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

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ACIER DE STRUCTURE ULTRA ÉPAIS PRÉSENTANT UNE EXCELLENTE RÉSISTANCE À LA PROPAGATION DE FISSURES FRAGILES ET SON PROCÉDÉ DE PRODUCTION

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(56) References cited:

EP-B1- 1 025 272	**WO-A1-99/32671**
WO-A1-2014/132627	**WO-A2-00/40764**
JP-A- H08 199 293	**JP-A- 2010 001 520**
JP-A- 2013 221 190	**JP-B2- H 064 903**
KR-A- 20110 075 321	**KR-A- 20140 113 975**

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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.

[0011] WO 1999/032671 discloses a steel entirely or partially including iron, carbon, manganese, nickel, nitrogen, copper, chromium, molybdenum, silicon, niobium, vanadium, titanium, aluminum, boron additives, a ferrite-phase as a microstructure, a second phase composed mainly of lath martensite and lower bainite and a phase composed of residual austenite.

[0012] WO 2014/132627 discloses a steel including carbon, silicon, manganese, phosphorus, sulphur, aluminum, niobium, titanium, copper, nickel, chromium, molybdenum and nitrogen, so as to satisfy certain relational expressions. It includes bainite and martensite microstructures as a main structure and polygonal ferrite of 10% or less.

Related Art Documents:

[0013]

Patent Document 1: Korean Patent Publication No. 2009-0069818
Patent Document 2: Korean Patent Publication No. 2002-0091844
Patent Document 3: WO 1999/032671
Patent Document 4: WO 2014/132627

[Disclosure]

[Technical Problem]

[0014] An aspect of the present disclosure may provide structural ultra-thick steel having excellent resistance to brittle crack propagation.

[0015] 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]

[0016] According to an aspect of the present disclosure, structural ultra-thick steel having excellent resistance to brittle crack propagation consists of: 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 consisting of 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, wherein the ferrite is acicular ferrite or polygonal ferrite, and the bainite is granular bainite, wherein when the microstructures have the complex-phase structure of ferrite, bainite, and pearlite a percentage of pearlite to the complex-phase structure is 30 vol% or less, wherein the steel has a grain size of 15 μm or less, the grain size having a high-angle grain boundary of 15° or higher measured in an EBSD manner in a central portion in a plate thickness direction, wherein the steel has a yield strength of 350 MPa or more, an impact transition temperature of -60°C or lower in of a central portion thereof, a thickness of 10-100 mm and 6,000 or more of Kca value obtained by performing an ESSO test.

[0017] According to another aspect of the present disclosure, a method of producing the structural ultra-thick steel having excellent resistance to brittle crack propagation comprises: reheating a slab or a bar consisting of 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 is 100-300°C, 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, wherein a cooling medium of the cooling device is at least one of water, air, a liquid coolant, and a vapor coolant, wherein a total cumulative reduction ratio at the time of rough rolling is 40% or higher, wherein the cooling of the steel sheet is performed at a central portion average cooling rate of 3-300 °C/s.

[0018] The foregoing technical solutions to the above-mentioned problems do not fully enumerate all of the features of the present disclosure.

[0019] 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]

[0020] 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]

[0021] 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]

[0022] 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.

[0023] 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.

[0024] According to an aspect of the present disclosure, structural ultra-thick steel having excellent resistance to brittle crack propagation includes: 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.

[0025] Such structural ultra-thick steel has a thickness of 10-100 mm, more preferably 50-100 mm.

[0026] Hereinafter, steel compositions and composition ranges in an embodiment will be described.

[0027] Carbon (C): 0.02-0.1% (hereinafter, a content of each composition refers to wt %).

[0028] Since C is the most important element in securing basic strength, C is required to be contained in steel within an appropriate range. 0.02% or more of C is added in order to obtain such an addition effect.

[0029] 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 the content of C is thus restricted to 0.02-0.1%.

Manganese (Mn): 0.8-2.5%

[0030] 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, 0.8% or more of Mn is added.

[0031] 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 the content of Mn is thus restricted to 0.8-2.5%.

Nickel (Ni): 0.05-1.5%

[0032] Since Ni is an important element to facilitate cross slip of potentials at low temperatures to improve impact toughness and hardenability, increasing strength, 0.05% or more of Ni is added 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 an upper limit of the content of Ni is thus restricted to 1.5%.

Niobium (Nb): 0.005-0.1%

[0033] Nb may be precipitated in the form of NbC or NbCN to increase strength of a base material.

[0034] 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.

[0035] Thus, 0.005% or more of Nb is added. However, an excessive amount of Nb may cause brittle cracking in an edge of the steel, and a lower limit of the content of Nb is thus restricted to 0.1%.

Titanium (Ti): 0.005-0.1%

[0036] 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. 0.005% or more of Ti is added in order to obtain such an addition effect.

[0037] 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 a content of Ti is thus restricted to 0.005-0.1%.

[0038] In an embodiment, the remainder thereof is 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.

[0039] These impurities are commonly known to a person skilled in the art, and are thus not specifically mentioned in this specification.

[0040] The steel according to an embodiment 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.

[0041] A ratio of pearlite is restricted to 30 vol% or less in the complex-phase structure of ferrite, bainite, and pearlite.

[0042] The ferrite is acicular ferrite or polygonal ferrite and the bainite is granular bainite. 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.

[0043] The steel has a grain size of 15 μm or less and 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 (EBSD) manner.

[0044] The steel has a yield strength of 350 MPa or more, and an impact transition temperature of -60°C or lower in the central portion thereof.

[0045] According to another aspect of the present disclosure, a method of producing structural ultra-thick steel having excellent resistance to brittle crack propagation includes: 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 is 100-300°C.

Slab Reheating Temperature: 950-1,100°C

[0046] A slab reheating temperature is restricted 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 an upper limit of the slab reheating temperature is thus 1,100°C.

[0047] 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: 100-300°C

[0048] The reheated slab is rough rolled. A rough rolling temperature is 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. The rough rolling temperature is restricted to 900-1,100°C in order to obtain such an effect.

[0049] 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 is 100-300°C.

[0050] Such a temperature difference between the central portion and the external surface is obtained by 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.

[0051] 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 thus becomes finer. An average grain size of the central portion is maintained at 15 μm or less.

[0052] 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. The temperature difference between the central portion and the external surface is 100-300°C in order to effectively provide further deformation to the central portion..

[0053] 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.

[0054] 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.

[0055] 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 100-300°C.

[0056] A total cumulative reduction ratio at the time of rough rolling is 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

[0057] A steel sheet is obtained by finish rolling the rough rolled bar at an Ar3 transformation point or higher.

[0058] At the time of finish rolling, an austenite structure may be transformed.

Cooling after Rolling: Cooling to 700°C or Lower

[0059] After finish rolling, the steel sheet is cooled to 700°C or lower.

[0060] 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.

[0061] The cooling of the steel sheet is performed at a central portion average cooling rate of 3-300 °C/s or more. When the central portion average cooling rate of the steel sheet is less than 3 °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.

[0062] Hereinafter, the present disclosure will be described in more detail through embodiments.

[0063] 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.

[0064] The scope of the present invention is determined by the matters described in the claims and those reasonably inferred therefrom.

[Mode for Invention]

[0065] 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 is shown in Table 2 below, and a cumulative reduction ratio was 50%.

[0066] 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.

[0067] 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.

[0068] 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.

[0069] 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+26%GB	506	11.3	-96	9314
INVENTIVE STEEL 2	165	95	AF	455	12.5	-86	8655
INVENTIVE STEEL 3	137	100	PF+23%P	395	13.1	-79	7956
INVENTIVE STEEL 4	259	90	AF+28%GB	486	9.7	-86	8165
INVENTIVE STEEL 5	215	95	AF+31%GB	512	10.1	-91	8964
INVENTIVE STEEL 6	189	100	PF+22%P	407	12.6	-77	7103
COMPARATIVE STEEL 1	23	90	PF+18%P	371	25.3	-53	5166
COMPARATIVE STEEL 2	35	85	AF+21%UB	495	29.6	-49	4931
COMPARATIVE STEEL 3	129	80	UB	578	32	-35	3655
COMPARATIVE STEEL 4	212	100	GB, 34%UB	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.

[0070] 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.

[0071] 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.

[0072] Accordingly, it can also be seen that a Kca value is 6,000 or less at -10°C.

[0073] 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.

[0074] 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.

[0075] Further, it can also be seen that a Kca value is 6,000 or less at -10°C.

[0076] 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.

[0077] 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.

[0078] 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 consisting of:

   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 consisting of 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
   wherein the ferrite is acicular ferrite or polygonal ferrite, and the bainite is granular bainite,
   wherein when the microstructures have the complex-phase structure of ferrite, bainite, and pearlite a percentage of pearlite to the complex-phase structure is 30 vol% or less,
   wherein the steel has a grain size of 15 μm or less, the grain size having a high-angle grain boundary of 15° or higher measured in an EBSD manner in a central portion in a plate thickness direction,
   wherein the steel has a yield strength of 350 MPa or more, an impact transition temperature of -60°C or lower in of a central portion thereof, a thickness of 10-100 mm and 6,000 or more of Kca value obtained by performing an ESSO test.

2. A method of producing a structural ultra-thick steel of claim 1 having excellent resistance to brittle crack propagation, the method comprising:

   reheating a slab or a bar consisting of 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 100-300°C,
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,
wherein a cooling medium of the cooling device is at least one of water, air, a liquid coolant, and a vapor coolant,
wherein a total cumulative reduction ratio at the time of rough rolling is 40% or higher,
wherein the cooling of the steel sheet is performed at a central portion average cooling rate of 3-300 °C/s.

3. The method of claim 2, 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.

4. The method of claim 2, 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.

Patentansprüche

1. Ultradicker Stahl, der eine ausgezeichnete Beständigkeit gegen die Ausbreitung spröder Risse aufweist, wobei der ultradicke Stahl aus Folgendem besteht:
zwischen 0,02 und 0,1 Gew.-% C, zwischen 0,8 und 2,5 Gew.-% Mn, zwischen 0,05 und 1,5 Gew.-% Ni, zwischen 0,005 und 0,1 Gew.-% Nb, zwischen 0,005 und 0,1 Gew.-% Ti und einem Rest aus Fe und anderen unvermeidlichen Verunreinigungen, wobei der strukturelle ultradicke Stahl Mikrostrukturen aufweist, die aus einer Struktur ausgewählt aus der Gruppe bestehend aus einer Einphasenstruktur aus Ferrit, einer Einphasenstruktur aus Bainit, einer Komplexphasenstruktur aus Ferrit und Bainit, einer Komplexphasenstruktur aus Ferrit und Perlit und eine Komplexphasenstruktur aus Ferrit, Bainit und Perlit, wobei der Ferrit nadelförmiger Ferrit oder polygonaler Ferrit ist und der Bainit körniger Bainit ist, wobei, wenn die Mikrostrukturen die Komplexphasenstruktur aus Ferrit, Bainit und Perlit aufweisen, ein Prozentsatz von Perlit zu der Komplexphasenstruktur 30 Vol.-% oder weniger beträgt, wobei der Stahl eine Korngröße von 15 μm oder weniger aufweist, wobei die Korngröße eine Hochwinkelkorngrenze von 15° oder mehr aufweist, gemessen in eine EBSD-Art in einem zentralen Abschnitt in Plattendickenrichtung, wobei der Stahl Folgendes aufweist: eine Streckgrenze von 350 MPa oder mehr, eine Schlagübergangstemperatur von -60 °C oder weniger in einem zentralen Abschnitt davon, eine Dicke von 10 bis 100 mm und einen Kca-Wert von 6.000 oder mehr, der durch Ausführen eines ESSO-Tests erhalten wurde.

2. Verfahren zum Herstellen eines ultradicken Stahls nach Anspruch 1, welcher eine ausgezeichnete Beständigkeit gegen die Ausbreitung spröder Risse aufweist, wobei das Verfahren Folgendes umfasst:

Wiedererwärmen einer Bramme oder der Stange, bestehend aus zwischen 0,02 und 0,1 Gew.-% C, zwischen 0,8 und 2,5 Gew.-% Mn, zwischen 0,05 und 1,5 Gew.-% Ni, zwischen 0,005 und 0,1 Gew.-% Nb, zwischen 0,005 und 0,1 Gew.-% Ti und einem Rest aus Fe und anderen unvermeidlichen Verunreinigungen auf 950 bis 1.100 °C und anschließendes Grobwalzen der wiedererwärmten Bramme oder Stange bei 900 bis 1.100 °C;
Erhalten eines Stahlblechs durch Fertigwalzen der grobgewalzten Bramme oder Stange an einem Ar3-Transformationspunkt oder höher; und
Abkühlen des Stahlblechs auf 700 °C oder weniger, wobei eine Temperaturdifferenz zwischen einem mittleren Abschnitt der Bramme oder der Stange in einer Dickenrichtung davon und einer Außenfläche der Bramme oder der Stange vor dem Walzen zum Zeitpunkt des Grobwalzens 100 bis 300 °C beträgt, wobei die Temperaturdifferenz zwischen dem mittleren Abschnitt der Bramme oder des Stabes in Dickenrichtung und der Außenfläche der Bramme oder der Stange durch Abkühlen der Bramme oder der Stange mit einer Kühlvorrichtung erhalten wird, wobei ein Kühlmittel der Kühlvorrichtung mindestens eines von Wasser, Luft, einem flüssigen Kühlmittel und/oder einem Dampfkühlmittel ist, wobei das gesamte kumulative Reduktionsverhältnis zum Zeitpunkt des Grobwalzens 40 % oder mehr beträgt, wobei das Abkühlen des Stahlblechs bei einer durchschnittlichen Abkühlungsrate des mittleren Abschnitts von 3 bis 300 °C/s durchgeführt wird.

3. Verfahren nach Anspruch 2, wobei die Temperaturdifferenz zwischen dem mittleren Abschnitt der Bramme oder der Stange in der Dickenrichtung und der Außenfläche der Bramme oder der Stange eine Differenz zwischen einer Oberflächentemperatur der Bramme oder der Stange, die unmittelbar vor dem Grobwalzen gemessen wird, und einer Temperatur des mittleren Abschnitts, die unter Berücksichtigung der Abkühlbedingungen und der Dicke der Bramme oder der Stange unmittelbar vor dem Grobwalzen berechnet ist.

4. Verfahren nach Anspruch 2, wobei das Grobwalzen in zwei oder mehr Durchgängen durchgeführt wird, und die Temperaturdifferenz zwischen dem mittleren Abschnitt der Bramme oder der Stange in der Dickenrichtung und der Außenfläche der Bramme oder der Stange eine Temperaturdifferenz ist, die durch Messen der Temperaturdifferenzen in den jeweiligen Durchgängen während des Grobwalzens und Berechnen eines Gesamtmittelwertes erhalten wird.

Revendications

1. Acier de construction ultra-épais présentant une excellente résistance à la propagation de fissures cassantes ; l'acier de construction ultra-épais étant constitué de :
0,02 à 0,1 % en poids de C, 0,8 à 2,5 % en poids de Mn, 0,05 à 1,5 % en poids de Ni, 0,005 à 0,1 % en poids de Nb, 0,005 à 0,1 % en poids de Ti, et le reste du Fe et d'autres impuretés inévitables, l'acier de construction ultra-épais présentant des microstructures constituées d'une structure choisie dans le groupe comprenant une structure monophasée de ferrite, une structure monophasée de bainite, une structure à phase complexe de ferrite et bainite, une structure à phase complexe de ferrite et perlite, et une structure à phase complexe de ferrite, de bainite et de perlite, et la ferrite est une ferrite aciculaire ou une ferrite polygonale, et la bainite est une bainite granulaire, lorsque les microstructures présentent la structure à phase complexe de ferrite, de bainite et de perlite, un pourcentage de perlite dans la structure à phase complexe est inférieur ou égal à 30 % en volume, l'acier présente une granulométrie inférieure ou égale à 15 μm, la granulométrie présentant une limite de grain à angle élevé supérieur ou égal à 15 ° mesurée à l'aide de la méthode EBSD dans une partie centrale, dans le sens de l'épaisseur de la plaque, l'acier présentant une limite d'élasticité supérieure ou égale à 350 MPa, une température de transition au choc inférieure ou égale à -60 °C dans une partie centrale de celui-ci, une épaisseur comprise entre 10 et 100 mm et une valeur de Kca supérieure ou égale à 6 000, obtenue par un test ESSO.

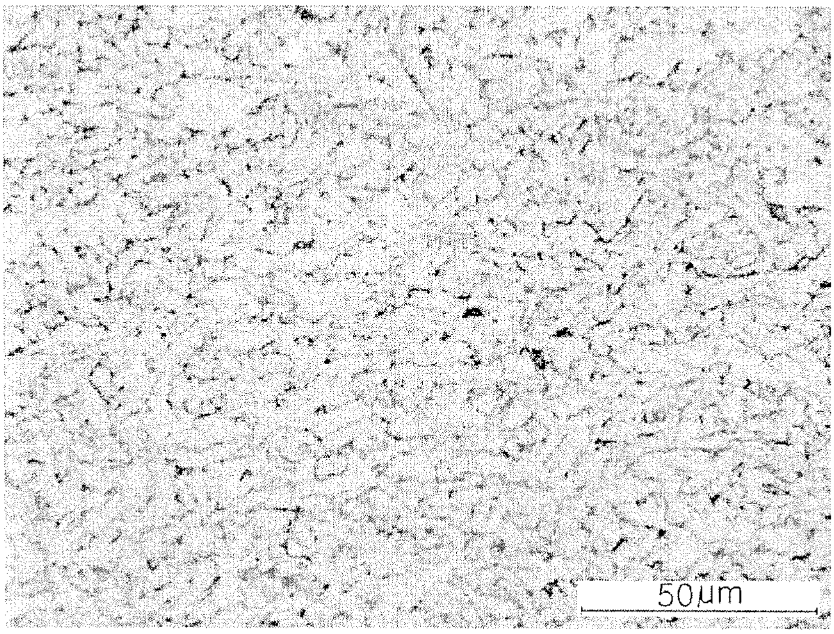
2. Procédé de production d'un acier de construction ultra-épais selon la revendication 1, présentant une excellente résistance à la propagation de fissures cassantes, le procédé comprenant :

le réchauffement d'une brame ou une barre constituée de 0,02 à 0,1 % en poids de C, 0,8 à 2,5 % en poids de Mn, 0,05 à 1,5 % en poids de Ni, 0,005 à 0,1 % en poids de Nb, 0,005 à 0,1 % en poids de Ti, et le reste du Fe et d'autres impuretés inévitables, jusqu'à 950-1, 100 °C, puis la procédure de laminage brut de la plaque ou de la brame réchauffée à 900-1, 100 °C ;
l'obtention d'une tôle d'acier en procédant au laminage de finition de la brame ou de la barre laminée de façon brute à un point de transformation supérieur ou égal à Ar3 ; et
le refroidissement de la tôle d'acier à une température égale ou inférieure à 700 °C, une différence de température entre une partie centrale de la brame ou de la barre dans le sens de l'épaisseur de celle-ci, et une surface externe de la brame ou de la barre avant le laminage au moment du laminage brut est comprise entre 100 et 300 °C, la différence de température entre la partie centrale de la brame ou de la barre dans le sens de l'épaisseur et la surface externe de la brame ou de la barre étant obtenue en refroidissant la brame ou la barre à l'aide d'un dispositif de refroidissement, un fluide de refroidissement du dispositif de refroidissement étant au moins l'eau, l'air, un liquide de refroidissement et une vapeur de refroidissement, un taux de réduction cumulatif total au moment du laminage brut étant supérieur ou égal à 40 %, le refroidissement de la tôle d'acier étant effectué à une vitesse de refroidissement moyenne de 3 à 300 °C/s dans la partie centrale.

3. Procédé selon la revendication 2, dans lequel la différence de température entre la partie centrale de la brame ou de la barre dans le sens de l'épaisseur et la surface externe de la brame ou de la barre est une différence entre une température de surface de la brame ou de la barre mesurée immédiatement avant le laminage brut et une température de la partie centrale calculée en tenant compte des conditions de refroidissement et de l'épaisseur de la brame ou de la barre immédiatement avant le laminage brut.

4. Procédé selon la revendication 2, dans lequel le laminage brut est effectué en au moins deux passes, et la différence de température entre la partie centrale de la brame ou de la barre dans le sens de l'épaisseur et la surface externe de la brame ou de la barre est une différence de température obtenue par la mesure des différences de température dans les passes respectives pendant le laminage brut et par le calcul d’une valeur moyenne totale.

【Figure 1】



REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 1999032671 A **[0011] [0013]**
- WO 2014132627 A **[0012] [0013]**
- KR 20090069818 **[0013]**
- KR 20020091844 **[0013]**