolled steel sheet is coiled at a temperature of less than 450°C, it may be very difficult to control the temperature uniformly by entering a boiling transition zone. Therefore, incorporation of a hard phase such as martensite and bainite may be caused, and burring properties may be remarkably reduced. Meanwhile, when the cooled hot rolled steel sheet is coiled at a temperature of higher than 600°C, another hard phase such as cementite may be formed, and burring

property may be reduced.

[Mode for Invention]

[0071] Hereinafter, the present disclosure will be described more specifically by way of examples. It should be noted, however, that the following examples are intended to illustrate the present disclosure in more detail, and not to limit the scope of the present disclosure. The scope of the present disclosure is determined by the matters described in the claims and the matters reasonably deduced therefrom.

[0072] Ingot steel having a component composition shown in Table 1 below was prepared.

[0073] Except for Comparative Examples 5, 6 and 7, a thin slab of 90 mm in thickness was prepared through a high-speed casting operation by applying a CEM process. The thin slab was rough rolled at a temperature of 1,000°C, without cooling to room temperature. The rough rolled thin slab was subjected to a finish rolling operation at the finish rolling temperature (FDT) shown in Table 2 below, cooled and air cooled to a temperature of 650°C at the cooling rate and the mass-flow velocity shown in Table 2 below, and then coiled at the coiling temperature (CT) shown in Table 2 below, to prepare a hot rolled steel sheet.

[0074] In the case of Comparative Examples 5, 6 and 7, slabs having a thickness of 220 mm were manufactured by applying a conventional milling method. The slabs were cooled to room temperature, and then subjected to a reheating operation (1250°C) and a rough rolling operation (1,000°C) (FDT). The rough rolled slab was subjected to a finish rolling operation at the finish rolling temperature (FDT) shown in Table 2 below, cooled and air cooled to a temperature of 650°C at the cooling rate and the mass-flow velocity shown in Table 2 below, and then coiled at the coiling temperature (CT) shown in Table 2 below, to prepare a hot rolled steel sheet.

[0075] The number of precipitates, the value of Relationship 3, the material uniformity, the hole expandability, the tensile strength (TS), the fracture elongation (EI), and the ferrite fraction were measured or evaluated, depending on the sizes of the hot rolled steel sheet, as shown in Table 3.

[0076] The tensile test was carried out on specimens taken in accordance with JIS-5 standard in a 90° direction, with respect to a rolling direction of the rolled plate. For the ferrite phase fraction, specimens of the rolled plate were etched with Nital etchant solution and LePera etchant solution, respectively, observed by an optical microscope at a magnification of 500 times, and analyzed and compared using an image analyzer.

[0077] Evaluation of hole extensibility was carried out by preparing a square specimen, 120 mm square, punching a hole having a diameter of 10 mm at the center of the specimen through a punching operation, and pushing a cone upwardly while placing the burrs in an upward direction, and was expressed as a value obtained by calculating a diameter of the hole expanded until just before occurring cracks in the circumference portion as a percentage of the initial hole diameter (10mm).

[0078] In order to confirm whether not only material deviation of strength, elongation, and the like, but also material deviation of hole expandability, may be secured, the material deviation of hole expandability in a width/length direction was measured. When material deviation of hole expandability in a width/length direction is within ±5% with respect to an average value, it is indicated as good. Meanwhile, when material deviation of hole expandability in a width/length direction exceeds ±5%, it is indicated as bad.

[0079] Precipitates were observed and analyzed in the area of about 1,400,000 nm² in the hot rolled steel sheet using a TEM, based on zone [100] axis. Interphase precipitation in a curved or straight form was observed along the face (331).

$$\phi = \sum_{d=0}^{10} PN \times \left(\sum_{d=10}^{20} PN + \sum_{d=20}^{50} PN + \sum_{d=50}^{100} PN \right)^{-1}$$

Relationship 3:

[0080] In Relationship 3, PN is the number of (Ti, Nb)C complex precipitates in a structure of the hot rolled steel sheet, and d is a diameter of the complex precipitate captured by a transmission microscope (TEM), and the unit thereof is nm.

[0081] $\sum_{d=0}^{10} PN$, $\sum_{d=10}^{20} PN$, $\sum_{d=20}^{50} PN$, $\sum_{d=50}^{100} PN$ refer to the number of precipitates having diameters of greater than 0 nm to 10 nm, greater than 10 nm to 20 nm, greater than 20 nm to 50 nm, and greater than 50 nm to 100 nm, respectively, and these were expressed in Table 3 below as PN10, PN20, PN50, and PN100, respectively.

[Table 1]

	C	Si	Mn	Nb	Ti	N	***RE1	RE2
**CE1	0.038	0.060	1.435	0.014	0.045	0.008	<u>0.292</u>	<u>0.039</u>
CE2	0.044	0.064	1.447	0.014	0.049	0.008	<u>0.277</u>	0.041
CE3	0.050	0.059	1.403	<u>0.003</u>	0.067	0.008	<u>0.302</u>	0.052
CE4	0.040	0.088	1.429	<u>0.005</u>	0.055	0.007	<u>0.314</u>	0.041
CE5	0.030	0.050	1.400	0.010	0.070	0.004	0.564	0.058
CE6	0.045	0.060	1.400	0.011	0.075	0.006	0.404	0.061
CE7	0.050	0.065	1.500	0.010	0.100	0.006	0.455	0.071
CE8	0.030	0.050	1.400	0.010	0.070	0.004	0.564	0.058
*IE1	0.049	0.069	1.427	0.014	0.076	0.007	0.360	0.061
IE2	0.046	0.067	1.418	0.014	0.066	0.007	0.391	0.054
IE3	0.049	0.077	1.416	0.011	0.077	0.007	0.377	0.061
IE4	0.043	0.080	1.553	0.013	0.081	0.006	0.457	0.059
IE5	0.030	0.050	1.400	0.010	0.070	0.004	0.564	0.058
IE6	0.044	0.061	1.472	0.011	0.075	0.006	0.412	0.058
IE7	0.030	0.050	1.400	0.010	0.085	0.006	0.644	0.069
*IE: Inventive Example, **CE: Comparative Example, ***RE: Relationship								

[0082] In Table 1, the unit of each element content was % by weight, and Relationships 1 and 2 were as follows:

$$\text{Relationship 1: } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

$$\text{Relationship 2: } 0.04 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{Mn} + \text{Si} + \text{Cr})$$

[0083] (In Relationships 1 and 2, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

[Table 2]

	Process	FDT (°C)	Cooling Rate (°C/s)	CT (°C)	Mass-Flow Velocity (mpm)
**CE1	CEM	808	<u>23</u>	622	190
CE2	CEM	778	<u>22</u>	596	190
CE3	CEM	769	32	506	190
CE4	CEM	764	<u>24</u>	566	190
CE5	***Conv. Mill	880	<u>28</u>	601	410
CE6	Conv. Mill	859	<u>26</u>	599	410
CE7	Conv. Mill	877	<u>27</u>	610	410
CE8	CEM	778	<u>24</u>	581	190
*IE1	CEM	770	35	481	190
IE2	CEM	771	33	501	190

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(continued)

	Process	FDT (°C)	Cooling Rate (°C/s)	CT (°C)	Mass-Flow Velocity (mpm)
IE3	CEM	774	36	477	190
IE4	CEM	769	30	523	190
IE5	CEM	771	33	499	190
IE6	CEM	770	31	514	190
IE7	CEM	779	32	514	190
*IE: Inventive Example, **CE: Comparative Example, ***Conv. Mill: Conventional Mill					

[Table 3]

	PN10	PN2 0	PN50	PN100	RE (3)	TS (MPa)	EI (%)	***HE (%)	****MU (%)	Ferrite (area%)
**CE1	14520	5720	4230	30	<u>1.45</u>	<u>543</u>	28	130	4	97
CE2	11250	2230	1940	0	<u>2.70</u>	<u>511</u>	31	140	3	98
CE3	18010	4010	2110	0	<u>2.94</u>	<u>551</u>	27	121	5	98
CE4	20940	4240	710	0	<u>4.23</u>	<u>505</u>	24	134	4	98
CE5	11790	19470	670	0	<u>0.59</u>	699	21	93	<u>20</u>	98
CE6	13920	16550	1140	0	<u>0.79</u>	674	21	89	<u>16</u>	97
CE7	19540	14760	2120	0	<u>1.16</u>	601	23	91	<u>21</u>	97
CE8	7643	3710	1430	0	<u>1.48</u>	<u>537</u>	25	119	<u>6</u>	96
*IE1	29830	1810	260	0	14.41	644	23	101	4	97
IE2	41750	3320	220	0	11.79	598	24	99	3	97
IE3	24510	330	70	0	61.28	609	22	97	2	96
IE4	17270	2910	170	0	5.61	640	21	105	4	98
IE5	35880	1180	220	0	25.63	599	24	92	3	97
IE6	21190	1910	190	0	10.09	617	25	109	4	96
IE7	33490	2140	240	0	14.07	607	25	120	2	96
*IE.: Inventive Example, **CE.: Comparative Example, RE: Relationship, ***HE: hole expandability, ****MU: material uniformity										

[0084] In Inventive Examples 1 to 7 satisfying all of the requirements of the present disclosure, it can be confirmed that both material uniformity and the hole expandability were excellent, and the tensile strength of 590 MPa or more was also secured.

[0085] Meanwhile, the content of each element in Comparative Examples 1 and 2 was in the effective range proposed by the present disclosure, but did not satisfy Relationship 1. In addition, the content of each element in Comparative Examples 3 and 4 did not satisfy the Nb content and Relationship 1. It can be confirmed that hole expandability thereof is excellent, but since a sufficient precipitation-hardening effect may not be realized, tensile strength thereof is low.

[0086] In the case of Comparative Examples 5, 6 and 7, the case of applying the conventional milling method, it can be confirmed that tensile strength thereof was excellent, but material uniformity was deteriorated.

[0087] In the case of Comparative Examples 5 and 8 and Inventive Example 5, the compositions thereof were the same as each other, but the manufacturing conditions thereof were different to each other. In the case of Comparative Example 5, it can be confirmed that material uniformity thereof was poor due to the conventional milling process. In the case of Comparative Example 8, it can be confirmed that material uniformity and tensile strength thereof are both excellent.

[0088] FIGS. 1, 2, and 3 are images of microstructure of Inventive Example 1, Comparative Example 1, and Comparative Example 7, respectively, captured by a scanning electron microscope. Compared with FIGS. 2 and 3, it can be seen from FIG. 1 that fine and uniform (Ti, Nb)C complex precipitates were formed in Inventive Example 1.

[0089] While exemplary embodiments have been shown and described above, it will be apparent to those skilled in the art that modifications and variations could be made without departing from the scope of the present disclosure as defined by the appended claims.

Claims

1. A precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, comprising, by weight, 0.02% to 0.05% of C, 0.01% to 0.3% of Si, 1.0% to 1.6% of Mn, 0.04% to 0.1% of Ti, 0.01% to 0.05% of Nb, 0.008% or less of N, and a remainder of Fe and inevitable impurities, satisfying Relationship 1, wherein a microstructure of the precipitation-hardening hot rolled steel sheet comprises 95 area% or more of ferrite and (Ti, Nb)C complex precipitates, the number of (Ti, Nb)C complex precipitates having a diameter of 10 nm or less is five or more times the number of (Ti, Nb)C complex precipitates having a diameter greater than 10 nm.

$$\text{Relationship 1: } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

(In Relationship 1, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

2. The precipitation-hardening hot rolled steel sheet according to claim 1, wherein the hot rolled steel sheet satisfies Relationship 2:

$$\text{Relationship 2: } 0.04 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{Mn} + \text{Si} + \text{Cr})$$

(In Relationship 2, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

3. The precipitation-hardening hot rolled steel sheet according to claim 1, wherein a distance between the (Ti, Nb)C complex precipitates is 30 nm or less.
4. The precipitation-hardening hot rolled steel sheet according to claim 1, wherein the (Ti, Nb)C complex precipitate is present in a frequency of 15,000/ μm^2 or more.
5. The precipitation-hardening hot rolled steel sheet according to claim 1, wherein the hot rolled steel sheet has a tensile strength of 590 MPa or more and material deviation in a width/length direction within $\pm 5\%$ with respect to an average value.
6. A production method for a precipitation-hardening hot rolled steel sheet, having excellent material uniformity and hole expandability, comprising:

continuous casting ingot steel comprising, by weight, 0.02% to 0.05% of C, 0.01% to 0.3% of Si, 1.0% to 1.6% of Mn, 0.04% to 0.1% of Ti, 0.01% to 0.05% of Nb, 0.008% or less of N, and a remainder of Fe and inevitable impurities, satisfying Relationship 1, to produce a thin slab;
rough rolling the thin slab to obtain a bar;
heating or concurrently heating the bar;
finish rolling the heated bar to obtain a hot rolled steel sheet;
cooling and air cooling the hot rolled steel sheet at a cooling rate of 30 °C/s or higher to a temperature within a range of 600°C to 700°C in a run-out table; and
coiling the cooled hot rolled steel sheet at a temperature within a range of 450°C to 600°C.

$$\text{Relationship 1: } 0.35 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{N}) \leq 0.70$$

(In Relationship 1, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

7. The production method according to claim 6, wherein the hot rolled steel sheet satisfies Relationship 2:

$$\text{Relationship 2: } 0.04 \leq (\text{Ti} + \text{Nb} + \text{V} + \text{Mo}) / (\text{C} + \text{Mn} + \text{Si} + \text{Cr})$$

(In Relationship 2, each element symbol refers to at.% of each element, and an element not included in the steel sheet is calculated as zero.)

8. The production method according to claim 6, wherein a thickness of the thin slab is 30 mm to 150 mm.

9. The production method according to claim 6, wherein a mass-flow velocity of the hot rolled steel sheet in the run-out table is 100 mpm to 200 mpm, and a difference in velocity is 10% or less.

10. The production method according to claim 6, further comprising coiling the heated bar between the heating operation and the finish rolling operation.

11. The production method according to claim 6, wherein the rough rolling operation is performed in a temperature within a range of 850°C to 1,150°C.

12. The production method according to claim 6, wherein heating or concurrently heating the bar in a temperature within a range of 850°C to 1,150°C in the heating operation.

13. The production method according to claim 6, wherein the finish rolling operation is performed in a temperature within a range of 770°C to 1,000°C.

Fig.1

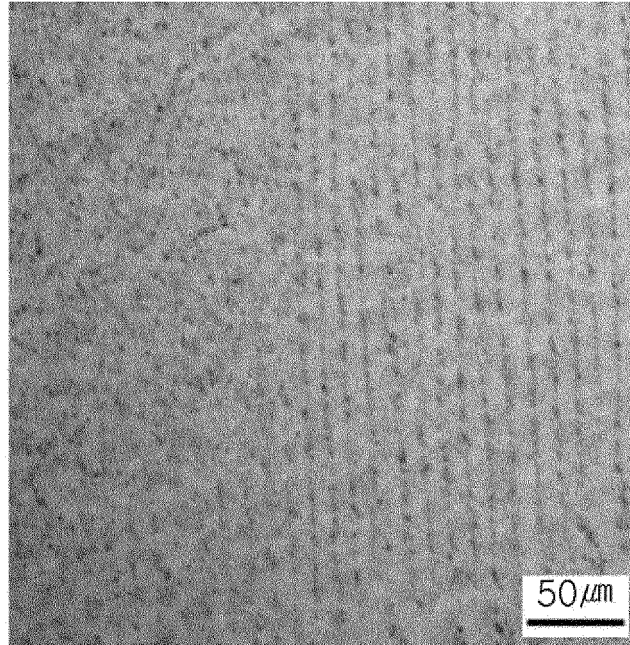


Fig. 2

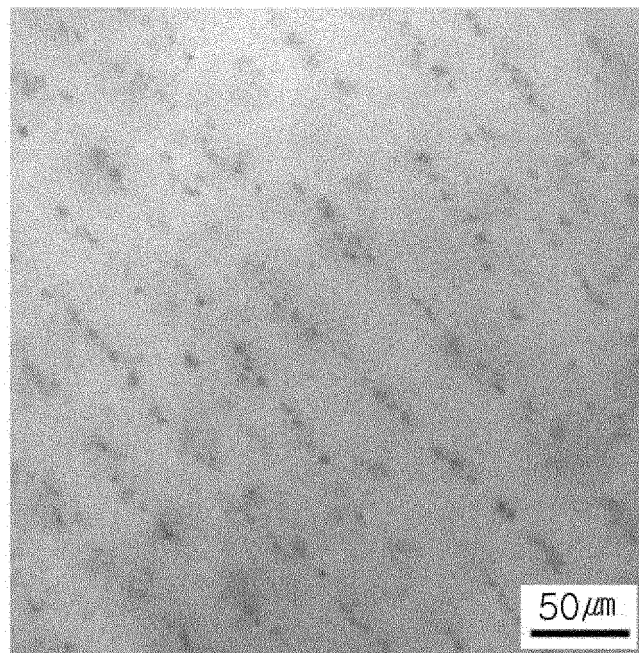
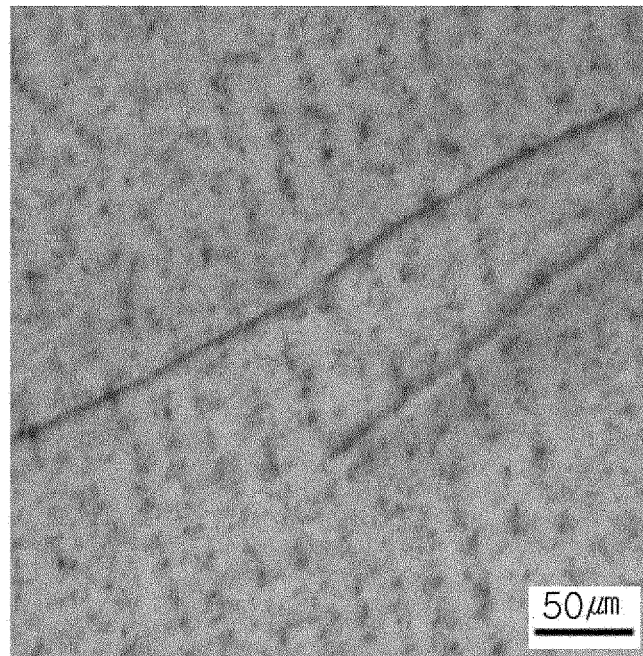


Fig.3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2017/006668

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/14(2006.01)i, C22C 38/02(2006.01)i, C22C 38/04(2006.01)i, C22C 38/12(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 38/14; C21D 9/46; C21D 8/02; C22C 38/00; B21B 1/46; B21B 3/00; C22C 38/02; C22C 38/04; C22C 38/12

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: material variation, burring characteristic, hole expansion characteristic, precipitation hardening, hot rolled steel sheets, complex sludge, ferrite, tensile strength

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2000-087142 A (NKK CORP.) 28 March 2000 See paragraphs [0015], [0032] and claim 1.	1-13
A	KR 10-2014-0085188 A (POSCO) 07 July 2014 See paragraphs [0011]-[0020] and claims 1-5.	1-13
A	KR 10-0711481 B1 (POSCO) 24 April 2007 See paragraphs [0068]-[0072], claims 1, 6 and table 1-2.	1-13
A	KR 10-2015-0025910 A (HYUNDAI STEEL COMPANY) 11 March 2015 See paragraphs [0008]-[0012] and claims 1-5.	1-13
A	KR 10-2014-0081048 A (POSCO) 01 July 2014 See paragraphs [0071]-[0101] and claims 1-2.	1-13

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

* Special categories of cited documents:

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

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"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

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Date of the actual completion of the international search

07 SEPTEMBER 2017 (07.09.2017)

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2017/006668

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2003321739 A [0012]
- KR 20120049993 [0012]
- KR 20120052022 [0012]