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

(11) EP 4 516 953 A1

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

(43) Date of publication:
05.03.2025 Bulletin 2025/10

(21) Application number: **23803268.4**

(22) Date of filing: **29.03.2023**

(51) International Patent Classification (IPC):
C22C 38/00 (2006.01) ***C21D 1/00*** (2006.01)
C21D 9/00 (2006.01) ***C21D 9/46*** (2006.01)
C22C 38/60 (2006.01)

(52) Cooperative Patent Classification (CPC):
C21D 1/00; C21D 9/00; C21D 9/46; C22C 38/00; C22C 38/60

(86) International application number:
PCT/JP2023/012741

(87) International publication number:
WO 2023/218785 (16.11.2023 Gazette 2023/46)

(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: **09.05.2022 JP 2022077128**

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(54) SLAB FOR HIGH-STRENGTH STEEL SHEET AND COOLING METHOD THEREOF, METHOD FOR PRODUCING HIGH-STRENGTH HOT-ROLLED STEEL SHEET, METHOD FOR PRODUCING HIGH-STRENGTH COLD-ROLLED STEEL SHEET, AND METHOD FOR PRODUCING HIGH-STRENGTH PLATED STEEL SHEET

(57) A slab for a high-strength steel sheet and a cooling method thereof that do not cause slab cracking during cooling of the slab are provided. In addition, producing methods of a high-strength hot-rolled steel sheet, a high-strength cold-rolled steel sheet, and a high-strength plated steel sheet using that slab are provided. The slab for a high-strength steel sheet is a slab continuously cast for a high-strength steel sheet, and is characterized in that an average prior austenite grain size at the position 10 mm from a slab surface layer is 2.0 mm or less, and that the slab has a microstructure in which bainitic ferrite and tempered martensite in total account for 50% or more and 97% or less by area, residual austenite accounts for 3% or more and 30% or less by area, ferrite accounts for 20% or less by area, and pearlite and quenched martensite in total account for 20% or less by area.

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Description

Technical Field

[0001] The present invention relates to a slab for a high-strength steel sheet and a cooling method thereof that prevent cracking during cooling. In addition, the present invention relates to methods of producing a high-strength hot-rolled steel sheet from that slab for a high-strength steel sheet, a high-strength cold-rolled steel sheet from that high-strength hot-rolled steel sheet, and producing a high-strength plated steel sheet from that high-strength cold-rolled steel sheet.

Background Art

[0002] In recent years, to further reduce the thickness of vehicle bodies and secure collision safety at the same time, the automotive field has been making progress toward further enhancing the strength of high-strength steel and increasing alloy contents to that end. Increasing the alloy contents causes a significant decrease in the toughness of slabs.

[0003] As the toughness of a slab decreases with an increase in the alloying degree, cracking in the slab during cooling, known as season cracking, has occurred more frequently. Such season cracking may cause the slab to fracture while being conveyed, preventing the slab from being hot rolled. Even if the slab does not fracture, the cracks in the slab may open during hot rolling, causing the resulting hot-rolled steel sheet to fracture. Meanwhile, small cracks in a slab may appear as surface defects, such as scabs or slivers, on the resulting steel sheet after hot rolling, cold rolling, annealing, or plating. Typically, cracks in the surface of a slab are removed with a grinder. However, in a case where the toughness of the slab has decreased with an increase in the alloying degree and the cracks in the slab develop due to the stress applied by the grinder, it may be impossible to remove the cracks in the slab completely. Furthermore, small cracks in the slab may be overlooked and appear as surface defects on the resulting steel sheet after hot rolling, cold rolling, annealing, or plating. For the above reasons, it is necessary to suppress cracking in slabs.

[0004] In this regard, measures against cracking of slabs, for example, like those described in Patent Literatures 1 and 2 have been explored. Patent Literature 1 discloses a method in which slow cooling is performed from 700 to 500°C which is a temperature range where austenite transforms into ferrite to thereby inhibit bainite-martensite transformation and reduce the stress exerted by expansion during the transformation. Patent Literature 2 discloses a method for reducing a temperature difference and reducing stress due to transformation by starting slow cooling of a slab immediately after the slab is cast, then slowly cooling the slab at a temperature of 700°C or higher for 10 hours or longer and further from 700 to 500°C.

Citation List

Patent Literature

[0005]

Patent Literature 1: JP-2020-139209A
Patent Literature 2: JP-2019-167560A

Summary of Invention

Technical Problem

[0006] However, the conventional techniques have the following problem.

[0007] When it comes to more highly alloyed slabs that have low toughness, the techniques of Patent Literatures 1 and 2 cannot completely inhibit season cracking of these slabs.

[0008] An object of the present invention, which has been made in view of these circumstances, is to provide a slab for a high-strength steel sheet and a cooling method thereof that, even when the slab is a low-toughness, highly alloyed slab, do not cause slab cracking during cooling of the slab. Another object is to provide producing methods of a high-strength hot-rolled steel sheet, a high-strength cold-rolled steel sheet, and a high-strength plated steel sheet using this slab.

Solution to Problem

[0009] To achieve the above objects, the present inventors have vigorously conducted studies. The inventors analyzed the fracture morphology of slab cracking and found that in the fracture surface, there was at least one type of fracture surface selected from an intergranular fracture surface along a prior austenite grain boundary and a transgranular fracture surface (cleavage fracture surface) that crosses a prior austenite grain boundary. We conducted further studies and gained the following insights:

(1) Intergranular fracture along a prior austenite grain boundary can be inhibited by setting an average prior austenite grain size at the position of 10 mm from a surface layer of the slab to 2.0 mm or less.
(2) Transgranular fracture crossing the inside of a prior austenite grain can be inhibited by setting the microstructure at the position 10 mm from the surface layer of the slab such that a total area ratio of bainitic ferrite and/or tempered martensite is 50% or more but 97% or less, that an area ratio of residual austenite is 3% or more but 30% or less, that an area ratio of ferrite is 20% or less, and that a total area ratio of pearlite and quenched martensite is 20% or less.
(3) Inhibiting slab cracking can inhibit surface defects in the steel sheet after hot rolling, cold rolling, annealing, or plating.

[0010] The present invention has been completed after further studies were conducted based on these insights.
[0011] The gist and the configuration of the present invention are as follows:

[1] A slab for a high-strength steel sheet which has been continuously cast, characterized in that an average prior austenite grain size at a position 10 mm from a slab surface layer is 2.0 mm or less, and that the slab has a microstructure in which a total area ratio of bainitic ferrite and tempered martensite is 50% or more but 97% or less, an area ratio of residual austenite is 3% or more but 30% or less, an area ratio of ferrite is 20% or less, and a total area ratio of pearlite and quenched martensite is 20% or less.
[2] The slab for a high-strength steel sheet according to 1 above, wherein the slab for a high-strength steel sheet has an ingredient composition containing, in mass%: C: 0.10% or more but 0.50% or less, Si: 0.10% or more but 2.50% or less, Mn: 1.00% or more but 5.00% or less, P: 0.100% or less, S: 0.0200% or less, Al: 0.005% or more but 2.500% or less, N: 0.0100% or less, and O: 0.0100% or less, and further optionally containing at least one type of element selected from the following: Ti: 0.200% or less, Nb: 0.200% or less, V: 0.200% or less, Ta: 0.10% or less, W: 0.10% or less, B: 0.0100% or less, Cr: 1.00% or less, Mo: 1.00% or less, Co: 1.00% or less, Ni: 1.00% or less, Cu: 1.00% or less, Sn: 0.200% or less, Sb: 0.200% or less, Ca: 0.0100% or less, Mg: 0.0100% or less, REM: 0.0100% or less, Zr: 0.100% or less, Te: 0.100% or less, Hf: 0.10% or less, and Bi: 0.200% or less, with the balance being Fe and unavoidable impurities.
[3] The slab for a high-strength steel sheet according to 1 above, wherein the slab for a high-strength steel sheet has an ingredient composition containing, in mass%: C: 0.10% or more but 0.50% or less, Si: 0.70% or more but 2.50% or less, Mn: 1.00% or more but 5.00% or less, P: 0.100% or less, S: 0.0200% or less, Al: 0.005% or more but 2.500% or less, N: 0.0100% or less, and O: 0.0100% or less, and further optionally containing at least one type of element selected from the following: Ti: 0.200% or less, Nb: 0.200% or less, V: 0.200% or less, Ta: 0.10% or less, W: 0.10% or less, B: 0.0100% or less, Cr: 1.00% or less, Mo: 1.00% or less, Co: 1.00% or less, Ni: 1.00% or less, Cu: 1.00% or less, Sn: 0.200% or less, Sb: 0.200% or less, Ca: 0.0100% or less, Mg: 0.0100% or less, REM: 0.0100% or less, Zr: 0.100% or less, Te: 0.100% or less, Hf: 0.10% or less, and Bi: 0.200% or less, with the balance being Fe and unavoidable impurities.
[4] A cooling method of a slab for a high-strength steel sheet, characterized in that the slab for a high-strength steel sheet with the ingredient composition according to 2 above is cooled such that a retention time in a temperature range of 1200°C or higher but 1450°C or lower at the position of a widthwise center 10 mm below a surface layer of the slab is 130 seconds or less; then cooled such that an average cooling rate while a surface temperature at a widthwise center of the slab is in the range of 700°C or higher but 850°C or lower is 25°C/hr or more; cooled such that an average cooling rate while the surface temperature is in the range of 550°C or higher but lower than 700°C is 20°C/hr or more; cooled such that an average cooling rate while the surface temperature is in the range of 400°C or higher but lower than 550°C is 15°C/hr or more; cooled such that an average cooling rate until the surface temperature reaches a cooling stop temperature of 250°C or higher but lower than 400°C is 10°C/hr or more; heated so that the surface temperature reaches a reheating temperature of higher than the cooling stop temperature but 450°C or lower; and then cooled such that an average cooling rate while the surface temperature is in the range of 200°C or higher but the reheating temperature or lower is 30°C/hr or less.
[5] A cooling method of a slab for a high-strength steel sheet, characterized in that the slab for a high-strength steel sheet with the ingredient composition according to 3 above is cooled such that a retention time in the temperature range of 1200°C or higher but 1450°C or lower at the position of a widthwise center 10 mm below a surface layer of the slab is 130 seconds or less; cooled such that an average cooling rate while a surface temperature at a widthwise center of the slab is in the range of 700°C or higher but 850°C or lower is 25°C/hr or more; cooled such that an average cooling rate while the surface temperature is in the range of 550°C or higher but lower than 700°C is 20°C/hr or more; cooled such that an average cooling rate while the surface temperature is in the range of 400°C or higher but lower than 550°C is 10°C/hr or more; and then cooled such that an average cooling rate while the surface temperature is in the range of

200°C or higher but lower than 400°C is 30°C/hr or less.

[6] A producing method of a high-strength hot-rolled steel sheet, characterized in that the slab for a high-strength steel sheet according to any one of 1 to 3 above is heated such that a slab heating temperature is 1000°C or higher but 1300°C or lower, rough rolled, and then finish rolled such that a finish rolling end temperature is 750°C or higher but 1000°C or lower, and wound such that a winding temperature is room temperature or higher but 750°C or lower.

[7] A producing method of a high-strength cold-rolled steel sheet, characterized in that: a high-strength hot-rolled steel sheet produced by the producing method according to 6 above is pickled and then cold-rolled such that a rolling reduction is 30% or more but 80% or less; and optionally, one process selected from the following is further performed: (a) a process in which the high-strength cold-rolled steel sheet obtained by the cold rolling is heated such that an annealing temperature is 750°C or higher but 950°C or lower, cooled to a cooling stop temperature of 300°C or higher but 600°C or lower, and then cooled to 100°C or lower; (b) a process in which the high-strength cold-rolled steel sheet obtained by the cold rolling is heated such that an annealing temperature is 750°C or higher but 950°C or lower, cooled to a cooling stop temperature of 130°C or higher but 400°C or lower, reheated to a temperature of 200°C or higher but 450°C or lower, and then cooled to 100°C or lower, and (c) a process in which the high-strength cold-rolled steel sheet obtained by the cold rolling is heated such that an annealing temperature is 750°C or higher but 950°C or lower, followed by water quenching at 500°C or higher, cooled by water to 100°C or lower, and then reheated at 100°C or higher but 300°C or lower.

[8] A producing method of a high-strength plated steel sheet, characterized in that: a high-strength cold-rolled steel sheet obtained by the cold rolling according to 7 above is heated such that an annealing temperature is 750°C or higher but 950°C or lower; the high-strength cold-rolled steel sheet is subjected to a molten-metal plating process and turned into a plated steel sheet; the plated steel sheet is then cooled under a condition of a cooling stop temperature of 150°C or lower; and the molten-metal plating process optionally adopts one type selected from zinc plating, zinc-based-alloy plating, zinc-Al-alloy plating, and Al plating.

[9] The producing method of a high-strength plated steel sheet according to 8, wherein the plated steel sheet having been subjected to the molten-metal plating process is subjected to an alloying process.

[10] A producing method of a high-strength plated steel sheet, characterized in that: using a high-strength cold-rolled steel sheet produced by the producing method according to 7 above, an electroplating process is performed on a surface; and optionally, the electroplating process adopts one type selected from zinc plating, zinc-based-alloy plating, zinc-Al-alloy plating, and Al plating.

Advantageous Effects of Invention

[0012] The present invention can provide a slab that, even when composed of ingredients for a high-strength steel sheet with a high alloy content, does not develop cracks during a cooling process. **In** addition, the present invention can provide producing methods of a high-strength hot-rolled steel sheet, a high-strength cold-rolled steel sheet, and a high-strength plated steel sheet using this slab that have few surface defects.

Description of Embodiments

[0013] Embodiments of the present invention will be specifically described below. The following embodiments illustrate steel structures and methods for embodying the technical idea of the present invention and are not intended to restrict the configuration to the one to be described below. Thus, various changes can be made to the technical idea of the present invention within the technical scope described in the claims.

[0014] First, appropriate ranges of the microstructure of a slab and reasons for restriction will be described. **In** the following description, "%" representing a constituent ratio in the microstructure means "area%" unless otherwise indicated.

[Average prior austenite grain size: 2.0 mm or less]

[0015] The average prior austenite grain size is a factor that determines the unit of fracture. As the grain size increases, the toughness of the slab decreases, resulting in slab cracking that exhibits an intergranular fracture surface. To inhibit this slab cracking, it is necessary that the average prior austenite grain size at the position 10 mm from the slab surface layer is 2.0 mm or less. It is preferably 1.8 mm or less, more preferably 1.5 mm or less. The average prior austenite grain size can be measured by a method described in Examples to be described later.

[Total of area ratios of bainitic ferrite and tempered martensite: 50% or more but 97% or less]

[0016] Since bainitic ferrite and tempered martensite have high toughness compared with pearlite and quenched martensite, they are important constituent elements in this embodiment and can enhance the toughness of the steel and inhibit slab cracking. To achieve this effect, the total of the area ratios of bainitic ferrite and tempered martensite at the position 10 mm from the surface layer of the slab needs to be 50% or more. It is preferably 60% or more, more preferably 70% or more, and even more preferably 80% or more. When the total area ratio exceeds 97%, the toughness-improving effect of residual austenite may not be produced; therefore, the total area ratio should be 97% or less. The area ratios of bainitic ferrite and tempered martensite can be measured by a method described in Examples to be described later.

[Area ratio of residual austenite: 3% or more but 30% or less]

[0017] Residual austenite, which is an extremely important constituent element in this embodiment, has a face-centered cubic lattice (FCC) crystal structure with no cleavage plane, and can therefore dramatically improve the toughness of the steel. When subjected to a high stress, residual austenite undergoes martensitic transformation. Even when a crack develops due to slab cracking, as martensite forms in a stress-concentrated part at a leading end of the crack, the stress concentration is mitigated and the crack can be stopped from growing. Thus, surface defects of the steel sheet after hot rolling, cold rolling, annealing, or plating can be inhibited. To achieve this effect, it is necessary that the area ratio of residual austenite at the position 10 mm from the slab surface layer is 3% or more. Preferably, it is 5% or more, more preferably 7% or more. When residual austenite exceeds 30%, unstable residual austenite increases and undergoes martensitic transformation under low stress, which may result in reduced toughness; therefore, the area ratio should be 30% or less. It is preferably 25% or less, more preferably 20% or less. The area ratio of residual austenite can be measured by a method described in Examples to be described later.

[Area ratio of ferrite: 20% or less]

[0018] Compared with bainitic ferrite, tempered martensite, quenched martensite, residual austenite, and pearlite, ferrite has a large grain size and low strength. Therefore, when stress is applied, the stress may be concentrated on ferrite and cracking originating from ferrite may occur. To inhibit such cracking, the area ratio of ferrite at the position 10 mm from the slab surface layer needs to be 20% or less. Preferably, it is 15% or less, more preferably 10% or less, and even more preferably 0%. The area ratio of ferrite can be measured by a method described in Examples to be described later.

[Total of area ratios of pearlite and quenched martensite: 20% or less]

[0019] Pearlite and quenched martensite are inferior in toughness to residual austenite, bainitic ferrite, and tempered martensite, and the presence of large amounts of pearlite and quenched martensite may result in cracking originating from these structures. To inhibit such cracking, the total of the area ratios of pearlite and quenched martensite at the position 10 mm from the slab surface layer needs to be 20% or less. Preferably 15% or less. More preferably 10% or less. Even more preferably 0%. The area ratios of pearlite and quenched martensite can be measured by a method described in Examples to be described later.

[0020] Next, appropriate ranges of the ingredient composition and reasons for limitation thereof will be described. In the following description, "%" representing a content of an ingredient element of the steel means "mass%" unless otherwise indicated.

[C: 0.10% or more but 0.50% or less]

[0021] C is an essential element that affects the fraction of residual austenite in the slab and increases the strength of the steel sheet. When the C content is less than 0.10%, it may be difficult to secure sufficient residual austenite in the slab. Or it may be difficult to achieve the tensile strength (TS) required for the steel sheet. On the other hand, when the C content exceeds 0.50%, the fraction of quenched martensite in the slab may become excessive. Therefore, the C content is preferably 0.10% or more but 0.50% or less. More preferably 0.12% or more. More preferably 0.45% or less. Even more preferably 0.15% or more. Even more preferably 0.40% or less.

[Si: 0.10% or more but 2.50% or less or 0.70% or more but 2.50% or less]

[0022] Si inhibits the formation of carbide during cooling of the slab and promotes the formation of residual austenite, and thus is an element that affects the fraction of residual austenite.

[0023] When a slab cooling method to be described later involves reheating, the Si content is preferably 0.10% or more. When the Si content is less than 0.10%, the fraction of residual austenite decreases, which may lead to slab cracking. More preferably 0.15% or more. Even more preferably 0.20% or more.

[0024] When the slab cooling method to be described later does not involve reheating but uniformly lowers the

temperature, the Si content is preferably 0.70% or more. When the Si content is less than 0.70%, the fraction of residual austenite decreases, resulting in slab cracking. More preferably 0.90% or more. Even more preferably 1.00% or more.
[0025] On the other hand, when the Si content exceeds 2.50%, firm scale forms on the hot-rolled steel sheet, which may result in surface defects. Therefore, the Si content is preferably 2.50% or less. More preferably 2.00% or less. Even more preferably 1.80% or less.

[Mn: 1.00% or more but 5.00% or less]

[0026] Mn is an essential element that affects the fraction of residual austenite and enhances the strength of the steel sheet. When the Mn content is less than 1.00%, it may be difficult to secure sufficient residual austenite in the slab. Or it may be difficult to achieve the tensile strength (TS) required for the steel sheet. On the other hand, when the Mn content exceeds 5.00%, the fraction of quenched martensite in the slab may become excessive. Therefore, the Mn content is preferably 1.00% or more but 5.00% or less. More preferably 1.20% or more. More preferably 4.50% or less. Even more preferably 1.40% or more. Even more preferably 4.00% or less.

[P: 0.100% or less]

[0027] P segregates at prior austenite grain boundaries to cause the embrittlement of these grain boundaries, which may result in slab cracking. Therefore, the P content is preferably 0.100% or less. While the lower limit of the P content is not defined, since P is a solid-solution strengthening element and can increase the strength of the steel sheet, it is more preferably 0.001% or more. More preferably 0.070% or less.

[S: 0.0200% or less]

[0028] S is an element that is present as sulfide and causes the embrittlement of the slab. Therefore, the S content is preferably 0.0200% or less. While the lower limit of the S content is not defined, in view of restrictions in production technique, it is more preferably is 0.0001% or more. More preferably 0.0050% or less.

[Al: 0.005% or more but 2.500% or less]

[0029] Al inhibits the formation of carbide during cooling of the slab and promotes the formation of residual austenite, and thus is an element that affects the fraction of residual austenite in the slab. For deoxidation, adding 0.005% or more Al is preferable. On the other hand, when the Al content exceeds 2.500%, the slab may become brittle. Therefore, the Al content is preferably 0.005% or more but 2.500% or less. More preferably 0.010% or more. More preferably 1.000% or less. Even more preferably 0.100% or less.

[N: 0.0100% or less]

[0030] N is an element that is present as nitride and causes the embrittlement of the slab. Therefore, the N content is preferably 0.0100% or less. While the lower limit of the N content is not defined, in view of restrictions in production technique, the N content is more preferably 0.0001% or more. More preferably 0.0050% or less.

[O: 0.0100% or less]

[0031] O is an element that is present as oxide and causes the embrittlement of the slab. Therefore, the O content is preferably 0.0100% or less. While the lower limit of the O content is not defined, in view of restrictions in production technique, the O content is more preferably 0.0001% or more. More preferably 0.0050% or less.
[0032] It is preferable that the slab for a high-strength steel sheet according to one embodiment of the present invention have an ingredient composition containing the above-described ingredients, with the balance including Fe and unavoidable impurities. It is favorable that the slab for a high-strength steel sheet according to one embodiment of the present invention should have an ingredient composition containing the above-described ingredients, with the balance being Fe and unavoidable impurities. Here, examples of unavoidable impurities include Zn, Pb, and As. Containing 0.100% or less these impurities in total is allowable.
[0033] In addition to the above-described ingredient composition, the slab for a high-strength steel sheet of the present invention may further contain, in mass%, at least one type of element selected from the following alone or in combination: Ti: 0.200% or less, Nb: 0.200% or less, V: 0.200% or less, Ta: 0.10% or less, W: 0.10% or less, B: 0.0100% or less, Cr: 1.00% or less, Mo: 1.00% or less, Ni: 1.00% or less, Co: 1.00% or less, Cu: 1.00% or less, Sn: 0.200% or less, Sb: 0.200% or less, Ca: 0.0100% or less, Mg: 0.0100% or less, REM: 0.0100% or less, Zr: 0.100% or less, Te: 0.100% or less, Hf: 0.10%

or less, and Bi: 0.200% or less.

[0034] When the content of each of Ti, Nb, and V is 0.200% or less, coarse precipitates or inclusions are not produced in large amounts and the toughness of the slab does not decrease. Therefore, the content of each of Ti, Nb, and V is preferably 0.200% or less. While the lower limit of the content of Ti, Nb, and V is not defined, as these elements raise the strength of the steel sheet by forming fine carbide, nitride, or carbonitride during hot rolling or continuous annealing, the content of each of Ti, Nb, and V is more preferably 0.001% or more. Therefore, when Ti, Nb, and V are contained, the content of each element should be 0.200% or less. More preferably 0.001% or more. Even more preferably 0.100% or less.

[0035] When the content of each of Ta and W is 0.10% or less, coarse precipitates or inclusions are not generated in large amounts and the toughness of the slab does not decrease. Therefore, the content of each of Ta and W is preferably 0.10% or less. While the lower limit of the content of Ta and W is not defined, as these elements raise the strength of the steel sheet by forming fine carbide, nitride, or carbonitride during hot rolling or continuous annealing, the content of each of Ta and W is more preferably 0.01% or more. Therefore, when Ta and W are contained, the content of each element should be 0.10% or less. More preferably 0.01% or more. Even more preferably 0.08% or less.

[0036] When B is 0.0100% or less, the toughness of the slab is not affected. Therefore, the B content is preferably 0.0100% or less. While the lower limit of the B content is not defined, since B is an element that segregates at austenite grain boundaries during hot rolling or annealing and improves hardenability, the B content is more preferably 0.0003% or more. Therefore, when B is contained, the content thereof should be 0.0100% or less. More preferably 0.0003% or more. Even more preferably 0.0080% or less.

[0037] When the content of each of Cr, Mo, and Ni is 1.00% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the content of each of Cr, Mo, and Ni is preferably 1.00% or less. While the lower limit of the content of Cr, Mo, and Ni is not defined, as these are elements that improve hardenability, the content of each of Cr, Mo, and Ni is more preferably 0.01% or more. Therefore, when Cr, Mo, and Ni are contained, the content of each element should be 1.00% or less. More preferably 0.01% or more. Even more preferably 0.80% or less.

[0038] When Co is 1.00% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the Co content is preferably 1.00% or less. While the lower limit of the C content is not defined, as Co is an element that improves hardenability, the Co content is more preferably 0.001% or more. Therefore, when Co is contained, the content thereof should be 1.00% or less. More preferably 0.001% or more. Even more preferably 0.80% or less.

[0039] When Cu is 1.00% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the Cu content is preferably 1.00% or less. While the lower limit of the Cu content is not defined, since Cu is an element that improves hardenability, the Cu content is more preferably 0.01% or more. Therefore, when Cu is contained, the content thereof should be 1.00% or less. More preferably 0.01% or more. Even more preferably 0.80% or less.

[0040] When Sn is 0.200% or less, the toughness of the slab is not affected. Therefore, the Sn content is preferably 0.200% or less. While the lower limit of the Sn content is not defined, as Sn is an element that improves hardenability, the Sn content is more preferably 0.001% or more. Therefore, when Sn is contained, the content thereof should be 0.200% or less. More preferably 0.001% or more. Even more preferably 0.100% or less.

[0041] When Sb is 0.200% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the Sb content is preferably 0.200% or less. While the lower limit of the Sb content is not defined, since Sb is an element that inhibits decarburization and enables the strength of the steel sheet to be adjusted, the Sb content is more preferably 0.001% or more. Therefore, when Sb is contained, the content thereof should be 0.200% or less. More preferably 0.001% or more. Even more preferably 0.100% or less.

[0042] When each of Ca, Mg, and REM is 0.0100% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the content of Ca, Mg, and REM is preferably 0.0100% or less. While the lower limit of the content of Ca, Mg, and REM is not defined, since these are elements that improve the toughness of the slab by turning the shapes of nitride and sulfide into spherical shapes, the content of each of Ca, Mg, and REM is more preferably 0.0005% or more. Therefore, when Ca, Mg, and REM are contained, the content of each element should be 0.0100% or less. More preferably 0.0005% or more. Even more preferably 0.0050% or less.

[0043] When each of Zr and Te is 0.100% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the content of Zr and Te is preferably 0.100% or less. While the lower limit of the content of Zr and Te is not defined, since these are elements that improve the toughness of the slab by turning the shapes of nitride and sulfide into spherical shapes, the content of each of Zr and Te is more preferably 0.001% or more. Therefore, when Zr and Te are contained, the content of each element should be 0.100% or less. More preferably 0.001% or more. Even more preferably 0.080% or less.

[0044] When Hf is 0.10% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the Hf content is preferably 0.10% or less. While the lower limit of the Hf content is not defined, since Hf is an element that improves the ultimate deformability of the steel sheet by turning the shapes of nitride and sulfide into spherical shapes, the Hf content is more preferably 0.01% or more. Therefore, when Hf is contained, the content thereof should be 0.10% or less. More preferably 0.01% or more. Even more preferably 0.08% or less.

[0045] When Bi is 0.200% or less, coarse precipitates or inclusions do not increase and the toughness of the slab does not decrease. Therefore, the Bi content is preferably 0.200% or less. While the lower limit of the Bi content is not defined, since Bi is an element that mitigates segregation, the Bi content is more preferably 0.001% or more. Therefore, when Bi is contained, the content thereof should be 0.200% or less. More preferably 0.001% or more. Even more preferably 0.100% or less.

[0046] Ti, Nb, V, Ta, W, B, Cr, Mo, Ni, Co, Cu, Sn, Sb, Ca, Mg, REM, Zr, Te, Hf, and Bi described above do not impair the effects of the present invention if their respective contents are below the preferable lower limit values, and therefore are included as unavoidable impurities.

<Cooling Method of Slab for High-Strength Steel Sheet According to First Embodiment>

[0047] Next, a favorable slab cooling method that achieves the above-described microstructure will be described. The cooling method of a slab for a high-strength steel sheet according to the first embodiment involves reheating during cooling. A steel slab is produced by selecting, from the above-described ingredient compositions, an ingredient composition suitable for a case that involves reheating during cooling of the slab, and smelting a steel raw material having that ingredient composition. In this embodiment, the smelting method of the steel raw material is not defined, and any of commonly known smelting methods, including a converter and an electric furnace, can suit. While it is preferable that the steel slab (slab) be produced by a continuous casting method to prevent macro segregation, the slab can also be produced by a thin-slab casting method etc.

[Retention time in range of 1200°C or higher but 1450°C or lower at position of widthwise center 10 mm below surface layer of slab after completion of casting: 130 seconds or less]

[0048] The prior austenite grain size is a factor that determines the unit of fracture, and as the grain size becomes larger, the toughness decreases. A factor that determines the prior austenite grain size is a retention time in the range of 1200°C or higher but 1450°C or lower, and the longer the retention time is, the larger the prior austenite grain size becomes. When the retention time in the range of 1200°C higher but 1450°C exceeds 130 seconds, an average prior austenite grain size can exceed 2.0 mm, which may lead to slab cracking. Therefore, the retention time in the range of 1200°C higher but 1450°C should be 130 seconds or less. Preferably 120 seconds or less. More preferably 110 seconds or less. Even more preferably 100 seconds or less. While the lower limit of the retention time in the range of 1200°C higher but 1450°C is not defined, when the retention time is too short, the risk of breakout during continuous casting due to uneven solidification increases; therefore, the retention time should be 40 seconds or more. More preferably 50 seconds or more. As this temperature is difficult to actually measure, a temperature history at the position 10 mm below the slab surface layer was calculated by heat-transfer analysis. The position analyzed was the slab widthwise center at which the retention time in the aforementioned temperature range is the longest inside the slab.

[Average cooling rate while surface temperature of slab widthwise center is in range of 700°C or higher but 850°C or lower: 25°C/hr or higher]

[0049] A temperature range of 700°C or higher but 850°C is where ferrite transformation occurs. When the cooling rate in this temperature range is low, the area ratio of ferrite in the slab becomes high and the toughness of the slab decreases. Controlling the area ratio of ferrite to be low requires a high cooling rate. To achieve such an effect, the average cooling rate in the range of 700°C or higher but 850°C or lower should be 25°C/hr or higher. Preferably 30°C/hr or higher, more preferably 40°C/hr or higher, and even more preferably 50°C/hr or higher. While the upper limit of the average cooling rate is not defined, the average cooling rate should be 1000°C/hr or lower, otherwise it would be difficult to control the cooling stop at 250°C or higher but lower than 400°C. Preferably 500°C/hr or lower and more preferably 200°C/hr or lower. Measurement of the cooling rate was performed using a thermocouple. The cooling rate was obtained from a temperature measured by installing the thermocouple at a center part of an upper surface that is a wide surface (long side) of the slab after the slab came out of a continuous caster. Cooling rates of the slab mentioned hereinafter are all cooling rates that were obtained by this method.

[Average cooling rate in range of 550°C or higher but lower than 700°C: 20°C/hr or higher]

[0050] A temperature range of 550°C or higher but lower than 700°C is a temperature range where ferrite transformation and pearlite transformation occur. When the cooling rate in this temperature range is low, the fraction of ferrite and/or pearlite in the slab becomes high and the toughness of the slab decreases. Therefore, the average cooling rate in the range of 550°C or higher but lower than 700°C should be 20°C/hr or higher. Preferably 30°C/hr or higher, more preferably 40°C/hr or higher, and even more preferably 50°C/hr or higher. While the upper limit of the average cooling rate is not defined, the average cooling rate should be 1000°C/hr or lower, otherwise it would be difficult to control the cooling stop at temperatures of 250°C or higher but lower than 400°C. Preferably 500°C/hr or lower, more preferably 200°C/hr or lower.

[Average cooling rate in range of 400°C or higher but lower than 550°C: 15°C/hr or higher]

[0051] A temperature range of 400°C or higher but lower than 550°C is a temperature range where pearlite transformation and bainitic transformation occur. When the cooling rate in this temperature range is low, the fraction of pearlite in the slab becomes high and the toughness of the slab decreases. Therefore, the average cooling rate in the range of 400°C or higher but lower than 550°C should be 15°C/hr or higher. Preferably 20°C/hr or higher, more preferably 30°C/hr or higher, and even more preferably 50°C/hr or higher. While the upper limit of the average cooling rate is not defined, the average cooling rate should be 500°C/hr or lower, otherwise it would be difficult to control the cooling stop at temperatures of 250°C or higher but lower than 400°C. Preferably 300°C/hr or lower, more preferably 100°C/hr or lower.

[Average cooling rate to cooling stop temperature of 250°C or higher and lower than 400°C: 10°C/hr or higher]

[0052] A temperature range of 250°C or higher but lower than 400°C is a temperature range where bainitic transformation and martensitic transformation occur. To concentrate carbon in untransformed austenite and form residual austenite by the subsequent reheating, untransformed austenite needs to be left without completing the transformation during cooling to a cooling stop temperature. Therefore, the cooling rate to the cooling stop temperature should be 10°C/hr or higher. Preferably 15°C/hr or higher, more preferably 20°C/hr or higher, and even more preferably 30°C/hr or higher. While the upper limit of the average cooling rate is not defined, the average cooling rate should be 500°C/hr or lower, otherwise it would be difficult to control of the cooling stop temperature. Preferably 300°C/hr or lower and more preferably 100°C/hr or lower. When the cooling stop temperature is lower than 250°C, the transformation is completed and residual austenite cannot be secured. Therefore, the cooling stop temperature should be 250°C or higher. Preferably 270°C or higher and more preferably 300°C or higher. When the cooling stop temperature is 400°C or higher, pearlite transformation progresses and residual austenite cannot be secured. Therefore, the cooling stop temperature should be lower than 400°C. Preferably 380°C or lower, more preferably 350°C or lower.

[Heating so as to reach reheating temperature higher than cooling stop temperature but 450°C or lower]

[0053] By reheating the slab from the cooling stop temperature, bainitic transformation is promoted and carbon is concentrated in untransformed austenite during the formation of bainitic ferrite, which promotes the formation of residual austenite. When martensitic transformation has occurred before the cooling stop, as a result of reheating, carbon is distributed and concentrated from martensite into untransformed austenite, which promotes the formation of residual austenite. At the cooling stop temperature or lower, carbon cannot be sufficiently concentrated in untransformed austenite and residual austenite cannot be secured. Therefore, the reheating temperature should be higher than the cooling stop temperature. Preferably the cooling stop temperature + 20°C or higher, more preferably the cooling stop temperature + 40°C or higher. When the reheating temperature exceeds 450°C, decomposition of untransformed austenite occurs and residual austenite cannot be secured. Therefore, the reheating temperature should be 450°C or lower. Preferably 430°C or lower, more preferably 410°C or lower.

[Average cooling rate in range of 200°C or higher but reheating temperature or lower: 30°C/hr or lower]

[0054] A temperature range of 200°C or higher but the reheating temperature or lower is a temperature range where bainitic transformation and martensitic transformation occur, with bainitic transformation occurring at a higher temperature than martensitic transformation. When the cooling rate in this temperature range is high, quenched martensite forms and the toughness of the slab decreases. In bainitic transformation, carbon is concentrated in untransformed austenite during formation of bainitic ferrite, which promotes formation of residual austenite. Securing the fraction of residual austenite and the fraction of bainite in the slab requires causing bainitic transformation for a sufficient time. When martensitic transformation has occurred before the cooling stop, carbon is distributed and concentrated from martensite into untransformed austenite, which promotes formation of residual austenite. Therefore, the average cooling rate in the range of 200°C or higher but the reheating temperature or lower should be 30°C/hr or lower. Preferably 25°C/hr or lower, more preferably 20°C/hr or lower. While the lower limit of the average cooling rate is not defined, the average cooling rate is preferably 5°C/hr or higher from the viewpoint of productivity.

<Cooling Method of Slab for High-Strength Steel Sheet According to Second Embodiment>

[0055] A cooling method of a slab for a high-strength steel sheet according to a second embodiment does not involve reheating during cooling and uniformly lowers the temperature. Different parts from the first embodiment will be described while the same parts will be omitted. A steel slab is produced in the same manner as in the first embodiment by selecting, from the above-described ingredient compositions, an ingredient composition suitable for a case that does not involve reheating during cooling of the slab, and smelting a steel raw material having that ingredient composition.

[Retention time in range of 1200°C or higher but 1450°C or lower at position of slab widthwise center 10 mm below surface layer: 130 seconds or less]

[0056] The same as in the first embodiment.

[Average cooling rate while surface temperature at slab widthwise center is in range of 700°C or higher but 850°C or lower: 25°C/hr or higher]

[0057] The same as in the first embodiment.

[Average cooling rate in range of 550°C or higher but lower than 700°C: 20°C/hr or higher]

[0058] The same as in the first embodiment.

[Average cooling rate in range of 400°C or higher but lower than 550°C: 10°C/hr or higher]

[0059] A temperature range of 400°C or higher to lower than 550°C is a temperature range where pearlite transformation and bainitic transformation occur. When the cooling rate in this temperature range is low, the fraction of pearlite in the slab becomes high and the toughness of the slab decreases. Therefore, the average cooling rate in the range of 400°C or higher but lower than 550°C should be 10°C/hr or higher. Preferably 15°C/hr or higher, more preferably 20°C/hr or higher, and even more preferably 30°C/hr or higher. Although the upper limit of the average cooling rate is not defined, the average cooling rate should be 500°C/hr or lower, otherwise it would be difficult to control the cooling rate in the range of 200°C or higher but lower than 400°C. Preferably 300°C/hr or lower and more preferably 100°C/hr or lower.

[Average cooling rate at range of 200°C or higher but lower than 400°C: 30°C/hr or lower]

[0060] A temperature range of 200°C or higher but lower than 400°C is a temperature range where bainitic transformation and martensitic transformation occur, with bainitic transformation occurring at a higher temperature than martensitic transformation. When the cooling rate in this temperature range is high, quenched martensite forms and the toughness of the slab decreases. In bainitic transformation, carbon is concentrated in untransformed austenite during formation of bainitic ferrite, which promotes formation of residual austenite. Securing the fraction of residual austenite and the fraction of bainite in the slab requires causing bainitic transformation for a sufficient time. Therefore, the cooling rate in the range of 200°C or higher but lower than 400°C should be 30°C/hr or lower. Preferably 25°C/hr or lower, and more preferably 20°C/hr or lower. While the lower limit of the average cooling rate is not defined, the average cooling rate is preferably 5°C/hr or higher from the viewpoint of productivity.

<Producing Method of High-Strength Steel Sheet>

[0061] The slab for a high-strength steel sheet of the above-described embodiment makes it possible to produce a high-strength hot-rolled steel sheet, a high-strength cold-rolled steel sheet, and a high-strength plated steel sheet, without causing slab cracking after continuous casting or causing surface defects, such as scab flaws and sliver flaws, in the steel sheet after hot rolling, cold rolling, annealing, or plating. The producing methods of these steel sheets are as follows.

[0062] First, any one of the above-described slabs for a high-strength steel sheet is used. In the case of a high-strength hot-rolled steel sheet, the slab is heated within a range of a heating temperature of 1000°C or higher but 1300°C or lower, rough-rolled and then finish-rolled at a finish rolling end temperature of 750°C or higher but 1000°C or lower, and wound at a winding temperature of room temperature or higher but 750°C or lower. After completion of finish rolling until winding, rapid cooling, maintaining and holding the sheet temperature, or air cooling may be performed. After winding, the steel sheet may be rolled at an elongation ratio of 0.05% or more but 1.00% or less. Pickling may also be performed. Pickling may be performed once or may be divided into multiple times. In this way, a high-strength hot-rolled steel sheet is produced.

[0063] In the case of a high-strength cold-rolled steel sheet, the above-described high-strength hot-rolled steel sheet is used. This steel sheet is pickled and then cold-rolled at a rolling reduction of 30% or more but 80% or less. Since pickling can remove oxides on the surface of the steel sheet, it is important in securing favorable chemical conversion treatability and plating quality of the high-strength steel sheet as a final product. Pickling may be performed once or may be divided into multiple times. It is preferable that cold rolling be performed by multi-pass rolling that requires at least two passes, such as tandem multi-stand rolling or reverse rolling, because thereby strain is introduced uniformly and efficiently and thus a uniform structure can be produced. In this way, a high-strength cold-rolled steel sheet 1 is produced.

[0064] Using the above-described high-strength cold-rolled steel sheet 1, this steel sheet is heated at an annealing temperature of 750°C or higher but 950°C or lower, cooled to a cooling stop temperature of 300°C or higher but 600°C or lower, and then cooled to 100°C or lower. After the cooling, the steel sheet may be rolled at an elongation ratio of 0.05% or more but 1.00% or less. In this way, a high-strength cold-rolled steel sheet 2 is produced.

[0065] Using the above-described high-strength cold-rolled steel sheet 1, this steel sheet is heated at an annealing temperature of 750°C or higher but 950°C or lower, cooled to a cooling stop temperature of 130°C or higher but 400°C or lower, subsequently reheated at 200°C or higher but 450°C or lower, and then cooled to 100°C or lower. After the cooling, the steel sheet may be rolled at an elongation ratio of 0.05% or more but 1.00% or less. In this way, a high-strength cold-rolled steel sheet 3 is produced.

[0066] Using the above-described high-strength cold-rolled steel sheet 1, this steel sheet is heated at an annealing temperature of 750°C or higher but 950°C or lower, starts to be water-quenched at 500°C or higher, is water-cooled to 100°C or lower, and is then reheated at 100°C or higher but 300°C or lower. After the reheating, the steel sheet may be rolled at an elongation ratio of 0.05% or more but 1.00% or less. In this way, a high-strength cold-rolled steel sheet 4 is produced.

[0067] Using the above-described high-strength cold-rolled steel sheet 1, this steel sheet is heated at an annealing temperature of 750°C or higher and 950°C or lower. The high-strength cold-rolled steel sheet is subjected to a molten-metal plating process to obtain a plated steel sheet, and this plated steel sheet is then cooled under the condition of a cooling stop temperature of 150°C or lower. In the molten-metal plating process, for example, the cold-rolled steel sheet is immersed in a hot-dip galvanizing bath at 440°C or higher and 500°C or lower. It is preferable to use a hot-dip galvanizing bath having a composition in which an Al amount is 0.10 mass% or more but 0.23 mass% or less and the balance is Zn and unavoidable impurities. It is preferable that the amount of plating deposited be 20 to 80 g/m^2 per side (double-sided plating). The amount of plating deposited can be adjusted by performing gas wiping etc. after the hot-dip galvanizing. After the cooling, the steel sheet may be rolled at an elongation ratio of 0.05% or more but 1.00% or less. In this way, a high-strength hot-dip galvanized steel sheet is produced. Other than galvanization, zinc-based-alloy plating, zinc-Al-alloy plating, Al plating, etc. can also be adopted.

[0068] After the molten-metal plating process, the plated steel sheet is subjected to an alloying process. For example, in the case of hot-dip galvanizing, the alloying process is preferably conducted in a temperature range of 460°C or higher but 600°C or lower. In this way, a high-strength alloyed hot-dip galvanized steel sheet is produced.

[0069] The high-strength cold-rolled steel sheets 1 to 4 are each subjected to an electroplating process on their surfaces to produce a high-strength plated steel sheet. As electroplating, other than zinc plating, zinc-based-alloy plating, zinc-Al-alloy plating, Al-plating, etc. can also be adopted.

[0070] Production conditions other than those described above are not particularly restricted and may follow ordinary methods.

Examples

[Measurement of average prior austenite grain size]

[0071] The measurement method of the average prior austenite grain size is as follows. A sample was cut out from a cooled slab at the position of the widthwise center such that a cross-section along the thickness of the slab parallel to the width direction of the slab served as a surface to be observed. Subsequently, the surface to be observed was mirror-polished with diamond paste, then finish-polished with colloidal silica, and further etched with 3 vol.% nital to reveal the structure in the surface to be observed. Using a light microscope, five fields were observed at 10x magnification at the position 10 mm below the slab surface layer to obtain images of the structure. From the obtained images of the structure, the prior austenite grain size was obtained for each of the five fields by a cutting method complying with JIS G 0551: 2020, and the resulting values were averaged to obtain the average prior austenite grain size.

[Measurement method of area ratio of ferrite]

[0072] In the measurement method of the ferrite area ratio, a surface to be observed of the slab is prepared in the same manner as in the above-described measurement method of the average prior austenite grain size. Subsequently, the surface to be observed is mirror-polished using a diamond paste, then finish-polished using colloidal silica, and further etched with 3 vol.% nital to reveal the structure. Using a scanning electron microscope (SEM), ten fields were observed at 50× magnification, under a condition of an acceleration voltage of 15 kV, at the position 10 mm below the slab surface layer. From the obtained images of the structure, the area ratio of ferrite was calculated for each of the ten fields using Photoshop (R) of Adobe Inc., and the resulting values were averaged to obtain the area ratio of ferrite. Ferrite has a large grain diameter compared with other structures (pearlite, bainitic ferrite, tempered martensite, quenched martensite, and residual austenite) and has a flat surface and a dark contrast, which allows it to be easily distinguished at 50× magnification.

[Measurement method of area ratios of bainitic ferrite, tempered martensite, quenched martensite, residual austenite, and pearlite]

[0073] In the measurement method of the area ratios of these structures, the structures are revealed in a surface to be observed of the slab in the same manner as in the above-described measurement method of ferrite. Using an SEM, ten fields were observed at 10000x magnification, under a condition of an acceleration voltage of 15 kV, at the position 10 mm below the slab surface layer, with ferrite excluded from these fields. From the obtained images of the structures, the area ratios of bainitic ferrite, tempered martensite, quenched martensite, residual austenite, and pearlite were calculated for each of the ten fields using Photoshop (R) of Adobe Inc. The resulting values were averaged, and the area ratios of the respective structures were calculated such that the total with the area ratio of ferrite measured by the above-described method would be 100%. Bainitic ferrite is a structure of a recessed portion. Tempered martensite is a structure of a recessed portion that includes fine carbide. Quenched martensite is a protruding structure and has fine depressions and protrusions inside the structure. Residual austenite is a protruding structure, the inside of which is flat. Pearlite is a depressed structure that includes lamellar carbide. Since the total area ratio of bainitic ferrite and tempered martensite is obtained, bainitic ferrite and tempered martensite need not be distinguishable from each other.

[Evaluation method of slab cracking]

[0074] In the evaluation method of slab cracking, a test was conducted based on the penetrant testing specified in JIS Z 2343: 2017 to evaluate the slab as to the presence or absence of cracks in a wide surface and a narrow surface part. After a developing solution was applied, the appearance of a penetrant was visually examined to visually check for cracks and flaws in the surface.

[Evaluation method of surface defects of steel sheet]

[0075] In the evaluation method of surface defects of the steel sheet after hot rolling, cold rolling, annealing, or plating, the steel sheet was visually evaluated by appearance examination. When there was no scab flaw, sliver flaw, or unplated area along the entire length and the entire width of the steel sheet, the evaluation on surface defects was "absent," and when a scab flaw, a sliver flaw, or an unplated area was observed at any part, the evaluation on surface defects was "present."

[Mechanical characteristics]

[0076] The measurement method of mechanical characteristics (tensile strength TS) is as follows. The tensile strength (TS) was measured by performing a tensile test in accordance with JIS Z 2241: 2011 using a JIS No. 5 test sample that was taken such that the long side of the tensile test sample was oriented in an orthogonal direction (C-direction) relative to a rolling direction of the steel sheet. In the present invention, a TS of 590 MPa or higher is defined as a high strength and evaluated as pass.

(Example 1)

[0077] Table 1 shows the ingredient compositions of steel slabs subjected to the test. Using these steel slabs, cooling of the steel slabs was performed under the cooling conditions as shown in Tables 2-1 and 2-2 that involved reheating. In Tables 2-1 and 2-2, "t1" is the retention time (s) in the range of 1200°C or higher but 1450°C or lower at the position of the slab widthwise center 10 mm below the surface layer; "v1" is the average cooling rate (°C/hr) while a surface temperature at the slab widthwise center is 700°C or higher but 850°C or lower; "v2" is the average cooling rate (°C/hr) at 550°C or higher but lower than 700°C; "v3" is the average cooling rate (°C/hr) at 400°C or higher but lower than 550°C; "v4" is the average cooling rate (°C/hr) to the cooling stop temperature of 250°C or higher but lower than 400°C; "Tf" is the cooling stop temperature (°C); "Th" is the reheating temperature (°C); and "v5" is the average cooling rate (°C/hr) at 200°C or higher but the reheating temperature or lower. The column "Cracking" shows whether cracking occurred during cooling of the slab.

Symbol "d(γ)" is the average prior austenite grain size (mm); "BF+TM" is the total area ratio (%) of bainitic ferrite and tempered martensite; "Rγ" is the area ratio (%) of residual austenite; "F" is the area ratio (%) of ferrite; and "P+FM" is the total area ratio (%) of pearlite and quenched martensite. When appropriate cooling conditions involving reheating were used, the steel slabs with their respective compositions subjected to the experiment could meet the prior austenite grain size and the microstructure according to the present invention, with no cracks found in these steel slabs. When conditions outside the ranges of the present invention were used, cracks were observed in the steel slabs.

[Table 1]

Steel Symbol	Ingredient Composition [mass%]										
	C	Si	Mn	P	s	Al	N	O	Ti	Nb	Other Elements
1A	0.35	0.51	2.21	0.005	0.0006	0.042	0.0030	0.0012	0.085		
1B	0.34	0.25	2.10	0.010	0.0013	0.041	0.0042	0.0006	0.025	0.020	B:0.0018, Cr:0.21, Sb:0.010
1C	0.35	0.50	2.78	0.004	0.0012	0.036	0.0039	0.0015	-	-	
1D	0.31	0.25	2.20	0.009	0.0007	0.028	0.0039	0.0015	-	-	Ca:0.005
1E	0.28	0.60	2.45	0.005	0.0011	0.029	0.0035	0.0008	0.015	-	B:0.0015, Mg:0.005, REM:0.005
1F	0.31	0.25	2.12	0.005	0.0006	0.031	0.0037	0.0006	-	0.072	Sn:0.05, Sb:0.008
1G	0.11	0.14	4.81	0.009	0.0007	0.028	0.0041	0.0012	0.048	-	V:0.08
1H	0.14	0.19	4.23	0.004	0.0015	0.045	0.0035	0.0005	0.024	0.010	Ta:0.05, Mo:0.05
1I	0.48	0.25	1.15	0.008	0.0009	0.036	0.0031	0.0010	-	-	Cr:0.78, Mo:0.40, Sb:0.010
1J	0.41	0.35	1.35	0.010	0.0010	0.047	0.0033	0.0005	-	-	W:0.05, Cr:0.53, Ni:0.13, Cu:0.25
1K	0.34	0.65	1.75	0.005	0.0008	0.032	0.0049	0.0010	0.021	0.020	Mo:0.42, Ni:0.10, Cu:0.20, Zr:0.04, Te:0.06
1L	0.23	0.62	3.20	0.027	0.0021	0.037	0.0043	0.0005	-	0.034	Hf:0.05, Bi:0.08
1M	0.36	0.42	1.85	0.007	0.0007	0.046	0.0037	0.0009	0.035	0.018	B:0.0020, Co:0.005
1N	0.38	0.02	2.40	0.005	0.0008	0.034	0.0034	0.0012	-	-	
1O	0.36	0.20	0.85	0.013	0.0021	0.043	0.0038	0.0008	-	-	Cr:0.62
1P	0.55	0.65	3.12	0.003	0.0007	0.036	0.0028	0.0005	-	-	
1Q	0.30	0.58	5.48	0.007	0.0007	0.046	0.0037	0.0009	-	-	
"-" means not added.											

[Table 2-1]

No.	Steel Symbol	Steel Slab Cooling Conditions								Cracking	Structure					Remarks
		t1	v1	v2	v3	v4	Tf	Th	v5		d(γ)	BF+TM	Rγ	F	P+FM	
		s	°C/hr	°C/hr	°C/hr	°C/hr	°C	°C	°C/hr	Present/absent	mm	%	%	%	%	
1-1	1A	120	83	50	31	18	300	350	16	Absent	1.5	85	13	0	2	Invention Example
1-2	1A	113	45	28	17	13	-	-	-	Present	1.4	94	1	2	3	Comparative Example
1-3	1A	103	80	48	30	18	220	310	18	Present	1.3	98	2	0	0	Comparative Example
1-4	1B	117	90	54	32	21	300	350	20	Absent	1.6	94	6	0	0	Invention Example
1-5	1B	105	23	20	17	15	300	350	15	Present	1.5	60	4	21	15	Comparative Example
1-6	1B	100	28	18	16	14	300	350	13	Present	1.4	60	3	15	22	Comparative Example
1-7	1C	109	58	35	22	15	300	340	12	Absent	1.6	82	12	3	3	Invention Example
1-8	1C	143	55	33	20	13	280	330	11	Present	2.2	82	11	4	3	Comparative Example
1-9	1C	95	22	15	9	5	270	320	5	Present	1.3	0	0	21	79	Comparative Example
1-10	1C	118	145	88	50	34	380	470	25	Present	1.7	88	2	0	10	Comparative Example
1-11	1C	112	90	55	35	22	385	440	34	Present	1.6	76	3	0	21	Comparative Example
1-12	1D	91	58	36	23	15	310	360	15	Absent	1.2	89	6	3	2	Invention Example
1-13	1E	102	160	96	58	33	320	350	20	Absent	1.3	87	11	0	2	Invention Example

[Table 2-2]

No.	Steel Symbol	Steel Slab Cooling Conditions								Cracking	Structure					Remarks
		t1	v1	v2	v3	v4	Tf	Th	v5		d(γ)	BF+TM	Rγ	F	P+FM	
		s	°C/hr	°C/hr	°C/hr	°C/hr	°C	°C	°C/hr	Present/absent	mm	%	%	%	%	
1-14	1F	108	102	65	38	25	300	370	15	Absent	1.1	92	5	0	3	Invention Example
1-15	1G	123	27	22	16	11	385	445	10	Absent	1.5	80	5	0	15	Invention Example
1-16	1H	96	35	24	18	11.16	365	420	10	Absent	1.2	83	5	0	12	Invention Example
1-17	1I	115	160	100	65	40	260	320	26	Absent	1.6	80	13	0	7	Invention Example
1-18	1J	105	95	55	35	22	290	340	20	Absent	1.4	80	15	0	5	Invention Example
1-19	1K	113	55	42	28	20	300	350	17	Absent	1.4	82	6	8	4	Invention Example
1-20	1L	123	45	35	22	15	300	360	14	Absent	1.6	85	8	4	3	Invention Example
1-21	1M	96	130	82	52	33	300	340	23	Absent	1.1	89	6	0	5	Invention Example
1-22	1N	112	152	92	55	32	280	320	25	Present	1.6	89	1	0	10	Comparative Example
1-23	1O	105	120	75	45	28	280	320	22	Present	1.5	90	2	0	8	Comparative Example
1-24	1P	113	105	63	40	25	280	330	18	Present	1.6	61	17	0	22	Comparative Example
1-25	1Q	102	92	58	33	22	290	340	17	Present	1.4	63	14	0	23	Comparative Example

(Example 2)

[0078] Tables 3-1 and 3-2 list ingredient compositions of steel slabs subjected to the test. Using these steel slabs, cooling of the steel slabs was performed under the cooling conditions as shown in Tables 4-1 and 4-2 that uniformly lowered the temperature. In Tables 4-1 and 4-2, "t1" is the retention time (s) in the range of 1200°C or higher but 1450°C or lower at the position of the slab widthwise center 10 mm below the surface layer; "v1" is the average cooling rate (°C/hr) while a surface temperature at the slab widthwise center is 700°C or higher but lower than 850°C; "v2" is the average cooling rate (°C/hr) while the surface temperature is 550°C or higher but 700°C or lower; "v3" is the average cooling rate (°C/hr) while the surface temperature is 400°C or higher but lower than 550°C; and "v6" is the average cooling rate (°C/hr) while the surface temperature is 200°C or higher but lower than 400°C. The column "Cracking" indicates whether cracking occurred during cooling of the slab. Symbol "d(y)" is the average prior austenite grain size (mm); "BF+TM" is the total area ratio (%) of bainitic ferrite and tempered martensite; "Ry" is the area ratio (%) of residual austenite; "F" is the area ratio (%) of ferrite; and "P+FM" is the total area ratio (%) of pearlite and quenched martensite. When appropriate cooling conditions that uniformly lowered the temperature were used, the steel slabs with their respective compositions subjected to the experiment could meet the prior austenite grain size and the microstructure according to the present invention, with no cracks found in these steel slabs. When conditions outside the ranges of the present invention were used, cracks were observed in the steel slabs.

[Table 3-1]

Steel Symbol	Ingredient Composition [mass%]											
	C	Si	Mn	P	s	Al	N	O	Ti	Nb	B	Other Elements
2A	0.18	1.52	2.76	0.008	0.0010	0.038	0.0033	0.0005	0.023	-	-	
2B	0.17	0.78	3.26	0.010	0.0013	0.981	0.0049	0.0021	-	-	-	Cr:0.12
2C	0.11	1.45	2.70	0.005	0.0009	0.039	0.0035	0.0007	0.020	-	0.0017	
2D	0.21	1.43	2.43	0.007	0.0013	0.036	0.0039	0.0010	-	-	-	Ca:0.005
2E	0.14	1.38	2.81	0.008	0.0008	0.040	0.0023	0.0008	0.010	-	0.0015	MG:0.005, REM:0.005
2F	0.21	1.53	2.70	0.005	0.0006	0.031	0.0037	0.0006	-	-	-	
2G	0.12	1.18	2.40	0.009	0.0007	0.028	0.0039	0.0015	0.058	-	.0021	
2H	0.12	1.46	2.81	0.004	0.0015	0.045	0.0035	0.0005	0.024	-	0.0018	V:0.08, Mo:0.05
2I	0.18	1.55	2.82	0.008	0.0012	0.036	0.0031	0.0010	-	0.010	-	Ta:0.05, Mo:0.40, Cu:0.12, Sb:0.010
2J	0.12	1.62	2.91	0.009	0.0008	0.045	0.0030	0.0005	0.012	-	0.0015	
2K	0.19	1.54	2.51	0.005	0.0008	0.032	0.0049	0.0010	-	-	-	Mo:0.06
2L	0.12	2.48	1.90	0.006	0.0006	0.037	0.0043	0.0005	-	-	-	
2M	0.10	1.41	4.10	0.008	0.0014	0.042	0.0045	0.0011	0.023	-	0.0020	Mo:0.15, Zr:0.06, Te:0.04
2N	0.19	1.46	2.80	0.005	0.0008	0.034	0.0034	0.0012	0.018	-	0.0010	
2O	0.16	0.93	3.30	0.020	0.0021	0.043	0.0038	0.0008	0.051	-	-	Hf:0.05, Bi:0.08
2P	0.16	0.75	3.50	0.013	0.0012	0.038	0.0028	0.0013	0.048	-	-	W:0.04
"-" means not added.												

[Table 3-2]

Steel Symbol	Ingredient Composition [mass%]											
	C	Si	Mn	P	s	Al	N	O	Ti	Nb	B	Other Elements
2Q	0.18	1.50	2.90	0.007	0.0007	0.046	0.0037	0.0009	0.020	0.020	0.0008	
2R	0.20	0.76	3.13	0.004	0.0006	0.035	0.0030	0.0006	0.020	0.014	0.0010	Cu:0.15, Sb:0.010
2S	0.19	1.00	3.05	0.006	0.0004	0.040	0.0035	0.0009	0.020	0.010	0.0025	Ni:0.05, Cu:0.12
2T	0.21	0.76	2.80	0.007	0.0009	2.135	0.0051	0.0012	0.020	-	0.0010	
2U	0.23	1.21	2.89	0.006	0.0005	0.041	0.0040	0.0006	0.021	0.020	0.0015	
2V	0.32	1.50	2.70	0.003	0.0007	0.036	0.0028	0.0005	-	-	-	Co:0.06
2W	0.45	2.00	2.21	0.007	0.0006	0.035	0.0021	0.0007	-	-	-	
2X	0.48	2.05	1.82	0.005	0.0007	0.040	0.0035	0.0006	0.018	0.015	0.0018	
2Y	0.15	0.76	4.80	0.008	0.0015	0.046	0.0042	0.0010	-	-	-	
2Z	0.18	0.92	2.50	0.013	0.0012	0.041	0.0036	0.0016	0.042	-	0.0020	Cr:0.20, Sn:0.05
2a	0.35	0.51	2.21	0.005	0.0006	0.042	0.0030	0.0012	0.085	-		
2b	0.05	0.78	2.42	0.020	0.0023	0.054	0.0050	0.0009	-	-	-	
2c	0.11	0.81	0.80	0.009	0.0007	0.033	0.0046	0.0010	-	-	-	Cr:0.62
2d	0.55	1.12	3.12	0.008	0.0011	0.034	0.0040	0.0007	-	-	-	
2e	0.23	2.80	2.90	0.005	0.0006	0.042	0.0030	0.0003	-	-	-	
2f	0.21	1.45	5.42	0.020	0.0020	0.037	0.0061	0.0013	-	-	-	
"-" means not added.												

[Table 4-1]

No.	Steel Symbol	Steel Slab Cooling Conditions					Cracking	Structure					Remarks
		t1	v1	v2	v3	v6		d(γ)	BF+TM	Rγ	F	P+FM	
		s	°C/hr	°C/hr	°C/hr	°C/hr	Present/Absent	mm	%	%	%	%	
2-1	2A	121	43	26	17	10	Absent	1.7	82	10	5	3	Invention Example
2-2	2A	118	150	85	42	23	Absent	1.6	82	8	3	7	Invention Example
2-3	2A	109	321	221	81	29	Absent	1.5	79	6	0	15	Invention Example
2-4	2A	120	10	4	5	3	Present	1.7	0	0	9	91	Comparative Example
2-5	2A	143	41	25	16	10	Present	2.5	81	9	6	4	Comparative Example
2-6	2B	123	45	27	18	11	Absent	1.7	76	12	8	4	Invention Example
2-7	2C	110	44	26	17	12	Absent	1.5	87	6	5	2	Invention Example
2-8	2D	100	27	22	13	8	Absent	1.2	70	5	15	10	Invention Example
2-9	2E	105	31	24	15	10	Absent	1.4	80	8	7	5	Invention Example
2-10	2F	95	40	25	16	10	Absent	1.1	80	11	6	3	Invention Example
2-11	2G	115	44	27	18	11	Absent	1.6	82	6	8	4	Invention Example
2-12	2H	122	42	25	16	10	Absent	1.7	84	8	5	3	Invention Example
2-13	2I	116	35	20	14	9	Absent	1.6	78	12	6	4	Invention Example
2-14	2J	100	40	26	15	10	Absent	1.1	86	6	6	2	Invention Example
2-15	2K	112	50	31	18	10	Absent	1.1	86	10	3	1	Invention Example
2-16	2L	98	70	42	31	18	Absent	1.1	77	15	3	5	Invention Example
2-17	2M	95	50	30	18	10	Absent	1.0	80	8	0	12	Invention Example
2-18	2N	100	38	23	14	8	Absent	1.1	81	10	6	3	Invention Example
2-19	2O	102	81	49	30	17	Absent	0.9	87	7	2	4	Invention Example
2-20	2P	108	62	38	24	14	Absent	1.2	87	7	3	3	Invention Example

[Table 4-2]

No.	Steel Symbol	Steel Slab Cooling Conditions					Cracking	Structure					Remarks
		t1	v1	v2	v3	v6		d(γ)	BF+TM	Rγ	F	P+FM	
		s	°C/hr	°C/hr	°C/hr	°C/hr	Present/Absent	mm	%	%	%	%	
2-21	2Q	113	46	36	23	13	Absent	1.4	82	10	5	3	Invention Example
2-22	2R	126	38	23	15	9	Absent	1.7	86	8	4	2	Invention Example
2-23	2S	107	40	25	16	9	Absent	1.2	82	8	7	3	Invention Example
2-24	2S	123	27	15	13	7	Present	1.6	46	4	15	35	Comparative Example
2-25	2T	96	90	53	33	19	Absent	1.1	79	14	2	5	Invention Example
2-26	2U	115	120	74	40	23	Absent	1.4	75	8	0	17	Invention Example
2-27	2U	95	45	29	18	10	Absent	0.9	82	12	4	2	Invention Example
2-28	2U	84	529	298	163	38	Present	0.7	70	8	0	22	Comparative Example
2-29	2V	102	50	32	19	11	Absent	1.2	81	15	2	2	Invention Example
2-30	2V	112	32	21	8	6	Present	1.4	60	9	6	25	Comparative Example
2-31	2W	105	55	30	18	10	Absent	1.3	71	18	1	10	Invention Example
2-32	2X	113	51	31	20	11	Absent	1.4	65	20	0	15	Invention Example
2-33	2Y	108	80	48	26	15	Absent	1.3	76	9	0	15	Invention Example
2-34	2Z	106	50	29	18	11	Absent	1.1	87	7	3	3	Invention Example
2-35	2a	119	30	19	10	6	Present	1.3	86	2	8	4	Comparative Example
2-36	2b	117	35	20	12	7	Absent	1.6	76	3	16	5	Comparative Example
2-37	2c	105	41	25	15	9	Absent	1.3	77	4	15	4	Comparative Example
2-38	2d	112	48	29	17	10	Present	1.5	48	31	0	21	Comparative Example
2-39	2e	114	55	33	20	11	Absent	1.5	70	16	4	10	Comparative Example
2-40	2f	121	51	31	19	11	Present	1.7	60	18	0	22	Comparative Example

[0079] Subsequently, cooled steel slabs were hot-rolled under the conditions listed in Tables 5-1 and 5-2, and then cold-rolled, annealed, and subjected to a plating process. **In** Tables 5-1 and 5-2, "THs" is the slab heating temperature (°C); "THf" is the finish-rolling end temperature (°C) of hot rolling; "THr" is the winding temperature (°C) of the hot-rolled steel strip. "CR" is the rolling reduction (%) of cold rolling, and represents a percentage of the sheet thickness after rolling relative to the sheet thickness before rolling. "TA" is the annealing temperature (°C) of the cold-rolled steel sheet; "TW" is the water-quenching start temperature (°C); "TAf" is the cooling stop temperature (°C) after annealing; and "TAh" is the subsequent reheating temperature (°C). **In** the column "Type," "CR" is a cold-rolled steel sheet; "GI" is a hot-dip galvanized steel sheet; "GA" is an alloyed hot-dip galvanized steel sheet; "EG" is an electrogalvanized steel sheet; "Al" is a molten-aluminum-plated steel sheet; and "HR" is a hot-rolled steel sheet. When the steel slabs according to the present invention in which no cracks were observed were hot-rolled as raw materials, no surface defects were found in the steel sheets and a tensile strength (TS) of 590 MPa or higher was achieved.

[Table 5-1]

No.	Steel Symbol	Hot Rolling Conditions			Cold Rolling	Annealing Conditions/Plating Conditions						Type	Surface Defects	TS	Remarks
		THs	THf	THr	CR	TA	TW	TAf	TAh	G	Alloying				
		°C	°C	°C	%	°C	°C	°C	°C	Present/Absent	Present/Absent		Present/Absent	MPa	
2-1	2A	1200	920	450	50	880	-	280	450	-	-	CR	Absent	1212	Invention Example
2-2	2A	1200	920	470	50	890	-	400	-	-	-	CR	Absent	1223	Invention Example
2-3	2A	1200	920	500	50	-	-	-	-	-	-	CR	Absent	1120	Invention Example
2-6	2B	1200	920	450	50	880	-	280	450	-	-	CR	Absent	1303	Invention Example
2-7	2C	1250	890	550	50	820	-	240	400	-	-	CR	Absent	1035	Invention Example
2-8	2D	1250	850	540	30	830	-	420	-	-	-	CR	Absent	1021	Invention Example
2-9	2E	1250	920	550	40	800	650	50	150	-	-	CR	Absent	1246	Invention Example
2-10	2F	1250	900	550	40	800	-	-	-	Present	Present	GA	Absent	1032	Invention Example
2-11	2G	1250	900	450	50	-	-	-	-	-	-	CR	Absent	1192	Invention Example
2-12	2H	1250	880	550	50	840	-	-	-	Present	Present	GA	Absent	992	Invention Example
2-13	2I	1250	950	520	65	840	-	-	-	Present	Present	GA	Absent	1195	Invention Example
2-14	2J	1250	920	520	50	840	-	250	400	-	-	CR	Absent	1250	Invention Example
2-15	2K	1250	950	520	50	800	-	-	-	Present	Present	GA	Absent	1012	Invention Example
2-16	2L	1250	870	540	50	800	-	-	-	Present	Present	GA	Absent	952	Invention Example

(continued)

No.	Steel Symbol	Hot Rolling Conditions			Cold Rolling	Annealing Conditions/Plating Conditions						Type	Surface Defects	TS	Remarks
		THs	THf	THr	CR	TA	TW	TAf	TAh	G	Alloying				
		°C	°C	°C	%	°C	°C	°C	°C	Present/Absent	Present/Absent		Present/Absent	MPa	
2-17	2M	1280	870	490	50	800	-	-	-	Present	Present	GA	Absent	986	Invention Example
2-18	2N	1250	920	600	40	790	-	-	-	Present	Present	GA	Absent	1185	Invention Example
2-19	2O	1250	900	500	40	840	-	-	-	Present	-	GI	Absent	1230	Invention Example
2-20	2P	1250	900	500	40	760	-	-	-	Present	Present	GA	Absent	1211	Invention Example

[Table 5-2]

No.	Steel Symbol	Hot Rolling Conditions			Cold Rolling	Annealing conditions/plating conditions						Type	Surface Defects	TS	Remarks
		THs	THf	THr	CR	TA	TW	TAf	TAh	G	Alloying				
		°C	°C	°C	%	°C	°C	°C	°C	Present/Absent	Present/Absent		Present/Absent	MPa	
2-21	2Q	1200	850	500	45	850	-	-	-	Present	Present	GA	Absent	1514	Invention Example
2-22	2R	1250	900	450	65	950	-	-	-	Present	Present	GA	Absent	1481	Invention Example
2-23	2S	1250	900	460	55	900	-	-	-	-	-	AI	Absent	1582	Invention Example
2-25	2T	1250	900	450	65	930	-	-	-	Present	Present	GA	Absent	1532	Invention Example
2-26	2U	1250	900	450	50	870	-	200	340	-	-	CR	Absent	1492	Invention Example
2-27	2U	1250	920	430	50	900	800	50	200	-	-	EG	Absent	1553	Invention Example
2-29	2V	1250	900	500	50	870	-	200	380	-	-	CR	Absent	1521	Invention Example
2-31	2W	1250	900	490	50	870	-	200	400	-	-	CR	Absent	1542	Invention Example
2-32	2X	1300	970	470	50	870	-	200	400	-	-	CR	Absent	1556	Invention Example
2-33	2Y	1250	920	450	50	830	-	400	-	-	-	CR	Absent	1320	Invention Example
2-34	2Z	1250	920	400	-	-	-	-	-	-	-	HR	Absent	1471	Invention Example
2-35	2a	1250	920	500	50	870	-	200	380	-	-	CR	Present	1477	Comparative Example
2-36	2b	1250	920	520	50	800	-	-	-	Present	Present	GA	Absent	490	Comparative Example
2-37	2c	1250	920	520	50	800	-	-	-	Present	Present	GA	Absent	560	Comparative Example

(continued)

No.	Steel Symbol	Hot Rolling Conditions			Cold Rolling	Annealing conditions/plating conditions						Type	Surface Defects	TS	Remarks
		THs	THf	THr	CR	TA	TW	TAf	TAh	G	Alloying				
		°C	°C	°C	%	°C	°C	°C	°C	Present/Absent	Present/Absent		Present/Absent	MPa	
2-39	2e	1250	920	430	-	-	-	-	-	-	-	HR	Present	1562	Comparative Example

Industrial Applicability

[0080] When the slab cooling method of the present invention is used, slab cracking after casting does not occur even in a low-toughness, highly alloyed slab, and thus the producing yield can be significantly improved. When the slab for a high-strength steel sheet of the present invention is used, a high-strength hot-rolled steel sheet, a high-strength cold-rolled steel sheet, and a high-strength plated steel sheet that are highly alloyed and yet free of surface defects can be produced. Applying these steel sheets to suspension parts, structural parts, and framework parts of an automobile can reduce the weight of the vehicle body while securing the reliability of the automobile. Thus, the present invention is industrially useful.

Claims

1. A slab for a high-strength steel sheet which has been continuously cast,
characterized in that
an average prior austenite grain size at a position 10 mm from a slab surface layer is 2.0 mm or less, and that the slab has a microstructure in which a total area ratio of bainitic ferrite and tempered martensite is 50% or more but 97% or less, an area ratio of residual austenite is 3% or more but 30% or less, an area ratio of ferrite is 20% or less, and a total area ratio of pearlite and quenched martensite is 20% or less.

2. The slab for a high-strength steel sheet according to claim 1, wherein

the slab for a high-strength steel sheet has an ingredient composition containing, in mass%:

C: 0.10% or more but 0.50% or less,
Si: 0.10% or more but 2.50% or less,
Mn: 1.00% or more but 5.00% or less,
P: 0.100% or less,
S: 0.0200% or less,
Al: 0.005% or more but 2.500% or less,
N: 0.0100% or less, and
O: 0.0100% or less, and

further optionally containing at least one type of element selected from the following:

Ti: 0.200% or less,
Nb: 0.200% or less,
V: 0.200% or less,
Ta: 0.10% or less,
W: 0.10% or less,
B: 0.0100% or less,
Cr: 1.00% or less,
Mo: 1.00% or less,
Co: 1.00% or less,
Ni: 1.00% or less,
Cu: 1.00% or less,
Sn: 0.200% or less,
Sb: 0.200% or less,
Ca: 0.0100% or less,
Mg: 0.0100% or less,
REM: 0.0100% or less,
Zr: 0.100% or less,
Te: 0.100% or less,
Hf: 0.10% or less, and
Bi: 0.200% or less,

with the balance being Fe and unavoidable impurities.

3. The slab for a high-strength steel sheet according to claim 1, wherein

the slab for a high-strength steel sheet has an ingredient composition containing, in mass%:

C: 0.10% or more but 0.50% or less,
Si: 0.70% or more but 2.50% or less,
Mn: 1.00% or more but 5.00% or less,
P: 0.100% or less,
S: 0.0200% or less,
Al: 0.005% or more but 2.500% or less,
N: 0.0100% or less, and
O: 0.0100% or less, and

further optionally containing at least one type of element selected from the following:

Ti: 0.200% or less,
Nb: 0.200% or less,
V: 0.200% or less,
Ta: 0.10% or less,
W: 0.10% or less,
B: 0.0100% or less,
Cr: 1.00% or less,
Mo: 1.00% or less,
Co: 1.00% or less,
Ni: 1.00% or less,
Cu: 1.00% or less,
Sn: 0.200% or less,
Sb: 0.200% or less,
Ca: 0.0100% or less,
Mg: 0.0100% or less,
REM: 0.0100% or less,
Zr: 0.100% or less,
Te: 0.100% or less,
Hf: 0.10% or less, and
Bi: 0.200% or less,

with the balance being Fe and unavoidable impurities.

4. A cooling method of a slab for a high-strength steel sheet, wherein
the slab for a high-strength steel sheet with the ingredient composition according to claim 2 is cooled such that a retention time in a temperature range of 1200°C or higher but 1450°C or lower at the position of a widthwise center 10 mm below a surface layer of the slab is 130 seconds or less; then cooled such that an average cooling rate while a surface temperature at a widthwise center of the slab is in a range of 700°C or higher but 850°C or lower is 25°C/hr or more; cooled such that an average cooling rate while the surface temperature is in a range of 550°C or higher but lower than 700°C is 20°C/hr or more; cooled such that an average cooling rate while the surface temperature is in a range of 400°C or higher but lower than 550°C is 15°C/hr or more; cooled such that an average cooling rate until the surface temperature reaches a cooling stop temperature of 250°C or higher but lower than 400°C is 10°C/hr or more; heated so that the surface temperature reaches a reheating temperature of higher than the cooling stop temperature but 450°C or lower; and then cooled such that an average cooling rate while the surface temperature is in a range of 200°C or higher but the reheating temperature or lower is 30°C/hr or less.

5. A cooling method of a slab for a high-strength steel sheet, wherein
the slab for a high-strength steel sheet with the ingredient composition according to claim 3 is cooled such that a retention time in a temperature range of 1200°C or higher but 1450°C or lower at the position of a widthwise center 10 mm below a surface layer of the slab is 130 seconds or less; cooled such that an average cooling rate while a surface temperature at a widthwise center of the slab is in a range of 700°C or higher but 850°C or lower is 25°C/hr or more; cooled such that an average cooling rate while the surface temperature is in a range of 550°C or higher but lower than 700°C is 20°C/hr or more; cooled such that an average cooling rate while the surface temperature is in a range of 400°C or higher but lower than 550°C is 10°C/hr or more; and then cooled such that an average cooling rate while the surface temperature is in a range of 200°C or higher but lower than 400°C is 30°C/hr or less.

6. A producing method of a high-strength hot-rolled steel sheet, wherein
that the slab for a high-strength steel sheet according to any one of claims 1 to 3 is heated such that a slab heating temperature is 1000°C or higher but 1300°C or lower, rough rolled, and then finish rolled such that a finish rolling end temperature is 750°C or higher but 1000°C or lower, and wound such that a winding temperature is room temperature or higher but 750°C or lower.

7. A producing method of a high-strength cold-rolled steel sheet, wherein
a high-strength hot-rolled steel sheet produced by the producing method according to claim 6 is pickled and then cold-rolled such that a rolling reduction is 30% or more but 80% or less; and optionally, one process selected from the following is further performed:

(a) a process in which the high-strength cold-rolled steel sheet obtained by the cold rolling is heated such that an annealing temperature is 750°C or higher but 950°C or lower, cooled to a cooling stop temperature of 300°C or higher but 600°C or lower, and then cooled to 100°C or lower;
(b) a process in which the high-strength cold-rolled steel sheet obtained by the cold rolling is heated such that an annealing temperature is 750°C or higher but 950°C or lower, cooled to a cooling stop temperature of 130°C or higher but 400°C or lower, reheated to a temperature of 200°C or higher but 450°C or lower, and then cooled to 100°C or lower, and
(c) a process in which the high-strength cold-rolled steel sheet obtained by the cold rolling is heated such that an annealing temperature is 750°C or higher but 950°C or lower, followed by water quenching at 500°C or higher, cooled by water to 100°C or lower, and then reheated at 100°C or higher but 300°C or lower.

8. A producing method of a high-strength plated steel sheet, wherein
a high-strength cold-rolled steel sheet obtained by the cold rolling according to claim 7 is heated such that an annealing temperature is 750°C or higher but 950°C or lower; the high-strength cold-rolled steel sheet is subjected to a molten-metal plating process and turned into a plated steel sheet; the plated steel sheet is then cooled under a condition of a cooling stop temperature of 150°C or lower; and the molten-metal plating process optionally adopts one type selected from zinc plating, zinc-based-alloy plating, zinc-Al-alloy plating, and Al plating.

9. The producing method of a high-strength plated steel sheet according to claim 8, wherein
the plated steel sheet having been subjected to the molten-metal plating process is subjected to an alloying process.

10. A producing method of a high-strength plated steel sheet, wherein
using a high-strength cold-rolled steel sheet produced by the producing method according to claim 7, an electroplating process is performed on a surface; and optionally, the electroplating process adopts one type selected from zinc plating, zinc-based-alloy plating, zinc-Al-alloy plating, and Al plating.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/012741

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 1/00***(2006.01)i; ***C21D 9/00***(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301A; C21D1/00 118B; C21D9/00 101W; C21D9/46 F; C21D9/46 J; C21D9/46 S; C22C38/00 301T; C22C38/00 301U; C22C38/00 301W; C22C38/60

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60; C21D1/00; C21D9/00; B22D11/00-11/22

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 2007-181861 A (SUMITOMO METAL INDUSTRIES, LTD.) 19 July 2007 (2007-07-19)	1-10
A	JP 2019-167560 A (NIPPON STEEL CORP.) 03 October 2019 (2019-10-03)	1-10
A	JP 2019-167559 A (NIPPON STEEL CORP.) 03 October 2019 (2019-10-03)	1-10
A	JP 2020-139210 A (KABUSHIKI KAISHA KOBE SEIKO SHO (KOBE STEEL, LTD.)) 03 September 2020 (2020-09-03)	1-10

☐ 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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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"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	Date of mailing of the international search report
08 June 2023	**20 June 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.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/012741

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2007-181861 A	19 July 2007	(Family: none)	
JP 2019-167560 A	03 October 2019	(Family: none)	
JP 2019-167559 A	03 October 2019	(Family: none)	
JP 2020-139210 A	03 September 2020	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2020139209 A **[0005]**
- JP 2019167560 A **[0005]**