



(11)

EP 4 556 138 A1

(12)

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

(43) Date of publication:
21.05.2025 Bulletin 2025/21

(21) Application number: **23862819.2**

(22) Date of filing: **28.07.2023**

(51) International Patent Classification (IPC):
B22D 11/00 ^(2006.01) **B22D 11/108** ^(2006.01)
B22D 11/12 ^(2006.01) **B22D 11/16** ^(2006.01)
C21D 8/02 ^(2006.01) **C21D 9/00** ^(2006.01)
C22C 38/00 ^(2006.01) **C22C 38/08** ^(2006.01)
C22C 38/54 ^(2006.01)

(52) Cooperative Patent Classification (CPC):
B22D 11/00; B22D 11/108; B22D 11/12;
B22D 11/16; C21D 8/02; C21D 9/00; C22C 38/00;
C22C 38/08; C22C 38/54

(86) International application number:
PCT/JP2023/027675

(87) International publication number:
WO 2024/053276 (14.03.2024 Gazette 2024/11)

(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: **09.09.2022 JP 2022143845**

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(54) **STEEL CAST SLAB, CONTINUOUS CASTING METHOD, AND METHOD FOR PRODUCING STEEL CAST SLAB**

(57) There is provided a steel slab which contains Ni in an amount of not less than 2.0 mass % and less than 7.5 mass % and has few surface cracks. The Ni-containing steel slab includes, in mass %: C: not less than 0.03% and not more than 0.10%; Si: not less than 0.01% and not more than 0.50%; Mn: not less than 0.10% and not more than 1.00%; P: not less than 0.001% and not more than 0.010%; S: not less than 0.0001% and not more than

0.0050%; Ni: not less than 2.0% and less than 7.5%; Al: not less than 0.010% and not more than 0.080%; N: not less than 0.0010% and not more than 0.0050%; and O: not less than 0.0005% and not more than 0.0040%, with the balance being Fe and incidental impurities. The density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more.

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Description

Technical Field

- 5 **[0001]** The present invention relates to a steel slab containing Ni (nickel), a continuous casting method, and a method for producing a steel slab.

Background Art

- 10 **[0002]** It is known that the addition of Ni to steel improves the low-temperature toughness. Steel containing Ni (hereinafter also referred to as Ni-containing steel) in an amount of around 9 mass % is called 9% Ni steel. 9% Ni steel can withstand use at temperatures below -160°C, and therefore is widely used, for example, for welded structures to be used at low temperatures, such as an LNG tank.

- 15 **[0003]** Ni-containing steel is known to be likely to form surface defects. For example, many cracks (hereinafter also referred to as surface cracks) are present on and near the surface of a cast slab.

[0004] It has been known that surface cracks in a steel slab containing Ni occur along crystal grain boundaries in a coarse solidified structure. In particular, surface cracks are considered to occur when a tensile stress such as a straightening stress, a bulging stress, or a thermal stress is applied to a steel slab in the temperature range of 600 to 900°C where the ductility of Ni-containing steel is low, i.e., in the secondary cooling zone of continuous casting.

- 20 **[0005]** More specifically, when a tensile stress is applied to a steel slab, S (sulfur), P (phosphorus), etc., contained in the steel slab, become concentrated in a particular area. The increase in the concentrations of S (sulfur) and P (phosphorus) leads to intergranular embrittlement of the steel slab. Therefore, in that area, the embrittled crystal grain boundaries will be fractured by a tensile stress, resulting in the occurrence of surface cracks.

- 25 **[0006]** In conventional practice, in order to prevent such surface cracks, the temperature of a steel slab is controlled during secondary cooling in the casting of the steel slab. For example, Patent Literature 1 discloses that when molten steel containing 5 to 10 mass % of Ni is continuously cast, the cooling rate and the surface temperature of a cast slab in the secondary cooling zone are controlled.

- 30 **[0007]** Patent Literature 2 discloses that when Ni-containing steel containing 8 to 10 mass % of Ni is continuously cast, the reduction of area in the casting process is estimated, and the secondary cooling intensity is controlled so that the reduction of area becomes 50% or more.

Citation List

Patent Literature

- 35 **[0008]**

PTL 1: Japanese Unexamined Patent Application Publication No. 08-10919

PTL 2: Japanese Unexamined Patent Application Publication No. 08-33964

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Summary of Invention

Technical Problem

- 45 **[0009]** Though a number of continuous casting methods, which are directed to reducing surface cracks, have been proposed as described above, it is difficult to completely suppress the occurrence of surface cracks. When surface cracks occur in a steel slab, the surface cracks are removed by so-called finishing, such as grinding of the surface e.g. with a grinder. Therefore, the occurrence of a large number of surface cracks requires a large finishing area and a long finishing time, resulting in a reduced productivity and an increased production cost.

- 50 **[0010]** In recent years, due to the rising price of Ni alloys, attempts have been made to reduce the Ni content in steel. For example, 7% Ni steel has been increasingly used as a substitute steel species for 9% Ni steel. 5% Ni steel has been used for liquefied ethylene fuel containers. Thus, there is a significantly increasing demand for Ni-containing steels having a Ni content of less than 7.5 mass %.

- 55 **[0011]** Steel species having a relatively low Ni content, such as less than 7.5 mass %, also have the above-described production problem, the occurrence of surface cracks in a steel slab along crystal grain boundaries in a coarse solidified structure.

[0012] The present invention has been made in view of the above problems. It is therefore an object of the present invention to provide a steel slab which contains Ni in an amount of not less than 2.0 mass % and less than 7.5 mass %, and

has few surface cracks, a continuous casting method, and a method for producing a steel slab.

Solution to Problem

[0013] In order to solve the above problems, the present invention has the following features.
[0014]

[1] A Ni-containing steel slab including, in mass %: C: not less than 0.03% and not more than 0.10%; Si: not less than 0.01% and not more than 0.50%; Mn: not less than 0.1% and not more than 1.0%; P: not less than 0.001% and not more than 0.010%; S: not less than 0.0001% and not more than 0.0050%; Ni: not less than 2.0% and less than 7.5%; Al: not less than 0.010% and not more than 0.080%; N: not less than 0.0010% and not more than 0.0050%; and O: not less than 0.0005% and not more than 0.0040%, with the balance being Fe and incidental impurities, wherein the density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more.

[2] The steel slab according to [1], further including, in mass %, at least one selected from the following: Cu: not less than 0.03% and not more than 1.50%; Cr: not less than 0.03% and not more than 1.00%; Mo: not less than 0.02% and not more than 1.00%; Nb: not less than 0.003% and not more than 0.100%; V: not less than 0.003% and not more than 0.100%; Ti: not less than 0.005% and not more than 0.020%; B: not less than 0.0002% and not more than 0.0025%; Ca: not less than 0.0005% and not more than 0.0050%; and Mg: not less than 0.0005% and not more than 0.0030%.

[3] A continuous casting method for casting the steel slab according to [1] or [2], including the step of adding a mold powder having a viscosity of 0.5 Pa·s (5 poise) or more at 1300°C into a casting mold.

[4] A continuous casting method for casting the steel slab according to [1] or [2], including the step of oscillating a casting mold at a frequency of 80 cycles per minute or more.

[5] A continuous casting method for casting the steel slab according to [1] or [2], including the steps of:

adding a mold powder having a viscosity of 0.5 Pa·s (5 poise) or more at 1300°C into a casting mold; and oscillating the casting mold at a frequency of 50 cycles per minute or more.

[6] A continuous casting method for casting the steel slab according to [1] or [2], including the steps of:

adding a mold powder having a viscosity of 0.15 Pa·s (1.5 poise) or more at 1300°C into a casting mold; and oscillating the casting mold at a frequency of 80 cycles per minute or more.

[7] A method for producing a steel slab containing Ni, including:

a finishing step of finishing a slab produced by the continuous casting method according to any one of [3] to [6]; and
a heating step of heating the slab after the finishing step at a temperature of 1100°C or less in a heating furnace.

Advantageous Effects of Invention

[0015] According to the present invention, the density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more. Therefore, the size of solidified cells can be made smaller than a conventional size. This makes it possible to reduce segregation of S (sulfur) and P (phosphorus) at the interfaces of solidified cells as compared with conventional steel slabs. Consequently, embrittlement at the interfaces of solidified cells can be reduced. In addition, stress that acts on the interfaces of solidified cells can be dispersed. This makes it possible to reduce the occurrence of cracks at the interfaces of solidified cells, thus reducing the occurrence of cracks on the surface of the steel slab. Accordingly, it becomes possible to reduce the processing time for a finishing treatment to remove surface cracks from the steel slab, thereby improving the productivity and reducing the production cost.

Description of Embodiments

[0016] The Ni-containing steel slab of the present invention (hereinafter also referred to simply as the steel slab) contains Ni in an amount of not less than 2.0 mass % and less than 7.5 mass %. The steel slab can be used, for example, as a low-temperature steel for use in a temperature range lower than room temperature.

[0017] The Ni-containing steel slab of the present invention contains, in mass %: C: not less than 0.03% and not more than 0.10%; Si: not less than 0.01% and not more than 0.50%; Mn: not less than 0.10% and not more than 1.00%; P: not less than 0.001% and not more than 0.010%; S: not less than 0.0001% and not more than 0.0050%; Ni: not less than 2.0% and less than 7.5%; Al: not less than 0.010% and not more than 0.080%; N: not less than 0.0010% and not more than

0.0050%; and O: not less than 0.0005% and not more than 0.0040%, with the balance being Fe and incidental impurities.

[0018] Containing C (carbon) as a compositional component in the steel slab can ensure the strength of the base material. In particular, the strength of the base material can be made good by making the C content in the steel slab 0.03 mass % (hereinafter expressed simply as "%") or more. When an excessive amount of C is contained in the steel slab, cementite or martensite island, which may serve as the origin of brittle fracture, will increase. It is therefore possible that suitable toughness may not be obtained. Suitable toughness of the steel slab can be obtained by making the C content in the steel slab 0.10% or less.

[0019] Containing Si (silicon) as a compositional component in the steel slab can enhance the deoxidization effect of removing oxygen contained in the steel slab. Further, containing Si as a compositional component in the steel slab can ensure the strength of the base material. When the Si content is high, martensite island tends to be formed in the structure of a welding heat-affected zone (HAZ), resulting in a failure to achieve good HAZ toughness.

[0020] Thus, suitable HAZ toughness can be ensured by making the Si content in the steel slab 0.50% or less. An excellent deoxidization effect can be achieved and the strength of the base material can be made good by making the Si content in the steel slab 0.01% or more.

[0021] Containing Mn as a compositional component in the steel slab can ensure the strength of the base material. When the Mn content is high, good HAZ toughness tends not to be achieved.

[0022] In particular, the strength of the base material can be made good by making the Mn content in the steel slab 0.10% or more. On the other hand, suitable HAZ toughness can be ensured by making the Mn content in the steel slab 1.00% or less.

[0023] The steel slab, when it contains P (phosphorus) as a compositional component, tends to cause intergranular embrittlement. Therefore, the steel slab preferably contains P (phosphorus) as a compositional component in the smallest possible amount. By making the P (phosphorus) content in the steel slab 0.010% or less, it is possible to prevent surface cracking from being promoted by intergranular embrittlement. This makes it possible to make the toughness of the base material and a HAZ good.

[0024] By making the P (phosphorus) content in the steel slab 0.001% or more, it is possible to reduce an increase in the load on dephosphorization refining in the steelmaking process, thereby reducing an increase in the production cost.

[0025] The steel slab, when it contains S (sulfur) as a compositional component, tends to cause intergranular embrittlement. Therefore, the steel slab preferably contains S (sulfur) as a compositional component in the smallest possible amount. By making the S (sulfur) content in the steel slab 0.0050% or less, it is possible to prevent intergranular embrittlement, thereby preventing it from promoting surface cracking. This makes it possible to make the toughness of the base material and a HAZ good. In particular, S (sulfur), as an inclusion such as MnS, reduces the toughness of the steel slab. Therefore, the S (sulfur) content in the steel slab is preferably low.

[0026] On the other hand, by making the S (sulfur) content in the steel slab 0.0001% or more, it is possible to reduce an increase in the load on dephosphorization refining in the steelmaking process, thereby reducing an increase in the production cost.

[0027] As described above, the steel slab contains Ni (nickel) as a compositional component in an amount of not less than 2.0% and less than 7.5%. Due to the above-described components being contained, the steel slab, even though it contains Ni in a smaller amount than 9% Ni steel, can achieve physical properties comparable to those of 9% Ni steel. From this viewpoint, the Ni content of the steel slab may be not less than 2.0% and less than 7.5%, preferably not less than 6.5% and less than 7.5%. The steel slab, when it contains Ni in an amount of less than 2.0%, tends not to achieve good low-temperature toughness.

[0028] Containing Al (aluminum) as a compositional component in the steel slab can enhance the deoxidization effect of removing oxygen contained in the steel slab. Further, containing Al (aluminum) as a compositional component in the steel slab can ensure the strength of the base material. When the content of Al (aluminum) is high, the toughness of the base material and a HAZ tends to be low due to coarse AlN.

[0029] Thus, suitable toughness of a HAZ can be ensured by making the Al (aluminum) content in the steel slab 0.080% or less. In particular, an excellent deoxidization effect can be achieved by making the Si content in the steel slab 0.010% or more.

[0030] When the steel slab contains N (nitrogen) as a compositional component, coarse metal nitrides such as AlN tend to be formed, resulting in a reduction in the toughness of the base material and a HAZ. Therefore, the steel slab preferably contains N (nitrogen) as a compositional component in the smallest possible amount.

[0031] Suitable toughness of the base material and a HAZ can be ensured by making the N (nitrogen) content in the steel slab 0.0050% or less. On the other hand, by making the N (nitrogen) content in the steel slab 0.0010% or more, it is possible to reduce an increase in the load on a denitrification treatment and a nitrogen absorption prevention treatment in the steelmaking process, thereby reducing an increase in the production cost.

[0032] Containing O (oxygen) as a compositional component in the steel slab tends to cause the formation of inclusions, resulting in a reduction in the toughness of the base material and a HAZ. Therefore, the steel slab preferably contains O (oxygen) as a compositional component in the smallest possible amount. Suitable toughness of the base material and a

HAZ can be ensured by making the O (oxygen) content in the steel slab 0.0040% or less.

[0033] On the other hand, by making the O (oxygen) content in the steel slab 0.0005% or more, it is possible to reduce an increase in the load on an inclusion removal treatment in the steelmaking process, thereby reducing an increase in the production cost.

[0034] Besides the above-described alloy elements, the steel slab preferably contains at least one selected from Cu, Cr, Mo, Nb, V, Ti, B, Ca, and Mg in order to improve the strength and toughness of the base material or a coupling.

[0035] The steel slab may contain Cu (copper) as a compositional component. Containing Cu (copper) as a compositional component in the steel slab can ensure the strength of the base material. When the content of Cu (copper) is high, good HAZ toughness tends not to be achieved.

[0036] Thus, good strength of the base material can be achieved by making the Cu (copper) content in the steel slab 0.03% or more. Suitable HAZ toughness can be ensured by making the Cu (copper) content in the steel slab 1.50% or less.

[0037] The steel slab may contain Cr (chromium) as a compositional component. Containing Cr (chromium) as a compositional component in the steel slab can ensure the strength of the base material. When the content of Cr (chromium) is high, good HAZ toughness tends not to be achieved.

[0038] Thus, good strength of the base material can be achieved by making the Cr (chromium) content in the steel slab 0.03% or more. Suitable HAZ toughness can be ensured by making the Cr (chromium) content in the steel slab 1.00% or less.

[0039] The steel slab may contain Mo (molybdenum) as a compositional component. Containing Mo (molybdenum) as a compositional component in the steel slab can ensure the strength of the base material. When the content of Mo (molybdenum) is high, good HAZ toughness tends not to be achieved.

[0040] Thus, good strength of the base material can be achieved by making the Mo (molybdenum) content in the steel slab 0.02% or more. Suitable HAZ toughness can be ensured by making the Mo (molybdenum) content in the steel slab 1.00% or less.

[0041] The steel slab may contain Nb (niobium) as a compositional component. Containing Nb (niobium) as a compositional component in the steel slab can ensure the strength of the base material and can reduce the size of crystal grains. When the content of Nb (niobium) is high, good HAZ toughness tends not to be achieved.

[0042] Thus, good strength of the base material can be achieved and the size of crystal grains in the slab can be reduced by making the Nb (niobium) content in the steel slab 0.003% or more. Suitable HAZ toughness can be ensured by making the Nb (niobium) content in the steel slab 0.100% or less.

[0043] The steel slab may contain V (vanadium) as a compositional component. Containing V (vanadium) as a compositional component in the steel slab can ensure the strength of the base material and can reduce the size of crystal grains. When the content of V (vanadium) is high, good HAZ toughness tends not to be achieved.

[0044] Thus, good strength of the base material can be achieved and the size of crystal grains in the slab can be reduced by making the V (vanadium) content in the steel slab 0.003% or more. Suitable HAZ toughness can be ensured by making the V (vanadium) content in the steel slab 0.100% or less.

[0045] The steel slab may contain Ti (titanium) as a compositional component. Containing Ti (titanium) as a compositional component in the steel slab can ensure the strength of the base material and can reduce the size of crystal grains in the slab. When the content of Ti (titanium) is high, the HAZ toughness tends to be low due to coarse TiN.

[0046] Thus, good strength of the base material can be achieved and the size of crystal grains can be reduced by making the Ti (titanium) content in the steel slab 0.005% or more. Suitable HAZ toughness can be ensured by making the Ti (titanium) content in the steel slab 0.020% or less.

[0047] The steel slab may contain B (boron) as a compositional component. Containing B (boron) as a compositional component, even in a minute amount, in the steel slab can improve the hardenability. This enables a significant increase in the strength upon controlled cooling and quenching heat treatment. When the content of B (boron) is high, the HAZ toughness tends to be low due to precipitation of coarse boron nitride or boron carbide.

[0048] Thus, good strength can be achieved by making the B (boron) content in the steel slab 0.0002% or more. Suitable HAZ toughness can be ensured by making the B (boron) content in the steel slab 0.0025% or less.

[0049] The steel slab may contain Ca (calcium) as a compositional component. Containing Ca (calcium) in the steel slab enables shape control of inclusions, thereby improving the toughness. Ca (calcium) combines with S to form CaS. CaS can reduce ductility-dip cracking at grain boundaries and can reduce surface cracking. When the content of Ca (calcium) is high, the HAZ toughness tends to be low due to the formation of coarse Ca-containing inclusions.

[0050] Thus, good strength can be achieved by making the Ca (calcium) content in the steel slab 0.0005% or more. Suitable HAZ toughness can be ensured by making the Ca (calcium) content in the steel slab 0.0050% or less.

[0051] The steel slab may contain Mg (magnesium) as a compositional component. Containing Mg (magnesium) in the steel slab enables shape control of inclusions, thereby improving the toughness. Mg (magnesium) combines with S to form MgS. MgS can reduce ductility-dip cracking at grain boundaries.

[0052] Further, MgS has a large effect on reducing the size of austenite grains, and therefore can reduce surface cracking during continuous casting or rolling. When the content of Mg (magnesium) is high, the HAZ toughness tends to be

low due to the formation of coarse Mg-containing inclusions.

[0053] Thus, good strength can be achieved by making the Mg (magnesium) content in the steel slab 0.0005% or more. Suitable HAZ toughness can be ensured by making the Mg (magnesium) content in the steel slab 0.0030% or less.

[0054] The density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more. The density of solidification nuclei at the surface is preferably not less than 0.35/mm² and less than 5.00/mm², more preferably not less than 0.50/mm² and less than 5.00/mm².

[0055] When the density of solidification nuclei is 5.00/mm² or more, it is undesirably necessary to use a stronger cooling mold powder and use a very high mold oscillation frequency. When a casting mold is cooled too strongly, the occurrence of longitudinal cracks due to uneven cooling of the steel slab in the mold tends to be prominent. In addition, an operational problem such as breakout is likely to occur due to insufficient inflow of such a mold powder. For these reasons, it will not be effective to make the density of solidification nuclei extremely high (5.00/mm² or more).

[0056] The density of solidification nuclei at the surface of the steel slab can be measured by the following method: For example, at the surface of the steel slab, an aggregate (solidified cell or dendrite cell) whose dendritic branches are oriented in approximately the same direction can be regarded as having grown from one solidification nucleus. Therefore, the density of solidification nuclei can be calculated by calculating the number of such aggregates per a given area.

[0057] Detailed investigation of actual Ni-containing steel slabs revealed that in order to suppress surface cracking, the number of solidification nuclei is desirably as large as possible. In particular, when the density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more, surface cracking can be effectively suppressed.

[0058] A description will now be given of a continuous casting method for casting the above-described steel slab.

[0059] One method for increasing the density of solidification nuclei at the surface of a continuously cast steel slab is to increase cooling during the initial stage of solidification in a continuous casting process, i.e., to increase cooling in a casting mold.

[0060] In general, a continuous casting process for a Ni-containing steel slab includes the step of adding a mold powder from above the surface of molten steel in a casting mold. The mold powder functions as an antioxidant, a heat retainer, a lubricant between the mold and a solidified shell, etc.

[0061] The mold powder flows into the gap between the solidified shell and the mold. Thus, molten steel is not in direct contact with the mold, and is indirectly cooled by the mold through an inflow layer of the mold powder.

[0062] The mold powder inflow layer may be formed thin by adjusting the viscosity of the mold powder. This can increase the heat removal capacity of the mold, thereby increasing the density of solidification nuclei.

[0063] The mold powder is composed of, for example, CaO, SiO₂, Na₂O, CaF₂, or Al₂O₃. The thermal conductivity of the mold powder is much lower than those of molten steel, which is a metal, and of copper which constitutes the continuous casting mold.

[0064] The transfer of heat from molten steel to the mold depends on the thickness of the mold powder inflow layer. The thinner the mold powder inflow layer, the higher the cooling efficiency of the mold; the thicker the mold powder inflow layer, the lower the cooling efficiency of the mold.

[0065] The thickness of the mold powder inflow layer can be estimated from the consumption of the mold powder. The thickness of the mold powder inflow layer is generally about 0.1 to 0.3 mm.

[0066] A mold powder having a high viscosity may be used in order to form the mold powder inflow layer thin. Thus, it is preferred to add a mold powder, having a viscosity at 1300°C of 0.5 Pa·s (5 poise) or more, into the mold during continuous casting of the steel slab.

[0067] The viscosity of the mold powder at 1300°C is preferably not less than 0.5 Pa·s (5 poise) and not more than 5.0 Pa·s (50 poise), more preferably not less than 1.0 Pa·s (10 poise) and not more than 5.0 Pa·s (50 poise).

[0068] By making the viscosity of the mold powder at 1300°C 0.5 Pa·s (5 poise) or more, the mold powder can be made not to flow easily into the gap between a solidified shell and the mold. Therefore, the thickness of the mold powder inflow layer can be decreased and the transfer of heat from molten steel to the mold can be increased. This makes it possible to increase the density of solidification nuclei, i.e. to make it 0.35/mm² or more, thereby suppressing the occurrence of surface cracks.

[0069] The density of solidification nuclei can also be controlled by oscillating the mold at a predetermined oscillation frequency (oscillation cycles). For example, by oscillating the mold, some of dendrites in the process of solidification are dissociated and attached to the surface of the mold powder inflow layer. Upon attachment of a dendrite to the surface of the mold powder inflow layer, a solidification nucleus will be formed at that site. Thus, the density of solidification nuclei can be increased.

[0070] The continuous casting process preferably includes the step of oscillating the mold, for example, at a frequency of 80 cycles per minute or more. The frequency at which the mold is oscillated is preferably 80 to 400 cycles per minute, more preferably 100 to 400 cycles per minute.

[0071] When the frequency at which the mold is oscillated is less than 80 cycles per minute, there is a possibility that a sufficient density of solidification nuclei cannot be ensured. On the other hand, when the frequency at which the mold is oscillated exceeds 400 cycles per minute, the mold tends to resonate, leading to unstable casting.

[0072] The viscosity of the mold powder can be changed depending on the oscillation frequency (oscillation cycles) of the mold. For example, when the oscillation frequency (oscillation cycles) of the mold is set to 50 cycles per minute, it is preferred to use a mold powder having a viscosity at 1300°C of 0.5 Pa·s (5 poise) or more. This can also make the density of solidification nuclei 0.35/mm² or more at the surface of the Ni-containing steel slab.

[0073] When the oscillation frequency (oscillation cycles) of the mold is set to 80 cycles per minute, it is preferred to use a mold powder having a viscosity at 1300°C of 0.15 Pa·s (1.5 poise) or more. This can also make the density of solidification nuclei 0.35/mm² or more at the surface of the Ni-containing steel slab.

[0074] It is particularly preferred to set the oscillation frequency (oscillation cycles) of the mold to 80 cycles per minute or more and to use a mold powder having a viscosity at 1300°C of 0.5 Pa·s (5 poise) or more. The use of such conditions can significantly reduce surface cracking of the steel slab.

[0075] The surface of the Ni-containing steel slab includes a surface having fine dimples and an extremely flat surface. The surface containing dimples is considered to be formed through fracture of grain boundaries in the low-ductility temperature range of 600 to 900°C.

[0076] The flat surface, from its shape, can be considered to be formed by a type of solidification cracking. In particular, in the process of solidification of molten steel, C, S, P, etc. are concentrated in a final solidification region, causing a decrease in the melting point. A region, which has completed its solidification and which surrounds the final solidification region where a low-melting liquid phase exists, will shrink to form the flat surface.

[0077] More specifically, during the growth of a solidified shell within the mold, solute elements such as C, S, and P are concentrated at the boundary between two solidified cells constituting the solidified shell. This results in the formation of a low-melting liquid phase, causing solidification cracks. Cracking will develop from the solidification cracks due to a thermal stress, a bending straightening stress, etc. in the secondary cooling zone, resulting in the occurrence of surface cracks.

[0078] Thus, surface cracks cannot be sufficiently reduced by merely relaxing a thermal stress, a bending straightening stress, etc. in the secondary cooling zone as has been conventionally practiced. In order to reduce surface cracks, it is important and necessary to reduce solidification cracks during the initial stage of solidification in the mold.

[0079] Solidification cracking is less likely to occur when solute elements are less concentrated in the final solidification region and when a smaller thermal stress acts on the final solidification region. For example, when the size of solidified cells is reduced, the cooling rate naturally increases, leading to reduced concentration of solute elements. Furthermore, when the size of solidified cells is small, thermal stress is dispersed, whereby a smaller thermal stress acts on the interface of each solidified cell. Reducing the size of solidified cells is thus effective in preventing solidification cracking.

[0080] It is known that there is generally a correlation between the number of solidified cells and the number of solidification nuclei, and that the size of solidified cells decreases with increase in the density of solidification nuclei. Accordingly, the size of solidified cells can be reduced by increasing the density of solidification nuclei in an area where molten steel is in contact with the mold.

[0081] The Ni-containing steel slab of the present invention, because of it having a high density of solidification nuclei, can have a reduced size of solidified cells. Thus, the present invention can provide a Ni-containing steel slab having fewer surface cracks.

[0082] According to the continuous casting method of the present invention, it is possible to control the initial solidification at the surface of the steel slab. Accordingly, a large number of solidification nuclei can be formed, and concentration of impurity elements, such as P (phosphorus) and S (sulfur), and C (carbon) at the interfaces of solidified cells can be reduced. This makes it possible to reduce solidification cracks at the interfaces of solidified cells, thus reducing so-called surface cracks that may occur on the surface of the steel slab.

[0083] As described above, in the Ni-containing steel slab according to the present invention, the density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more. This enables a reduction in the size of solidified cells. It therefore becomes possible to reduce concentration of S and P at the interfaces of solidified cells, thereby suppressing embrittlement at the interfaces of solidified cells. In addition, stress that acts on the interfaces of solidified cells is dispersed, making it possible to reduce solidification cracks at the interfaces of solidified cells and to thereby reduce the occurrence of cracks on the surface of the steel slab.

[0084] A description will now be given of a method for producing a steel slab, using the slab produced by the above-described continuous casting, according to the present invention. The method for producing a Ni-containing steel slab includes: a finishing step of finishing a slab produced by the continuous casting method; and a heating step of heating the slab after the finishing step at a temperature of 1100°C or less in a heating furnace.

[0085] In the steel slab production method, the slab produced by the continuous casting of molten steel is used to produce a steel slab. Conventionally, the as-cast slab is heated at 1000 to 1200°C (first heat treatment). The slab that has undergone the first heat treatment is subjected to preliminary rolling (light blooming) to reduce its thickness to about 60 to 90% of the original thickness. The slab that has undergone the preliminary rolling is finished by grinding the slab and removing defects until no defects remain in the slab. The slab that has undergone the finishing is heated at 1000 to 1200°C (second heat treatment). The slab that has undergone the second heat treatment is subjected to rolling (main rolling).

[0086] It has been confirmed that a steel slab produced by conventional production methods have cracks, accompanied

with scales, at austenite grain boundaries. The composition of such scales contains Fe_2SiO_4 (fayalite). The presence of Fe_2SiO_4 (fayalite) is considered to be one of the causes of such cracks accompanied with scales.

[0087] Fe_2SiO_4 scales are formed in steel containing 0.05% or more of silicon (Si) along with the formation of Fe_2SiO_4 . The eutectic temperature of Fe_2SiO_4 with wustite (FeO) is 1170°C. Fe_2SiO_4 is a liquid-phase oxide at temperatures greater than or equal to the eutectic temperature.

[0088] When Fe_2SiO_4 scales are formed, grain boundaries become fragile. Since Fe_2SiO_4 scales are in the form of a liquid phase at high temperatures, they easily diffuse to grain boundaries and the depths of the parent phase.

[0089] After the formation of Fe_2SiO_4 scales, grain boundary cracking may occur due to thermal stress or to strain during rolling. Therefore, even when the formation of surface defects is suppressed in the continuous casting, defects may be formed on the surface of a steel slab as a product due to the presence of Fe_2SiO_4 (fayalite).

[0090] Therefore, when producing a steel slab, the production process is preferably carried out at a temperature less than or equal to the eutectic temperature of Fe_2SiO_4 . In other words, the heating temperature of a heating furnace is preferably made less than or equal to the eutectic temperature of Fe_2SiO_4 .

[0091] The formation of Fe_2SiO_4 scales at grain boundaries is also associated with segregation of elements such as P and S in the relevant regions. Therefore, even when the production process is carried out at a temperature less than or equal to the eutectic temperature, for example, at about 1100°C, liquid-phase Fe_2SiO_4 scales may be formed in part of the relevant regions.

[0092] Therefore, in order to reduce the occurrence of cracks accompanied with Fe_2SiO_4 scales, the heating step is preferably performed at 1100°C or less, more preferably at 1050°C or less. A rolling step is preferably performed after the slab is heated in the heating step under such conditions.

[0093] When a slab is formed while controlling the density of solidification nuclei by the continuous casting method of the present invention, the slab has superior toughness to conventional slabs. Therefore, the use of the slab can produce a steel slab without performing preliminary rolling such as light blooming.

[0094] Thus, when a slab is formed while controlling the density of solidification nuclei by the continuous casting method of the present invention, a steel slab can be produced by performing the following steps (1) to (3).

[0095]

(1) The slab formed is finished by grinding the surface to a depth of about 3 to 6 mm and removing defects until no defects remains in the slab (finishing step).

(2) The finished slab is heated at 1100°C or less (heating step).

(3) The slab that has undergone the heating step is rolled (main rolling).

[0096] By performing the heat treatment of the slab at a temperature of 1100°C or less, defects on the surface of the steel slab (product) can be reduced to a level which is non-problematic as a product. In other words, by producing a steel slab in such a manner, the formation of Fe_2SiO_4 scales can be suppressed, making it possible to produce a steel slab (product) with fewer defects using a single rolling step.

EXAMPLE 1

[0097] Molten steels were prepared by melting 3.5% Ni steels having a Ni content of 3.5 mass %, 5% Ni steels having a Ni content of 5.0 mass %, or 5% Ni steels having a Ni content of 7.0 mass %. A converter and an RH vacuum degassing apparatus were used to prepare the molten steels.

[0098] A test for casting the molten steels was conducted using a vertical bending-type continuous slab casting machine. The vertical bending-type continuous slab casting machine had a thickness of 250 mm and a width of 2100 mm. A total of 20 heats were tested (Test Nos. 1 to 20). Table 1 shows the chemical compositions of Test Nos. 1 to 20. Table 2 shows casting conditions for Test Nos. 1 to 20 in the continuous casting machine.

[Table 1]

		Chemical components of Ni-containing steel (mass %)															
		C	Si	Mn	P	S	Ni	Al	N	O	Cu	Cr	Mo	Nb	V	Ti	B
7% Ni steel	Test No.1	0.06	0.06	0.15	0.004	0.0010	7.4	0.026	0.0052	0.0025	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.2	0.06	0.06	0.15	0.004	0.0010	7.4	0.025	0.0028	0.0022	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.3	0.06	0.06	0.15	0.003	0.0010	7.4	0.024	0.0028	0.0022	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.4	0.06	0.06	0.15	0.004	0.0010	7.4	0.022	0.0030	0.0020	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.5	0.06	0.06	0.15	0.003	0.0010	7.4	0.026	0.0028	0.0022	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
7% Ni steel	Test No.6	0.10	0.06	0.15	0.004	0.0010	7.0	0.026	0.0053	0.0024	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.7	0.10	0.06	0.15	0.004	0.0010	7.0	0.025	0.0026	0.0026	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.8	0.10	0.06	0.15	0.003	0.0010	7.0	0.028	0.0025	0.0030	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.9	0.10	0.06	0.15	0.004	0.0010	7.0	0.024	0.0024	0.0022	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.10	0.10	0.06	0.15	0.004	0.0010	7.0	0.022	0.0026	0.0028	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
5% Ni steel	Test No.11	0.05	0.07	0.80	0.003	0.0010	5.0	0.026	0.0055	0.0025	0.01	0.40	0.10	0.001	0.001	0.002	0.0001
	Test No.12	0.05	0.07	0.80	0.003	0.0010	5.0	0.024	0.0025	0.0024	0.01	0.40	0.10	0.001	0.001	0.002	0.0001
	Test No.13	0.05	0.08	0.75	0.004	0.0010	5.0	0.028	0.0022	0.0023	0.01	0.40	0.10	0.001	0.001	0.002	0.0001
	Test No.14	0.05	0.07	0.80	0.003	0.0010	5.0	0.024	0.0024	0.0025	0.01	0.40	0.10	0.001	0.001	0.002	0.0001
	Test No.15	0.05	0.08	0.75	0.005	0.0010	5.0	0.022	0.0028	0.0023	0.01	0.40	0.10	0.001	0.001	0.002	0.0001
3.5% Ni steel	Test No.16	0.10	0.06	0.80	0.004	0.0010	3.5	0.026	0.0054	0.0024	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.17	0.10	0.06	0.80	0.004	0.0010	3.5	0.025	0.0025	0.0022	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.18	0.10	0.06	0.83	0.005	0.0010	3.5	0.022	0.0024	0.0026	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.19	0.10	0.06	0.80	0.004	0.0010	3.5	0.024	0.0026	0.0025	0.01	0.40	0.20	0.001	0.001	0.001	0.0001
	Test No.20	0.10	0.06	0.82	0.005	0.0010	3.5	0.022	0.0028	0.0024	0.01	0.40	0.20	0.001	0.001	0.001	0.0001

Table 2]

		Size of steel slab w (mm) × t (mm)	Casting speed (m/min)	Viscosity of mold powder (Pa·s)	Consumption of mold powder (kg/m ²)	Oscillation of mold ampl. (mm) × freq. (cpm)
5	Test No.1	2100 × 250	0.8	0.20	0.48	8 mm × 60 cpm
	Test No.2	2100 × 250	0.8	0.06	0.55	8 mm × 60 cpm
	Test No.3	2100 × 250	0.8	2.00	0.28	8 mm × 60 cpm
10	Test No.4	2100 × 250	0.8	0.20	0.44	8 mm × 60 cpm
	Test No.5	2100 × 250	0.8	2.00	0.30	8 mm × 60 cpm
	Test No.6	2100 × 250	0.8	0.20	0.46	8 mm × 60 cpm
15	Test No.7	2100 × 250	0.8	0.08	0.56	8 mm × 60 cpm
	Test No.8	2100 × 250	0.8	1.00	0.35	8 mm × 60 cpm
	Test No.9	2100 × 250	0.8	0.20	0.48	8 mm × 60 cpm
20	Test No.10	2100 × 250	0.8	1.00	0.34	8 mm × 60 cpm
	Test No.11	2100 × 250	0.8	0.20	0.46	8 mm × 60 cpm
	Test No.12	2100 × 250	0.8	0.06	0.58	8 mm × 60 cpm
25	Test No.13	2100 × 250	0.8	1.00	0.33	8 mm × 60 cpm
	Test No.14	2100 × 250	0.8	0.20	0.44	8 mm × 60 cpm
	Test No.15	2100 × 250	0.8	1.00	0.33	8 mm × 60 cpm
30	Test No.16	2100 × 250	0.8	0.20	0.46	8 mm × 60 cpm
	Test No.17	2100 × 250	0.8	0.07	0.58	8 mm × 60 cpm
	Test No.18	2100 × 250	0.8	0.50	0.32	8 mm × 60 cpm
	Test No.19	2100 × 250	0.8	0.20	0.48	8 mm × 80 cpm
	Test No.20	2100 × 250	0.8	0.50	0.35	8 mm × 80 cpm

35 **[0099]** For Test Nos. 1, 4, 6, 9, 11, 14, and 16, the casting speed was 0.8 m/min. The amplitude of the oscillation of the mold was 8 mm. The frequency of the oscillation was 60 cycles per minute. A mold powder having a viscosity of 0.20 Pa·s at 1300°C was used.

40 **[0100]** For Test Nos. 2, 3, 5, 7, 8, 10, 12, 13, 15, 17, and 18, the casting speed was 0.8 m/min. The amplitude of the oscillation of the mold was 8 mm. The frequency of the oscillation was 60 cycles per minute. A mold powder having a viscosity of 0.06 to 2.00 Pa·s at 1300°C was used.

[0101] For Test No. 19, the casting speed was 0.8 m/min. The amplitude of the oscillation of the mold was 8 mm. The frequency of the oscillation was 80 cycles per minute. A mold powder having a viscosity of 0.20 Pa·s at 1300°C was used.

[0102] For Test No. 20, the casting speed was 0.8 m/min. The amplitude of the oscillation of the mold was 8 mm. The frequency of the oscillation was 80 cycles per minute. A mold powder having a viscosity of 0.5 Pa·s at 1300°C was used.

45 **[0103]** Each steel slab after casting was cut to a length of 300 mm. The cut sample was subjected to the following treatment, and then evaluated for surface cracks: The surface of the sample was shot-blasted to remove a surface oxide film. Surface cracks were then determined by penetrant testing. The lengths and number of the surface cracks were measured.

50 **[0104]** To examine the depths of surface cracks, the sample was ground to positions at a distance of 3 mm, 6 mm, and 9 mm from the surface. Surface cracks were determined on each ground surface by penetrant testing. The lengths and number of the surface cracks were measured.

[0105] The density of solidification nuclei at the surface of each slab was measured by the following method. A sample was taken from the surface of each steel slab, and the sample was shot-blasted to remove a surface oxide film. The surface of the steel slab from which the oxide film had been removed was mirror-ground, and then etched with picric acid to reveal a solidified structure.

55 **[0106]** The solidified structure was photographed. In the photograph, an aggregate (solidified cell or dendrite cell) whose dendritic branches were oriented in approximately the same direction was regarded as having grown from one solidification nucleus. The density of solidification nuclei was calculated by calculating the number of such aggregates

per a given area.

[0107] In particular, the number of aggregates in the photograph of the solidified structure was counted as the number of solidified cells, and the count was divided by the area occupied by the solidified cells to determine the density of solidification nuclei. The size of solidified cells tends to increase with increase in the distance from an oscillation mark. Therefore, solidified cells were counted in areas, each ranging from one oscillation mark to an adjacent oscillation mark, and the average value was determined.

[0108] Table 3 shows the investigation results of the density of solidification nuclei and the total crack length (crack length $\times$ number of cracks) for Test Nos. 1 to 20.

[Table 3]

	Density of solidification nuclei (/mm ²)	Total crack length (crack length $\times$ number of cracks) (mm/m ²)				Remarks
		Surface	3-mm surface	6-mm surface	9-mm surface	
Test No.1	0.28	5588	188	12	0	Comparative
Test No.2	0.40	28	0	0	0	Present invention
Test No.3	0.52	21	0	0	0	Present invention
Test No.4	1.00	12	0	0	0	Present invention
Test No.5	3.60	2	0	0	0	Present invention
Test No.6	0.29	5488	182	14	0	Comparative
Test No.7	0.42	25	0	0	0	Present invention
Test No.8	0.60	15	0	0	0	Present invention
Test No.9	0.90	10	0	0	0	Present invention
Test No.10	4.20	2	0	0	0	Present invention
Test No.11	0.33	3668	144	4	0	Comparative
Test No.12	0.43	24	0	0	0	Present invention
Test No.13	0.55	18	0	0	0	Present invention
Test No.14	0.80	8	0	0	0	Present invention
Test No.15	4.50	2	0	0	0	Present invention
Test No.16	0.27	2340	86	0	0	Comparative
Test No.17	0.44	20	0	0	0	Present invention
Test No.18	0.50	14	0	0	0	Present invention
Test No.19	0.80	8	0	0	0	Present invention
Test No.20	1.80	2	0	0	0	Present invention

[0109] In Test Nos. 1, 6, 11, and 16, the density of solidification nuclei was less than 0.35/mm². In Test Nos. 1, 5, 9, and 13, many surface cracks occurred. In Test Nos. 1, 6, 11, and 16, cracks were found at a position at a distance of 3 mm or 6 mm from the surface.

[0110] On the other hand, in Test Nos. 2-5, 7-10, 12-15, and 17-20, the density of solidification nuclei was higher than 0.35/mm². The results of Test Nos. 2-5, 7-10, 12-15, and 17-20 indicate that the occurrence of surface cracks decreases with increase in the density of solidification nuclei.

[0111] In particular, a significant decrease in surface cracks was observed in Test Nos. 5, 10, 15, and 20 in which the density of solidification nuclei exceeded 1.50/mm². In the remarks column of Table 3, tests within the scope of the present invention are each shown as "present invention", and the other tests are each shown as "comparative".

(Steel Slab Production Test)

[0112] The slabs of Test Nos. 1 to 20 were each subjected to a heating step and a rolling step, which were performed by the following method, to produce a steel slab (hereinafter also referred to as a product). The product was produced by

"method A" which corresponds to a conventional production method, or "method B" which corresponds to a production method according to the present invention.

(Method A)

[0113] A cast slab was finished by grinding the surface to a depth of about 3 to 6 mm and removing defects until no defects remained in the slab. The finished slab was heated at 1050°C or 1200°C (first heat treatment). The slab that had undergone the first heat treatment was subjected to preliminary rolling (light blooming) to reduce its thickness from 250 mm to 190 mm. The slab that had undergone the preliminary rolling was finished by grinding the surface to a depth of about 3 to 6 mm and removing defects until no defects remained in the slab. The finished slab was heated at 1050°C or 1200°C (second heat treatment). The slab that had undergone the second heat treatment was subjected to main rolling to reduce its thickness from 190 mm to 25 mm. Thereafter, an inspection of defects (hereinafter also referred to as product inspection) was performed on ground surfaces positioned at a distance of 3 mm, 6 mm, and 9 mm from the surface of the rolled slab.

(Method B)

[0114] A cast slab was finished by grinding the surface to a depth of about 3 to 6 mm and removing defects until no defects remained in the slab (finishing step). The finished slab was heated at 1050°C or 1200°C (heating step). The slab that had undergone the heating step was subjected to main rolling to reduce its thickness from 250 mm to 25 mm. Thereafter, a product inspection was performed on ground surfaces positioned at a distance of 3 mm, 6 mm, and 9 mm from the surface of the rolled slab.

[0115] The following three-grade evaluation was made in the product inspection:

O: no product defects

Δ: small amount of product defects (usable as a product after finishing)

×: large amount of product defects (unusable as a product because of defects remaining after finishing)

[0116] Table 4 shows the occurrence of surface defects in each product after rolling.

[Table 4]

	Finishing of slab	(Method A) Light blooming performed		(Method B) Light blooming not performed	
		Heating temp. 1200°C	Heating temp. 1050°C	Heating temp. 1200°C	Heating temp. 1050°C
Test No. 1	9-mm finishing	Δ	Δ	×	×
Test No.2	3-mm finishing	Δ	○	×	○
Test No.3	3-mm finishing	Δ	○	×	○
Test No.4	3-mm finishing	Δ	○	×	○
Test No.5	3-mm finishing	Δ	○	Δ	○
Test No.6	9-mm finishing	Δ	Δ	×	×
Test No.7	3-mm finishing	Δ	○	×	○
Test No.8	3-mm finishing	Δ	○	×	○
Test No.9	3-mm finishing	Δ	○	×	○
Test No.10	3-mm finishing	Δ	○	Δ	○
Test No.11	9-mm finishing	Δ	Δ	×	×
Test No.12	3-mm finishing	Δ	○	×	○
Test No.13	3-mm finishing	Δ	○	×	○
Test No.14	3-mm finishing	Δ	○	×	○
Test No.15	3-mm finishing	Δ	○	Δ	○
Test No.16	6-mm finishing	Δ	Δ	×	×

(continued)

	Finishing of slab	(Method A) Light blooming performed		(Method B) Light blooming not performed	
		Heating temp. 1200°C	Heating temp. 1050°C	Heating temp. 1200°C	Heating temp. 1050°C
Test No.17	3-mm finishing	Δ	○	×	○
Test No.18	3-mm finishing	Δ	○	×	○
Test No.19	3-mm finishing	Δ	○	×	○
Test No.20	3-mm finishing	Δ	○	Δ	○
○: no product defects Δ: a small amount of product defects (finishable) ×: a large amount of product defects (non-finishable)					

[0117] The steel slab products, produced by the method A at a slab heating temperature of 1200°C, all had a small amount of residual product defects but in such a degree as not to cause a production trouble.

[0118] For the 5-7% Ni steels of Test Nos. 1, 6, and 11, the amount of finishing was 9 mm. On the other hand, the amount of finishing was 3 to 6 mm for the other 5-7% Ni steels. The amount of finishing was 6 mm for the 3.5% Ni steel of Test No. 16. On the other hand, the amount of finishing was 3 mm for the other 3.5% Ni steels. Thus, the amount of finishing can be significantly reduced in the examples according to the present invention as compared with the comparative examples.

[0119] For those products of Test Nos. 2-5, 7-10, 12-15, and 17-20 which were produced at a slab heating temperature of 1050°C, they were all rated as "O: no product defects" even when the slabs had not undergone light blooming. This indicates that these examples can significantly reduce process cost and stably improve product quality.

[0120] Inspection of product defects using an EPMA (Electron Probe Micro-Analyzer) revealed that in the test examples in which the slabs were heated at 1200°C, a large amount of Fe_2SiO_4 scales were contained in the defects. This indicates that the influence of oxide scales greatly contributes to the formation of defects upon heating of a slab.

Claims

1. A Ni-containing steel slab comprising, in mass %: C: not less than 0.03% and not more than 0.10%; Si: not less than 0.01% and not more than 0.50%; Mn: not less than 0.10% and not more than 1.00%; P: not less than 0.001% and not more than 0.010%; S: not less than 0.0001% and not more than 0.0050%; Ni: not less than 2.0% and less than 7.5%; Al: not less than 0.010% and not more than 0.080%; N: not less than 0.0010% and not more than 0.0050%; and O: not less than 0.0005% and not more than 0.0040%, with the balance being Fe and incidental impurities, wherein the density of solidification nuclei at the surface of the steel slab is 0.35/mm² or more.
2. The steel slab according to claim 1, further comprising, in mass %, at least one selected from the following: Cu: not less than 0.03% and not more than 1.50%; Cr: not less than 0.03% and not more than 1.00%; Mo: not less than 0.02% and not more than 1.00%; Nb: not less than 0.003% and not more than 0.100%; V: not less than 0.003% and not more than 0.100%; Ti: not less than 0.005% and not more than 0.020%; B: not less than 0.0002% and not more than 0.0025%; Ca: not less than 0.0005% and not more than 0.0050%; and Mg: not less than 0.0005% and not more than 0.0030%.
3. A continuous casting method for casting the steel slab according to claim 1 or 2, comprising the step of adding a mold powder having a viscosity of 0.5 Pa·s (5 poise) or more at 1300°C into a casting mold.
4. A continuous casting method for casting the steel slab according to claim 1 or 2, comprising the step of oscillating a casting mold at a frequency of 80 cycles per minute or more.
5. A continuous casting method for casting the steel slab according to claim 1 or 2, comprising the steps of:
 - adding a mold powder having a viscosity of 0.5 Pa·s (5 poise) or more at 1300°C into a casting mold; and
 - oscillating the casting mold at a frequency of 50 cycles per minute or more.
6. A continuous casting method for casting the steel slab according to claim 1 or 2, comprising the steps of:

adding a mold powder having a viscosity of 0.15 Pa·s (1.5 poise) or more at 1300°C into a casting mold; and oscillating the casting mold at a frequency of 80 cycles per minute or more.

7. A method for producing a steel slab containing Ni, comprising:

5 a finishing step of finishing a slab produced by the continuous casting method according to claim 3; and
a heating step of heating the slab after the finishing step at a temperature of 1100°C or less in a heating furnace.

8. A method for producing a steel slab containing Ni, comprising:

10 a finishing step of finishing a slab produced by the continuous casting method according to claim 4; and
a heating step of heating the slab after the finishing step at a temperature of 1100°C or less in a heating furnace.

9. A method for producing a steel slab containing Ni, comprising:

15 a finishing step of finishing a slab produced by the continuous casting method according to claim 5; and
a heating step of heating the slab after the finishing step at a temperature of 1100°C or less in a heating furnace.

10. A method for producing a steel slab containing Ni, comprising:

20 a finishing step of finishing a slab produced by the continuous casting method according to claim 6; and
a heating step of heating the slab after the finishing step at a temperature of 1100°C or less in a heating furnace.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/027675

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/00(2006.01)i; **B22D 11/108**(2006.01)i; **B22D 11/12**(2006.01)i; **B22D 11/16**(2006.01)i; **C21D 8/02**(2006.01)i;
C21D 9/00(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/08**(2006.01)i; **C22C 38/54**(2006.01)i

FI: B22D11/00 A; B22D11/108 F; B22D11/12 Z; B22D11/16 I05; C21D8/02 B; C21D9/00 I01L; C22C38/00 301A;
 C22C38/08; C22C38/54

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)

B22D11/00; B22D11/108; B22D11/12; B22D11/16; C21D8/02; C21D9/00; C22C38/00; C22C38/08; C22C38/54

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.
Y	JP 2009-248099 A (JFE STEEL CORP) 29 October 2009 (2009-10-29) claims 1-6, paragraphs [0001]-[0012], [0008], [0017]-[0062]	1-10
Y	JP 2001-081516 A (NKK CORP) 27 March 2001 (2001-03-27) claim 1, paragraphs [0001]-[0004], [0009], [0015]-[0032], tables 1-3	1-10
Y	JP 57-026141 A (NKK CORP) 12 February 1982 (1982-02-12) claims 1-2, p. 1, lower right column, line 1 to p. 5, lower right column, line 4, tables 1-2, fig. 1-7	1-10
A	JP 08-010919 A (KAWASAKI STEEL CORP) 16 January 1996 (1996-01-16) entire text	1-10
A	JP 01-228644 A (NIPPON STEEL CORP) 12 September 1989 (1989-09-12) entire text	1-10
A	JP 02-250917 A (NIPPON STEEL CORP) 08 October 1990 (1990-10-08) entire text	1-10

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

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Date of the actual completion of the international search	Date of mailing of the international search report
18 August 2023	29 August 2023
Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915 Japan	
	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2023/027675

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2009-248099 A	29 October 2009	(Family: none)	
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JP 57-026141 A	12 February 1982	US 4408652 A claims 1-7, column 1, line 1 to column 6, line 16, table 1-2, fig. 1-7 DE 3129154 A1	
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JP 02-250917 A	08 October 1990	(Family: none)	

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REFERENCES CITED IN THE DESCRIPTION

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- JP 8010919 A [0008]
- JP 8033964 A [0008]