(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 488 393 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
08.01.2025 Bulletin 2025/02

(21) Application number: **23763188.2**

(22) Date of filing: **07.02.2023**

(51) International Patent Classification (IPC):
C21D 8/02 $^{(2006.01)}$
C22C 30/02 $^{(2006.01)}$
C22C 19/05 $^{(2006.01)}$
C22C 38/00 $^{(2006.01)}$
C22C 38/58 $^{(2006.01)}$
C22C 38/60 $^{(2006.01)}$
C22F 1/00 $^{(2006.01)}$
C22F 1/10 $^{(2006.01)}$

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C22C 19/05; C22C 30/02; C22C 38/00; C22C 38/58; C22C 38/60; C22F 1/00; C22F 1/10

(86) International application number:
PCT/JP2023/003970

(87) International publication number:
WO 2023/166926 (07.09.2023 Gazette 2023/36)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **01.03.2022 JP 2022030891**

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(54) HIGH-NI ALLOY THICK STEEL SHEET HAVING EXCELLENT WELD HIGH-TEMPERATURE CRACKING RESISTANCE, AND METHOD FOR PRODUCING SAME

(57) A high-Ni alloy steel plate excellent in weld hot cracking resistance includes in mass%: C $\leq$ 0.15%, Si: 0.05-1.0%, Mn: 0.05-2.0%, P $\leq$ 0.035%, S $\leq$ 0.0015%, Cr: 16-28%, Ni: 18-65%, Al: 0.01-1.0%, Ti: 0.15-1.5%, B: 0.0002-0.0030%, N $\leq$ 0.05%, O $\leq$ 0.003%, Mo: 0.01-10%, Cu: 0.01-4.0%, Co: 0.01-3.0%, V: 0.01-0.5%, Mg $\leq$ 0.0050%; and a balance consisting of Fe and impurities, in which a grain size number G defined by JIS G0552 is 1.0 or more and a standard deviation of a concentration distribution of solid solute Ti in a thickness direction is 0.045% or less. A manufacturing method of a high-Ni alloy steel plate excellent in weld hot cracking resistance includes conducting a high-temperature long-time heat treatment at a temperature of 1200 degrees C or more for eight hours or more in a step prior to a final hot rolling.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a high-Ni alloy thick steel plate that is usable as a hot-temperature material and excellent in weld hot cracking resistance, and a manufacturing method thereof.

BACKGROUND ART

[0002] Representative examples of commercially available high-Ni alloy steel containing Al and Ti are alloy 800 and alloy 825. In response to recent increase in demands in developing countries, it has been requested to develop technologies for supplying commercial products that are inexpensive and excellent in surface qualities and usage characteristics. In view of the above request, the steel manufacturing process has been changed from a typical ingot process to a continuous cast process. Especially, the high-Ni alloy steel, which is highly susceptible to slab internal cracks at the time of casting, edge cracks during hot working, and surface defects on the product, has been a target for improvement and development in terms of design for chemical composition of the alloy and smelting, casting, and hot working techniques in order to enhance productivity using the continuous cast process.

[0003] For instance, Patent Literature 1, which is a patent publication relating to the continuous cast technology, discloses a component system and a manufacturing method, where Ti, N, and Si contents are reduced to a lower level, for reducing the generation of surface defects. Patent Literature 2 discloses a manufacturing method, where Ca alloy is not added, for preventing nozzle clogging and surface defects. This literature describes a problem that addition of Ca alloy causes bonding to oxygen in a molten alloy to generate oxide-based non-metallic inclusions, which agglomerate to grow in size, resulting in linear defects on a surface of a final product alloy plate. Patent Literature 3 discloses that CaO-MgO-Al2O3-based inclusions are contained as requisite components and a ratio of numbers of CaO and MgO in all of the number of the inclusions is defined to be 50% or less in order to prevent agglomeration of coarse TiN, which causes surface defects.

[0004] The above-described related arts define the component system and the composition of the inclusions in order to enhance productivity, especially in order to reduce the surface defects.

CITATION LIST

PATENT LITERATURE(S)

[0005]

Patent Literature 1: JP 2003-147492 A
Patent Literature 2: JP 2014-189826 A
Patent Literature 3: JP 2018-59148 A

SUMMARY OF THE INVENTION

PROBLEM(S) TO BE SOLVED BY THE INVENTION

[0006] The inventors have found disadvantages for practical use of high-Ni alloy steel: specifically, the high-Ni alloy steel not only has poor productivity but also causes cracks to be likely to occur during welding work since the high-Ni alloy steel exhibits low weld hot cracking resistance due to being an austenitic single-phase steel. The hot crack is roughly categorized into solidification crack caused at a melted portion and liquation crack caused at a HAZ (Heat Affected Zone). A problem to be solved in the invention is to enhance the weld hot cracking resistance, especially to stabilize the liquation cracking susceptibility at a low level, which has not been studied for the high-Ni alloy steel containing Al and Ti.

[0007] The high-Ni alloy steel containing Al and Ti is an alloy said to have relatively good hot workability. However, when a cast piece contains S of several ppm or more, the hot workability of the cast piece, which has a solidification structure, becomes insufficient for hot working. Accordingly, it is necessary to add a minute amount of Ca alloy or Mg alloy to improve the hot workability. However, when the high-Ni alloy steel (i.e. a target of the invention) is continuously cast with the Ca or Mg alloy being added and a steel product is produced from a slab, bloom, or billet of the steel, welding high-temperature crack is sometimes caused on a structural object constructed by welding the steel product due to heat stress generated by heat input during a welding process. Especially, the liquation crack caused at the HAZ is sometimes regarded as a problem in the high-Ni alloy steel containing Al and Ti. Making the problem worse, a certain component system, which allows favorable welding of a steel plate using a steel ingot smelted and cast by a unit of several tens of kilograms, causes the liquation crack at an HAZ of a steel plate produced using a steel ingot smelted and cast by a unit of several tons. Accordingly, optimization is necessary in terms of not only the components but also to the structure. Especially, a thick steel plate, which is produced through a hot rolling step and a product heat treatment step, is slow in the cooling rate inside a cast slab in proportion to the slab thickness and thus is likely to cause segregation. Such a tendency becomes eminent when a slab having a thickness of 160 mm or more is used as an original slab for producing the steel plate. Meanwhile, it is necessary to define the thickness of the original slab three times as large as a thickness of a product in order to render a recrystallization structure of a high-alloy thick steel plate favorable. Especially, an original slab having a thickness of 160 mm or more is necessary in order to produce a thick steel plate having a thickness exceeding 50 mm. Accordingly, when steel plates having a variation of thicknesses are to be industrially manufactured, it is preferable that the slabs used for manufacturing the steel plates are concentrated to those having a thickness of 160 mm or more in view of production efficiency.

[0008] An object of the invention is to provide a high-Ni alloy thick steel plate that is excellent in weld hot cracking resistance and capable of solving the above-described problem, and a manufacturing method thereof. It should be noted that the thick steel plate defined in the invention refers to a hot rolled steel plate or a steel plate produced by applying temper rolling on a hot rolled steel plate, where a cold rolled steel plate is excluded from the scope of the invention.

MEANS FOR SOLVING THE PROBLEM(S)

[0009] In order to determine the cause of the above problem and solve the problem, the inventors smelted high-Ni alloy steel containing Al and Ti (basic composition) with Ca added (i.e. the steel according to the invention) using an actual machine and produced a cast piece. The produced cast piece was subjected to hot rolling, annealing, and heat treatment in a laboratory to produce a steel product. A bind-welding crack test was performed on the obtained steel product to evaluate liquation cracking susceptibility at the time of welding process. In addition, a study for solving the problem was made using EPMA analysis and the like.

[0010] It was found that TiC, TiN, or TiNC was generated independently or in a manner to surround oxide inclusions in the steel ingot of the high-Ni alloy steel studied by the inventors. Among the above, precipitation behavior of TiC, which is large-sized and acts as a start point of the liquation crack, is focused. Especially for liquation crack, it is found that: there is a region for precipitates containing TiC to locally accumulate in a Ti positive segregation portion within a thickness of the steel plate; the liquation crack occurs starting from TiC generated in the accumulation region; and accumulation of TiC and the liquation crack occur when a concentration distribution of solid solute Ti exceeds 0.045% in terms of a standard deviation. The invention has been made in view of the above.

[0011] Specifically, some of main features of the invention are as follows.

(1) A high Ni alloy thick steel plate excellent in weld hot cracking resistance includes, in mass%: C: 0.15% or less, Si: 0.05 to 1.0%, Mn: 0.05 to 2.0%, P: 0.035% or less, S: 0.0015% or less, Cr: 16 to 30%, Ni: 18 to 65%, Al: 0.01 to 1.0%, Ti: 0.15 to 1.5%, B: 0.0002 to 0.0030%, N: 0.05% or less, O: 0.003% or less, Mo: 0.01 to 10%, Cu: 0.01 to 4.0%, Co: 0.01 to 3.0%, V: 0.01 to 0.5%, Mg: 0.0050% or less; and a balance consisting of Fe and impurities, in which a grain size number G defined by JIS G0552 is 1.0 or more and a standard deviation of a concentration distribution of solid solute Ti in a thickness direction is 0.045% or less.

(2) The high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to (1) further includes, in mass%, in place of a part of Fe, one or two elements selected from the group consisting of A group and B group below:

A group: one or more of Ca: 0.0003 to 0.0050%, Sn:0.0001 to 0.05%, Zn + Pb + Bi: 0.0010% or less, Zr: 0.0001 to 0.5%, Hf: 0.0001 to 0.5%, and La + Ce + Nd + Pr: 0.0001 to 0.0050%; and
B group: one or more of W: 0.01 to 3.0%, Nb: 0.001 to 4.0%, and Ta: 0.001 to 1.0%.

(3) In the high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to (1) or (2), the high-Ni alloy thick steel plate is used in a welded structure.

(4) A manufacturing method of the high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to (1) or (2), the method includes: preparing a steel ingot produced by continuous cast and having a thickness of 160 mm or more and a ratio of a slab thickness to a product thickness being 3.0 or more; and conducting a high-temperature long-time heat treatment at a temperature of 1200 degrees C or more for eight hours or more in a step prior to a final hot rolling.

(5) A manufacturing method of the high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to (3), the method includes: preparing a steel ingot produced by continuous cast and having a thickness of 160 mm or more and a ratio of a slab thickness to a product thickness being 3.0 or more; and conducting a high-temperature long-time heat treatment at a temperature of 1200 degrees C or more for eight hours or more in a step prior to a final hot rolling.

[0012] According to the above aspect of the invention, a welded structure with a high-Ni alloy thick steel plate containing Al and Ti, which is usable as a high-temperature material, can be easily and stably manufactured. There can be provided a high-Ni alloy thick steel plate containing Al and Ti that is excellent in hot workability, unlikely to cause cracks at a heat affected zone by welding when a welded structure is produced, and excellent in creep properties at a high temperature and oxidation resistance.

DESCRIPTION OF EMBODIMENT(S)

Chemical Composition

[0013] Initially, the reason for specifying a content of each of requisite components of the invention will be described below. It should be noted that the content of each of the components are represented by mass%.

S: 0.15% or Less

[0014] C is an element added in order to ensure strength of a high-temperature material and a heat-resistant alloy. Especially, when a high-temperature strength property is required, a content of C of 0.015% or more, preferably 0.05% or more is added. The C content is limited to 0.15% or less. C is present in a form of a TiC precipitates in the alloy of the invention. When the C content exceeds 0.15%, Cr carbide is generated, so that high-temperature property and corrosion resistance are deteriorated. The C content is preferably 0.10% or less, more preferably 0.085% or less.

Si: 0.05 to 1.0%

[0015] A content of Si of 0.05% or more is added for deoxidation and improvement in oxidation resistance. However, the added content of Si exceeding 1.0% results in increase in the solidification cracking susceptibility and liquation cracking susceptibility of the steel, and possibility for intermetallic compound to be precipitated, so that the high-temperature property is deteriorated. Therefore, an upper limit of the Si content is limited to 1.0%. The upper limit of the Si content is preferably 0.7%, more preferably 0.5%.

Mn:0.05 to 2.0%

[0016] Mn is effective for enhancing stability of an austenitic phase to improve heat resistance. Therefore, it is preferable to actively add Mn to the alloy of the invention. In order to improve the heat resistance, a content of Mn of 0.05% or more is added. However, when the content of the added Mn exceeds 2.0%, contrary to expectations, the intermetallic compound is likely to be precipitated to deteriorate the heat resistance and adversely affect the solidification cracking susceptibility. Therefore, an upper limit of the Mn content is defined as 2.0%. The upper limit of the Mn content is preferably 1.5%, more preferably 1.3%.

P: 0.035% or Less

[0017] P is an element inevitably mixed from a raw material and has an effect of increasing the solidification cracking susceptibility. Therefore, an upper limit of a P content is limited to 0.035% or less. The P content is preferably 0.030% or less.

S: 0.0015% or Less

[0018] S is an element inevitably mixed from a raw material and deteriorates hot workability and oxidation resistance. Therefore, an upper limit of an S content is limited to 0.0015% or less, preferably 0.0010% or less. S is an element whose content can be lowered by refining. However, a large cost is required in order to extremely lower the S content. Therefore, a lower limit of the S content is preferably 0.0001%.

Cr: 16 to 28%

[0019] Cr is a requisite element in order for the heat-resistant alloy used as a high-temperature material to exhibit oxidation resistance. Therefore, a content of Cr is 16% or more, preferably 18% or more. However, when the content exceeds 28%, stability of the structure at a high temperature is lowered even with a large content of Ni, so that the intermetallic compound is precipitated and the heat resistance is deteriorated. The upper limit of the Ni content is preferably 26%. It should be noted that the most appropriate Cr content differs depending on the contents of Ni, Si, Mo, and other elements. For instance, when the Ni content is approximately 30%, the most appropriate Cr content is approximately 20%. Alternatively, when a Ni+Cu content is approximately 45%, the most appropriate Cr+Mo content is approximately 25%.

Ni: 18 to 65%

[0020] Ni stabilizes an austenite structure at a high temperature and improves toughness and corrosion resistance against various acids. Therefore, a content of Ni is 18% or more, preferably 20% or more, more preferably 25% or more. More contents of Cr, Mo, Al, and Ti, which are necessary for ensuring the heat resistance, can be added by increasing the Ni content. Meanwhile, because Ni is an expensive element, the upper limit of the Ni content in the steel of the invention is defined to be 65% or less in view of production cost.

Al: 0.01 to 1.0%

[0021] Al is a deoxidizing element and has an effect of forming a NiAl ordered phase in a high-Ni alloy to enhance a high-temperature strength. In the invention, it is necessary that a content of Al of 0.01 % or more, preferably 0.05% or more is required in order to control a composition of oxides to enhance hot workability. However, when the Al content exceeds 1.0%, the intermetallic compound is likely to be precipitated to inhibit the heat resistance. Further, an excessive Al content results in increase in the liquation cracking susceptibility during a welding process. Therefore, an upper limit of the Al content is defined as 1.0%. The upper limit of the Al content is preferably 0.60%.

Ti: 0.15 to 1.5%

[0022] Ti has an effect of forming a NiTi ordered phase in a high-Ni alloy to enhance the high-temperature strength. For the above purpose, it is necessary that the Ti content is 0.15% or more, preferably 0.2% or more. However, when the Ti content exceeds 1.5%, the intermetallic compound is likely to be precipitated to inhibit the heat resistance. Further, an excessive Ti content results in increase in the liquation cracking susceptibility during a welding process. The upper limit of the Ti content is preferably 1.0%, more preferably 0.85%.

B: 0.0002 to 0.0030%

[0023] B is an element for improving the hot workability of the steel and significantly facilitates hot drawing process in a high-temperature range. In addition, since B improves high-temperature creep strength, B is actively added especially for a steel used in a high-temperature environment. Though it is not clearly known how B improves the hot workability, it is believed that B, which is segregated in grain boundaries, enhances the grain boundary strength. The effect of improving the hot drawability by mixing B is exhibited when the B content is 0.0002% or more. Accordingly, a lower limit of the B content is 0.0002%. However, an excessive B content promotes the solidification crack. Therefore, the upper limit of the B content is defined to be 0.0030%. The upper limit of the B content is preferably 0.0015%.

N: 0.05% or Less

[0024] N is an element effective for improving the high-temperature strength. Meanwhile, N reacts with Ti and Al, which are actively added in the invention, to form AlN and/or TiN that are non-metallic inclusions deteriorating the material properties. In addition, N forms a complex with oxides to promote nozzle clogging during a continuous cast process. N is thus a harmful element. Therefore, the N content is 0.05% or less. The N content is preferably 0.04% or less, more preferably 0.03% or less.

O: 0.003% or Less

[0025] Oxygen reacts with Ca, Mg, Al, and Ti in the alloy of the invention to form oxide inclusions. A content of oxygen, which depends on the total amount of the oxide inclusion, is an important factor as an index for deoxidation of the alloy. When the oxygen content exceeds 0.003%, desired deoxidation equilibrium cannot be achieved and nozzle clogging is likely to occur during the continuous cast process. In addition, oxygen promotes generating coarse TiC that is to be the start point for the liquation crack, which causes adverse effects on the weld hot cracking resistance (i.e. a target to be achieved by the invention). Therefore, an upper limit of the oxygen content is defined as 0.003%. The upper limit of the oxygen content is preferably 0.0025%, more preferably 0.002%. On the other hand, reduction in the oxygen content, which advantageously reduces nozzle clogging and welding high-temperature crack by reducing oxide inclusions and inclusions containing coarse TiC, in turn generates excessive Ca and excessive Mg in the alloy to lower the hot workability. Therefore, a lower limit of the oxygen content is preferably 0.0003% or more.

Mo: 0.01 to 10%

[0026] Mo is an element that enhances the high-temperature strength and corrosion resistance of the alloy. In order to enhance these properties, the Mo content is 0.01% or more, preferably 0.05% or more, and still more preferably 0.15% or more. Meanwhile, because Mo is an expensive element, the upper limit of the Mo content in the steel of the invention is defined to be 10% in order to reduce the cost of the alloy. The upper limit of the Mo content is preferably 3.0%, more preferably 2.0%.

Cu: 0.01 to 4.0%

[0027] Cu is an element that enhances the corrosion resistance of the alloy against acids and dew point corrosion resistance, which is a frequent issue of concern in high-temperature equipment, and also enhances the high-temperature strength and the structure stability. In order to enhance the heat resistance and corrosion resistance, a Cu content is 0.01% or more, preferably 0.02% or more, and still more preferably 0.05% or more. However, when the Cu content exceeds 4.0%, the alloy is likely to be embrittled when being solidified. Therefore, the upper limit of the Cu content is defined to be 4.0%. The upper limit of the Cu content is preferably 3.0%, more preferably 2.0%.

Co: 0.01 to 3.0%

[0028] Co is an element that is effective for enhancing the high-temperature structure stability and the corrosion resistance of the alloy. In order to enhance these properties, a Co content is 0.01% or more, preferably 0.02% or more, and still more preferably 0.1% or more. When the Co content exceeds 3.0%, effects corresponding to the cost of Co, which is an expensive element, cannot be achieved. Therefore, the upper limit of the Co content is defined to be 3.0%. The upper limit of the Co content is preferably 1.5%.

V: 0.01 to 0.5%

[0029] When a content of V of 0.01% or more is added, V has an effect of improving the high-temperature properties of the alloy by solid solution strengthening or precipitation strengthening. However, when the V content exceeds 0.5%, the solidification cracking susceptibility is increased. The lower limit of the V content is preferably 0.02%, more preferably 0.03%. Further, the V content is preferably in a range from 0.03% to 0.5%.

Mg: 0.0050% or Less

[0030] Mg is an element that usually provides an effect of improving the hot workability of the alloy if a content of Mg is small. In the invention, addition of Mg exerts adverse effect of promoting generation of MgO inclusions, which increase the liquation cracking susceptibility during a welding process. In addition, excessive Mg that does not form oxides segregates in the grain boundaries to lower the grain boundary strength in a high temperature range (e.g., 900 degrees C). Thus, the hot workability is lowered and the liquation cracking susceptibility is increased in the high temperature range. When deoxidation is strengthened in producing the steel of the invention, Mg is inevitably picked up from slag, furnace wall, and the like. In view of the above findings, Mg, whose content has to be lowered as far as possible in the invention, is not added in the alloy. An upper limit of the Mg content is defined as 0.0050%. The upper limit of the Mg content is preferably 0.0040%.

Grain Size Number G Defined by JIS G0552 $\geq$ 1.0

[0031] P, S, and Mg, which lower the melting point of the steel, segregate in the grain boundaries of austenitic high-alloy steel. The ratio of the grain boundaries in a total volume decreases as the grain size increases, in accordance with which the concentration of P, S, and Mg increases in the grain boundaries. The increase in the concentration of P, S, and Mg lowers the melting point in the grain boundaries, which results in increase in the liquation cracking susceptibility during a welding process. As a result of vigorous study, it is found that the liquation cracking susceptibility increases irrespective of distribution of the concentration of solid solute Ti when the grain size number G < 1.0. Accordingly, it is defined that the grain size number G $\geq$ 1.0. Though the upper limit is not specifically defined, since the high-temperature creep strength decreases when the grain size number G exceeds 8, the grain size number G is preferably in a range from 1 to 8. Especially, the grain size number G is in a range from 1 to 6, preferably 1 to 5 for use requiring creep strength, and the grain size number G is in a range from 3 to 8 for use requiring grain boundary corrosion resistance, moisture oxidation resistance, and high temperature corrosion resistance. As such, it is most preferable that the grain size number G is selected in use according to the usage.

Standard Deviation of Solid Solute Ti Concentration Distribution ≤ 0.045%

[0032] TiC inevitably precipitates in a heat-resistant high alloy added with Ti. A process for generating TiC will be described below. While TiN is preferentially generated in a high-temperature liquid phase, TiC precipitates in a solid-liquid coexistent phase and solid phase. Though most of TiC forms micro precipitates of approximately 0.2 μm or less, some of TiC forms coarse precipitates of a size ranging from 1 micrometer to several tens of micrometers. When the precipitates containing such coarse TiC are present in the grain boundaries, C and Ti in TiC disperse into matrix by heat input during a welding process to lower the melting point at an interface between TiC and matrix, thereby creating start points of liquation crack caused at the HAZ. If solid solute Ti in the steel is not uniformly dispersed, a large number of TiC precipitates of approximately 1 micrometer to several micrometers locally accumulate, where minute grains of approximately 10 micrometers to several tens of micrometers, which are pinned to the accumulating precipitates, are locally generated. It is revealed that the liquation crack during a welding process is caused when the large number of coarse TiC present in the grain boundaries of the thus generated minute grains are liquated by eutetic melting. In other words, in order to improve weldability of Ti-containing heat-resistant high alloy, it is requisite to reduce Ti segregation in the steel plate as much as possible, in addition to the design of components.

[0033] As an index showing the degree of Ti segregation, the inventors has focused on distribution of concentration of solid solute Ti in the steel. Specifically, the analysis result of the concentration of the solid solute Ti at a desired point where no TiC and TiN is generated in a desired cross section of the steel can be obtained by performing a point analysis at the desired point using an EPMA, EDX, or the like. As for a steel plate, since the Ti concentration caused by segregation varies in the thickness direction, in order to determine the concentration distribution, a line analysis in the thickness direction is performed by EPMA or EDX to collect numerical data of the Ti concentration, based on which a standard deviation of the data after removing the numerical data of the points where TiC or TiN is generated is calculated. After a survey on the standard deviation of the solid solute Ti, it is found that the liquation cracking susceptibility of the high alloy steel plate containing Ti is significantly reduced when the standard deviation of the Ti concentration is 0.045% or less. Preferably, the standard deviation is 0.040% or less. It should be noted that a sample used for the line analysis in the thickness direction of a cross section is taken from a point corresponding to an inner side with respect to a point corresponding to half of t (t: the thickness of an original slab (cast ingot)) from an end in the width direction, where the line analysis is performed over the entire thickness (i.e. from a top surface to a bottom surface in the thickness direction). However, it is sometimes difficult to perform the measurement over the entire thickness depending on the specification of the analyzer machine and plate thickness. In such a case, the measurement is performed so that an analysis length of a section corresponding to 1/4t to 3/4t of the original slab from the surface in the thickness direction accounts for 50% or more of a total analysis length (i.e., 50% when a line analysis is performed over the entire thickness of a product) and 10 mm or more. When the thickness of a final product is less than 10 mm, the line analysis is performed over the entire thickness of the product.

Heat-Keeping Conditions in Step Prior to Final Hot Rolling Step: 1200 Degrees C or More for Eight Hours or More

[0034] High alloy thick steel plate is typically produced through smelting, casting, hot rolling, and heat treatment in units of several tons to one hundred and several tens of tons. Smelting process is performed in an order of a melting step using an electric furnace, rough decarbonization step using a converter furnace, and finish decarbonization step using VOD, AOD, or a combination of VOD and AOD. Subsequently, the casting process is performed by continuous casting or ingot casting. The hot rolling is a process for keeping a slab at an appropriate temperature depending on properties of the steel and rolling the slab to a predetermined thickness. It should be noted that high alloy thick steel plate, which has a large deformation resistance during hot working, is sometimes subjected to the hot rolling process for a plurality of times to a desired product thickness and then subjected to a product heat treatment and a refinement step, thereby providing a product steel.

[0035] In order to reduce segregation of Ti in a steel plate product of high alloy containing Ti, it is necessary to optimize a cooling rate at the time of solidification and electromagnetic stirring conditions. However, it is difficult to completely eliminate segregation only by the above measures in producing a steel ingot of several tons to ten and several tons or more. Especially, it is extremely difficult to eliminate the segregation in a slab whose thickness is 160 mm or more, where cooling rate is low. Accordingly, it is necessary to apply heat treatment at a high temperature for a long time in the heat treatment after the casting if the segregation cannot be eliminated only by the measures during the steel-making. However, if the heat treatment is applied at the stage of the product heat treatment, the crystal grains in the steel plate excessively grow in size to increase the liquation cracking susceptibility, contrary to expectations.

[0036] After vigorous study, it is revealed that, in order to achieve the requirements of the invention, it is necessary to apply a high-temperature long-time heat treatment at 1200 degrees C or more, preferably 1230 degrees C or more and for eight hours or more, preferably for 15 hours or more in a step prior to the final hot rolling. The high-temperature long-time heat treatment is optionally performed in a step prior to the initial rolling process. More preferably, the advantages of the invention can be most effectively achieved by applying the heat treatment at a high temperature for a long time while distances between segregation bands are small and high dispersion path (e.g. dislocations and recrystallized grain boundaries) is introduced as much as possible. Accordingly, when a plurality of rolling steps are to be performed, it is most preferable to introduce the high-temperature long-time heat treatment step between a rolling step (breakdown rolling) preceding the final rolling and the final rolling step (final hot rolling).

[0037] The grain size number G in the steel plate increases as the heat treatment temperature is lowered and the heat treatment time is shortened in the product heat treatment performed after the hot rolling. The grain size number G in the steel plate to be 1.0 or more can be achieved by adjusting the temperature and time in the product heat treatment performed after the hot rolling in accordance with the chemical composition of the steel plate.

[0038] The chemical composition of the high-Ni alloy of the invention includes the above components and a balance consisting of Fe and impurities. Further, in place of a part of Fe, the following component(s) (mass%) is optionally contained. The reason for specifying the contents of the optional elements will be described below.

Chemical Composition

[0039]

Ca: 0.0003 to 0.0050%
Sn:0.0001 to 0.05%
Zn + Pb + Bi: 0.0010% or less
Zr: 0.0001 to 0.5%
Hf: 0.0001 to 0.5%
La + Ce + Nd + Pr: 0.0001 to 0.0050%

[0040] At a content of Ca of 0.0003% or more, preferably 0.0010% or more, more preferably 0.0015% or more, Ca fixes S in the alloy in a form of CaS to improve the hot workability and weld hot cracking resistance of the alloy. The reaction progresses as follows. Ca is bonded with oxygen in the alloy to form CaO and CaO-Al2O3 to substantially annihilate oxygen dissolved in the alloy (free oxygen). Subsequently, residual Ca reacts with S in the alloy to form CaS. However, excessively added Ca deteriorates ductility at a high temperature (around 1100 degrees C). Therefore, an upper limit of the Ca content is defined to be 0.0050%. The upper limit of the Ca content is preferably 0.0045%.

[0041] Sn is an element that improves the corrosion resistance and the high-temperature creep strength of the steel at a content of 0.0001% or more, preferably 0.005% or more. Sn is optionally added as necessary. However, the hot workability is deteriorated when Sn is added at a content exceeding 0.05%. Therefore, the upper limit of Sn content is defined to be 0.05%.

[0042] Further, Zn, Pb, and Bi considerably lower the hot workability in an austenitic single-phase alloy. Accordingly, the upper limit of each of the contents of these elements has to be strictly defined. Preferably, Zn ≤ 0.0010%, Pb ≤ 0.0010%, Bi ≤ 0.0010% and a sum of the contents of Zn, Pb, and Bi is defined to be 0.0010% or less.

[0043] Zr and Hf fix P and S each at a content of 0.0001% or more, preferably 0.005% or more to improve the solidification cracking susceptibility and the high-temperature corrosion resistance of the steel. Zr and Hf are optionally added as necessary. However, when Zr and Hf are added in a large amount exceeding 0.5%, productivity (e.g. hot workability) and surface texture are deteriorated. Accordingly, the upper limit of the content of each of Zr and Hf is defined to be 0.5%.

[0044] La, Ce, Nd, and Pr are elements that fix P and S at a sum of contents of 0.0001% or more, preferably 0.0010% or more to improve oxidation resistance and solidification cracking susceptibility, and promote increase in TiC at the sum of contents exceeding 0.0050% to increase the liquation cracking susceptibility of the steel. Therefore, the upper limit of the sum of contents of these elements is defined to be 0.0050%. It should be noted that these elements are added in an independent form of metal of each element, in a form of an alloy, misch metal, or the like.

[0045] The reason for specifying the contents of the optional elements will be further described below.

W: 0.01 to 3.0%

[0046] W, which is an element that enhances the strength of heat-resistant alloy similar to Mo, is optionally added at a content of 0.01% or more, preferably 0.05% or more, and further preferably 0.1% or more, as necessary. In order to enhance the heat resistance of the steel of the invention, the upper limit of the W content is 3.0%.

Nb: 0.001 to 4.0%, Ta: 0.001 to 1.0%

[0047] Nb and Ta will be described below. Nb and Ta, which are optionally added as necessary, has an effect of improving the high-temperature strength of the steel by solid solution strengthening or precipitation strengthening. Excessive addition of Nb and/or Ta results in increase in the solidification cracking susceptibility. Therefore, upper limits of the Nb content and the Ta content are defined to be 4.0% and 1.0%, respectively. The upper limit of each of Nb and Ta content is preferably 0.8%. The lower limit of each of the Nb and Ta contents is 0.001%, preferably 0.01%, more preferably 0.03%. Further, each of the Nb and Ta content is preferably in a range from 0.03% to 0.8%.

[0048] The thick steel plate according to the invention refers to a steel plate whose thickness is 3 mm or more.

Example 1

[0049] Example 1 will be described below. Nine pieces of steel ingots of different chemical components were prepared by melting steel in an 80-ton electric furnace, adding Al, Ti, and optionally Ca in a secondary smelting step, continuously casting the steel to produce a continuously cast steel ingot of 400-mm thickness and 700-mm width, and cutting the continuously cast steel ingot at 250-mm lengths. These steel ingots were bisected at a point of 200-mm thickness and trisected into 100-mm pieces in a section of 200 mm to 500 mm in the width direction to produce cast pieces of 200-mm thickness, 100-mm width, and 250-mm length, which were used as materials to be rolled.

[0050] The material to be rolled was subjected to heating before breakdown rolling and the breakdown rolling (200-mm thick/80-mm thick), intermediate heat treatment after the breakdown rolling and before the final hot rolling, heating before the final hot rolling, and the final hot rolling (80-mm thick/13-mm thick), and further product heat treatment to produce a 13-mm thick and 130-mm wide steel plate. The standard deviation of the solid solute Ti concentration distribution of the thick steel plate falling within the definition of the invention can be achieved by satisfying suitable producing conditions defined in the invention in any one of or in total of the heating before the breakdown rolling, the intermediate heat treatment, and heating before the final hot rolling.

[0051] Chemical component values of the produced steel plates are shown in separate Tables 1-1 and 1-2. It should be noted that the balance of the components listed in Tables 1-1 and 1-2 consists of Fe and impurity elements. The units are all expressed in mass%. It should also be noted that blank columns in Tables 1-1 and 1-2 show that the corresponding components are at an impurity level.

Table 1-1

Steel Ingot No	Component (mass%)																		Note
	C	Si	Mn	P	S	Cr	Ni	Al	Ti	B	N	O	Mo	Cu	Co	V	Ca	Mg	
1	0.026	0.25	0.32	0.022	0.0005	20.42	30.89	0.36	0.23	0.0002	0.007	0.0010	0.01	0.02	0.05	0.03	0.0025	0.0023	Inventive Ex.
2	0.070	0.38	1.16	0.023	0.0002	19.84	30.81	0.50	0.48	0.0004	0.007	0.0011	0.23	0.11	0.32	0.04	0.0018	0.0026	
3	0.014	0.21	0.37	0.016	0.0004	21.91	38.92	0.14	0.69	0.0014	0.007	0.0009	3.06	2.12	0.06	0.06	0.0019	0.0038	
4	0.017	0.27	0.55	0.022	0.0001	21.85	42.95	0.04	0.65	0.0006	0.009	0.0006	2.90	1.97	0.04	0.04	0.0010	0.0031	
5	0.009	0.18	0.22	0.015	0.0000	20.03	43.35	0.21	1.15	0.0003	0.005	0.0008	2.78	1.75	0.69	0.36	0.0004	0.0033	
6	0.008	0.15	0.08	0.012	0.0000	22.49	60.05	0.18	0.35	0.0006	0.009	0.0014	8.47	0.05	0.06	0.02	0.0032	0.0015	
7	0.025	0.18	0.12	0.013	0.0014	21.84	62.26	0.17	0.23	0.0009	0.021	0.0015	8.44	0.02	0.02	0.02	0.0038	0.0021	
8	0.027	0.22	0.34	0.017	0.0003	22.49	59.86	0.12	0.23	0.0013	0.031	0.0017	7.16	0.06	0.13	0.03	0.0025	0.0018	
9	0.009	0.48	0.38	0.012	0.0004	23.25	60.23	0.45	0.22	0.0005	0.008	0.0031	5.23	0.05	0.52	0.07		0.0035	

Table 1-2

Steel Ingot No	Component (mass%)											Note
	Sn	**Zn**	Pb	Bi	Zn+Pb+ Bi	Zr	Hf	La+Ce+ Nd+Pr	**W**	**Nb**	**Ta**	
1	0.004	0.0001	0.0002	0.0001	0.0004			0.0038				Inventive Ex.
2												
3												
4						0.11	0.13					
5												
6										3.34	0.002	
7		0.0001		0.0002	0.0003					2.58	0.45	
8									0.83	3.52	0.00	
9												

[0052] The concentration distribution of the solid solute Ti in the steel was evaluated as follows. The test material (13-mm thick), which was cut at a portion near the center in the width direction to show an observation surface on a cross section parallel to the rolling direction and the thickness direction, was embedded in resin and the observation surface was mirror-finished. Line analysis was performed on the observation surface in the thickness direction between top layers of top and bottom sides under conditions of acceleration voltage of 15 kV, beam diameter of 7 μm using EPMA to collect numerical data of the Ti concentration at 7.44 μm intervals. The collected numerical data were averaged. Then, the data points were compared with the average, where data points whose Ti concentration was 1.25 or more times larger than the average were determined to be data points at which TiN or TiC precipitates were detected and were removed from evaluation process. Then, the residual data points were used as the concentration data of the solid solute Ti. The average of the Ti concentration and the standard deviation were again calculated on the used data to determine the standard deviation (%) of the concentration distribution of the solid solute Ti in the thickness direction. It should be noted that the standard deviation was calculated using EXCEL function of STDTV.P.

[0053] Further, austenitic grain boundaries were exposed on the observation surface of the observation test piece by etching using cerium nitrate, where the grain size number was measured by a comparison method using a plate I of ASTME112 in randomly selected five fields of view. The average of the measurements was determined as the grain size number G.

[0054] In a bind welding test, top and bottom surfaces of the test material were each ground by 0.5 mm to thin the test material to 12-mm thick. Then, two plates (50-mm wide, 100-mm long, and 12-mm thick) were cut out. Subsequently, V-shaped bevel (bevel angle: 30 degrees, root face: 1.5 mm) was formed at one side of 100-mm length, where the plates were placed on a thick plate made of SS400 with the bevels being abutted and the entire circumference (except for the abutted portion) was welded to be fixed. The abutted portion was TIG-welded using AWSERNiCr-3 as a welding material under the following conditions: electric current: 180 A, voltage: in a range from 9.5 to 11.5 V, welding speed: 10 cm/min, and feeding speed of the welding material: 35 cm/min. Cross sections of the welded portion were observed at five parts for each of the test pieces. The number of the cross section(s) where a crack was observed was evaluated as a bind cracked portion. The test piece produced no crack in all of five cross sections was determined to be good, whereas the test piece produced a crack in at least one of the cross sections was determined to be fault.

[0055] Table 2 collectively shows signs of the steel plates, steel ingot No., heat treatment conditions, standard deviation of Ti concentration distribution measured by the line analysis, measurements of the grain size number G, and results of the bind welding crack test.

Table 2

Steel Plate Sign	Steel Ingot No	Heat Treatment Conditions				Steel Plate Material		Quality	Note
		Before-Breakdown-Rolling Heating Conditions	Intermediate Heating Conditions	Before-Final-Hot-Rolling Heating Conditions	Product Heat Treatment Conditions	Standard Deviation of Ti Concentration Distribution (mass%)	Grain Size Number **G**	Bind Welding Cracks (n5)	
A	1	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.032	1.8	0	Inventive Ex.
B	1	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1210°C × Uniform Heating 20 min.	0.029	0.2	1	Comp.
C	2	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	11 60°C × Uniform Heating 20 min.	0.037	2.2	0	Inventive Ex.
D	2	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1210°C × Uniform Heating 20 min.	0.035	0.8	3	Comp.
E	2	1180°C × Uniform Heating 1h	None	1250°C × Uniform Heating 20h	11 60°C × Uniform Heating 20 min.	0.041	2.8	0	Inventive Ex.
F	2	1250°C × Uniform Heating 20h	None	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.039	3.2	0	Inventive Ex.
G	2	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 5h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.048	2.6	1	Comp.
H	3	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1100°C × Uniform Heating 20 min.	0.043	2.4	0	Inventive Ex.
I	3	1180°C × Uniform Heating 1h	None	1220°C × Uniform Heating 1h	1100°C × Uniform Heating 20 min.	0.059	2.0	2	Comp.

(continued)

Steel Plate Sign	Steel Ingot No	Heat Treatment Conditions				Steel Plate Material		Quality	Note
		Before-Breakdown-Rolling Heating Conditions	Intermediate Heating Conditions	Before-Final-Hot-Rolling Heating Conditions	Product Heat Treatment Conditions	Standard Deviation of Ti Concentration Distribution (mass%)	Grain Size Number **G**	Bind Welding Cracks (n5)	
J	4	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1100°C × Uniform Heating 20 min.	0.035	1.8	0	Inventive Ex.
K	4	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1200°C × Uniform Heating 20 min.	0.033	0.4	3	Comp.
L	5	1220°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1130°C × Uniform Heating 20 min.	0.044	1.2	0	Inventive Ex.
M	6	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	11 60°C × Uniform Heating 20 min.	0.039	3.8	0	Inventive Ex.
N	6	1180°C × Uniform Heating 1h	None	1220°C × Uniform Heating 1h	11 60°C × Uniform Heating 20 min.	0.050	4.2	3	Comp.
O	6	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1210°C × Uniform Heating 20 min.	0.027	0.8	2	Comp.
P	7	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.029	4.0	0	Inventive Ex.
Q	8	1180°C × Uniform Heating 1h	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	11 60°C × Uniform Heating 20 min.	0.028	3.8	0	Inventive Ex.
R	9	1180°C × Uniform Heating 1h	1200°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	11 60°C × Uniform Heating 20 min.	0.035	4.2	0	Inventive Ex.

[0056] As shown in Table 2, steel plates A, C, E, F, H, J, L, M, P, Q, and R, which satisfied the requirements of the invention, produced no crack in the bind welding test. In contrast, the steel plates B, D, K, and O whose grain size number G was less than 1.0 and the steel plates G, I, and N whose standard deviation of the Ti concentration was greater than 0.045% showed at least one cracked portion in the bind welding test.

Example 2

[0057] Example 2 will be described below. A part of the to-be-rolled material prepared in Example 1 (i.e., the material produced by bisecting 400-mm thick continuous cast steel ingot at a position of 200-mm thick) was also used as the to-be-rolled material in Example 2. In Example 2, the to-be-rolled material was initially subjected to a soaking process. Subsequently, the material was subjected to heating before rolling and the hot rolling to reduce the thickness thereof from 200 mm to 60 mm. Further, the material was subjected to the product heat treatment to produce a thick steel plate of 60-mm thickness. The standard deviation of the solid solute Ti concentration distribution of the thick steel plate that falls within the definition of the invention can be achieved by satisfying suitable producing conditions defined in the invention in any one of or in total of the soaking process and the heating before rolling.

[0058] Ti segregation prominently occurs in a part ranging from one fourth to three fourth of thickness from a surface of the original slab (corresponding to an equiaxed crystal region of the steel ingot (original slab)). Accordingly, the produced thick steel plate (60-mm thick), the backside of which corresponds to the thickness center portion of the steel ingot (original slab), was sliced at a 15-mm thickness position starting from the backside and then ground for 2 mm at the backside and 1 mm at the sliced face to produce a 12-mm thick test material. EPMA line analysis was performed over the entire thickness of the test material. The bind welding test, evaluation of grain size number, and EPMA analysis using the test material were performed in the same manner as those in Example 1.

[0059] Table 3 collectively shows signs of the steel plates, steel ingot No., heat treatment conditions, measurements of the grain size number, standard deviation of Ti concentration distribution measured by the line analysis, and results of the bind welding crack test.

Table 3

Steel Plate Sign	Steel Ingot No	Heat Treatment Conditions			Steel Plate Material		Quality	Note
		Soaking Conditions	Before-Rolling Heating Conditions	Product Heat Treatment Conditions	Standard Deviation of Ti Concentration Distribution (mass%)	Grain Size Number G	Bind Welding Cracks (n5)	
a	1	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.034	1.4	0	Inventive Ex.
b	1	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1210°C × Uniform Heating 20 min.	0.035	-0.2	2	Comp.
c	2	1250°C × Uniform Heating 8h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.043	3.0	0	Inventive Ex.
d	2	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1210°C × Uniform Heating 20 min.	0.039	0.2	2	Comp.
e	2	None	1250°C × Uniform Heating 20h	1160°C × Uniform Heating 20 min.	0.040	2.8	0	Inventive Ex.

(continued)

Steel Plate Sign	Steel Ingot No	Heat Treatment Conditions			Steel Plate Material		Quality	Note
		Soaking Conditions	Before-Rolling Heating Conditions	Product Heat Treatment Conditions	Standard Deviation of Ti Concentration Distribution (mass%)	Grain Size Number G	Bind Welding Cracks (n5)	
f	2	1250°C × Uniform Heating 5h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.049	3.2	2	Comp.
g	3	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1100°C × Uniform Heating 20 min.	0.042	2.0	0	Inventive Ex.
h	3	None	1220°C × Uniform Heating 1h	1100°C × Uniform Heating 20 min.	0.063	2.0	4	Comp.
i	4	1 250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1100°C × Uniform Heating 20 min.	0.035	1.8	0	Inventive Ex.
j	4	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1200°C × Uniform Heating 20 min.	0.035	0.0	3	Comp.
k	5	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1130°C × Uniform Heating 20 min.	0.042	1.4	0	Inventive Ex.
l	6	1220°C × Uniform Heating 8h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.043	4.5	0	Inventive Ex.
m	6	None	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.055	3.8	3	Comp.
n	6	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1210°C × Uniform Heating 20 min.	0.030	0.4	1	Comp.
o	7	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.031	3.6	0	Inventive Ex.
P	8	1250°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.030	3.2	0	Inventive Ex.

(continued)

Steel Plate Sign	Steel Ingot No	Heat Treatment Conditions			Steel Plate Material		Quality	Note
		Soaking Conditions	Before-Rolling Heating Conditions	Product Heat Treatment Conditions	Standard Deviation of Ti Concentration Distribution (mass%)	Grain Size Number G	Bind Welding Cracks (n5)	
q	9	1200°C × Uniform Heating 20h	1220°C × Uniform Heating 1h	1160°C × Uniform Heating 20 min.	0.032	2.8	0	Inventive Ex.

[0060] As shown in Table 3, steel plates a, c, e, g, i, k, l, o, p, and q, which satisfied the requirements of the invention, produced no crack in the bind welding test. In contrast, the steel plates b, d, j, and n whose grain size number G was less than 1.0 and the steel plates f, h, and m whose standard deviation of the Ti concentration was greater than 0.045% showed at least one cracked portion in the bind welding test.

[0061] As can be understood from the above Examples, it is clarified that high-Ni alloy excellent in weld hot cracking resistance can be produced by the invention.

INDUSTRIAL APPLICABILITY

[0062] According to the invention, a welded structure with a high-Ni alloy thick steel plate containing Al and Ti, which is usable in a high temperature application, can be suitably produced, so that design freedom can be enhanced and weld repair cost can be reduced. Further, these alloys are not only usable for high-temperature application but also widely usable for welded structures that are to be used for high corrosion resistant application.

[0063] Stable weld quality can be provided in response to increasing demand for high-Ni alloy, which greatly contributes to industrial progress.

Claims

1. A high-Ni alloy thick steel plate excellent in weld hot cracking resistance, comprising, in mass%:

   C: 0.15% or less, Si: 0.05 to 1.0%, Mn: 0.05 to 2.0%, P: 0.035% or less, S: 0.0015% or less, Cr: 16 to 28%, Ni: 18 to 65%, Al: 0.01 to 1.0%, Ti: 0.15 to 1.5%, B: 0.0002 to 0.0030%, N: 0.05% or less, O: 0.003% or less, Mo: 0.01 to 10%, Cu: 0.01 to 4.0%, Co: 0.01 to 3.0%, V: 0.01 to 0.5%, Mg: 0.0050% or less; and a balance consisting of Fe and impurities, wherein
   a grain size number G defined by JIS G0552 is 1.0 or more and a standard deviation of a concentration distribution of solid solute Ti in a thickness direction is 0.045% or less.

2. The high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to claim 1, further comprising, in mass%, in place of a part of Fe, one or two elements selected from the group consisting of A group and B group below:

   A group:
   one or more of Ca: 0.0003 to 0.0050%, Sn:0.0001 to 0.05%, Zn + Pb + Bi: 0.0010% or less, Zr: 0.0001 to 0.5%, Hf: 0.0001 to 0.5%, and La + Ce + Nd + Pr: 0.0001 to 0.0050%; and
   B group:
   one or more of W: 0.01 to 3.0%, Nb: 0.001 to 4.0%, and Ta: 0.001 to 1.0%.

3. The high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to claim 1 or 2, wherein the high-Ni alloy thick steel plate is used in a welded structure.

4. A manufacturing method of the high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to claim 1 or 2, the method comprising:

   preparing a steel ingot produced by continuous cast and having a thickness of 160 mm or more and a ratio of a slab

thickness to a product thickness being 3.0 or more; and
conducting a high-temperature long-time heat treatment at a temperature of 1200 degrees C or more for eight hours or more in a step prior to a final hot rolling.

5. A manufacturing method of the high-Ni alloy thick steel plate excellent in weld hot cracking resistance according to claim 3, the method comprising:

preparing a steel ingot produced by continuous cast and having a thickness of 160 mm or more and a ratio of a slab thickness to a product thickness being 3.0 or more; and
conducting a high-temperature long-time heat treatment at a temperature of 1200 degrees C or more for eight hours or more in a step prior to a final hot rolling.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/003970

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i; ***C22C 30/02***(2006.01)i; ***C22C 19/05***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/58***(2006.01)i; ***C22C 38/60***(2006.01)i; ***C22F 1/00***(2006.01)i; ***C22F 1/10***(2006.01)i

FI: C22C30/02; C22C38/58; C22C19/05 Z; C22F1/10 H; C21D8/02 D; C22F1/00 604; C22F1/00 623; C22F1/00 630K; C22F1/00 630M; C22F1/00 640B; C22F1/00 650A; C22F1/00 682; C22F1/00 683; C22F1/00 684C; C22F1/00 691B; C22F1/00 691C; C22F1/00 694A; C22C38/60; C22C38/00 302Z

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)

C21D8/02; C22C30/00-30/06; C22C19/00-19/07; C22C38/00-38/60; C22F1/00; C22F1/10

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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 2014-84493 A (NIPPON YAKIN KOGYO CO., LTD.) 12 May 2014 (2014-05-12) entire text	1-5
A	JP 58-56024 B2 (POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORP.) 13 December 1983 (1983-12-13) entire text	1-5
A	WO 2018/181570 A1 (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 04 October 2018 (2018-10-04) entire text	1-5
P, A	WO 2022/220242 A1 (NIPPON STEEL STAINLESS STEEL CORP.) 20 October 2022 (2022-10-20) entire text	1-5

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search **22 March 2023**	Date of mailing of the international search report **04 April 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/003970

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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