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(54) HIGH-STRENGTH STEEL HAVING SUPERIOR BRITTLE CRACK ARRESTABILITY, AND PRODUCTION METHOD THEREFOR

HOCHFESTER STAHL MIT HERVORRAGENDER SPRÖDBRUCHSTABLITÄT UND HERSTELLUNGSVERFAHREN DAFÜR

ACIER À HAUTE RÉSISTANCE AYANT UNE EXCELLENTE RÉSISTANCE À LA PROPAGATION DE FISSURES ET SON PROCÉDÉ DE PRODUCTION

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(73) Proprietor: **POSCO**
Gyeongsangbuk-do 37859 (KR)

(72) Inventors:
- **LEE, Hak-Cheol**
Pohang-si
Gyeongsangbuk-do 37877 (KR)
- **JANG, Sung-Ho**
Pohang-si
Gyeongsangbuk-do 37877 (KR)

(74) Representative: **Potter Clarkson**
The Belgrave Centre
Talbot Street
Nottingham NG1 5GG (GB)

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Description

[Technical Field]

[0001] The present disclosure relates to a high-strength steel having excellent brittle crack arrestability and a method of manufacturing the same.

[Background Art]

[0002] Recently, in designing structures used in domestic and international shipbuilding, marine engineering, architecture and civil engineering fields, the development of an extremely thick steel having high strength properties is required.

[0003] When high-strength steel is used in designing structures, since such structures may be lightened, an economical benefit may be obtained; and since a thickness of a steel sheet may be reduced, ease of machining and welding operations may be secured simultaneously.

[0004] In general, for a high-strength steel, when an extremely thick steel sheet is manufactured, due to a reduction in a total reduction ratio, sufficient deformation does not occur in a central portion, so a structure of a central portion may become coarse. Therefore, as hardenability is increased, a low temperature transformation phase such as bainite, or the like, is generated.

[0005] In addition, due to the structure having been coarsened, it may be difficult to secure impact toughness in a central portion.

[0006] In detail, in the case of brittle crack arrestability referring to stability of a structure, when a high-strength steel is applied to a major structure such as a ship, or the like, cases in which guaranteed levels of brittle crack arrestability are required have increased. However, when a low temperature transformation phase is generated in a central portion, a phenomenon in which brittle crack arrestability is significantly reduced occurs. Therefore, it may be difficult to improve brittle crack arrestability of an extremely thick high-strength steel.

[0007] Meanwhile, in the case of a high-strength steel having yield strength of 390 MPa or more, in order to improve brittle crack arrestability, various techniques have been introduced, such as the application of surface cooling during finish rolling for refinement of a grain size in a surface layer, grain size adjusting by applying bending stress during rolling, refinement of a surface layer by two phase region rolling, and the like.

[0008] However, various techniques are helpful in refining a structure in a surface layer, but do not solve the problem of impact toughness degradation due to coarsening of a structure in a central portion. Therefore, the various techniques are not fundamental measures for brittle crack arrestability.

[0009] In addition, because the techniques themselves are expected to significantly reduce productivity when applied to a general production system, such techniques are problematic in terms of commercial applications.EP 2 660 346 describes a high-strength steel sheet superior toughness at cryogenic temperatures, and a method for manufacturing the same. KR 100 723 201 B1 describes thick steel plates for ship building.

[Disclosure]

[Technical Problem]

[0010] An aspect of the present disclosure is to provide a high-strength steel having excellent brittle crack arrestability.

[0011] Another aspect of the present disclosure is to provide a method of manufacturing a high-strength steel having excellent brittle crack arrestability.

[Technical Solution]

[0012] According to an aspect of the present disclosure, a high-strength steel sheet having excellent brittle crack arrestability includes 0.05 wt% to 0.1 wt% of carbon (C), 0.9 wt% to 1.5 wt% of manganese (Mn), 0.8 wt% to 1.5 wt% of nickel (Ni), 0.005 wt% to 0.1 wt% of niobium (Nb), 0.005 wt% to 0.1 wt% of titanium (Ti), 0.1 wt% to 0.6 wt% of copper (Cu), 0.1 wt% to 0.4 wt% of silicon (Si), 100 ppm or less of phosphorous (P), 40 ppm or less of sulfur (S), and the remainder being iron (Fe) and other inevitably contained impurities, the high-strength steel having a microstructure being 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 having a thickness of 50 mm or more, wherein the contents of Cu and Ni are set such that a Cu/Ni weight ratio is 0.6 or less, wherein the ferrite is acicular ferrite or polygonal ferrite, and the bainite is granular bainite, wherein in the high-strength steel plate, a grain size having a high-angle boundary of 15 degrees or more measured, in an electron backscattered diffraction (EBSD) method, in a central portion of a steel thickness, is 21.2μm or less, and wherein an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel sheet in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 26% or less, and wherein the yield strength of the high-strength steel is 390 MPa or more.

[0013] When the microstructure of the steel is a complex-phase structure including pearlite, a fraction of pearlite may be 20% or less.

[0014] The steel thickness may be 80mm to 100mm.

[0015] According to another aspect of the present disclosure, a method of manufacturing a high-strength steel sheet having excellent brittle crack arrestability includes: reheating a slab at 950°C to 1100°C, the steel of the slab consisting of 0.05 wt% to 0.1 wt % of carbon (C), 0.9 wt% to 1.5 wt% of manganese (Mn), 0.8 wt% to 1.5 wt% of nickel (Ni), 0.005 wt% to 0.1 wt% of niobium (Nb), 0.005 wt% to 0.1 wt% of titanium (Ti), 0.1 wt% to 0.6 wt% of copper (Cu), 0.1 wt% to 0.4 wt% of silicon (Si), 100 ppm or less of phosphorous (P), 40 ppm or less of sulfur (S), and the remainder being iron (Fe) and other inevitably contained impurities, and then rough rolling the slab at a temperature of 1100°C to 900°C; obtaining a steel sheet having a thickness of 50 mm or more by finish rolling a rough-rolled bar at a temperature of 850°C to Ar_3; and cooling the steel sheet to a temperature of 700°C or less, wherein the contents of Cu and Ni are set such that a Cu/Ni weight ratio is 0.6 or less, wherein the rough rolling is performed in two or more passes, wherein an outer surface of the slab or bar maintains a temperature lower than that of a central portion in the thickness direction before each pass of the rough rolling, wherein an average value of the temperature differences between the central portion in a thickness direction of the slab or bar and an outer surface of the slab or bar immediately before each pass of the rough rolling is 100°C to 300°C, wherein the temperature differences are differences between a temperature of an outer surface of the slab or bar measured immediately before each pass of the rough rolling, and a temperature of a central portion calculated in consideration of a cooling condition and a thickness of the slab or bar immediately before each pass of the rough rolling, and wherein a crystal grain size of a central portion of the bar before the finish rolling after the rough rolling is 200 μm or less, and wherein the cooling of the steel sheet is performed at a cooling rate of a central portion of the steel sheet of 2°C/s or more.

[0016] During the rough rolling, a reduction ratio per pass with respect to three final passes may be 5% or more, and a total cumulative reduction ratio may be 40% or more.

[0017] A crystal grain size of a central portion of the bar in a thickness direction before the finish rolling after the rough rolling may preferably be 150 μm or less, and more preferably 100 μm or less.

[0018] A reduction ratio during the finish rolling may be set such that a ratio of a slab thickness (mm) / a steel sheet thickness (mm) after finish rolling may be 3.5 or above, preferably 3.8 or above.

[0019] The cooling of the steel sheet is performed at a cooling rate of a central portion of the steel sheet in a thickness direction of 2°C/s or more.

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

[0021] In addition, the solution of the problems described above does not list all the features of the present disclosure.

[0022] Various features, advantages, and effects of the present disclosure will be more fully understood by reference to the following specific embodiments.

[Advantageous Effects]

[0023] According to an embodiment in the present disclosure, a high-strength steel having high yield strength and excellent brittle crack arrestability is obtained.

[Description of Drawings]

[0024] FIG. 1 is an image of a central portion of Inventive steel 1 in a thickness direction, captured with an optical microscope.

[Best Mode for Invention]

[0025] The inventors conducted research and experiments into improving yield strength and brittle crack arrestability of a thick steel having a thickness of 50 mm or more, and the present disclosure has been proposed based on the results thereof.

[0026] According to the present disclosure, a steel composition, a structure, a texture, and manufacturing conditions of a steel are controlled, so yield strength and brittle crack arrestability of a steel having a thick thickness are further improved.

[0027] A main concept in the present disclosure is as follows.

1) To improve strength through solid solution strengthening, a steel composition is appropriately controlled. In detail, for solid solution strengthening, the content of each of Mn, Ni, Cu, and Si is optimized.

2) To improve strength through hardenability improvement, a steel composition is appropriately controlled. In detail, to improve hardenability, in addition to the content of carbon, the content of each of Mn, Ni, and Cu is optimized. As described above, by improving hardenability, a fine structure to a central portion of a thick steel having a thickness of 50 mm or more, even at a cooling rate which is slow, is secured.

3) To improve strength and brittle crack arrestability, a structure of a steel is refined. In detail, a structure of a central portion of a steel is refined.
As described above, the structure of a central portion of a steel is refined, so strength is improved due to strengthening by grain refinement, while brittle crack arrestability is improved by significantly reducing the generation and propagation of cracks.

4) To improve brittle crack arrestability, a texture of a steel is controlled.
Taking into consideration that a crack is propagated in a width direction of a steel, that is, in a direction perpendicular to a rolling direction, and a brittle fracture surface of a body-centered cubic (BCC) structure is a (100) plane, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction is significantly reduced.
A texture of an area of a central portion in which a microstructure is relatively coarse in comparison with a surface is controlled.
As described above, the texture of a steel, i.e. the texture of an area of a central portion of a steel, is controlled. Even when a crack is generated, propagation of the crack is significantly reduced, so brittle crack arrestability is improved.

5) To allow a structure of a steel to be further refined, rough rolling conditions are controlled.

[0028] During rough rolling, a pressing condition is controlled, and a sufficient temperature difference between a central portion and a surface is secured, so a fine structure is secured in a central portion of a steel.
[0029] Hereinafter, a high-strength steel having excellent brittle crack arrestability, one aspect of the present disclosure, will be described in detail.
[0030] According to an aspect of the present disclosure, a high-strength steel having excellent brittle crack arrestability includes the features as defined in claim 1.
[0031] Hereinafter, a steel component and a component range of the present disclosure will be described.

C (carbon): 0.05% to 0.10% (hereinafter, the contents of respective components refer to weight%)

[0032] C is the most important element in securing basic strength, so C needs to be contained in a steel in an appropriate range. In order to obtain such an additive effect, C is added in an amount of 0.05% or more.
[0033] However, when the content of C exceeds 0.10%, due to the generation of a large amount of martensite-austenite constituent (MA), high strength of ferrite itself, and generation of a large amount of a low temperature transformation phase, or the like, low temperature toughness may be reduced. Thus, the content of C is limited to 0.05% to 0.10%, preferably limited to 0.061% to 0.091%, and more preferably limited to 0.065% to 0.085%.

Mn (manganese): 0.9% to 1.5%

[0034] Mn is a useful element for improving strength due to solid solution strengthening and for improving hardenability to allow a low temperature transformation phase to be generated. In order to obtain an effect described above, Mn is added in an amount of 0.9% or more.
[0035] However, when the content of Mn exceeds 1.5%, due to an excessive increase in hardenability, the generation of upper bainite and martensite is promoted. In addition, segregation in a central portion is caused, so a coarse low temperature transformation phase is generated. Thus, impact toughness and brittle crack arrestability are reduced.
[0036] Thus, the content of Mn is limited to 0.9% to 1.5%, preferably limited to 0.97% to 1.39%, and more preferably limited to 1.15% to 1.30%.

Ni (nickel): 0.8% to 1.5%

[0037] Ni is an important element, allowing dislocation cross-slip to be easily performed at a low temperature to improve impact toughness, and improving hardenability to improve strength. In order to obtain an effect described above, Ni is added in an amount of 0.8% or more. However, when Ni is added in an amount of 1.5% or more, hardenability is excessively increased, so a low temperature transformation phase is generated. Thus, toughness may be reduced and manufacturing costs may be increased. In this case, an upper limit of the content of Ni is limited to 1.5%.

[0038] The content of Ni is preferably limited to 0.89% to 1.42% and more preferably limited to 1.01% to 1.35 %.

Nb (niobium): 0.005% to 0.1%

[0039] Nb is precipitated in the form of NbC or NbCN, thereby improving strength of a base material.

[0040] In addition, Nb, dissolved during reheating at a high temperature, is significantly finely precipitated in the form of NbC during rolling, so recrystallization of austenite is suppressed. Thus, a structure may be refined.

[0041] Thus, Nb is added in an amount of 0.005% or more. However, when Nb is added excessively, a brittle crack may be caused in an edge of a steel. In this case, an upper limit of the content of Nb is limited to 0.1%.

[0042] The content of Nb is preferably limited to 0.012% to 0.028% and more preferably limited to 0.018% to 0.024%.

Ti (titanium): 0.005% to 0.1%

[0043] Ti is precipitated as TiN during reheating, and thus inhibits growth of a crystal grain in a base material and in a weld heat affected zone, thereby significantly improving low temperature toughness. In order to obtain an additive effect described above, Ti is added in an amount of 0.005% or more.

[0044] However, when Ti is added in an amount exceeding 0.1%, a continuous casting nozzle may be clogged, or low temperature toughness may be reduced by crystallization of a central portion. In this case, the content of Ti is limited to 0.005% to 0.1%.

[0045] The content of Ti is preferably limited to 0.009% to 0.024% and more preferably limited to 0.011% to 0.018%.

P (phosphorous): 100 ppm or less, Sulfur (S): 40 ppm or less

[0046] P and S are elements causing brittleness in a grain boundary or causing brittleness by forming a coarse inclusion. In order to improve brittle crack arrestability, P is limited to 100 ppm or less and S is limited to 40 ppm or less.

Si (silicon): 0.1% to 0.4%

[0047] Si improves strength of a steel and has a strong deoxidizing effect, and thus is an essential element in producing clean steel. In order to obtain an effect described above, Si is added in an amount of 0.1% or more. However, when a large amount of Si is added, a coarse MA phase is generated, so brittle crack arrestability may be reduced. In this case, an upper limit of the content of Si is limited to 0.4%.

[0048] The content of Si is preferably limited to 0.22% to 0.32% and more preferably limited to 0.25% to 0.3 %.

Cu (copper): 0.1% to 0.6%

[0049] Cu is a main element in improving strength of a steel by improving hardenability and causing solid solution strengthening, and is a main element in increasing a yield strength due to generation of ε (epsilon) Cu precipitate when tempering is applied. Thus, Cu is added in an amount of 0.1% or more. However, when a large amount of Cu is added, in a steelmaking process, due to hot shortness, a crack in a slab may be generated. In this case, an upper limit of the content of Cu is limited to 0.6%.

[0050] The content of Cu is preferably limited to 0.21% to 0.51% and more preferably is limited to 0.18% to 0.3%.

[0051] The contents of Cu and Ni are set such that a Cu/Ni weight ratio is 0.6 or less and preferably 0.5 or less.

[0052] When the Cu/Ni weight ratio is set as described above, a surface quality may be further improved.

[0053] According to an exemplary embodiment, iron (Fe) is provided as a remainder thereof.

[0054] On the other hand, in an ordinary manufacturing process, non-intended impurities are inevitably present, from a raw material or a surrounding environment, which may not be excluded.

[0055] The impurities may be known to those skilled in the art, and thus, may not be particularly described in this specification.

[0056] The steel according to an exemplary embodiment has a microstructure including a single 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.

[0057] The ferrite is polygonal ferrite or acicular ferrite, and the bainite is preferably granular bainite.

[0058] For example, as the contents of Mn and Ni increase, fraction of acicular ferrite and granular bainite increases, so strength also increases.

[0059] When a microstructure of the steel is a complex-phase structure containing pearlite, fraction of pearlite is preferably limited to 20% or less.

[0060] In the steel, a grain size having a high-angle boundary of 15 degrees or more, measured in an EBSD method, in a central portion is 30 μm or less.

[0061] As described above, the grain size of a structure of a central portion of the steel is refined to be 30 μm or less, so strength is improved due to strengthening by grain refinement, while brittle crack arrestability is improved by significantly reducing the generation and propagation of cracks.

[0062] An area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 40% or less.

[0063] Main reasons for controlling a texture as described above are as follows.

[0064] A crack is propagated in a width direction of a steel, that is, in a direction perpendicular to a rolling direction, and a brittle fracture surface of a body-centered cubic structure (BCC) is a (100) plane.

[0065] In this case, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction is significantly reduced.

[0066] A texture of an area of a central portion in which a microstructure is relatively coarse in comparison with a surface is controlled.

[0067] As described above, a texture of a steel and, particularly, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is controlled to be 40% or less. Even when a crack is generated, propagation of the crack is significantly reduced, so brittle crack arrestability is improved.

[0068] The steel has a yield strength of 390 MPa or more.

[0069] The steel has a thickness of 50 mm or more, preferably has a thickness of 50 mm to 100 mm, and more preferably has a thickness of 80 mm to 100 mm.

[0070] Hereinafter, a method of manufacturing a high-strength steel having excellent brittle crack arrestability, another aspect of the present disclosure, will be described in detail.

[0071] According to another aspect of the present disclosure, a method of manufacturing a high-strength steel is defined in claim 4.

Reheating of Slab

[0072] A slab is reheated before rough rolling.

[0073] A reheating temperature of a slab is set to be 950 °C or more, to dissolve carbonitride of Ti and/or Nb formed during casting. In addition, in order to sufficiently dissolve carbonitride of Ti and/or Nb, it is preferably to heat at 1000°C or more. However, when the slab is reheated to an excessively high temperature, austenite may be coarsened. Thus, an upper limit of the reheating temperature is limited to 1100°C.

Rough Rolling

[0074] The slab, having been reheated, is rough rolled.

[0075] A rough rolling temperature is a temperature (Tnr) at which recrystallization of austenite is stopped or more. Due to rolling, effects in which a casting structure such as a dendrite formed during casting or the like is destroyed and a size of austenite is reduced may be obtained. To obtain the effects described above, the rough rolling temperature is limited to 1100°C to 900°C.

[0076] In an exemplary embodiment, during rough rolling, a temperature difference between a central portion and a surface of the slab or bar immediately before the rough rolling should be 100°C to 300°C.

[0077] As described above, as the temperature difference between a central portion and a surface is given during rough rolling, a surface of the slab or bar maintains a temperature lower than that of a central portion. While the temperature difference exists, when rough rolling is performed, more deformation occurs in a central portion in which a temperature is relatively high than in the surface in which a temperature is relatively low. Thus, a crystal grain size of a central portion is more refined. In this case, an average grain size of a central portion is maintained to be 30 μm or less.

[0078] In this technique, a phenomenon, in which the surface in which a temperature is relatively low has strength higher than that of a central portion in which a temperature is relatively high, so more deformation occurs in a central portion having relatively low strength, is used. To effectively give more deformation in a central portion, a temperature difference between a central portion and a surface is 100°C to 300°C.

[0079] Here, the temperature difference between a central portion and a surface of the slab or bar indicates a difference between a temperature of a surface of the slab or bar measured immediately before rough rolling, and a temperature of a central portion, calculated in consideration of a cooling condition and a thickness of the slab or bar immediately before rough rolling.
[0080] Measuring of a temperature of a surface and a thickness of the slab is performed before first rough rolling, and measuring of a temperature of a surface and a thickness of the bar is performed before rough rolling, starting from a second process of rough rolling.
[0081] In addition, when rough rolling is performed in two or more passes, a temperature difference between a central portion and a surface of the slab or bar indicates that a temperature difference, in which a temperature difference for each pass of rough rolling is measured and a total average value is calculated, is 100°C to 300°C.
[0082] In an exemplary embodiment, in order to refine a structure of a central portion during rough rolling, with respect to three final passes during rough rolling, a reduction ratio per pass is 5% or more, and a total cumulative reduction ratio is preferably 40% or more.
[0083] When rough rolling is performed, in a structure re-crystallized due to initial rolling, growth of a crystal grain occurs due to a high temperature. However, when three final passes are performed, while waiting for rolling, a bar is air-cooled, so a growth rate of the crystal grain slows down. Thus, during rough rolling, reduction ratios of three final passes are significant for a grain size of a final microstructure.
[0084] In addition, when a reduction ratio per a pass of rough rolling is lowered, sufficient deformation is not transferred to a central portion, so toughness degradation caused by coarsening of a central portion may occur. Thus, a reduction ratio per pass of three final passes is preferably limited to 5% or more.
[0085] On the other hand, for refinement of a structure of a central portion, a total cumulative reduction ratio during rough rolling is preferably set to be 40% or more.

Finish Rolling

[0086] The bar having been rough rolled is finish rolled at 850°C to Ar_3 (a ferrite transformation start temperature), so a steel sheet is obtained.
[0087] In order to obtain a further refined microstructure, a finish rolling temperature of finish rolling is 850°C or less.
[0088] When finish rolling is performed, an austenite structure becomes a deformed austenite structure.
[0089] A crystal grain size of a central portion of a bar before finish rolling after the rough rolling is 200 μm or less, preferably 150 μm or less, and more preferably 100 μm or less.
[0090] The crystal grain size of a central portion of a bar before finish rolling after the rough rolling may be controlled according to a rough rolling condition, or the like.
[0091] As described above, when a crystal grain size of a central portion of a bar before finish rolling after the rough rolling is controlled, due to refinement of an austenite crystal grain, a final microstructure is refined, so yield/tensile strength are increased and low temperature toughness is improved.
[0092] A reduction ratio during the finish rolling may be set such that a ratio of a slab thickness (mm)/a steel sheet thickness (mm) after finish rolling is 3.5 or above, preferably 3.8 or more.
[0093] As described above, when a reduction ratio during finish rolling is controlled, as a reduction amount increases during rough rolling and finish rolling, due to refinement of a final microstructure, yield/tensile strength may be increased and low temperature toughness may be improved. Moreover, due to a reduction in a grain size of a central portion in a thickness direction, toughness of a central portion may be improved.
[0094] After finish rolling, a steel sheet has a thickness of 50 mm or more, preferably has a thickness of 50 mm to 100 mm, and more preferably has a thickness 80 mm to 100 mm.

Cooling

[0095] After finish rolling, a steel sheet is cooled to 700°C or less
When a cooling end temperature exceeds 700°C, a microstructure is not properly formed, so yield strength may be 390 Mpa or less.
[0096] Cooling of the steel sheet is performed at a cooling rate of a central portion of the steel sheet in a thickness direction of 2°C/s or more. When a cooling rate of a central portion of the steel sheet in a thickness direction is less than 2°C/s, a microstructure is not properly formed, so yield strength may be 390 Mpa or less.
[0097] In addition, cooling of the steel sheet may be performed at an average cooling rate from 3°C/s to 300°C/s.

[Mode for Invention]

[0098] Hereinafter, an embodiment in the present disclosure will be described in further detail with reference to Embodiments.

[0099] It should be noted, however, that the following embodiments are intended to illustrate the present disclosure in more detail and not to limit the scope of the invention.

[0100] In other words, the scope of the invention is determined by the matters described in the claims and matters able to be reasonably deduced therefrom.

Embodiment 1

[0101] After a steel slab with a thickness of 400 mm having a composition of Table 1 was reheated at a temperature of 1050°C, rough rolling was performed at a temperature of 1020°C, so a bar was manufactured. When a slab was rough rolled, an average temperature difference between a central portion and a surface is illustrated in Table 2, a cumulative reduction ratio of 50% is equally applied.

[0102] The average temperature difference between a central portion and a surface during rough rolling of Table 2 refers to a difference between a temperature of a surface of a slab or bar measured immediately before rough rolling, and a temperature of a central portion calculated in consideration of an amount of water sprayed to a bar and a slab thickness immediately before rough rolling, and is a result in which a temperature difference for each pass of rough rolling is measured and a total average value is calculated.

[0103] A thickness of the bar having been rough rolled was 180 mm, and a crystal grain size before finish rolling after rough rolling was 80 μm.

[0104] After the rough rolling, finish rolling was performed at a finish rolling temperature of 770°C, so a steel sheet having a thickness of Table 2 was obtained, and cooling was performed to a temperature of 700°C or less at a cooling rate of 5°C/sec thereafter.

[0105] With respect to the steel sheet manufactured as described above, a microstructure, yield strength, an average grain size of a central portion measured in EBSD, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness, a Kca value (a brittle crack arrestability coefficient) were investigated, and a result thereof is illustrated in Table 2.

[0106] A Kca value of Table 2 is a value evaluated by performing an ESSO test with respect to a steel sheet.

[Table 1]

Steel Grade	Steel Composition (Weight%)									
	C	Si	Mn	Ni	Cu	Ti	Nb	P (ppm)	S (ppm)	Cu/Ni weight ratio
Inventive steel 1	0.061	0.23	1.25	0.89	0.35	0.015	0.019	75	16	0.39
Inventive steel 2	0.082	0.31	1.36	0.95	0.44	0.016	0.017	77	25	0.46
Inventive steel 3	0.054	0.32	1.09	1.26	0.36	0.009	0.023	82	34	0.29
Inventive steel 4	0.072	0.22	1.39	1.13	0.21	0.024	0.012	65	19	0.19
Inventive steel 5	0.069	0.29	1.17	1.21	0.45	0.02	0.019	68	22	0.36
Inventive steel 6	0.091	0.31	0.97	1.42	0.51	0.019	0.028	71	31	0.36
Comparative steel 1	0.072	0.25	1.21	0.97	0.36	0.017	0.026	69	16	0.37
Comparative steel 2	0.12	0.29	1.32	1.12	0.39	0.017	0.023	59	13	0.35
Comparative steel 3	0.068	0.61	1.39	1.08	0.45	0.019	0.027	55	25	0.42
Comparative steel 4	0.077	0.32	1.95	1.32	0.21	0.026	0.019	67	26	0.16
Comparative steel 5	0.062	0.19	1.21	2.2	0.35	0.021	0.031	49	30	0.16
Comparative steel 6	0.072	0.22	1.06	1.11	0.48	0.016	0.022	130	65	0.43

[Table 2]

Steel Grade	Temperature difference between central portion and surface during rough rolling (°C)	Product thickness (mm)	*Microstructure, phase fraction (%)	(100) texture	Yield strength (Mpa)	Average grain size (μm) of central portion	Kca ($N/mm^{1.5}$, @-10°C)
Inventive steel 1	165	85	PF+P(16%)	23	396	21.2	9012
Inventive steel 2	203	90	AF	18	442	12.7	8554
Inventive steel 3	112	85	AF+GB (24%)	26	509	15.6	7356
Inventi ve steel 4	215	85	AF+GB(20%)	19	492	13.9	7855
Inventive steel 5	188	90	AF+GB(38%)	21	521	17.7	6918
Inventive steel 6	196	100	PF+P(17%)	16	401	20.9	6522
Comparative steel 1	21	85	PF+P(18%)	43	398	35.4	4564
Comparative steel 2	116	90	UB	42	579	38.3	3866
Comparative steel 3	154	85	AF+UB(21%)	32	534	25.6	4211
Comparative steel 4	201	90	UB	42	607	34.2	3901
Comparative steel 5	165	90	GB,UB(22%)	31	551	31.2	3244
Comparative steel 6	123	95	AF+GB(17%)	29	498	23.1	4855
* PF: Polygonal Ferrite, P: Pearlite, AF: Acicular Ferrite, GB: Granular Bainite, UB: Upper Bainite, Phase fraction (%): Volume %							

[0107] As illustrated in Table 2, in the case of Comparative steel 1, an average temperature difference between a central portion and a surface during rough rolling presented in the present disclosure is controlled to be less than 70°C. When rough rolling is performed, as sufficient deformation is not given to a central portion, a grain size of a central portion is 35.4 pm, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 40% or more, and a Kca value measured at -10°C does not exceed 6000, required for steel for shipbuilding according to the related art.

[0108] In the case of Comparative steel 2, the content of C has a value higher than an upper limit of the content of C according to the present disclosure. When rough rolling is performed, through cooling, a grain size of austenite of a central portion is refined, but upper bainite is generated. Thus, a grain size of a final microstructure is 38.3 pm, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 40% or more. Moreover, upper bainite in which brittleness may easily occur is included as a base structure, so a Kca value is a value of 6000 or less at -10°C.

[0109] In the case of Comparative steel 3, the content of Si has a value higher than an upper limit of the content of Si according to the present disclosure. When rough rolling is performed, through cooling, a grain size of austenite of a central portion is refined, but upper bainite is partially generated in a central portion. Moreover, as a large amount of Si is added, a large amount of a MA structure is coarsely generated, so a Kca value is a value of 6000 or less at -10°C.

[0110] In the case of Comparative steel 4, the content of Mn has a value higher than an upper limit of the content of Mn according to the present disclosure. Due to high hardenability, a microstructure of a base material is upper bainite. When rough rolling is performed, through cooling, a grain size of austenite of a central portion is refined, but a grain size of a final microstructure is 34.2 μm, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 40% or more, and a Kca value is a value of 6000 or less at -10°C.

[0111] In the case of Comparative steel 5, the content of Ni has a value higher than an upper limit of the content of Ni according to the present disclosure. Due to high hardenability, a microstructure of a base material is granular bainite and upper bainite. When rough rolling is performed, through cooling, a grain size of austenite of a central portion is refined, but a grain size of a final microstructure is 31.2 μm, and a Kca value is a value of 6000 or less at -10°C.

[0112] In the case of Comparative steel 6, the content of each of P and S has a value higher than an upper limit of the content of each of P and S according to the present disclosure. Even when other conditions are satisfied with conditions presented in the present disclosure, due to high P and S, brittleness may occur. Thus, a Kca value is a value of 6000 or less at -10°C.

[0113] On the contrary, in the cases of Inventive steel 1 through 6, satisfying a composition range according to the present disclosure and in which a grain size of austenite of a central portion is refined through cooling during rough rolling, yield strength satisfies 390 MPa or more, and a grain size of a central portion satisfies 30 μm or less. Moreover, a complex-phase structure of ferrite and pearlite, a single-phase structure of acicular ferrite, or a complex-phase structure of acicular ferrite and granular bainite is included as a microstructure.

[0114] Moreover, an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 40% or less, and a Kca value satisfies a value of 6000 or more at -10°C.

[0115] FIG. 1 is an image of a central portion of Inventive steel 1 in a thickness direction captured with an optical microscope. As illustrated in FIG. 1, it is confirmed that a structure of a central portion in a thickness direction is refined.

Embodiment 2

[0116] Except for a change in a Cu/Ni weight ratio of a steel slab as illustrated in Table 3, a steel sheet was manufactured with the same composition and manufacturing conditions as Inventive steel 2 of Embodiment 1, surface properties of the steel sheet having been manufactured were investigated, and a result thereof is illustrated in Table 3.

[0117] In Table 3, surface properties of the steel sheet refer to a measure of whether a star crack in a surface occurred due to hot shortness.

[Table 3]

Steel Grade	Steel Composition (wt%)										Surface Properties
	C	Si	Mn	Ni	Cu	Ti	Nb	P (ppm)	S (ppm)	Cu/Ni weight ratio	
Inventive steel 7	0.082	0.31	1.36	0.84	0.41	0.016	0.017	77	25	0.48	Non-occurrence
Inventive steel 2				0.95	0.44					0.46	Non-occurrence
Inventive steel 8				0.37	0.12					0.32	Non-occurrence
inventive steel 9				0.28	0.10					0.35	Non-occurrence
Comparative steel 7				0.23	0.18					0.78	Occurrence
Comparative steel 8				0.48	0.33					0.71	Occurrence

[0118] As illustrated in Table 3, when a Cu/Ni weight ratio is properly controlled, it is confirmed that surface properties of a steel sheet are improved.

Embodiment 3

[0119] Except for a change in a crystal grain size (μm) before finish rolling after rough rolling as illustrated in Table 4, a steel sheet was manufactured in the same composition and manufacturing condition as Inventive steel 1 of Embodiment 1. Properties of an average grain size of a central portion of a steel sheet having been manufactured were investigated, and a result thereof is illustrated in Table 4.

[Table 4]

Steel Grade	Crystal grain size (μm) before finish rolling after rough rolling	Average grain size (μm) of central portion
Inventive steel 1	80	21.2
Inventive steel 8	125	29.7
Inventive steel 9	107	25.6
Inventive steel 10	75	19.8
Inventive steel 11	155	21.5
Inventive steel 12	110	24.5

[0120] As illustrated in Table 4, as a crystal grain size of a central portion of a bar after rough rolling decreases, it is confirmed that an average grain size of a central portion is refined. Thus, it is expected that brittle crack propagation resistance is to be improved.

[0121] While exemplary embodiments with respect to a high-strength steel and a related manufacturing method have been shown and described above, the scope of the present invention is defined by the appended claims.

Claims

1. A high-strength steel sheet having excellent brittle crack arrestability, the high-strength steel of the sheet consisting of:

   0.05 wt% to 0.1 wt% of carbon (C), 0.9 wt% to 1.5 wt% of manganese (Mn), 0.8 wt% to 1.5 wt% of nickel (Ni), 0.005 wt% to 0.1 wt% of niobium (Nb), 0.005 wt% to 0.1 wt% of titanium (Ti), 0.1 wt% to 0.6 wt% of copper (Cu), 0.1 wt% to 0.4 wt% of silicon (Si), 100 ppm or less of phosphorous (P), 40 ppm or less of sulfur (S), and the remainder being iron (Fe) and other inevitably contained impurities, the high-strength steel having a microstructure being 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 having a thickness of 50 mm or more,
   wherein the contents of Cu and Ni are set such that a Cu/Ni weight ratio is 0.6 or less,
   wherein the ferrite is acicular ferrite or polygonal ferrite, and the bainite is granular bainite,
   wherein in the high-strength steel sheet, a grain size having a high-angle boundary of 15 degrees or more measured, in an electron backscattered diffraction (EBSD) method, in a central portion of a steel thickness, is 30μm or less,
   wherein an area ratio of a (100) plane forming an angle within 15 degrees with respect to a plane perpendicular to a rolling direction in a region of the high-strength steel sheet in a range of 20% of an overall steel thickness based on a position equal to 1/2 of the steel thickness is 40% or less, and
   wherein the yield strength of the high-strength steel is 390 MPa or more.

2. The high-strength steel sheet having excellent brittle crack arrestability of claim 1, wherein when the microstructure of the steel is a complex-phase structure including pearlite, a fraction of pearlite is 20% or less.

3. The high-strength steel sheet having excellent brittle crack arrestability of claim 1, wherein a steel thickness is 80 mm to 100 mm.

4. A method of manufacturing a high-strength steel sheet having excellent brittle crack arrestability according to claim 1, the method comprising:

reheating a slab to a temperature of 950°C to 1100°C, the steel of the slab consisting of 0.05 wt% to 0.1 wt% of carbon (C), 0.9 wt% to 1.5 wt% of manganese (Mn), 0.8 wt% to 1.5 wt% of nickel (Ni), 0.005 wt% to 0.1 wt% of niobium (Nb), 0.005 wt% to 0.1 wt% of titanium (Ti), 0.1 wt% to 0.6 wt% of copper (Cu), 0.1 wt% to 0.4 wt% of silicon (Si), 100 ppm or less of phosphorous (P), 40 ppm or less of sulfur (S), and the remainder being iron (Fe) and other inevitably contained impurities, and then rough rolling the slab at a temperature of 1100°C to 900°C;
obtaining a steel sheet having a thickness of 50 mm or more by finish rolling a rough-rolled bar at a temperature of 850°C to Ar_3; and
cooling the steel sheet to a temperature of 700°C or less,
wherein the contents of Cu and Ni are set such that a Cu/Ni weight ratio is 0.6 or less,
wherein the rough rolling is performed in two or more passes,
wherein an outer surface of the slab or bar maintains a temperature lower than that of a central portion in the thickness direction before each pass of the rough rolling,
wherein an average value of the temperature differences between the central portion in a thickness direction of the slab or bar and an outer surface of the slab or bar immediately before each pass of the rough rolling is 100°C to 300°C,
wherein the temperature differences are differences between a temperature of an outer surface of the slab or bar measured immediately before each pass of the rough rolling, and a temperature of a central portion calculated in consideration of a cooling condition and a thickness of the slab or bar immediately before each pass of the rough rolling, and
wherein a crystal grain size of a central portion of the bar before the finish rolling after the rough rolling is 200 μm or less, and
wherein the cooling of the sheet is performed at a cooling rate of a central portion of the steel sheet of 2°C/s or more.

5. The method of manufacturing a high-strength steel sheet having excellent brittle crack arrestability of claim 4, wherein a reduction ratio per pass, with respect to three final passes when the rough rolling is performed, is 5% or more, and a total cumulative reduction ratio is 40% or more.

6. The method of manufacturing a high-strength steel sheet having excellent brittle crack arrestability of claim 4, wherein a reduction ratio during the finish rolling is set such that a ratio of a slab thickness in mm / a steel sheet thickness in mm after the finish rolling is 3.5 or above.

7. The method of manufacturing a high-strength steel sheet having excellent brittle crack arrestability of claim 4, wherein the cooling of the steel sheet is performed at an average cooling rate from 3°C/s to 300°C/s.

Patentansprüche

1. Hochfestes Stahlblech, das eine ausgezeichnete Sprödrisshemmfähigkeit aufweist, wobei das hochfeste Stahl des Blechs aus Folgendem besteht:
0,05 Gew.-% bis 0,1 Gew.-% Kohlenstoff (C), 0,9 Gew.-% bis 1,5 Gew.-% Mangan (Mn), 0,8 Gew.-% bis 1,5 Gew.-% Nickel (Ni), 0,005 Gew.-% bis 0,1 Gew.-% Niob (Nb), 0,005 Gew.-% bis 0,1 Gew.-% Titan (Ti), 0,1 Gew.-% bis 0,6 Gew.-% Kupfer (Cu), 0,1 Gew.-% bis 0,4 Gew.-% Silicium (Si), 100 ppm oder weniger Phosphor (P), 40 ppm oder weniger Schwefel (S), und wobei der Rest aus Eisen (Fe) und anderen unvermeidlich enthaltenen Verunreinigungen besteht, wobei der hochfeste Stahl mit einer Mikrostruktur eine Struktur hat, die aus der Gruppe ausgewählt ist, die aus einer Einphasenstruktur von Ferrit; einer Einphasenstruktur aus Bainit; einer Komplexphasenstruktur aus Ferrit und Bainit; einer Komplexphasenstruktur aus Ferrit und Perlit und einer Komplexphasenstruktur aus Ferrit, Bainit und Perlit mit einer Dicke von 50 mm oder mehr besteht, wobei die Gehalte an Cu und Ni so eingestellt sind, dass ein Cu/Ni-Gewichtsverhältnis 0,6 oder weniger beträgt, wobei der Ferrit nadelförmiger Ferrit oder polygonaler Ferrit ist und der Bainit körniger Bainit ist, wobei in dem hochfesten Stahlblech eine Korngröße mit einer Hochwinkelgrenze von 15 Grad oder mehr, gemessen in einem Elektronenrückstreuungsbeugungsverfahren *(electron backscattered diffraction,* EBSD), in einem zentralen Abschnitt einer Stahldicke 30 μm oder weniger beträgt, wobei ein Flächenverhältnis von einer (100) Ebene, die einen Winkel innerhalb von 15 Grad in Bezug auf eine Ebene senkrecht zu einer Walzrichtung in einem Bereich des hochfesten Stahlblechs in einem Bereich von 20 % einer Gesamtstahl-

dicke bildet, basierend auf einer Position gleich 1/2 der Stahldicke 40 % oder weniger beträgt, und wobei die Streckgrenze des hochfesten Stahls 390 MPa oder mehr beträgt.

2. Hochfestes Stahlblech mit ausgezeichneter Sprödrisshemmfähigkeit nach Anspruch 1, wobei, wenn die Mikrostruktur des Stahls eine Komplexphasenstruktur einschließlich Perlit ist, ein Anteil an Perlit 20 % oder weniger beträgt.

3. Hochfestes Stahlblech mit ausgezeichneter Sprödrisshemmfähigkeit nach Anspruch 1, wobei eine Stahldicke 80 mm bis 100 mm beträgt.

4. Verfahren zum Herstellen eines hochfesten Stahlblechs, das die ausgezeichnete Sprödrisshemmfähigkeit gemäß Anspruch 1 aufweist, wobei das Verfahren umfasst:

Wiedererhitzen einer Bramme auf eine Temperatur zwischen 950 °C und 1.100 °C und anschließendes Grobwalzen der Bramme bei einer Temperatur zwischen 1.100 °C und 900 °C, wobei die Bramme aus 0,05 Gew.-% bis 0,1 Gew.-% Kohlenstoff (C), 0,9 Gew.-% bis 1,5 Gew.-% Mangan (Mn), 0,8 Gew.-% bis 1,5 Gew.-% Nickel (Ni), 0,005 Gew.-% bis 0,1 Gew.-% Niob (Nb), 0,005 Gew.-% bis 0,1 Gew.-% Titan (Ti), 0,1 Gew.-% bis 0,6 Gew.-% Kupfer (Cu), 0,1 Gew.-% bis 0,4 Gew.-% Silicium (Si), höchstens 100 ppm Phosphor (P) und höchstens 40 ppm Schwefel (S) besteht, und wobei der Rest aus Eisen (Fe) und anderen unvermeidlich enthaltenen Verunreinigungen besteht;
Erhalten eines Stahlblechs mit einer Dicke von 50 mm oder mehr durch Fertigwalzen eines grobgewalzten Stabes bei einer Temperatur von 850 °C auf Ar_3; und
Abkühlen des Stahlblechs auf eine Temperatur von 700 °C oder weniger, wobei die Gehalte an Cu und Ni so eingestellt sind, dass ein Cu/Ni-Gewichtsverhältnis 0,6 oder weniger beträgt, wobei das Grobwalzen in zwei oder mehr Durchgängen durchgeführt wird, wobei eine Außenfläche der Bramme oder Stange vor jedem Durchgang des Grobwalzens eine Temperatur aufrechthält, die niedriger als die eines Mittelabschnitts in Dickenrichtung ist, wobei ein Durchschnittswert der Temperaturunterschiede zwischen dem Mittelabschnitt in einer Dickenrichtung der Bramme oder des Stabes und einer Außenfläche der Bramme oder des Stabes unmittelbar vor jedem Durchgang des Rohwalzens 100 °C bis 300 °C beträgt, wobei die Temperaturunterschiede Unterschiede zwischen einer Temperatur einer Außenfläche der Bramme oder des Stabes sind, die unmittelbar vor jedem Durchgang des Grobwalzens gemessen wird, und einer Temperatur eines zentralen Abschnitts, unter Berücksichtigung eines Abkühlungszustands und einer Dicke der Bramme oder des Stabes, die unmittelbar vor jedem Durchgang des groben Walzens berechnet wird, wobei eine Kristallkorngröße eines zentralen Abschnitts des Stabes vor dem Fertigwalzen nach dem Grobwalzen 200 μm oder weniger beträgt, und wobei das Abkühlen des Blechs mit einer Abkühlgeschwindigkeit eines zentralen Abschnitts des Stahlblechs von 2 °C/s oder mehr durchgeführt wird.

5. Verfahren zur Herstellung eines hochfesten Stahlblechs mit ausgezeichneter Sprödrisshemmfähigkeit nach Anspruch 4, wobei ein Reduktionsverhältnis pro Durchgang in Bezug auf drei Enddurchgänge, wenn das Grobwalzen durchgeführt wird, 5 % oder mehr beträgt und ein kumulatives Gesamtreduktionsverhältnis 40 % oder mehr beträgt.

6. Verfahren zur Herstellung eines hochfesten Stahlblechs mit ausgezeichneter Sprödrisshemmfähigkeit nach Anspruch 4, wobei ein Reduktionsverhältnis während des Fertigwalzens so eingestellt wird, dass ein Verhältnis einer Plattendicke in mm zu einer Stahlblechdicke in mm nach dem Fertigwalzen 3,5 oder mehr beträgt.

7. Verfahren zur Herstellung eines hochfesten Stahlblechs mit ausgezeichneter Sprödrisshemmfähigkeit nach Anspruch 4, wobei das Abkühlen des Stahlblechs mit einer durchschnittlichen Abkühlgeschwindigkeit von 3 °C/s bis 300 °C/s durchgeführt wird.

Revendications

1. Tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes, constituée par :

0,05 % en poids à 0,1 % en poids de carbone (C), 0,9 % en poids à 1,5 % en poids de manganèse (Mn), 0,8 % en poids à 1,5 % en poids de nickel (Ni), 0,005 % en poids à 0,1 % en poids de niobium (Nb), 0,005 % en poids à 0,1 % en poids de titane (Ti), 0,1 % en poids à 0,6 % en poids de cuivre (Cu), 0,1 % en poids à 0,4 % en poids de silicium (Si), 100 ppm ou moins de phosphore (P), 40 ppm ou moins de soufre (S), et le reste étant du fer (Fe) et d'autres impuretés inévitablement présentes, l'acier à haute résistance présentant une micros-

tructure étant une structure choisie dans le groupe constitué par une structure monophasée de ferrite, une structure monophasée de bainite, une structure à phase complexe de ferrite et de bainite, une structure à phase complexe de ferrite et de perlite et une structure à phase complexe de ferrite, de bainite et de perlite, et présentant une épaisseur de 50 mm ou plus,
les teneurs en Cu et Ni étant fixées de sorte qu'un rapport pondéral de Cu/Ni est de 0,6 ou moins,
la ferrite étant de la ferrite aciculaire ou de la ferrite polygonale et la bainite étant une bainite granulaire,
dans la tôle d'acier à haute résistance, une granulométrie ayant une limite d'angle élevé de 15 degrés ou plus, mesurée selon une méthode de diffraction d'électrons rétrodiffusés (EBSD), sur une partie centrale d'une épaisseur d'acier, étant de 30 μm ou moins,
un rapport de surface (100) d'un plan formant un angle à moins de 15 degrés par rapport à un plan perpendiculaire à une direction de laminage dans une région de la tôle d'acier à haute résistance dans une plage de 20 % d'une épaisseur totale sur la base d'une position égale à 1/2 de l'épaisseur d'acier étant de 40 % ou moins, et
la limite d'élasticité de l'acier à haut résistance étant de 390 MPa ou plus.

2. Tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes selon la revendication 1, dans laquelle lorsque la microstructure de l'acier est une structure à phase complexe comportant de la perlite, une fraction de la perlite est de 20 % ou moins.

3. Tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes selon la revendication 1, dans laquelle une épaisseur d'acier est de 80 mm à 100 mm.

4. Procédé de fabrication d'une tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes selon la revendication 1, le procédé comprenant :

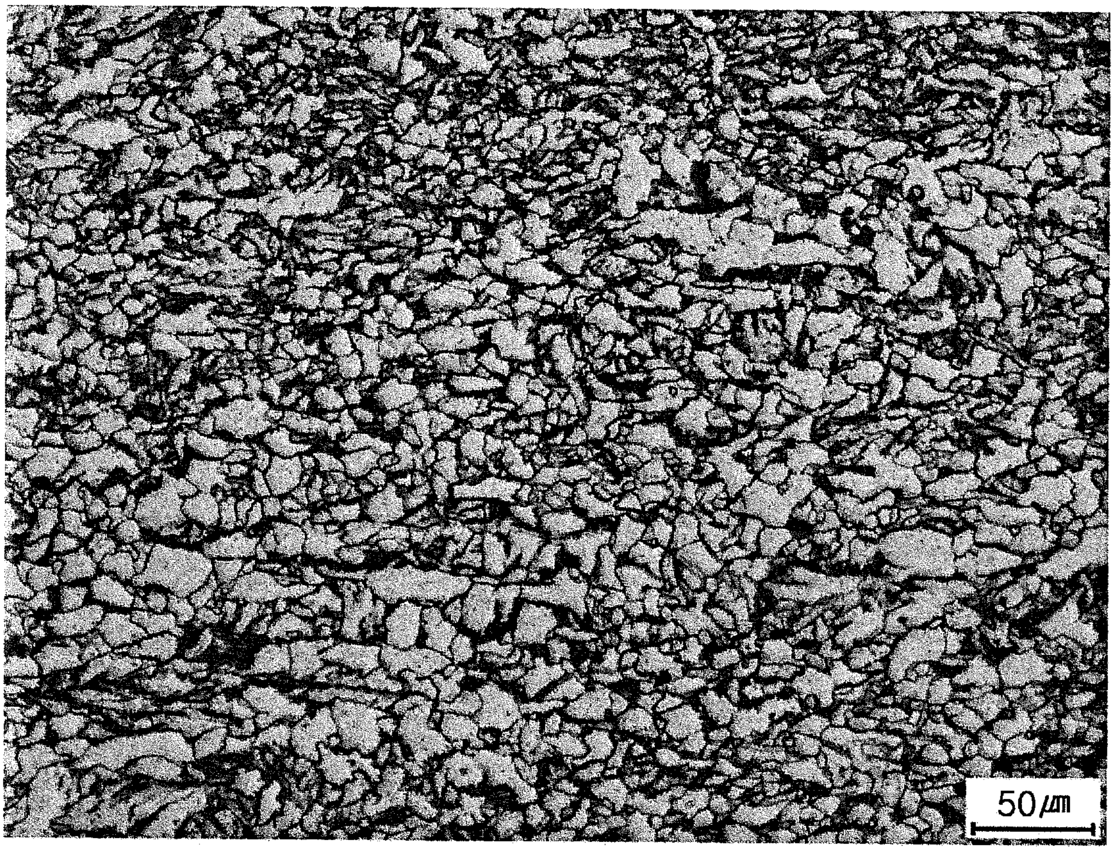
le réchauffage d'une brame à une température comprise entre 950 °C et 1 100 °C, la brame comprenant 0,05 % en poids à 0,1 % en poids de carbone (C), 0,9 % en poids à 1,5 % en poids de manganèse (Mn), 0,8 % en poids à 1,5 % en poids de nickel (Ni), 0,005 % en poids à 0,1 % en poids de niobium (Nb), 0,005 % en poids à 0,1 % en poids de titane (Ti), 0,1 % en poids à 0,6 % en poids de cuivre (Cu), 0,1 % en poids à 0,4 % en poids de silicium (Si), 100 ppm de phosphore ou moins (P), 40 ppm de soufre ou moins (S) et le reste étant du fer (Fe) et d'autres impuretés inévitablement présentes, puis le laminage brut de la brame à une température comprise entre 1 100 °C et 900 °C ;
l'obtention d'une tôle d'acier présentant une épaisseur de 50 mm ou plus par laminage de finition d'une barre laminée de façon brute à une température de 850 °C à Ar_3; et
le refroidissement de la tôle d'acier à une température de 700 °C ou moins, dans lequel les teneurs en Cu et Ni sont définies de sorte qu'un rapport pondéral de Cu/Ni est de 0,6 ou moins, le laminage brut étant effectué en deux passages ou plus, la surface extérieure de la brame ou de la barre maintenant une température inférieure à celle d'une partie centrale dans le sens de l'épaisseur avant chaque passage du laminage brut, une valeur moyenne des différences de température entre la partie centrale dans une direction d'épaisseur de la brame ou de la barre et une surface extérieure de la brame ou de la barre immédiatement avant chaque passage du laminage brut est comprise entre 100 °C et 300 °C, les différences de température étant des différences entre une température d'une surface extérieure de la brame ou de la barre mesurée immédiatement avant chaque passage du laminage brut, et une température d'une partie centrale calculée en tenant compte d'une condition de refroidissement et d'une épaisseur de la brame ou de la barre immédiatement avant chaque passage du laminage brut, et une granulométrie cristalline d'une partie centrale de la barre avant le laminage de finition après le laminage brut étant de 200 μm ou moins, et le refroidissement de la tôle étant effectué à une vitesse de refroidissement d'une partie centrale de la tôle d'acier de 2 °C/s ou plus.

5. Procédé de fabrication d'une tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes selon la revendication 4, dans lequel un rapport de réduction par passage, par rapport à trois passages finaux lorsque le laminage brut est effectué, est de 5 % ou plus, et un rapport de réduction cumulative totale est de 40 % ou plus.

6. Procédé de fabrication d'une tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes selon la revendication 4, dans lequel un rapport de réduction pendant le laminage de finition est établi de sorte qu'un rapport d'une épaisseur de brame en mm/d'une épaisseur de tôle d'acier en mm après le laminage de finition est de 3,5 ou plus.

7. Procédé de fabrication d'une tôle d'acier à haute résistance présentant une excellente capacité d'arrêt de fissures cassantes selon la revendication 4, dans lequel le refroidissement de la tôle d'acier est effectué à une vitesse de refroidissement moyenne de 3 °C/s à 300 °C/s.

[Figure 1]



REFERENCES CITED IN THE DESCRIPTION

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