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(54) **HIGH-STRENGTH THICK STEEL PLATE FOR CONSTRUCTION HAVING EXCELLENT CHARACTERISTICS FOR PREVENTING DIFFUSION OF BRITTLE CRACKS, AND PRODUCTION METHOD THEREFOR**

(57) Provided is a high-strength thick steel plate for structural use having a thickness of 50 mm or more and excellent brittle crack arrestability which can be preferably used for ships and a method for manufacturing the steel plate. The thick steel plate having excellent brittle crack arrestability has a specified chemical composition and a metallographic structure mainly including a ferrite phase and including a texture, in which the integration

degree I of the RD//{(110) plane in the surface portion is 1.3 or more and the integration degree I of the RD//{(110) plane in the central portion in the thickness direction is 1.8 or more, a Charpy fracture appearance transition temperature vTrs in the surface portion of -60°C or lower and a Charpy fracture appearance transition temperature vTrs in the central portion in the thickness direction of -50°C or lower.

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Description

[Technical Field]

[0001] The present invention relates to a high-strength thick steel plate for structural use having excellent brittle crack arrestability and a method for manufacturing the steel plate, and in particular, to a steel plate having a thickness of 50 mm or more which can be preferably used for ships.

[Background Art]

[0002] In the case of large-scale structures such as ships, since an accident due to a brittle fracture has a great effect on economy and environment, improvement of safety is always demanded and steel materials used for the structures are required to have good toughness and brittle crack arrestability at a temperature at which the steel materials are used.

[0003] In the case of ships such as container carriers and bulk carriers, high-strength steel plates having a heavy thickness are used for the outer plates of the ships' hulls responding to required structural strength, and recently, there is a growing trend toward increasing the strength and thickness of steel materials due to an increase in the size of ships' hulls. Generally, since there is a tendency for the brittle crack arrestability of a steel plate to decrease with increasing strength or thickness of the steel plate, there is a growing demand for improved brittle crack arrestability.

[0004] As a method for improving the brittle crack arrestability of a steel material, a method in which Ni content is increased has been known in the past, and 9%-Ni steel is commercially used for the storage tanks of liquefied natural gases.

[0005] However, since an increase in the amount of Ni added is inevitably accompanied by a large increase in cost, it is difficult to apply the Ni containing steel to any usage other than LNG storage tanks.

[0006] On the other hand, in the case of a comparatively thin steel plate having a thickness of less than 50 mm which is applied to ships and line pipes which are not subjected to such an ultra low temperature as that of LNG, it is possible to provide the steel plate with excellent brittle crack arrestability by decreasing a grain size by a so-called TMCP (Thermo-Mechanical Control Process) method in order to improve low-temperature toughness.

[0007] In addition, Patent Literature 1 proposes a steel material having an ultra-fine crystallization structure in the surface portion in order to improve brittle crack arrestability without an increase in alloy cost.

[0008] The steel material having excellent brittle crack arrestability according to Patent Literature 1 is characterized in that, focusing on the fact that shear lips (plastic deformation areas), which are formed in the surface portion of a steel material when a brittle crack propagates, are effective for improving brittle crack arrestability, the crystal grain size in the portion of shear-lips is decreased in order to absorb the propagation energy of a propagating brittle crack.

[0009] It is disclosed that, regarding a method for manufacturing the steel material, an ultra fine ferrite structure or bainite structure is formed in the surface portion of the steel material by repeating once or more a process, in which the surface portion of a hot-rolled steel plate is cooled down to a temperature equal to or lower than the A_{r3} transformation point by performing controlled cooling and then the controlled cooling is stopped in order to allow the surface portion to recuperate to have a temperature equal to or higher than the transformation point, while the steel material is rolled in order for transformation or recrystallization due to deformation to repeatedly occur.

[0010] Moreover, in Patent Literature 2, it is disclosed that, in order to improve the brittle crack arrestability of a steel material having a microstructure mainly including a ferrite-pearlite phase, it is important to form a layer, in either of the surface portions of the steel material, including 50% or more of a ferrite structure having ferrite grains with a circle-equivalent average grain size of 5 μm or less and an aspect ratio of the grains of 2 or more, and to prevent the variation of a ferrite grain size, and that, as a method for preventing the variation, the maximum rolling reduction per pass of finishing rolling is controlled to be 12% or less in order to prevent local recrystallization.

[0011] However, in the case of the steel materials having excellent brittle crack arrestability according to Patent Literatures 1 and 2, since the specified structure is formed by once cooling only the surface portion of the steel material, by allowing the cooled surface portion to recuperate and by rolling the steel material at the time of the recuperation, it is not easy to perform control on a practical production scale, and, in particular in the case of a thick material having a thickness of more than 50 mm, loads applied by this processing to rolling and cooling equipment are heavy.

[0012] On the other hand, Patent Literature 3 discloses a technique which is a modification of TMCP and in which, focusing on not only a decrease in ferrite crystal grain size but also a subgrain formed in a ferrite crystal grain, brittle crack arrestability is improved.

[0013] Specifically, for the case of a thickness of 30 to 40 mm, without the necessity of complicated temperature controlling such as the cooling and recuperation of the surface of a steel plate, brittle crack arrestability is improved by controlling (a) rolling conditions such that fine ferrite crystal grains are achieved, (b) rolling conditions such that a fine ferrite structure is formed in a portion constituting 5% or more of the thickness of the steel material, (c) rolling conditions such that subgrains are formed by growing a texture in the fine ferrite and by rearranging dislocations introduced by

applying deformation (rolling) using thermal energy and (d) cooling conditions such that an increase in the grain size of the formed fine ferrite crystal grains and in the grain size of the formed fine subgrains is prevented.

[0014] In addition, in controlled rolling, a method, in which brittle crack arrestability is improved by applying reduction force of rolling to a transformed ferrite phase in order to grow a texture, is also known. Resistance to brittle fractures is increased by forming a separation parallel to the plate surface on the fracture surface of a steel material in order to reduce stress at the brittle crack tip.

[0015] For example, Patent Literature 4 discloses that brittle fracture resistance is improved by performing controlled rolling in order to form a microstructure having an X-ray intensity ratio in the (110) plane showing a texture developing degree of 2 or more and including large-size grains having a diameter equivalent to a circle in the crystal grains of 20 μm or more in an amount of 10% or less.

[0016] Patent Literature 5 discloses, as a steel for welded structural use having excellent brittle crack arrestability in the joint part, a steel plate having an X-ray plane intensity ratio in the (100) plane showing a texture developing degree on a plane inside the plate parallel to the rolling surface of the plate of 1.5 or more. It is disclosed that the steel plate has excellent brittle crack arrestability owing to the difference in angle between the direction of applied stress and the direction of crack propagation as a result of the growth of the texture mentioned above.

[Citation List]

[Patent Literature]

[0017]

[PTL 1] Japanese Examined Patent Application Publication No. 7-100814

[PTL 2] Japanese Unexamined Patent Application Publication No. 2002-256375

[PTL 3] Japanese Patent No. 3467767

[PTL 4] Japanese Patent No. 3548349

[PTL 5] Japanese Patent No. 2659661

[Summary of Invention]

[Technical Problem]

[0018] Nowadays, a thick steel plate having a thickness of more than 50 mm is used for a mega-container carrier of more than 6,000 TEU (twenty-foot equivalent unit). In the literature by Inoue et al.: Long Brittle Crack Propagation of Heavy-Thick Shipbuilding Steels, Conference proceedings, the Japan Society of Naval Architects and Ocean Engineers (3), 2006, pp. 359 to 362, it is reported that, from the results of the evaluation of the brittle crack arrestability of a steel plate having a thickness of 65 mm, a brittle crack was not arrested in a large brittle crack arrestability test on a base metal.

[0019] In addition, it is reported that, from the results of an ESSO test compliant with WES 3003 on the sample, the value of Kca at an operating temperature of -10°C (hereinafter, also expressed by $\text{Kca}(-10^{\circ}\text{C})$) was less than 3000 $\text{N/mm}^{3/2}$, which indicates that it is a problem to be solved to ensure the safety of a ship's hull structure built using a steel sheet having a thickness of more than 50 mm.

[0020] The steel plates having excellent brittle crack arrestability according to Patent Literatures 1 through 5 described above are mainly intended for a steel plate having a thickness of about 50 mm or less as indicated by the manufacturing conditions and the disclosed experimental data. It is not clear whether specified properties can be obtained in the case where the disclosed techniques are applied to thick material having a thickness of more than 50 mm, and the properties regarding crack propagation in the thickness direction which are required for ship's hull structures have never been tested at all.

[0021] Therefore, an object of the present invention is to provide a high-strength thick steel plate having excellent brittle crack arrestability which can be stably manufactured using a very simple industrial process in which rolling conditions are optimized to control a texture in the thickness direction and a method for manufacturing the steel plate.

[Solution to Problem]

[0022] The present inventors diligently conducted investigations in order to solve the problems described above and found the following knowledge regarding a high-strength thick steel plate having excellent crack arrestability despite the steel plate having a heavy thickness.

1. From the results of the close investigations regarding the fracture surface of a thick steel plate having a thickness

of more than 50 mm in an ESSO test compliant with WES 3003, in the case of a fracture surface shape as illustrated in Fig. 1(b), it was found that a stress intensity factor in a crack tip portion decreases with decreasing brittle crack width, which results in an increase in the arrestability of a steel plate. Figs. 1(a) and 1(b) are schematic diagrams illustrating that a crack 3 which has penetrated from a notch 2 of a test piece 1 for an ESSO test compliant with

2. In order to obtain the fracture surface shape as described above, it is necessary to increase arrestability in the surface portion and in the central portion in the thickness direction. As a method for increasing arrestability in the surface portion and in the central portion in the thickness direction, it is effective to increase toughness in the surface portion and in the central portion in the thickness direction. However, there is a limit to an increase in toughness in the central portion in the thickness direction due to the limit to a cooling rate, rolling reduction and the like in the case of a thick steel plate having a thickness of more than 50 mm.

3. As a method for increasing arrestability other than increasing toughness, it is effective to control a texture in the central portion in the thickness direction. In particular, it is effective to control a texture such that a crack propagating in the rolling or width direction is directed diagonally to the rolling or width direction by integrating the (110) plane in parallel to the rolling direction.

4. Moreover, while the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range, cumulative rolling reduction is controlled to be 20% or more and average rolling reduction per pass is controlled to be 5% or less in order to decrease a grain size in a microstructure in the surface portion. Subsequently, while the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range, by controlling cumulative rolling reduction to be 40% or more and by controlling average rolling reduction per pass to be 7% or more, an increase in toughness and the growth of a texture in the central portion in the thickness direction can be achieved and the microstructure described above can be realized.

[0023] Further investigations have been conducted on the basis of the obtained knowledge and, as a result, the present invention has been completed. That is to say, the present invention is as follows.

1. A high-strength thick steel plate for structural use having excellent brittle crack arrestability, the steel plate having a metallographic structure mainly including a ferrite phase and including a texture, in which the integration degree I of the RD//(110) plane (Rolling Direction parallel to (110) plane) in a surface portion is 1.3 or more and the integration degree I of the RD//(110) plane in a central portion in the thickness direction is 1.8 or more, a Charpy fracture appearance transition temperature $vTrs$ in the surface portion of $-60^{\circ}C$ or lower and a Charpy fracture appearance transition temperature $vTrs$ in the central portion in the thickness direction of $-50^{\circ}C$ or lower.

2. The high-strength thick steel plate for structural use having excellent brittle crack arrestability according to item 1, the Charpy fracture appearance transition temperature and the integration degree I of the RD//(110) plane in the surface portion and the central portion in the thickness direction satisfying the relational expression (1) below:

$$vTrs_{(surface)} + 1.9 \times vTrs_{(1/2t)} - 6 \times I_{RD//(110)[surface]} - 84 \times I_{RD//(110)[1/2t]} \leq -350 \quad \cdots (1),$$

where $vTrs_{(surface)}$: the fracture appearance transition temperature of the surface portion ($^{\circ}C$),
 $vTrs_{(1/2t)}$: the fracture appearance transition temperature of the central portion in the thickness direction ($^{\circ}C$),
 $I_{RD//(110)[surface]}$: the integration degree of the RD//(110) plane in the surface portion,
and $I_{RD//(110)[1/2t]}$: the integration degree of the RD//(110) plane in the central portion in the thickness direction.

3. The high-strength thick steel plate for structural use having excellent brittle crack arrestability according to item 1 or 2, the steel plate having a chemical composition containing, by mass%, C: 0.03% or more and 0.20% or less, Si: 0.03% or more and 0.5% or less, Mn: 0.5% or more and 2.2% or less, Al: 0.005% or more and 0.08% or less, P: 0.03% or less, S: 0.01% or less, N: 0.0050% or less, Ti: 0.005% or more and 0.03% or less and the balance being Fe and inevitable impurities.

4. The high-strength thick steel plate for structural use having excellent brittle crack arrestability according to item 3, the steel plate having the chemical composition further containing, by mass%, one or more of Nb: 0.005% or more and 0.05% or less, Cu: 0.01% or more and 0.5% or less, Ni: 0.01% or more and 1.0% or less, Cr: 0.01% or more and 0.5% or less, Mo: 0.01% or more and 0.5% or less, V: 0.001% or more and 0.10% or less, B: 0.0030% or less, Ca: 0.0050% or less and REM: 0.010% or less.

5. A method for manufacturing a high-strength thick steel plate for structural use having excellent brittle crack arrestability, the method including heating a slab having the chemical composition according to item 3 or 4 at a

temperature of 900°C or higher and 1150°C or lower, performing rolling in which total cumulative rolling reduction in the austenite recrystallization temperature range and in the austenite non-recrystallization temperature range is 65% or more, in which, while the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range, cumulative rolling reduction is controlled to be 20% or more and average rolling reduction per pass is controlled to be 5.0% or less and in which, subsequently, while the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range, cumulative rolling reduction is controlled to be 40% or more and average rolling reduction per pass is controlled to be 7.0% or more and performing accelerated cooling on the rolled steel plate down to a temperature of 600°C or lower at a cooling rate of 4.0°C/s or more.

6. The method for manufacturing a high-strength thick steel plate for structural use having excellent brittle crack arrestability according to item 5, the method further including a process in which the steel plate which has been subjected to accelerated cooling down to a temperature of 600°C or lower is tempered at a temperature equal to or lower than the A_{C1} point.

[Advantageous Effects of Invention]

[0024] According to the present invention, a high-strength thick steel plate having a thickness of 50 mm or more having excellent brittle crack arrestability, in which a texture in the thickness direction is appropriately controlled, and a method for manufacturing the steel plate can be provided, and it is effective to apply the present invention to a steel plate having a thickness of preferably more than 50 mm, more preferably 55 mm or more. In addition, in the field of shipbuilding, the present invention contributes to the improvement of the safety of ships by being applied to hatch side coamings and deck part materials in high-strength deck structures of large container carriers and bulk carriers, which results in a large advantage in industry.

[Brief Description of Drawings]

[0025] [Fig. 1] Fig. 1 is a schematic diagram illustrating the fracture surface shape of an ESSO test compliant with WES 3003 of a thick steel plate having a thickness of more than 50 mm, where (a) is a diagram illustrating a plane view of a test piece and (b) is a diagram illustrating the fracture surface of the test piece.

[Description of Embodiments]

[0026] In the present invention, 1. the toughness and a texture in the surface portion and the central portion in the thickness direction and 2. a metallographic structure are specified.

1. Toughness and texture

[0027] In the present invention, in order to obtain a fracture surface shape illustrated in Fig. 1 with which crack arrestability can be increased against a crack propagating in the horizontal direction (planar direction) such as the rolling direction or a direction at a right angle to the rolling direction, toughness and the integration degree I of the RD//{(110) plane in the surface portion and the central portion in the thickness direction are appropriately specified.

[0028] Firstly, since it is prerequisite that the toughness of a base metal be excellent in order to prevent crack propagation, in the case of the steel plate according to the present invention, it is specified that a Charpy fracture appearance transition temperature $vTrs$ in the surface portion be -60°C or lower and that a Charpy fracture appearance transition temperature $vTrs$ in the central portion in the thickness direction be -50°C or lower. It is preferable that the Charpy fracture appearance transition temperature $vTrs$ in the central portion in the thickness direction be -60°C or lower.

[0029] In addition, by growing the texture of the RD//{(110) plane, cleavage planes are integrated diagonally to the main direction of a crack in order to form fine branched cracks, which results in an increase in brittle crack arrestability owing to a stress relaxation effect at a brittle crack tip. In order to achieve a K_{Ic} (-10°C) of 6000 N/mm^{3/2} or more which represents a target brittle crack arrestability in order to ensure the structural safety of a thick steel plate having a thickness of more than 50 mm which is increasingly being used nowadays for the outer plates of ships' hulls of container carriers and bulk carriers, it is necessary that the integration degree I of the RD//{(110) plane in the surface portion be 1.3 or more, preferably 1.6 or more, and that the integration degree I of the RD//{(110) plane in the central portion in the thickness direction be 1.8 or more, preferably 2.0 or more.

[0030] Here, the integration degree I of the RD//{(110) plane in the surface portion or the central portion in the thickness direction is defined in the following way. Firstly, by performing mechanical polishing and electrolytic polishing on a surface, being parallel to the steel plate surface, of a sample having a thickness of 1 mm cut out of the surface portion or the central portion in the thickness direction, a test piece for X-ray diffractometry is prepared. Incidentally, in the case

of the surface portion, the surface of the sample nearer to the outermost surface is polished. By performing X-ray diffraction measurement using a Mo X-ray source on this test piece, the pole figures of (200), (110) and (211) planes are obtained. Three dimensional orientation distribution function is calculated from the obtained pole figures by using a Bunge method. Subsequently, using the calculated three dimensional orientation distribution function, by integrating the values of the three dimensional orientation distribution function in the orientation in which (110) plane is parallel to the rolling direction in the 19 cross sections in total which are selected at an interval of 5° in the range from $\phi_2 = 0^\circ$ to $\phi_2 = 90^\circ$ in terms of Bunge notation, an integrated value is obtained. The value of the integrated value divided by the number of orientations which have been selected for the integration is called the integration degree I of the RD//{(110) plane.

[0031] In addition to the specification of the toughness and the texture of a base metal described above, it is preferable that the Charpy fracture appearance transition temperature and the integration degrees I of the RD//{(110) plane in the surface portion and the central portion in the thickness direction satisfy the relational expression (1) below:

$$vTrs_{(surface)} + 1.9 \times vTrs_{(1/2t)} - 6 \times I_{RD//\{(110)\} [surface]} - 84 \times I_{RD//\{(110)\} [1/2t]} \leq -350 \quad \dots (1),$$

where $vTrs_{(surface)}$: the fracture appearance transition temperature of the surface portion (°C),

$vTrs_{(1/2t)}$: the fracture appearance transition temperature of the central portion in the thickness direction (°C),

$I_{RD//\{(110)\} [surface]}$: the integration degree of the RD//{(110) plane in the surface portion,

and $I_{RD//\{(110)\} [1/2t]}$: the integration degree of the RD//{(110) plane in the central portion in the thickness direction.

[0032] As a result of the relational expression (1) being satisfied, it is possible to achieve better brittle crack arrestability.

2. Metallographic structure

[0033] In the present invention, a metallographic structure mainly includes a ferrite phase. Here, in the present invention, "a metallographic structure mainly includes a ferrite phase" means that the area fraction of a ferrite phase is 60% or more with respect to the whole metallographic structure. The area fraction of the remainder consisting of, for example, a bainite phase, a martensite phase (including martensite islands) and a pearlite phase is 40% or less.

[0034] In the case where a metallographic structure mainly including a ferrite phase is obtained by performing rolling under ordinary rolling conditions for an austenite phase, although target toughness can be obtained in a structure mainly including a ferrite phase, since there is sufficient transformation time for an austenite phase to transform into a ferrite phase after rolling has been performed, the obtained texture becomes a random structure, which results in the target value of the integration degree I of the RD//{(110) plane in the surface portion, that is, 1.3 or more, preferably 1.6 or more, not being achieved, and which results in the target value of the integration degree I of the RD//{(110) plane in the central portion in the thickness direction, that is, 1.8 or more, preferably 2.0 or more, not being achieved. Therefore, by appropriately controlling rolling conditions as described below, even in a structure mainly including a ferrite phase, it is possible to achieve an integration degree I of the RD//{(110) plane in the surface portion of 1.3 or more, preferably 1.6 or more, and an integration degree I of the RD//{(110) plane in the central portion in the thickness direction of 1.8 or more, preferably 2.0 or more.

3. Chemical composition

[0035] The preferable chemical composition in the present invention will be described hereafter. % represents mass% in the description.

C: 0.03% to 0.20%

[0036] Although C is a chemical element which increases the strength of steel and it is necessary that the C content be 0.03% or more in order to achieve the desired strength in the present invention, in the case where the C content is more than 0.20%, there is not only a decrease in weldability but also a negative influence on toughness. Therefore, it is preferable that the C content be 0.03% to 0.20%, more preferably 0.05% to 0.15%.

Si: 0.03% to 0.5%

[0037] Although Si is effective as a deoxidizing chemical element and as a chemical element for increasing the strength

of steel, the effect cannot be realized in the case where the Si content is less than 0.03%. On the other hand, in the case where the Si content is more than 0.5%, there is not only the deterioration of the surface quality of steel but also a significant decrease in toughness. Therefore, it is preferable that the Si content be 0.03% or more and 0.5% or less.

5 Mn: 0.5% to 2.2%

[0038] Mn is added as a chemical element for increasing strength. Since the effect is insufficient in the case where the Mn content is less than 0.5%, and since there is a decrease in weldability and an increase in steel material cost in the case where the Mn content is more than 2.2%, it is preferable that the Mn content be 0.5% or more and 2.2% or less.

10 Al: 0.005% to 0.08%

[0039] Al is effective as a deoxidizing agent, and it is necessary that the Al content be 0.005% or more in order to realize this effect, but, in the case where the Al content is more than 0.08%, there is not only a decrease in toughness but also a decrease in the toughness of a weld metal when welding is performed. Therefore, it is preferable that the Al content be 0.005% to 0.08%, more preferably 0.02% to 0.04%.

15 N: 0.0050% or less

[0040] N increases the strength of steel by controlling a crystal grain size as a result of combining with Al in steel to form AlN when rolling is performed, but, since there is a decrease in toughness in the case where the N content is more than 0.0050%, it is preferable that the N content be 0.0050% or less.

20 P and S

[0041] Since P and S are inevitable impurities in steel, and since there is a decrease in toughness in the case where the P content is more than 0.03% or in the case where the S content is more than 0.01%, it is preferable that the content of P and S be respectively 0.03% or less and 0.01% or less, more preferably 0.02% or less and 0.005% or less respectively.

25 Ti: 0.005% to 0.03%

[0042] A small content of Ti is effective for increasing the toughness of a base metal by decreasing a crystal grain size as a result of forming a nitride, carbide or carbonitride. This effect is realized in the case where the Ti content is 0.005% or more, but, since there is a decrease in the toughness of a base metal and a welded heat affected zone in the case where the Ti content is more than 0.03%, the Ti content is set to be 0.005% to 0.03%.

[0043] Although the chemical composition described above is the preferable base chemical composition in the present invention, one or more of Nb, Cu, Ni, Cr, Mo, V, B, Ca and REM may be added in order to further improve the properties.

30 Nb: 0.005% to 0.05%

[0044] Nb contributes to an increase in strength as a result of precipitating in the form of NbC when ferrite transformation occurs or reheating is performed. In addition, since Nb is effective for expanding a temperature range in which recrystallization does not occur when rolling is performed under conditions for forming an austenite phase, which results in a decrease in ferrite grain size, Nb contributes to an increase in toughness. This effect is realized in the case where the Nb content is 0.005% or more, but, since there is conversely a decrease in toughness as a result of the precipitation of large-size NbC in the case the Nb content is more than 0.05%, it is preferable that the upper limit of the Nb content be 0.05%.

35 Cu, Ni, Cr and Mo

[0045] Cu, Ni, Cr and Mo are all chemical elements which increase the hardenability of steel. Since these chemical elements directly contribute to an increase in strength after rolling has been performed and may be added in order to improve functional properties such as toughness, high temperature strength or weather resistance, and since these effects are realized in the case where the contents of these chemical elements are respectively 0.01% or more, it is preferable that the contents of these chemical elements be respectively 0.01% or more in the case where these chemical elements are added. However, since there is a decrease in toughness and weldability in the case where the contents of these chemical elements are excessively large, it is preferable that the upper limits of the contents of Cu, Ni, Cr and Mo be respectively 0.5%, 1.0%, 0.5% and 0.5% in the case where these chemical elements are added.

V: 0.001% to 0.10%

[0046] V is a chemical element which increases the strength of steel by precipitation strengthening as a result of precipitating in the form of V(C,N). The V may be contained in the amount of 0.001% or more in order to realize this effect, but there is a decrease in toughness in the case where the V content is more than 0.10%. Therefore, in the case where V is added, it is preferable that the V content be in the range of 0.001% to 0.10%.

B: 0.0030% or less

[0047] A small amount of B may be added as a chemical element which increases the hardenability of steel. However, in the case where the B content is more than 0.0030%, since there is a decrease in the toughness of a weld zone, it is preferable that the B content be 0.0030% or less in the case where B is added.

Ca: 0.0050% or less and REM: 0.010% or less

[0048] Since Ca and REM increase toughness as a result of decreasing a grain size in a structure in a welded heat affected zone and there is no decrease in the effect of the present invention even in the case where these chemical elements are added, these chemical elements may be added as needed. However, in the case where the contents of these chemical elements are excessively large, since there is a decrease in the toughness of a base metal as a result of forming large-size inclusions, it is preferable that the upper limit of the contents of Ca and REM be respectively 0.0050% and 0.010% in the case where these are added.

4. Manufacturing conditions

[0049] The preferable manufacturing conditions in the present invention will be described hereafter.

[0050] It is preferable that manufacturing conditions such as the heating temperature of a slab as a steel material, hot rolling conditions and cooling conditions be specified. In particular, regarding hot rolling, it is preferable to specify, in addition to total cumulative rolling reduction, cumulative rolling reduction and average rolling reduction per pass for each of the cases where the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range and where the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range. By specifying these conditions, it is possible to achieve the desired properties regarding toughness and the integration degree I of the RD//{(110) plane in the surface portion and the central portion in the thickness direction of a thick steel plate and strength in a portion located at 1/4 of the thickness.

[0051] Firstly, molten steel having the chemical composition described above is produced using, for example, a converter furnace and made into a slab using, for example, a continuous casting method. Subsequently, the slab is heated at a temperature of 900°C to 1150°C and then hot-rolled.

[0052] Although it is effective for obtaining good toughness that the heating temperature is low in order to decrease a crystal grain size before rolling is performed, it is impossible to secure sufficient time for performing rolling in the austenite recrystallization temperature range in the case where the heating temperature is lower than 900°C. On the other hand, in the case where the heating temperature is higher than 1150°C, since there is not only a decrease in toughness due to an increase in austenite grain size but also a decrease in yield due to a significant loss caused by oxidation, it is preferable that the heating temperature be 900°C to 1150°C, more preferably, the heating temperature be in the range of 1000°C to 1100°C from the viewpoint of toughness.

[0053] Generally, in the case where a metallographic structure mainly including a ferrite phase is obtained by performing rolling under ordinary conditions for an austenite phase, although target toughness can be obtained, since there is sufficient time for an austenite phase to transform into a ferrite phase after rolling has been performed, the obtained texture becomes a random structure. Therefore, the target values in the present invention of the integration degree I of the RD//{(110) plane in the surface portion, that is, 1.3 or more, preferably 1.6 or more, and of the integration degree I of the RD//{(110) plane in the central portion in the thickness direction, that is, 1.8 or more, preferably 2.0 or more, cannot be achieved. Therefore, in the present invention, it is preferable to specify hot rolling conditions as described below. By this method, even in a structure mainly including a ferrite phase, it is possible to achieve an integration degree I of the RD//{(110) plane in the surface portion of 1.3 or more, preferably 1.6 or more, and an integration degree I of the RD//{(110) plane in the central portion in the thickness direction of 1.8 or more, preferably 2.0 or more.

[0054] It is preferable that hot rolling be performed, firstly, while the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range, under the conditions that the cumulative rolling reduction is 20% or more and the average rolling reduction per pass is 5.0% or less. By controlling the cumulative rolling reduction to be 20% or more, since an austenite grain size becomes small, a grain size in a metallographic structure which is finally obtained becomes small, which results in an increase in toughness. On the other hand, by controlling the average

rolling reduction per pass in this temperature range to be 5.0% or less, since it is possible to introduce strain into a steel material, in particular in the portion in the vicinity of the surface portion of the steel material, it is possible to control the integration degree I of the RD//{110} plane in the surface portion to be 1.3 or more, preferably 1.6 or more, and to further decrease the grain size in the surface portion, which results in an increase in the toughness of the surface portion.

[0055] Subsequently, it is preferable that rolling is performed, while the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range, under the conditions that the cumulative rolling reduction is 40% or more and the average rolling reduction per pass is 7.0% or more. By controlling the cumulative rolling reduction in this temperature range to be 40% or more, a texture in the central portion in the thickness direction can be sufficiently grown. In addition, by controlling the average rolling reduction per pass to be 7.0% or more, it is possible to control the integration degree I of the RD//{110} plane in the central portion in the thickness direction to be 1.8 or more, preferably 2.0 or more.

[0056] In addition, it is preferable to control the total cumulative rolling reduction in the austenite recrystallization temperature range and in the austenite non-recrystallization temperature range to be 65% or more. This is because, by controlling the total cumulative rolling reduction to be 65% or more, it is possible to apply sufficient reduction to a structure, which results in the values of target toughness and strength being achieved.

[0057] The austenite recrystallization temperature range and the austenite non-crystallization temperature range are determined by performing preliminary experiments using steel having the chemical composition described above in which the steel is subjected to heating and processing history under various conditions.

[0058] Here, although there is no limitation on the finishing temperature of hot rolling, from the view point of rolling efficiency, it is preferable that the finishing temperature be in the austenite non-recrystallization temperature range.

[0059] It is preferable that the rolled steel plate be cooled down to a temperature of 600°C or lower at a cooling rate of 4.0°C/s or more. By controlling the cooling rate to be 4.0°C/s or more, since there is not an increase in grain size in a structure, the structure having a small grain size can be obtained, which results in the target excellent toughness being achieved. In the case where the cooling rate is less than 4.0°C/s, since there is an increase in grain size in a structure, the target toughness cannot be achieved. By controlling the cooling stop temperature to be 600°C or lower, since the progression of recrystallization is prevented, it is possible to maintain the desired texture which has been achieved through the hot rolling and the subsequent cooling. In the case where the cooling stop temperature is higher than 600°C, since recrystallization progresses even after the cooling has been stopped, the desired texture cannot be achieved. Here, the cooling rate and cooling stop temperature described above are determined by using the temperature of the central portion in the thickness direction of the steel plate. The temperature of the central portion in the thickness direction can be derived from, for example, the thickness, the surface temperature, the cooling conditions and the like using, for example, simulation calculation. For example, by calculating the temperature distribution in the thickness direction using a difference method, the temperature of the central portion in the thickness direction of the steel plate can be derived.

[0060] A temper treatment may be performed on the cooled steel plate. By performing a tempering treatment, it is possible to further increase the toughness of steel plate. By controlling a tempering temperature to be equal to or lower than the A_{C1} point in terms of the average temperature of the steel plate, it is possible to prevent the desired structure obtained through rolling and cooling from being lost. In the present invention, the A_{C1} point (°C) is derived using the equation below.

$$A_{C1} \text{ point} = 751 - 26.6C + 17.6Si - 11.6Mn - 169Al - 23Cu - \\ 23Ni + 24.1Cr + 22.5Mo + 233Nb - 39.7V - 5.7Ti - 895B,$$

where an atomic symbol in the equation above represents the content (mass%) of the chemical element in the steel and where the symbol is assigned a value of 0 in the case where the chemical element is not contained.

[0061] The average temperature of the steel plate can be derived from, for example, the thickness, the surface temperature and the cooling conditions using, for example, simulation calculation, as is the case with the temperature of the central portion in the thickness direction.

[EXAMPLES]

[0062] By producing molten steels (steel codes A through O) having the chemical compositions given in Table 1 using a converter furnace, by casting the molten steel into slabs (having a thickness of 250 mm) using a continuous casting method, by hot-rolling the slabs into hot-rolled steel plates having a thickness of 50 to 80 mm and by cooling the hot-rolled steel plate, sample steels No. 1 through No. 29 were obtained. Some of the sample steels were subjected to a tempering treatment after having been cooled. The hot rolling conditions, the cooling conditions and the tempering conditions are given in Table 2.

[0063] By performing a tensile test using a JIS No. 14A test piece having a diameter of $\phi 14$ cut out of the portion located at 1/4 of the thickness of the obtained thick steel plate such that the longitudinal direction of the test piece was at a right angle to the rolling direction, a yield strength and a tensile strength were determined.

[0064] In addition, by performing a Charpy impact test using JIS No. 4 impact test pieces cut out of the surface portion and the central portion in the thickness direction (herein after, also represented by 1/2t portion) such that the longitudinal direction of the test pieces was parallel to the rolling direction, a fracture appearance transition temperature (vTrs) was determined. Here, among the surfaces of the impact test piece of the surface portion, one which was the nearest to the surface of the steel plate corresponded to the depth of 1 mm from the surface of the steel plate.

[0065] Subsequently, in order to evaluate brittle crack arrestability, Kca value at a temperature of -10°C (Kca(-10°C)) was determined by performing an ESSO test compliant with WES 3003.

[0066] Moreover, the integration degree I of the RD//(110) plane in the central portion in the thickness direction was derived in the following way. Firstly, by performing mechanical polishing and electrolytic polishing on the surface parallel to the steel plate surface of a sample having a thickness of 1 mm cut out of the central portion in the thickness direction, a test piece for X-ray diffractometry was prepared. By performing X-ray diffraction measurement using a Mo X-ray source on this test piece, the pole figures of (200), (110) and (211) planes were obtained. Three dimensional orientation distribution function was calculated from the obtained pole figures by using a Bunge method. Subsequently, using the calculated three dimensional orientation distribution function, by integrating the values of the three dimensional orientation distribution function in the orientation in which (110) plane was parallel to the rolling direction in the 19 cross sections which were selected at an interval of 5° in the range from $\phi_2 = 0^{\circ}$ to $\phi_2 = 90^{\circ}$ in terms of Bunge notation, an integrated value was obtained. The value of the integrated value divided by the number 19 of the orientations which had been selected for the integration was defined as the integration degree I of the RD//(110) plane.

[0067] The results of these tests are given in Table 3. Sample steel plates (serial Nos. 1 through 13 and 27 through 29), which had the toughness indexes in the surface portion and the central portion in the thickness direction and textures which were within the range according to the present invention, had a Kca(-10°C) of $6000 \text{ N/mm}^{3/2}$ or more, which means these sample steel plates had excellent brittle crack arrestability. In addition, sample steel plates (serial Nos. 1 through 13), each of which had the Charpy fracture appearance transition temperature and the integration degree I of the RD//(110) plane in the surface portion and the central portion in the thickness direction satisfying the relational expression (1), had higher Kca(-10°C) than sample steel plates (serial Nos. 27 through 29) that do not satisfy the relational expression (1).

[0068] On the other hand, sample steel plates (serial Nos. 21 through 26), which were prepared under manufacturing conditions outside the range according to the present invention and had toughness or textures not satisfying the specifications according to the present invention, had a Kca(-10°C) of less than $6000 \text{ N/mm}^{3/2}$. Sample steel plates (serial Nos. 14 through 20), which had chemical compositions outside the preferable ranges according to the present invention, had toughness not satisfying the specifications according to the present invention and a Kca(-10°C) of less than $6000 \text{ N/mm}^{3/2}$.

[Reference Signs List]

[0069]

- 1 test piece for ESSO test compliant with WES 3003
- 2 notch
- 3 crack
- 4 tip shape
- 5 base metal

[Table 1]

Table 1

Steel Code	C	Si	Mn	P	S	Al	Nb	Ti	V	Cu	Ni	Cr	Mo	N	B	Ca	REM	Ceq
A	0.07	0.2	1.52	0.013	0.002	0.03	-	0.011	-	-	-	0.13	-	0.0033	-	-	-	0.35
B	0.09	0.16	1.45	0.007	0.001	0.03	-	0.016	-	0.11	-	-	-	0.0024	-	-	0.005	0.34
C	0.13	0.36	1.32	0.011	0.003	0.05	-	0.024	-	-	-	-	-	0.0041	0.0012	-	-	0.35
D	0.08	0.27	1.34	0.006	0.002	0.04	-	0.013	-	-	0.33	-	-	0.0022	-	-	-	0.33
E	0.08	0.23	1.62	0.013	0.003	0.06	-	0.015	-	-	-	-	-	0.0043	-	-	-	0.35
F	0.08	0.33	1.46	0.021	0.001	0.06	-	0.022	0.05	-	-	-	-	0.0041	-	-	-	0.33
G	0.11	0.15	1.34	0.009	0.005	0.04	-	0.009	0.009 -	-	-	-	0.05	0.0046	-	-	-	0.34
H	0.04	0.14	1.78	0.014	0.002	0.05	-	0.022	-	-	-	-	-	0.0023	-	0.0030	-	0.34
I	0.07	0.24	1.51	0.014	0.004	0.03	-	0.045	-	-	-	0.05	-	0.0034	-	-	-	0.33
J	0.09	0.3	1.48	0.006	0.003	0.02	0.009	0.006	-	-	-	-	-	0.0074	-	-	-	0.34
K	0.06	0.22	1.52	0.013	0.004	0.03	-	0.015	0.06	-	-	-	-	0.0027	-	-	0.052	0.33
L	0.11	0.16	1.44	0.043	0.002	0.02	-	0.012	-	0.06	-	-	-	0.0033	-	-	-	0.35
M	0.05	0.2	1.32	0.015	0.003	0.03	-	0.013	-	-	-	0.64	-	0.0041	-	-	-	0.40
N	0.07	0.17	1.38	0.008	0.027	0.04	-	0.021	-	-	0.25	-	0.05	0.0023	-	-	-	0.33
O	0.07	0.65	1.61	0.012	0.003	0.04	-	0.007	-	-	-	-	-	0.0046	-	-	-	0.34

Note 1: Ceq = C+Mn/6+Cu/15+Ni/15+Cr/5+Mo/5+V/5
 (An atomic symbol represents the content (mass%) of a chemical element represented by the symbol, and the symbol is assigned a value of 0 in the case where the chemical element is not contained.)

[Table 2]

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Table 2

Serial No.	Steel Code	Thickness (mm)	Heating, Rolling and Cooling Condition								Tempering Temperature (°C)
			Heating Temperature (°C)	Cumulative Rolling Reduction in γ Recrystallization Range (%)	Average Rolling Reduction in γ Recrystallization Range (%)	Cumulative Rolling Reduction in γ Non-Recrystallization Range (%)	Average Rolling Reduction in γ Non-Recrystallization Range (%)	Total Cumulative Rolling Reduction (%)	Cooling Rate (°C/s)	Cooling Stop Temperature (°C)	
1	A	60	1100	37	4.7	62	8.1	76	7.9	340	-
2	B	55	1080	40	4.1	63	7.4	78	8.4	420	-
3	C	65	980	45	4.3	53	7.2	74	6.9	380	-
4	D	60	1140	35	3.8	63	8.1	76	7.6	410	-
5	E	70	1050	42	4.5	52	8.7	72	6.4	550	-
6	F	50	1080	60	3.3	50	7.4	80	9.4	340	-
7	G	80	1140	28	3.4	56	9.5	68	5.2	240	570
8	H	55	1060	54	4.8	52	7.4	78	8.3	380	-
9	A	75	1120	43	2.4	47	7.6	70	5.8	330	-
10	D	60	1000	40	3.7	60	8.2	76	7.8	190	580
11	E	75	1080	47	3.1	43	7.4	70	5.5	520	-
12	G	70	1140	34	3.6	57	8.9	72	6.2	430	-
13	H	55	1050	37	4.8	65	7.5	78	8.7	370	-
14	I	80	1100	35	3.7	51	7.4	68	4.9	310	-
15	J	60	1070	47	4.1	55	8.1	76	7.4	370	-
16	K	75	1040	42	2.7	48	7.9	70	5.6	350	-
17	L	50	1130	52	3.9	54	8.8	80	9.1	450	-
18	M	65	1050	47	4.6	51	9.4	74	6.7	410	-
19	N	80	1040	24	4.7	58	7.8	68	4.8	370	-
20	O	70	1070	38	4.1	55	7.4	72	6.8	380	-
21	B	60	1300	34	3.2	64	8.3	76	7.7	440	-

(continued)

Serial No.	Steel Code	Thickness (mm)	Heating, Rolling and Cooling Condition								Tempering Temperature (°C)
			Heating Temperature (°C)	Cumulative Rolling Reduction in γ Recrystallization Range (%)	Average Rolling Reduction in γ Recrystallization Range (%)	Cumulative Rolling Reduction in γ Non-Recrystallization Range (%)	Average Rolling Reduction in γ Non-Recrystallization Range (%)	Total Cumulative Rolling Reduction (%)	Cooling Rate (°C/s)	Cooling Stop Temperature (°C)	
22	C	75	1120	36	2.7	53	8.1	70	Air Cooling (≤ 0.5)	-	-
23	D	55	1000	44	7.4	61	9.1	78	8.6	410	-
24	F	80	970	14	4.5	63	7.4	68	5.1	390	-
25	G	70	1110	60	4.3	30	4.1	72	6.8	400	-
26	H	65	1000	39	3.3	57	8.6	74	7.1	670	-
27	A	60	1050	38	4.8	61	7.1	76	7.6	210	550
28	F	70	1100	43	4.9	51	7.3	72	6.5	420	-
29	B	65	1130	50	4.7	48	7.2	74	7.1	510	-

Note 1: "Cumulative Rolling Reduction in γ Recrystallization Range" means cumulative rolling reduction when the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range.

Note 2: "Average Rolling Reduction in γ Recrystallization Range" means average rolling reduction per pass when the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range.

Note 3: "Cumulative Rolling Reduction in γ Non-Recrystallization Range" means cumulative rolling reduction when the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range.

Note 4: "Average Rolling Reduction in γ Non-Recrystallization Range" means average rolling reduction per pass when the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range.

[Table 3]

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Table 3

Serial No.	Steel Code	Thickness (mm)	YS (MPa)	TS (MPa)	vTrs of Surface Portion (°C)	vTrs of 1/2t Portion (°C)	RD/(110) of Surface Portion	RD/(110) of 1/2t Portion	Left Side of Relational Expression (1)	Kca(-10°C) (N/mm ^{3/2})
1	A	60	421	582	-72	-68	2.1	2.4	-415	6700
2	B	55	392	563	-81	-76	1.9	2.6	-455	7600
3	C	65	378	552	-69	-73	1.7	2.1	-394	6200
4	D	60	374	520	-77	-64	1.9	2.6	-428	6900
5	E	70	383	513	-83	-78	2.3	2.4	-447	7200
6	F	50	451	601	-98	-92	1.7	2.1	-459	7700
7	G	80	375	530	-73	-67	1.8	2.3	-404	6700
8	H	55	433	614	-88	-74	1.9	2.1	-416	6600
9	A	75	427	588	-76	-70	2.1	2.6	-440	7200
10	D	60	370	534	-68	-71	1.6	2.1	-389	6400
11	E	75	381	527	-71	-68	2.1	2.3	-406	6500
12	G	70	390	580	-87	-71	2.6	2.7	-464	7900
13	H	55	461	614	-91	-87	1.8	2.1	-444	7100
14	I	80	426	601	-17	-14	1.8	2.2	-239	4800
15	J	60	442	594	-24	-16	1.9	2.3	-259	4700
16	K	75	388	534	-15	-15	2.2	2.2	-242	4500
17	L	50	387	560	-34	-26	2.4	2.1	-274	5100
18	M	65	477	597	-14	-8	1.7	2.4	-241	4400
19	N	80	434	614	-22	-14	1.6	2.6	-277	4800
20	O	70	411	564	-26	-20	1.8	2.2	-260	5000
21	B	60	388	522	-36	-24	2.1	2.3	-287	5100
22	C	75	391	544	-27	-21	2.1	2.2	-264	4500
23	D	55	404	564	-34	-64	1.7	2.1	-342	5700
24	F	80	375	577	-11	-7	1.7	2.3	-228	4500
25	G	70	398	589	-71	-64	1.8	1.1	-296	4700

(continued)

Serial No.	Steel Code	Thickness (mm)	YS (MPa)	TS (MPa)	vTrs of Surface Portion (°C)	vTrs of 1/2t Portion (°C)	RD/(110) of Surface Portion	RD/(110) of 1/2t Portion	Left Side of Relational Expression (1)	Kca(-10°C) (N/mm ^{3/2})
26	H	65	384	572	-68	-66	1.2	1.3	-310	5400
27	A	60	423	566	-62	-54	1.7	1.9	-334	6000
28	F	70	402	534	-68	-63	1.4	1.8	-347	6000
29	B	65	411	547	-72	-52	1.3	2.0	-347	6100
Note 1: Underlined value is out of the range according to the present invention. Note 2: Relational Expression (1) $vTrs_{(surface)} + 1.9 \times vTrs_{(1/2t)} - 6 \times RD/(110)_{(surface)} - 84 \times RD/(110)_{(1/2t)} \leq -350$ Note 3: 1/2t represents the central portion in the thickness direction.										

Claims

1. A high-strength thick steel plate for structural use having excellent brittle crack arrestability, the steel plate having a metallographic structure mainly including a ferrite phase and including a texture, in which the integration degree I of the RD//{(110)} plane in a surface portion is 1.3 or more and the integration degree I of the RD//{(110)} plane in a central portion in the thickness direction is 1.8 or more, wherein a Charpy fracture appearance transition temperature $vTrs$ in the surface portion is -60°C or lower and a Charpy fracture appearance transition temperature $vTrs$ in the central portion in the thickness direction is -50°C or lower.
2. The high-strength thick steel plate for structural use having excellent brittle crack arrestability according to Claim 1, wherein the Charpy fracture appearance transition temperature and the integration degree I of the RD//{(110)} plane in the surface portion and the central portion in the thickness direction satisfy the relational expression (1) below:

$$vTrs_{(surface)} + 1.9 \times vTrs_{(1/2t)} - 6 \times I_{RD//\{(110)\} [surface]} - 84 \times I_{RD//\{(110)\} [1/2t]} \leq -350 \quad \dots (1),$$

where $vTrs_{(surface)}$: the fracture appearance transition temperature of the surface portion ($^{\circ}\text{C}$),
 $vTrs_{(1/2t)}$: the fracture appearance transition temperature of the central portion in the thickness direction ($^{\circ}\text{C}$),
 $I_{RD//\{(110)\} [surface]}$: the integration degree of the RD//{(110)} plane in the surface portion,
and $I_{RD//\{(110)\} [1/2t]}$: the integration degree of the RD//{(110)} plane in the central portion in the thickness direction.

3. The high-strength thick steel plate for structural use having excellent brittle crack arrestability according to Claim 1 or 2, wherein the steel plate has a chemical composition containing, by mass%, C: 0.03% or more and 0.20% or less, Si: 0.03% or more and 0.5% or less, Mn: 0.5% or more and 2.2% or less, Al: 0.005% or more and 0.08% or less, P: 0.03% or less, S: 0.01% or less, N: 0.0050% or less, Ti: 0.005% or more and 0.03% or less and the balance being Fe and inevitable impurities.
4. The high-strength thick steel plate for structural use having excellent brittle crack arrestability according to Claim 3, the steel plate having the chemical composition further containing, by mass%, one or more of Nb: 0.005% or more and 0.05% or less, Cu: 0.01% or more and 0.5% or less, Ni: 0.01% or more and 1.0% or less, Cr: 0.01% or more and 0.5% or less, Mo: 0.01% or more and 0.5% or less, V: 0.001% or more and 0.10% or less, B: 0.0030% or less, Ca: 0.0050% or less and REM: 0.010% or less.
5. A method for manufacturing a high-strength thick steel plate for structural use having excellent brittle crack arrestability, the method comprising heating a slab having the chemical composition according to Claim 3 at a temperature of 900°C or higher and 1150°C or lower, performing rolling in which total cumulative rolling reduction in the austenite recrystallization temperature range and in the austenite non-recrystallization temperature range is 65% or more, in which, while the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range, cumulative rolling reduction is controlled to be 20% or more and average rolling reduction per pass is controlled to be 5.0% or less and in which, subsequently, while the central portion in the thickness direction has a temperature in the austenite non-recrystallization temperature range, cumulative rolling reduction is controlled to be 40% or more and average rolling reduction per pass is controlled to be 7.0% or more and performing accelerated cooling on the rolled steel plate down to a temperature of 600°C or lower at a cooling rate of 4.0°C/s or more.
6. The method for manufacturing a high-strength thick steel plate for structural use having excellent brittle crack arrestability according to Claim 5, the method further comprising a process in which the steel plate which has been subjected to accelerated cooling down to a temperature of 600°C or lower is tempered at a temperature equal to or lower than the A_{C1} point.
7. A method for manufacturing a high-strength thick steel plate for structural use having excellent brittle crack arrestability, the method comprising heating a slab having the chemical composition according to Claim 4 at a temperature of 900°C or higher and 1150°C or lower, performing rolling in which total cumulative rolling reduction in the austenite recrystallization temperature range and in the austenite non-recrystallization temperature range is 65% or more, in which, while the central portion in the thickness direction has a temperature in the austenite recrystallization temperature range, cumulative rolling reduction is controlled to be 20% or more and average rolling reduction per pass is controlled to be 5.0% or less and in which, subsequently, while the central portion in the thickness direction has

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a temperature in the austenite non-recrystallization temperature range, cumulative rolling reduction is controlled to be 40% or more and average rolling reduction per pass is controlled to be 7.0% or more and performing accelerated cooling on the rolled steel plate down to a temperature of 600°C or lower at a cooling rate of 4.0°C/s or more.

- 5 **8.** The method for manufacturing a high-strength thick steel plate for structural use having excellent brittle crack arrestability according to Claim 7, the method further comprising a process in which the steel plate which has been subjected to accelerated cooling down to a temperature of 600°C or lower is tempered at a temperature equal to or lower than the A_{C1} point.

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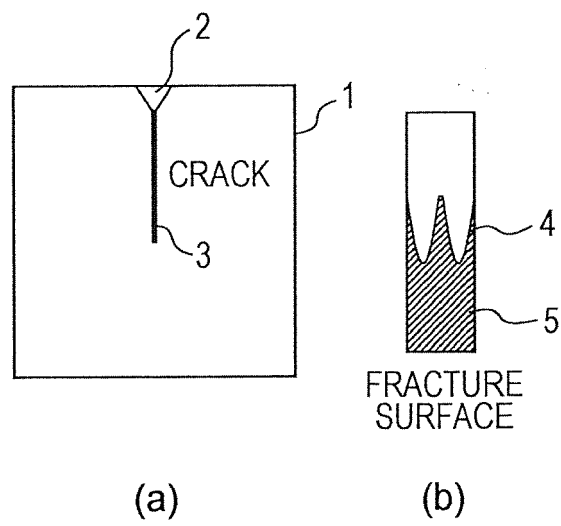
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FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/063410

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/14(2006.01) i, C22C38/58(2006.01) i, C21D8/02(2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60, C21D8/00-8/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2012

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-202931 A (JFE Steel Corp.), 16 September 2010 (16.09.2010), claims (Family: none)	1-8
A	JP 8-209239 A (Kobe Steel, Ltd.), 13 August 1996 (13.08.1996), claims; paragraph [0011] (Family: none)	1-8
A	JP 2008-214646 A (JFE Steel Corp.), 18 September 2008 (18.09.2008), claims (Family: none)	1-8

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

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

06 August, 2012 (06.08.12)

Date of mailing of the international search report

14 August, 2012 (14.08.12)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/063410

5	C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
10	A	JP 2011-241462 A (Kobe Steel, Ltd.), 01 December 2011 (01.12.2011), claims (Family: none)	1-8
15			
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50			
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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 7100814 A [0017]
- JP 2002256375 A [0017]
- JP 3467767 B [0017]
- JP 3548349 B [0017]
- JP 2659661 B [0017]

Non-patent literature cited in the description

- **INOUE et al.** Long Brittle Crack Propagation of Heavy-Thick Shipbuilding Steels. *Conference proceedings, the Japan Society of Naval Architects and Ocean Engineers*, 2006, 359-362 [0018]