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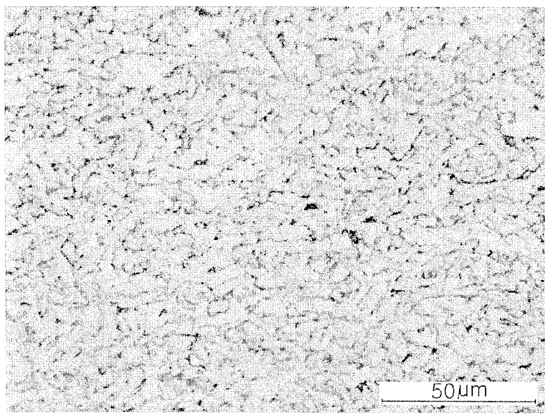
(54) STRUCTURAL ULTRA-THICK STEEL HAVING EXCELLENT RESISTANCE TO BRITTLE CRACK PROPAGATION, AND PRODUCTION METHOD THEREFOR

(57) The present invention provides structural ultra-thick steel having excellent resistance to brittle crack propagation and a production method therefor. Provided according to the present invention are: structural ultra-thick steel, which has excellent resistance to brittle crack propagation, comprises 0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0. 1 wt % of Nb, and 0.005-0. 1 wt % of Ti with the remainder being Fe and other inevitable impurities, and has microstructures including one structure selected from the group consisting of a single-phase structure of ferrite, a single-phase structure of bainite, a complex-phase structure of ferrite and bainite, a complex-phase structure of ferrite and pearlite, and a complex-phase structure of ferrite, bainite, and pearlite; and a production method therefor. According to one aspect of the present invention, ultra-thick structural steel, which has excellent resistance to brittle crack propagation and has excellent yield strength and an excellent impact transition temperature in the center, can be obtained.

【Figure 1】



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Description

[Technical Field]

[0001] The present disclosure relates to structural ultra-thick steel having excellent resistance to brittle crack propagation, and a production method therefor.

[Background Art]

[0002] In recent years, the development of ultra-thick steel having high-strength characteristics has been required in designing structures that have been used in fields such as domestic and overseas shipbuilding, maritime construction, architecture, and civil engineering.

[0003] When using high-strength steel to design structures, structures may be lightened in terms of the weight thereof, while obtaining an economic advantage through the thickness of a steel sheet, thus simultaneously achieving ease in machining and welding.

[0004] In general, in the case of high-strength steel, since a central portion thereof may not be sufficiently transformed, depending on a reduction in the total reduction ratio, during the manufacturing of ultra-thick steel, the structure of the central portion may be coarse. Hence, the hardenability of the high-strength steel may be increased, to thus generate a low temperature transformation phase, such as bainite or the like.

[0005] In addition, coarsened structures may cause difficulties in securing impact toughness in the central portion.

[0006] When resistance to brittle crack propagation representing the stability of structures is applied to primary structures, such as a ship and the like, the number of cases requiring guarantees is increasing. However, when a low temperature transformation phase is generated in the central portion, the resistance to brittle crack propagation may be significantly reduced. Thus, it may be very difficult to improve the resistance of an ultra-thick high-strength steel to brittle crack propagation.

[0007] Meanwhile, in order to improve the resistance of high-strength steel, having a yield strength of 350 MPa or more, to brittle crack propagation, various technologies have been implemented, such as the adjustment of gain size through the application of surface cooling during finish rolling and through the application of bending stress during rolling, surface refinement through reverse rolling, and the like, in order to miniaturize the grain size of surface layers of high-strength steel.

[0008] However, such technologies help to miniaturize the structure of surface layers, but cannot solve the problem of a reduction in impact toughness caused by structural coarsening of the central portion, so may not become fundamental measures to the resistance to brittle crack propagation.

[0009] Furthermore, the technologies themselves may be expected to cause significant reductions in productivity when being employed in common mass production systems; thus, it may be difficult to commercialize such technologies.

[0010] Moreover, when a large amount of an element, such as nickel (Ni) or the like, helping to improve toughness, is added to high-strength steel, the resistance thereof to brittle crack propagation may be improved. However, since a Ni element is relatively expensive, it may be difficult to apply the Ni element commercially in terms of manufacturing costs.

Related Art Documents:

[0011]

Patent Document 1: Korean Patent Publication No. 2009-0069818
Patent Document 2: Korean Patent Publication No. 2002-0091844

[Disclosure]

[Technical Problem]

[0012] An aspect of the present disclosure may provide structural ultra-thick steel having excellent resistance to brittle crack propagation.

[0013] Another aspect of the present disclosure may provide a method of producing structural ultra-thick steel having excellent resistance to brittle crack propagation by controlling alloy compositions and microstructures.

[Technical Solution]

[0014] According to an aspect of the present disclosure, structural ultra-thick steel having excellent resistance to brittle crack propagation may include: 0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0.1 wt % of Nb, 0.005-0.1 wt % of Ti, and the remainder of Fe and other inevitable impurities, the structural ultra-thick steel having microstructures including one structure selected from the group consisting of a single-phase structure of ferrite, a single-phase structure of bainite, a complex-phase structure of ferrite and bainite, a complex-phase structure of ferrite and pearlite, and a complex-phase structure of ferrite, bainite, and pearlite.

[0015] The structural ultra-thick steel may have a grain size of 15 μm or less, the grain size having a high-angle grain boundary of 15° or higher, measured in an ESBD manner in a central portion of the steel in a plate thickness direction thereof.

[0016] The structural ultra-thick steel may have a yield strength of 350 MPa or more, and an impact transition temperature of -60°C or lower in a central portion thereof.

[0017] According to another aspect of the present disclosure, a method of producing structural ultra-thick steel having excellent resistance to brittle crack propagation may include: reheating a slab or a bar including 0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0.1 wt % of Nb, 0.005-0.1 wt % of Ti, and the remainder of Fe and other inevitable impurities to 950-1, 100°C and then rough rolling the reheated slab or bar at 900-1, 100°C; obtaining a steel sheet by finish rolling the rough rolled slab or bar at an Ar3 transformation point or higher; and cooling the steel sheet to 700°C or lower, in which a temperature difference between a central portion of the slab or the bar in a thickness direction and an external surface of the slab or the bar before rough rolling may be 100°C or higher.

[0018] A total cumulative reduction ratio at the time of rough rolling may be 40% or higher.

[0019] The cooling of the steel sheet may be performed at a central portion cooling rate of 2 °C/s.

[0020] The cooling of the steel sheet may be performed at an average cooling rate of 3-300 °C/s.

[0021] The foregoing technical solutions to the above-mentioned problems do not fully enumerate all of the features of the present disclosure.

[0022] Various features of the present disclosure and the resulting advantages and effects will be understood in more detail with reference to the following detailed examples.

[Advantageous Effects]

[0023] According to an aspect of the present disclosure, structural ultra-thick steel having excellent resistance to brittle crack propagation, excellent yield strength and an excellent impact transition temperature in a central portion thereof, may be obtained.

[Description of Drawings]

[0024] FIG. 1 is an image obtained by observing a central portion of Inventive Steel 1 in a plate thickness direction thereof with an optical microscope.

[Best Mode for Invention]

[0025] The inventors of the present disclosure have conducted research to secure structural ultra-thick steel having excellent yield strength and an excellent impact transition temperature in a central portion thereof, compared to that in the related art, while solving conventional problems, to appropriately control alloy design and microstructures of the structural ultra-thick steel, thus recognizing that resistance of the structural ultra-thick steel to brittle crack propagation may be improved. Based on this, the inventors have completed the present invention.

[0026] Hereinafter, structural ultra-thick steel having excellent resistance to brittle crack propagation according to an aspect of the present disclosure will be described in detail.

[0027] According to an aspect of the present disclosure, structural ultra-thick steel having excellent resistance to brittle crack propagation may include: 0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0.1 wt % of Nb, 0.005-0.1 wt % of Ti, and the remainder of Fe and other inevitable impurities, the structural ultra-thick steel having microstructures including one structure selected from the group consisting of a single-phase structure of ferrite, a single-phase structure of bainite, a complex-phase structure of ferrite and bainite, a complex-phase structure of ferrite and pearlite, and a complex-phase structure of ferrite, bainite, and pearlite.

[0028] Such structural ultra-thick steel may have a thickness of 10-100 mm, more preferably 50-100 mm.

[0029] Hereinafter, steel compositions and composition ranges in an embodiment will be described.

[0030] Carbon (C): 0.02-0.1% (hereinafter, a content of each composition may refer to wt %).

[0031] Since C is the most important element in securing basic strength, C may be required to be contained in steel within an appropriate range. It may be preferable to add 0.02% or more of C in order to obtain such an addition effect.

[0032] However, when the content of C exceeds 0.1%, low temperature toughness may be degraded due to generation of a large amount of martensite-austenite (M/A) constituents and high strength of ferrite itself, and it may thus be preferable to restrict the content of C to 0.02-0.1%.

Manganese (Mn): 0.8-2.5%

[0033] Since Mn is an element useful in improving strength by solid solution strengthening and to enhance hardenability so as to generate a low temperature transformation phase, it may be preferable to add 0.8% or more of Mn.
[0034] However, when a content of Mn exceeds 2.5%, an excessive increase in hardenability may promote generation of upper bainite and martensite to degrade impact toughness and resistance to brittle crack propagation, and it may thus be preferable to restrict the content of Mn to 0.8-2.5%.

Nickel (Ni): 0.05-1.5%

[0035] Since Ni is an important element to facilitate cross slip of potentials at low temperatures to improve impact toughness and hardenability, increasing strength, it may be preferable to add 0.05% or more of Ni in order to improve impact toughness and resistance to brittle crack propagation. However, when 1.5% or more of Ni is added, hardenability may be excessively increased to generate a low temperature transformation phase, degrading toughness and increasing manufacturing costs, and it may thus be preferable to restrict an upper limit of the content of Ni to 1.5%.

Niobium (Nb): 0.005-0.1%

[0036] Nb may be precipitated in the form of NbC or NbCN to increase strength of a base material.
[0037] Further, Nb, dissolved when reheated to a high temperature, may be precipitated very finely in the form of NbC at the time of rolling to suppress recrystallization of austenite, thus miniaturizing a structure.
[0038] Thus, it may be preferable to add 0.005% or more of Nb. However, an excessive amount of Nb may cause brittle cracking in an edge of the steel, and it may thus be preferable to restrict a lower limit of the content of Nb to 0.1%.

Titanium (Ti): 0.005-0.1%

[0039] Ti is precipitated as TiN when reheated and is an element that may significantly improve low temperature toughness by suppressing the growth of crystal grains of the base material and a weld heat affected zone. It may be preferable to add 0.005% or more of Ti in order to obtain such an addition effect.
[0040] However, when greater than 0.1% of Ti is added, low temperature toughness may be reduced due to clogging of a continuous casting nozzle or crystallization of the central portion, and it may thus be preferable to restrict a content of Ti to 0.005-0.1%.
[0041] In an embodiment, the remainder thereof may be iron (Fe). However, in a common manufacturing process, impurities of raw materials or steel manufacturing environments may be inevitably included in the steel, and such impurities may not be removed from the steel.
[0042] These impurities are commonly known to a person skilled in the art, and are thus not specifically mentioned in this specification.
[0043] The steel according to an embodiment may have microstructures including one structure selected from the group consisting of a single-phase structure of ferrite, a single-phase structure of bainite, a complex-phase structure of ferrite and bainite, a complex-phase structure of ferrite and pearlite, and a complex-phase structure of ferrite, bainite, and pearlite.
[0044] It may be preferable to restrict a ratio of pearlite to 30 vol% or less in the complex-phase structure of ferrite, bainite, and pearlite.
[0045] It may be preferable that the ferrite be acicular ferrite and the bainite be granular bainite. At this time, polygonal ferrite may be used as the ferrite, if necessary.
[0046] For example, as the contents of Mn and Ni increase, fractions of acicular ferrite or polygonal ferrite and granular bainite may increase. Accordingly, strength may also increase.
[0047] The steel may preferably have a grain size of 15 μm or less, which may have a high-angle grain boundary of 15° or higher measured in the central portion in a plate thickness direction of the steel in an electron backscatter diffraction (ESBD) manner.
[0048] The steel may preferably have a yield strength of 350 MPa or more, and an impact transition temperature of -60°C or lower in the central portion thereof.
[0049] According to another aspect of the present disclosure, a method of producing structural ultra-thick steel having excellent resistance to brittle crack propagation may include: reheating a slab or a bar including 0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0.1 wt % of Nb, 0.005-0.1 wt % of Ti, and the remainder of Fe and other inevitable impurities to 950-1,100°C and then rough rolling the reheated slab or bar at 900-1, 100°C; obtaining a steel

sheet by finish rolling the rough rolled slab or bar at an Ar3 transformation point or higher; and cooling the steel sheet to 700°C or lower, in which a temperature difference between a central portion of the slab or the bar in a thickness direction thereof and an external surface of the slab or the bar before rough rolling may be 100°C or higher.

Slab Reheating Temperature: 950-1,100°C

[0050] It may be preferable to restrict a slab reheating temperature to 950°C or higher, which is performed to dissolve a carbonitride of Ti and/or Nb formed during casting. Further, it may be more preferable to reheat the slab to 1, 000 °C or higher in order to sufficiently dissolve the carbonitride of Ti and/or Nb. However, when the slab is reheated to an excessively high temperature, there may be concerns that austenite is coarsened, and it may thus be preferable that an upper limit of the slab reheating temperature be 1,100°C.

Rough Rolling Temperature: 900-1,100°C and Temperature Difference between Central Portion of Slab or Bar in Thickness Direction and External Surface of Slab or Bar before Rough Rolling: 100°C or Higher

[0051] The reheated slab may be rough rolled. It may be preferable that a rough rolling temperature be a temperature (Tnr) or higher at which recrystallization of austenite stops. Effects of destroying a cast structure, such as a dendrite or the like, formed during casting by rolling, and of reducing a size of austenite may also be obtained. It may be preferable to restrict the rough rolling temperature to 900-1,100°C in order to obtain such an effect.

[0052] In an embodiment, the temperature difference between the central portion of the slab or the bar in the thickness direction thereof and the external surface of the slab or the bar immediately before rolling at the time of rough rolling may be 100°C or higher.

[0053] Such a temperature difference between the central portion and the external surface may be obtained by, for example, cooling a heated slab or bar with a cooling device. The cooling device is not particularly limited and, for example, at least one of water, air, a liquid coolant, and a vapor coolant may be used as a cooling medium.

[0054] As described above, the temperature difference between the central portion of the slab or the bar in the thickness direction thereof and the external surface of the slab or the bar may be given at the time of rough rolling to maintain a surface portion of the slab or the bar at a temperature lower than that of the central portion. When rolling is performed in a state in which such a temperature difference exists, the central portion having a temperature relatively higher than that of the surface portion may be further deformed, and a grain size of the central portion may thus become finer. Preferably, an average grain size of the central portion may be maintained at 15 μm or less.

[0055] This is a technology utilizing a phenomenon in which since the surface portion having a relatively low temperature has strength higher than that of the central portion having a relatively high temperature, the central portion having relatively low strength may be further deformed. It may be preferable that the temperature difference between the central portion and the external surface be 100°C or higher in order to effectively provide further deformation to the central portion, and a more preferable temperature difference may be from 100-300°C.

[0056] Here, the temperature difference between the central portion of the slab or the bar in the thickness direction thereof and the external surface of the slab or the bar may refer to a difference between a surface temperature of the slab or the bar measured immediately before rough rolling and a temperature of the central portion calculated by considering cooling conditions and a thickness of the slab or the bar immediately before rough rolling.

[0057] The measurements of the surface temperature and the thickness of the slab may be taken before initial rough rolling, and the measurements of the surface temperature and the thickness of the bar may be taken before initial rough rolling after two rough rolling processes.

[0058] When rough rolling is performed in two or more passes, the temperature difference between the central portion of the slab or the bar in the thickness direction thereof and the external surface of the slab or the bar may refer to the fact that a temperature difference, obtained by measuring temperature differences in the respective passes during rough rolling and calculating a total average value, is 100°C or higher.

[0059] In an embodiment, it may be preferable that a total cumulative reduction ratio at the time of rough rolling be 40% or more in order to miniaturize the structure of the central portion at the time of rough rolling.

Finish Rolling Temperature: Ar3 (a ferrite transformation initiation temperature) or higher

[0060] A steel sheet may be obtained by finish rolling the rough rolled bar at an Ar3 transformation point or higher.

[0061] At the time of finish rolling, an austenite structure may be transformed.

Cooling after Rolling: Cooling to 700°C or Lower

[0062] After finish rolling, the steel sheet may be cooled to 700°C or lower.

[0063] When a cooling termination temperature exceeds 700°C, a microstructure may not be properly formed, and there may thus be a possibility that the yield strength is 350 MPa or less.

[0064] The cooling of the steel sheet may be performed at a central portion cooling rate of 2 °C/s or more. When the central portion cooling rate of the steel sheet is less than 2 °C/s, the microstructure may not be properly formed, and there may thus be a possibility that the yield strength is 350 MPa or less.

[0065] Further, the cooling of the steel sheet may be performed at an average cooling rate of 3-300°C/s.

[0066] Hereinafter, the present disclosure will be described in more detail through embodiments.

[0067] It should be noted, however, that the following embodiments are intended to illustrate the present disclosure by way of illustration and not to limit the scope of the present disclosure.

[0068] The scope of the present invention is determined by the matters described in the claims and those reasonably inferred therefrom.

[Mode for Invention]

[0069] A steel slab having a composition illustrated in Table 1 below was reheated to 1,070°C, and rough rolled at a temperature of 1,050°C. An average temperature difference between an external surface and a central portion of the steel slab at the time of rough rolling of the steel slab may be shown in Table 2 below, and a cumulative reduction ratio was 50%.

[0070] The average temperature difference between the external surface and the central portion at the time of rough rolling as illustrated in Table 2 may represent a difference between a surface temperature of a slab or a bar measured immediately before rough rolling and a temperature of the central portion calculated by considering an amount of water injected to the slab or the bar and a thickness of the slab or the bar immediately before rough rolling, and the average temperature difference may be a result obtained by measuring temperature differences in respective passes during rough rolling and calculating a total average value.

[0071] After rough rolling, a steel sheet having a thickness illustrated in Table 2 below was obtained by finish rolling the steel slab at a finish rolling temperature of 780°C, and was cooled to a temperature of 700°C or lower at a cooling rate of 5 °C/s.

[0072] With respect to the steel sheet manufactured as described above, microstructures, yield strength, an average grain size of the central portion, an impact transition temperature of the central portion, and a Kca value (a brittle crack propagation resistance coefficient) were measured, and the results are illustrated in Table 2 below.

[0073] The Kca value illustrated in Table 2 may be an estimate value obtained by performing an ESSO test.

[Table 1]

CLASSIFICATION	C (wt%)	Mn (wt%)	Ni (wt%)	Ti (wt%)	Nb (wt%)
INVENTIVE STEEL 1	0.032	2.05	0.12	0.018	0.019
INVENTIVE STEEL 2	0.067	1.77	0.35	0.023	0.012
INVENTIVE STEEL 3	0.074	1.25	0.95	0.021	0.023
INVENTIVE STEEL 4	0.063	1.63	0.75	0.015	0.015
INVENTIVE STEEL 5	0.053	1.74	1.02	0.018	0.021
INVENTIVE STEEL 6	0.091	1.21	0.43	0.023	0.029
COMPARATIVE STEEL 1	0.082	0.92	0.65	0.012	0.018
COMPARATIVE STEEL 2	0.061	1.65	0.37	0.017	0.012
COMPARATIVE STEEL 3	0.12	1.59	0.23	0.021	0.011
COMPARATIVE STEEL 4	0.076	2.05	2.25	0.015	0.019
COMPARATIVE STEEL 5	0.071	2.65	0.45	0.017	0.022

[Table 2]

CLASSIFICATION	AVERAGE CENTRAL PORTION-SURFACE TEMPERATURE DIFFERENCE DURING ROUGH ROLLING (°C)	PRODUCT THICKNESS (mm)	* MICROSTRUCTURE, PHASE FRACTION (%)	YIELD STRENGTH (MPa)	AVERAGE GRAIN SIZE OF CENTRAL PORTION (μm)	IMPACT TRANSITION TEMPERATURE OF CENTRAL PORTION (°C)	Kca ($N/mm^{1.5}$, @-10°C)
INVENTIVE STEEL 1	256	85	AF+GB (26%)	506	11.3	-96	9314
INVENTIVE STEEL 2	165	95	AF	455	12.5	-86	8655
INVENTIVE STEEL 3	137	100	PF+P (23%)	395	13.1	-79	7956
INVENTIVE STEEL 4	259	90	AF+GB (28%)	486	9.7	-86	8165
INVENTIVE STEEL 5	215	95	AF+GB (31%)	512	10.1	-91	8964
INVENTIVE STEEL 6	189	100	PF+P (22%)	407	12.6	-77	7103
COMPARATIVE STEEL 1	23	90	PF+P (18%)	371	25.3	-53	5166
COMPARATIVE STEEL 2	35	85	AF+UB (21%)	495	29.6	-49	4931
COMPARATIVE STEEL 3	129	80	UB	578	32	-35	3655
COMPARATIVE STEEL 4	212	100	GB, UB (34%)	566	26	-50	3984
COMPARATIVE STEEL 5	155	85	UB	613	38	-20.	2850

*PF: Polygonal Ferrite, P: Pearlite AF: Acicular Ferrite, GB: Granular Bainite, and UB: Upper Bainite. Here, the product thicknesses show that they were evaluated for thick steels.

[0074] As illustrated in Table 2, in the case of Comparative Steels 1 and 2, it can be seen that the average temperature difference between the central portion in the thickness direction and the external surface at the time of rough rolling presented in an embodiment is controlled to less than 100°C, that since a sufficient degree of deformation is not given to the central portion at the time of rough rolling, grain sizes of the central portion are 25.3 μm and 29.6 μm, respectively; thus, an impact transition temperature of the central portion is less than -60°C. Further, it can also be seen that the Kca value measured at -10°C does not exceed 6,000, required in a common steel for shipbuilding.

[0075] In the case of Comparative Steels 3 and 5, it can be seen that Comparative Steels 3 and 5 have values greater than the upper limits of the contents of C and Mn proposed in an embodiment, that even though a grain size of austenite in the central portion is miniaturized through cooling at the time of rough rolling, grain sizes of final microstructures are 32 μm or more and 38 μm or more, respectively, due to the generation of upper bainite, and that since Comparative Steels 3 and 5 have the upper bainite, in which brittleness may easily occur, as a base structure; thus, an impact transition temperature of the central portion is -60°C or higher.

[0076] Accordingly, it can also be seen that a Kca value is 6, 000 or less at -10°C.

[0077] In the case of Comparative Steel 4, it can be seen that Comparative Steel 4 has a value greater than the upper limit of the content of Ni proposed in an embodiment, and that, in terms of high hardenability, microstructures of a base metal are granular bainite and upper bainite.

[0078] Thus, it can be seen that, even though the grain size of austenite in the central portion is miniaturized through cooling at the time of rough rolling, a grain size of the final microstructure is 26 μm, that the upper bainite, in which brittleness may easily occur, is a base structure; thus, an impact transition temperature of the central portion is -60°C or higher.

[0079] Further, it can also be seen that a Kca value is 6,000 or less at -10°C.

[0080] In contrast, in the case of Inventive Steels 1 to 6, which satisfy the composition range in an embodiment and in which the grain size of austenite in the central portion is miniaturized through cooling at the time of rough rolling, it can be seen that Inventive Steels 1 to 6 satisfy a yield strength of 350 MPa or more, and a grain size of 15 μm or less in central portions thereof, and have, as microstructures, ferrite and pearlite structures, a single-phase structure of acicular ferrite, or a complex-phase structure of acicular ferrite or polygonal ferrite and granular bainite, and a complex-phase structure of acicular ferrite, pearlite, and granular bainite. Accordingly, it can be seen that an impact transition temperature of the central portion is -60°C or lower and that a Kca value satisfies 6,000 or more at -10°C.

[0081] As illustrated in FIG. 1, depicting an image obtained by observing the central portion of Inventive Steel 1 in a thickness direction thereof with an optical microscope, in the case of Inventive Steel 1, it can be seen that a structure of the central portion is fine.

Claims

1. A structural ultra-thick steel having excellent resistance to brittle crack propagation, the structural ultra-thick steel comprising:

   0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0.1 wt % of Nb, 0.005-0.1 wt % of Ti, and the remainder of Fe and other inevitable impurities, the structural ultra-thick steel having microstructures including one structure selected from the group consisting of a single-phase structure of ferrite, a single-phase structure of bainite, a complex-phase structure of ferrite and bainite, a complex-phase structure of ferrite and pearlite, and a complex-phase structure of ferrite, bainite, and pearlite.

2. The structural ultra-thick steel of claim 1, wherein the ferrite is acicular ferrite or polygonal ferrite, and the bainite is granular bainite.

3. The structural ultra-thick steel of claim 1, having a grain size of 15 μm or less, the grain size having a high-angle grain boundary of 15° or higher measured in an ESBD manner in a central portion in a plate thickness direction.

4. The structural ultra-thick steel of claim 1, having a yield strength of 350 MPa or more, and an impact transition temperature of -60 °C or lower in of a central portion thereof.

5. The structural ultra-thick steel of claim 1, having a thickness of 10-100 mm.

6. A method of producing a structural ultra-thick steel having excellent resistance to brittle crack propagation, the method comprising:

reheating a slab or a bar including 0.02-0.1 wt % of C, 0.8-2.5 wt % of Mn, 0.05-1.5 wt % of Ni, 0.005-0.1 wt % of Nb, 0.005-0 .1 wt % of Ti, and the remainder of Fe and other inevitable impurities to 950-1,100°C and then rough rolling the reheated slab or bar at 900-1,100°C;
obtaining a steel sheet by finish rolling the rough rolled slab or bar at an Ar3 transformation point or higher; and cooling the steel sheet to 700°C or lower,
wherein a temperature difference between a central portion of the slab or the bar in a thickness direction thereof and an external surface of the slab or the bar before rolling at the time of rough rolling is 100°C or higher.

7. The method of claim 6, wherein the temperature difference between the central portion of the slab or the bar in the thickness direction and the external surface of the slab or the bar is from 100-300°C.

8. The method of claim 6, wherein the temperature difference between the central portion of the slab or the bar in the thickness direction and the external surface of the slab or the bar is a difference between a surface temperature of the slab or the bar measured immediately before rough rolling and a temperature of the central portion calculated by considering cooling conditions and a thickness of the slab or the bar immediately before rough rolling.

9. The method of claim 6, wherein the rough rolling is performed in two passes or more, and the temperature difference between the central portion of the slab or the bar in the thickness direction and the external surface of the slab or the bar is a temperature difference obtained by measuring temperature differences in the respective passes during the rough rolling and calculating a total average value.

10. The method of claim 6, wherein the temperature difference between the central portion of the slab or the bar in the thickness direction and the external surface of the slab or the bar is obtained by cooling the slab or the bar with a cooling device.

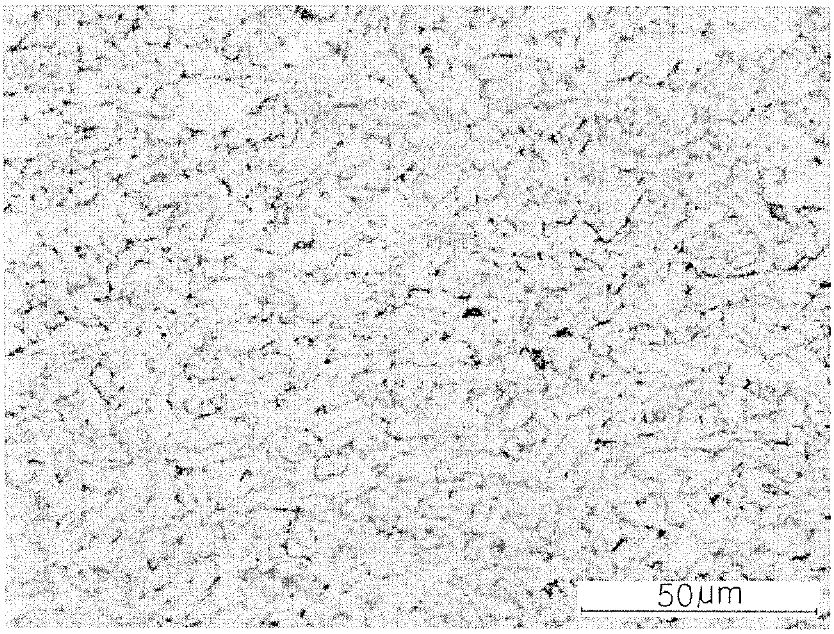
11. The method of claim 10, wherein a cooling medium of the cooling device is at least one of water, air, a liquid coolant, and a vapor coolant.

12. The method of claim 6, wherein a total cumulative reduction ratio at the time of rough rolling is 40% or higher.

13. The method of claim 6, wherein the cooling the steel sheet is performed at a central portion cooling rate of 2 °C/s or more.

14. The method of claim 6, wherein the cooling the steel sheet is performed at an average cooling rate of 3-300 °C/s.

【Figure 1】



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2015/013557

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i, C22C 38/08(2006.01)i, C22C 38/12(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 38/04; C22C 38/06; C21D 8/02; C22C 38/00; C22C 38/14; B21B 3/02; C22C 38/08; 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: carbon, manganese, nickel, niobium, titanium, ferrite, bainite, perlite, brittle fracture, rough rolling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 06-004903 B2 (NIPPON STEEL CORP.) 19 January 1994 See column 12, lines 21-25 and claims 4, 13.	1-5
A		6-14
A	KR 10-2011-0075321 A (POSCO) 06 July 2011 See paragraphs [0054]-[0063] and claims 1-6.	1-14
A	JP 08-199293 A (NIPPON STEEL CORP.) 06 August 1996 See paragraphs [0013]-[0018] and claim 2.	1-14
A	KR 10-2014-0113975 A (JFE STEEL CORPORATION) 25 September 2014 See paragraphs [0096]-[0098] and claims 1-4.	1-14
A	JP 2013-221190 A (NIPPON STEEL & SUMITOMO METAL CORP.) 28 October 2013 See paragraphs [0030]-[0045] and claims 1-3.	1-14

☐ 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
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"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	Date of mailing of the international search report
18 MARCH 2016 (18.03.2016)	**18 MARCH 2016 (18.03.2016)**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2015/013557

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		TW I504759 B	21/10/2015
		WO 2013-099179 A1	04/07/2013
JP 2013-221190 A	28/10/2013	NONE	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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