



(11) **EP 4 682 280 A1**

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

(43) Date of publication:
21.01.2026 Bulletin 2026/04

(21) Application number: **24770602.1**

(22) Date of filing: **04.03.2024**

(51) International Patent Classification (IPC):
C22C 38/00 ^(2006.01) **C21D 1/18** ^(2006.01)
C21D 9/00 ^(2006.01) **C21D 9/46** ^(2006.01)
C22C 38/60 ^(2006.01) **C22C 21/00** ^(2006.01)

(52) Cooperative Patent Classification (CPC):
C21D 1/18; C21D 9/00; C21D 9/46; C22C 38/00;
C22C 38/60; C22C 21/00

(86) International application number:
PCT/JP2024/008038

(87) International publication number:
WO 2024/190491 (19.09.2024 Gazette 2024/38)

(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:
GE KH MA MD TN

(30) Priority: **13.03.2023 JP 2023038696**

(71) Applicant: **NIPPON STEEL CORPORATION**
Chiyoda-ku
Tokyo 100-8071 (JP)

(72) Inventors:
• **YABU, Shohei**
Tokyo 100-8071 (JP)
• **TABATA, Shinichiro**
Tokyo 100-8071 (JP)

(74) Representative: **Vossius & Partner**
Patentanwälte Rechtsanwälte mbB
Siebertstrasse 3
81675 München (DE)

(54) **STEEL MEMBER AND STEEL SHEET**

(57) This steel member has a predetermined chemical composition, in which, when a range between a 1/8 position of a thickness and a 3/8 position of the thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness from the surface as a center, is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area ratio, martensite, bainite, and tempered martensite: 90%

or more in total, and at the 1/4 depth position, when a random intensity ratio of {111}<011> is denoted by I1, a random intensity ratio of {111}<112> is denoted by I2, a random intensity ratio of {100}<011> is denoted by I3, and a random intensity ratio of {100}<001> is denoted by I4, the steel member has a texture in which I1, I2, I3, and I4 satisfy $(I1 + I3)/(I2 + I4) \leq 1.20$.

EP 4 682 280 A1

Description

TECHNICAL FIELD

5 [0001] The present invention relates to a steel member and a steel sheet.

[0002] Priority is claimed on Japanese Patent Application No. 2023-038696, filed March 13, 2023, the content of which is incorporated herein by reference.

BACKGROUND ART

10 [0003] In the field of steel sheets for a vehicle, against the background of tightening of recent environmental regulations and collision safety standards, the application of steel sheets having high tensile strength (high strength steel sheets) has expanded in order to improve both fuel efficiency and collision safety. However, press formability of a steel sheet decreases with high-strengthening, which makes it difficult to manufacture a product having a complex shape.

15 [0004] Specifically, ductility of the steel sheet decreases with the high-strengthening, and there is a problem in that the steel sheet is fractured at a highly processed portion in the case of being processed into a complex shape. In addition, with the high-strengthening of the steel sheet, residual stress after processing causes springback and wall curvature, which also causes a problem that dimensional accuracy is deteriorated. Therefore, it is not easy to perform press forming on a steel sheet having high strength, particularly a tensile strength of 780 MPa or more, into a product having a complex shape.

20 Roll forming rather than press forming makes it easier to process a high strength steel sheet, but the application thereof is limited to components having a uniform cross section in a longitudinal direction thereof.

[0005] Therefore, in recent years, for example, as disclosed in Patent Documents 1 to 3, hot stamping has been adopted as a technology of press-forming a material that is difficult to form, such as a high strength steel sheet. The hot stamping is a hot forming technology of heating a material to be subjected to forming and then forming the material.

25 [0006] In this technology, the material is formed after being heated. Therefore, the steel is soft at the time of forming and has good formability. Accordingly, even a high strength steel sheet can be accurately formed into a complex shape. Furthermore, in the hot stamping, since quenching is performed simultaneously with forming by a press die, steel (steel member) after the forming has sufficient strength.

[0007] For example, according to Patent Document 1, it is disclosed that it is possible to impart a tensile strength of 1,400 MPa or more to a steel member obtained by forming a steel sheet through the hot stamping.

30 [0008] In recent years, countries around the world have set higher CO₂ reduction targets, and each vehicle manufacturer has progressed in reducing fuel consumption in consideration of collision safety. Not only gasoline vehicles but also rapidly developing electric vehicles require, in terms of materials, higher strength materials to protect not only passengers but also batteries from collision and to cancel out the amount of an increase in weight. For example, in a steel member used in vehicles and the like, there is a need for a higher strength (higher than 1.5 GPa) steel that exceeds the strength described above in Patent Document 1 or a strength generally used as a steel member currently formed by hot stamping.

35

[0009] Regarding a high strength steel having a tensile strength of more than 1.5 GPa, for example, Patent Document 2 discloses a press-formed article that has excellent toughness and a tensile strength of 1.8 GPa or more and is hot press-formed. Patent Document 3 discloses a steel having a tensile strength as extremely high as 2.0 GPa or more, and further having good toughness and ductility. Patent Document 4 discloses a steel having a tensile strength as high as 1.8 GPa or more and further having good toughness. Patent Document 5 discloses a steel having a tensile strength as extremely high as 2.0 GPa or more and further having good toughness.

40

Citation List

Patent Documents

[0010]

50 Patent Document 1: Japanese Unexamined Patent Application, First Publication No. 2002-102980

Patent Document 2: Japanese Unexamined Patent Application, First Publication No. 2012-180594

Patent Document 3: Japanese Unexamined Patent Application, First Publication No. 2012-1802

Patent Document 4: PCT International Publication No. WO2015/182596

55 Patent Document 5: PCT International Publication No. WO2015/182591

SUMMARY OF INVENTION

Technical Problem

[0011] Many metal materials deteriorate in various properties with high-strengthening, and particularly increase in susceptibility to hydrogen embrittlement. It is known that a steel member has an increased susceptibility to hydrogen embrittlement when a tensile strength thereof is 1.2 GPa or more, and there are concerns that hot stamped members having a tensile strength of more than 1.5 GPa have an even greater susceptibility to hydrogen embrittlement. In order to apply a hot stamped member of more than 1.5 GPa to a vehicle body for a further reduction in weight of the vehicle body, it is desirable to further improve hydrogen embrittlement resistance.

[0012] An object of the present invention is to provide a steel member having high strength and excellent hydrogen embrittlement resistance, and a steel sheet suitable as a material for the steel member.

Solution to problem

[0013] In order to obtain a steel member having a high tensile strength and excellent hydrogen embrittlement resistance, the present inventors investigated influences of a steel sheet that serves as a material and a microstructure on these properties. As a result, the following findings were obtained.

[0014]

(a) Most of commonly used steel sheets showing a tensile strength of about 1.5 GPa (1,500 MPa) after a heat treatment including quenching such as hot stamping contain about 0.200 mass% of C, and strength after the heat treatment is secured due to this C.

[0015] In order to achieve a further reduction in the weight of the vehicle body, the present inventors conducted a detailed examination to obtain a steel member having a tensile strength as high as more than 1.5 GPa after a heat treatment by increasing a C content. As a result, it was found that by setting the C content to 0.260 mass% or more, an ultrahigh strength of more than 1.5 GPa in terms of tensile strength can be obtained after a heat treatment including quenching such as hot stamping.

[0016] On the other hand, there were concerns that susceptibility to hydrogen embrittlement increases with ultrahigh-strengthening to a tensile strength of more than 1.5 GPa and hydrogen embrittlement cracking is caused by hydrogen generated in a corrosive environment while a vehicle is in operation.

[0017] (b) The present inventors examined a method for improving the hydrogen embrittlement resistance in a high strength steel member having a tensile strength of more than 1.5 GPa. As a result, it was found that the hydrogen embrittlement resistance can be improved by developing a specific texture.

[0018] The present invention has been made in view of the above findings. The gist of the present invention is as follows.

[1] A steel member according to an aspect of the present invention includes, as a chemical composition, by mass%: C: 0.260% to 0.700%; Si: 0% to 2.000%; Mn: 0% to 3.00%; Al: 0% to 1.000%; Nb: 0% to 0.100%; Ti: 0% to 0.200%; Cr: 0% to 1.00%; B: 0% to 0.0200%; Mo: 0% to 1.00%; W: 0% to 2.00%; Co: 0% to 1.00%; Ni: 0% to 2.00%; Cu: 0% to 2.00%; V: 0% to 1.00%; Ca: 0% to 0.200%; Mg: 0% to 0.20%; REM: 0% to 0.300%; Sb: 0% to 1.00%; Sn: 0% to 1.00%; Zr: 0% to 1.00%; As: 0% to 1.00%; Se: 0% to 1.00%; Bi: 0% to 1.00%; Ta: 0% to 1.00%; Re: 0% to 1.00%; Os: 0% to 1.00%; Ir: 0% to 1.00%; Tc: 0% to 1.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; and a remainder: Fe and impurities, in which, when a range between a 1/8 position of a thickness and a 3/8 position of the thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness from the surface as a center, is defined as a 1/4 depth position, a microstructure at the 1/4 depth position includes, by area ratio, martensite, bainite, and tempered martensite: 90% or more in total, and at the 1/4 depth position, when a random intensity ratio of {111}<011> is denoted by I1, a random intensity ratio of {111}<112> is denoted by I2, a random intensity ratio of {100}<011> is denoted by I3, and a random intensity ratio of {100}<001> is denoted by I4, the steel member has a texture in which the I1, the I2, the I3, and the I4 satisfy Expression (1),

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1).$$

[2] In the steel member according to [1], the chemical composition may contain one or more selected from the group consisting of, by mass%, Nb: 0.005% to 0.100%, Ti: 0.005% to 0.200%, Cr: 0.01% to 1.00%, B: 0.0010% to 0.0200%, Mo: 0.01% to 1.00%, W: 0.001% to 2.00%, Co: 0.01% to 1.00%, Ni: 0.01% to 2.00%, Cu: 0.01% to 2.00%, V: 0.01% to 1.00%, Ca: 0.001% to 0.200%, Mg: 0.01% to 0.20%, REM: 0.001% to 0.300%, Sb: 0.01% to 1.00%, Sn: 0.01% to 1.00%, Zr: 0.01% to 1.00%, As: 0.01% to 1.00%, Se: 0.01% to 1.00%, Bi: 0.01% to 1.00%, Ta: 0.01% to 1.00%, Re: 0.01% to 1.00%, Os: 0.01% to 1.00%, Ir: 0.01% to 1.00%, and Tc: 0.01% to 1.00%.

[3] In the steel member according to [1] or [2], a Vickers hardness at the 1/4 depth position may be 450 or more.
 [4] In the steel member according to any one of [1] to [3], the surface of the steel member may have a coating.
 [5] In the steel member according to [4], the coating may be an Fe-Al-based coating or an Fe-Zn-based coating.
 [6] A steel sheet according to another aspect of the present invention includes, as a chemical composition, by mass%:
 C: 0.260% to 0.700%; Si: 0% to 2.000%; Mn: 0% to 3.00%; Al: 0% to 1.000%; Nb: 0% to 0.100%; Ti: 0% to 0.200%; Cr: 0% to 1.00%; B: 0% to 0.0200%; Mo: 0% to 1.00%; W: 0% to 2.00%; Co: 0% to 1.00%; Ni: 0% to 2.00%; Cu: 0% to 2.00%; V: 0% to 1.00%; Ca: 0% to 0.200%; Mg: 0% to 0.20%; REM: 0% to 0.300%; Sb: 0% to 1.00%; Sn: 0% to 1.00%; Zr: 0% to 1.00%; As: 0% to 1.00%; Se: 0% to 1.00%; Bi: 0% to 1.00%; Ta: 0% to 1.00%; Re: 0% to 1.00%; Os: 0% to 1.00%; Ir: 0% to 1.00%; Tc: 0% to 1.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; and a remainder: Fe and impurities, in which, when a range between a 1/8 position of a sheet thickness and a 3/8 position of the sheet thickness in a sheet thickness direction from a surface of the steel sheet, with respect to a 1/4 position of the sheet thickness from the surface as a center, is defined as a 1/4 depth position, at the 1/4 depth position, when a random intensity ratio of {111}<011> is denoted by I1, a random intensity ratio of {111}<112> is denoted by I2, a random intensity ratio of {100}<011> is denoted by I3, and a random intensity ratio of {100}<001> is denoted by I4, the steel sheet has a texture in which the I1, the I2, the I3, and the I4 satisfy Expression (1),

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1).$$

[7] In the steel sheet according to [6], the chemical composition may contain one or more selected from the group consisting of, by mass%, Nb: 0.005% to 0.100%, Ti: 0.005% to 0.200%, Cr: 0.01% to 1.00%, B: 0.0010% to 0.0200%, Mo: 0.01% to 1.00%, W: 0.001% to 2.00%, Co: 0.01% to 1.00%, Ni: 0.01% to 2.00%, Cu: 0.01% to 2.00%, V: 0.01% to 1.00%, Ca: 0.001% to 0.200%, Mg: 0.01% to 0.20%, REM: 0.001% to 0.300%, Sb: 0.01% to 1.00%, Sn: 0.01% to 1.00%, Zr: 0.01% to 1.00%, As: 0.01% to 1.00%, Se: 0.01% to 1.00%, Bi: 0.01% to 1.00%, Ta: 0.01% to 1.00%, Re: 0.01% to 1.00%, Os: 0.01% to 1.00%, Ir: 0.01% to 1.00%, and Tc: 0.01% to 1.00%.
 [8] In the steel sheet according to [6] or [7], the surface of the steel sheet may have a coating.
 [9] In the steel sheet according to [8], the coating may be an Al-based coating or a Zn-based coating.

Advantageous Effects of Invention

[0019] According to the above aspects of the present invention, it is possible to provide a steel member having high tensile strength and excellent hydrogen embrittlement resistance, and a steel sheet that is a material for the steel member.

DESCRIPTION OF EMBODIMENTS

[0020] A steel member according to an embodiment of the present invention (a steel member according to the present embodiment), a steel sheet according to an embodiment of the present invention suitable as a material thereof (a steel sheet according to the present embodiment), and manufacturing methods thereof will be described.

[Steel Member]

[0021] The steel member according to the present embodiment has a chemical composition, which will be described later, and a microstructure at a 1/4 depth position (a range between a 1/8 position of a thickness and a 3/8 position of the thickness in a thickness direction (in a case of including a steel sheet, a sheet thickness direction of the steel sheet) from a surface of the steel member, with respect to a 1/4 position of the thickness from the surface as a center, hereinafter, the same applies) includes, by area ratio, martensite, bainite, and tempered martensite: 90% or more in total.

[0022] In addition, in the steel member according to the present embodiment, at the 1/4 depth position, when a random intensity ratio of {111}<011> is denoted by I1, a random intensity ratio of {111}<112> is denoted by I2, a random intensity ratio of {100}<011> is denoted by I3, and a random intensity ratio of {100}<001> is denoted by I4, the steel member has a texture in which the I1, the I2, the I3, and the I4 satisfy $(I1 + I3)/(I2 + I4) \leq 1.20$.

[0023] The steel member according to the present embodiment may be coated on the surface. Even in that case, in the present embodiment, since the coating itself is not a steel member, the chemical composition, microstructure, texture, and the like of the steel member are a chemical composition, a microstructure, a texture, and the like of a part excluding the coating (this part is sometimes referred to as a "base steel member" or "base metal steel member"). In a case where the surface of the steel member according to the present embodiment is coated, that is, the surface of the steel member according to the present embodiment serving as a reference for the 1/4 depth position is a surface of the part excluding the coating (base steel member), that is, a boundary between the base steel member and the coating. Therefore, for example, in a case where front and back surfaces of the steel member are coated, a thickness t_1 of the steel member including the coating is measured, a thickness t_2 of the coating is then measured by a method described later, and a thickness (thickness

of the base steel member) $t_3 = t_1 - 2 \times t_2$ of the steel member is calculated. Thereafter, a range separated by $t_3/8$ to $(3 \times t_3)/8$ in the thickness direction from a center of the thickness t_1 of the steel member including the coating can be set as the 1/4 depth position.

[0024] The details will be described below.

[0025] A shape of the steel member according to the present embodiment is not particularly limited. That is, the steel member may be a flat sheet, or may be a formed body obtained by forming a steel sheet into a predetermined shape. A hot-formed steel member is often a formed body, for example, a hot-stamping formed body. However, in the present embodiment, a case of a formed body and a case of a flat sheet are collectively referred to as a "steel member".

<Chemical Composition>

[0026] Specifically, the chemical composition of the steel member according to the present embodiment includes, by mass%: C: 0.260% to 0.700%; Si: 0% to 2.000%; Mn: 0% to 3.00%; Al: 0% to 1.000%; Nb: 0% to 0.100%; Ti: 0% to 0.200%; Cr: 0% to 1.00%; B: 0% to 0.0200%; Mo: 0% to 1.00%; W: 0% to 2.00%; Co: 0% to 1.00%; Ni: 0% to 2.00%; Cu: 0% to 2.00%; V: 0% to 1.00%; Ca: 0% to 0.200%; Mg: 0% to 0.20%; REM: 0% to 0.300%; Sb: 0% to 1.00%; Sn: 0% to 1.00%; Zr: 0% to 1.00%; As: 0% to 1.00%; Se: 0% to 1.00%; Bi: 0% to 1.00%; Ta: 0% to 1.00%; Re: 0% to 1.00%; Os: 0% to 1.00%; Ir: 0% to 1.00%; Tc: 0% to 1.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; and a remainder: Fe and impurities.

[0027] The reasons for limiting the amount of each element are as follows. In the following description, % regarding the amount of the element is mass% unless otherwise specified.

C: 0.260% to 0.700%

[0028] C is an element that enhances hardenability of steel and improves strength of a steel member obtained after a steel sheet is subjected to a heat treatment including quenching such as hot stamping (post-quenching). When a C content is less than 0.260%, it becomes difficult to secure sufficient strength (more than 1.5 GPa (1,500 MPa)) in the steel member after quenching (obtained after being subjected to quenching). Therefore, the C content is set to 0.260% or more. The C content is set to preferably 0.280% or more, and more preferably 0.310% or more. In addition, in a case of obtaining a higher tensile strength, for example, 2,300 MPa or more, the C content is preferably 0.450% or more.

[0029] On the other hand, when the C content is more than 0.700%, the strength of the steel member after quenching becomes excessively high, and a decrease in hydrogen embrittlement resistance becomes significant. Therefore, the C content is set to 0.700% or less. The C content is set to preferably 0.650% or less, and more preferably 0.600% or less.

Si: 0% to 2.000%

[0030] Si does not have to be contained (may be 0%), but is an effective element for enhancing the hardenability of the steel and stably securing the strength of the steel member after quenching. Therefore, Si may be contained. In a case where the above effects are obtained, a Si content is set to preferably 0.100% or more, and more preferably 0.350% or more.

[0031] On the other hand, when the Si content in steel is more than 2.000%, a heating temperature required for austenitic transformation becomes significantly high during the heat treatment (quenching). Accordingly, there are cases where the cost required for the heat treatment increases, or ferrite remains during heating, resulting in a decrease in the strength of the steel member. Therefore, the Si content is set to 2.000% or less. The Si content is preferably set to 1.500% or less.

Mn: 0% to 3.00%

[0032] Mn does not have to be contained (may be 0%), but is a very effective element for enhancing the hardenability of the steel and stably securing the strength after quenching. Further, Mn is an element that lowers an Ac3 point and promotes lowering of a quenching treatment temperature. Therefore, Mn may be contained. In a case of obtaining the above effect, a Mn content is set to preferably 0.05% or more, and more preferably 0.15% or more or 0.40% or more.

[0033] On the other hand, when the Mn content is more than 3.00%, the hydrogen embrittlement resistance of the steel member after quenching deteriorates. Therefore, the Mn content is set to 3.00% or less. The Mn content is set to preferably 2.50% or less, and more preferably 1.50% or less.

Al: 0% to 1.000%

[0034] Al is an element generally used as a steel deoxidizing agent. Therefore, Al may be contained. An Al content may be 0%, but in order to obtain the above effects, the Al content is preferably set to 0.010% or more. The Al content may be set

to 0.020% or more or 0.030% or more as necessary.

[0035] On the other hand, when the Al content is more than 1.000%, the above effect is saturated and the economic efficiency is lowered. Therefore, in a case where A1 is contained, the Al content is set to 1.000% or less. The Al content may be set to 0.300% or less, 0.100% or less, or 0.075% or less as necessary.

[0036] The Al content mentioned here is the total A1 content.

Nb: 0% to 0.100%

[0037] Nb is an element that forms fine carbides, nitrides, or carbonitrides in steel and suppresses Cu hot embrittlement cracking in a hot rolling step through a grain refining effect of these precipitates. In addition, in the steel member according to the present embodiment, the hydrogen embrittlement resistance of the steel member is improved by concentrating W of Nb-based precipitates (making a W concentration higher than a W concentration of a base steel material). Therefore, Nb may be contained.

[0038] A Nb content may be 0%, but in a case where the above effects are obtained, the Nb content is preferably set to 0.005% or more. The Nb content is more preferably 0.010% or more.

[0039] On the other hand, when the Nb content is more than 0.100%, the carbonitrides become coarse and bending straightening cracking in a continuous casting step is promoted. In addition, solute Nb inhibits the development of grain boundaries having a specific rotation angle in the steel member, which will be described later, resulting in a decrease in the hydrogen embrittlement resistance of the steel member. Therefore, the Nb content is set to 0.100% or less. The Nb content is preferably 0.080% or less. The Nb content may be set to 0.060% or less or 0.040% or less as necessary.

Ti: 0% to 0.200%

[0040] Ti is an element that forms fine carbides, carbonitrides, and the like together with Nb in steel, suppresses Cu hot embrittlement cracking in the hot rolling step through the grain refining effect thereof, and has an action of improving the hydrogen embrittlement resistance of the steel member. In addition, Ti is an element that also forms nitrides by being preferentially bonded to N in the steel, suppresses the consumption of solute B due to precipitation of BN, and promotes an effect of improving the hardenability by B, which will be described later. Therefore, Ti may be contained.

[0041] A Ti content may be 0%, but in a case where the above effects are obtained, the Ti content is preferably set to 0.005% or more. The Ti content is set to more preferably 0.010% or more, and even more preferably 0.015% or more.

[0042] On the other hand, when the Ti content is more than 0.200%, the carbonitrides and the like become coarse and bending straightening cracking in the continuous casting step is promoted. In addition, solute Ti inhibits the development of grain boundaries having a specific rotation angle in the steel member, which will be described later, resulting in a decrease in the hydrogen embrittlement resistance of the steel member. In addition to the carbonitrides with Nb and TiN, the amount of TiC precipitated increases and C is consumed, so that the strength of the steel member after quenching decreases.

[0043] Accordingly, the Ti content is set to 0.200% or less. The Ti content is preferably set to 0.080% or less. The Ti content may be set to 0.060% or less or 0.040% or less as necessary.

Cr: 0% to 1.00%

[0044] Cr is an effective element for enhancing the hardenability of the steel and stably securing the strength of the steel member after quenching. Therefore, Cr may be contained. A Cr content may be 0%, but in a case where the above effects are obtained, the Cr content is set to preferably 0.01% or more, and more preferably 0.03% or more.

[0045] On the other hand, when the Cr content is more than 1.00%, the above effects are saturated and the cost increases. Furthermore, since Cr has an action of stabilizing iron carbides, when the Cr content is more than 1.00%, there are cases where coarse iron carbides remain undissolved during the heat treatment of the steel sheet, and the hydrogen embrittlement resistance of the steel member decreases. Therefore, the Cr content is set to 1.00% or less. The Cr content is set to preferably 0.50% or less, more preferably 0.20% or less, and even more preferably 0.15% or less.

B: 0% to 0.0200%

[0046] B is an element having an action of enhancing the hardenability of the steel even in a small amount. In addition, B is an element that strengthens grain boundaries and improves the hydrogen embrittlement resistance by being segregated at the grain boundaries, and is an element that suppresses the growth of austenite grains when the steel sheet is heated. Therefore, B may be contained. The B content may be 0%, but in a case where the above effects are obtained, the B content is set to preferably 0.0005% or more, and more preferably 0.0010% or more or 0.0020% or more.

[0047] On the other hand, when the B content is more than 0.0200%, a large amount of coarse compounds are precipitated, and the hydrogen embrittlement resistance of the steel member decreases. Accordingly, in a case where B is

to be contained, the B content is set to 0.0200% or less. The B content is set to preferably 0.0100% or less or 0.0050% or less.

Mo: 0% to 1.00%

[0048] Mo is a very effective element for enhancing the hardenability of the steel and stably securing the strength of the steel member after quenching. In particular, a synergistic effect on the improvement in the hardenability can be obtained by including a compound of Mo and B. Therefore, Mo may be contained. A Mo content may be 0%, but in a case where the above effects are obtained, the Mo content is set to preferably 0.01% or more, and more preferably 0.03% or more.

[0049] On the other hand, when the Mo content is more than 1.00%, the above effect is saturated and the cost increase is significant. Therefore, in a case where Mo is contained, the Mo content is set to 1.00% or less. In order to reduce the cost, the Mo content is preferably set to 0.80% or less, 0.50% or less, or 0.25% or less.

W: 0% to 2.00%

[0050] W is an effective element for enhancing the hardenability of steel and stably securing the strength of the steel member after quenching. In addition, W is an element that improves corrosion resistance in a corrosive environment. In addition, W is an element that segregates to grain boundaries and is also an element that contributes to the development of the above-described texture. Therefore, W may be contained.

[0051] In a case where a W content is less than 0.01%, it is not possible to sufficiently obtain the effect. The W content may be 0%, but in a case where the above effects are obtained, the W content is set to preferably 0.01% or more, more preferably 0.05% or more, even more preferably 0.10% or more, and still more preferably 0.20% or more.

[0052] On the other hand, in a case where the W content is more than 2.00%, the above-described effects are saturated and economic efficiency is lowered. Therefore, the W content is set to 2.00% or less. In order to reduce an alloying cost, the W content is set to preferably 1.50% or less, and more preferably 1.00% or less, 0.50% or less, or 0.20% or less.

Co: 0% to 1.00%

[0053] Co is a very effective element for enhancing the hardenability of the steel and stably securing the strength of the steel member after quenching. In particular, a synergistic effect on the improvement in the hardenability can be obtained by including a compound of Co and B. Therefore, Co may be contained. A Co content may be 0%, but in a case where the above effects are obtained, the Co content is set to preferably 0.10% or more, and more preferably 0.20% or more.

[0054] On the other hand, when the Co content is more than 1.00%, the above effect is saturated and the cost increase is significant. Therefore, in a case where Co is contained, the Co content is set to 1.00% or less. In order to reduce the alloying cost, the Co content is preferably set to 0.80% or less, 0.50% or less, or 0.25% or less.

Ni: 0% to 2.00%

[0055] Ni is an effective element for enhancing the hardenability of the steel and stably securing the strength of the steel member after quenching. In addition, Ni is an element having an action of suppressing Cu hot embrittlement cracking in the manufacturing of a steel sheet. Therefore, Ni may be contained. A Ni content may be 0%, but in a case where the above effects are obtained, the Ni content is set to preferably 0.01% or more, and more preferably 0.03% or more.

[0056] On the other hand, when the Ni content is more than 2.00%, the above effect is saturated and the cost increases. Therefore, the Ni content is set to 2.00% or less. The Ni content is set to preferably 1.00% or less, more preferably 0.50% or less, and even more preferably 0.20% or less.

Cu: 0% to 2.00%

[0057] Cu is an effective element for enhancing the hardenability of steel and stably securing the strength of the steel member after quenching. In addition, Cu is an element that improves corrosion resistance in a corrosive environment. Therefore, Cu may be contained. A Cu content may be 0%, but in a case where the above effects are obtained, the Cu content is preferably set to 0.01% or more. The Cu content is more preferably 0.03% or more.

[0058] On the other hand, in a case where the Cu content is more than 2.00%, the above-described effects are saturated and the cost increases. Therefore, the Cu content is set to 2.00% or less. In order to reduce the alloying cost, the Cu content is set to preferably 1.50% or less, and more preferably 1.00% or less, 0.80% or less, or 0.50% or less.

V: 0% to 1.00%

[0059] V is an element that forms fine carbides in steel and improves the hydrogen embrittlement resistance of the steel member through a refining effect or hydrogen trapping effect of carbides thereof. Therefore, V may be contained. A V content may be 0%, but in a case where the above effects are obtained, the V content is preferably set to 0.01% or more, and more preferably set to 0.05% or more.

[0060] On the other hand, when the V content is more than 1.00%, the above effect is saturated and the economic efficiency is lowered. Therefore, in a case where V is contained, the V content is set to 1.00% or less. In order to reduce the alloying cost, the V content is set to preferably 0.80% or less, and more preferably 0.50% or less, 0.30% or less, or 0.10% or less.

Ca: 0% to 0.200%

[0061] Ca is an element having an effect of refining inclusions in steel and enhancing the hydrogen embrittlement resistance of the steel member after quenching. Therefore, Ca may be contained. A Ca content may be 0%, but in a case where the above effects are obtained, the Ca content is preferably set to 0.001 % or more, and more preferably set to 0.010% or more or 0.020% or more.

[0062] On the other hand, in a case where the Ca content is more than 0.200%, the effects are saturated and the cost increases. Accordingly, in a case where Ca is to be contained, the Ca content is set to 0.200% or less. The Ca content is set to preferably 0.100% or less, and more preferably 0.050% or less.

Mg: 0% to 0.20%

[0063] Mg is an element having an effect of refining inclusions in steel and enhancing the hydrogen embrittlement resistance after the heat treatment. Therefore, Mg may be contained. A Mg content may be 0%, but in a case where the above effects are obtained, the Mg content is preferably set to 0.01% or more. The Mg content is more preferably 0.02% or more.

[0064] On the other hand, when the Mg content is more than 0.20%, the effect is saturated and the cost increases. Therefore, in a case where Mg is contained, the Mg content is set to 0.20% or less. The Mg content is preferably 0.10% or less, and more preferably 0.05% or less.

REM: 0% to 0.300%

[0065] Similar to Ca, REM is an element having an effect of refining inclusions in steel and improving the hydrogen embrittlement resistance of the steel member after quenching. Therefore, REM may be contained. A REM content may be 0%, but in a case where the above effects are obtained, the REM content is preferably set to 0.001% or more, and more preferably set to 0.010% or more or 0.020% or more.

[0066] On the other hand, when the REM content is more than 0.300%, the effect is saturated and the cost increases. Therefore, in a case where REM is contained, the REM content is set to 0.300% or less. In order to reduce the alloying cost, the REM content is preferably set to 0.200% or less, 0.100% or less, or 0.050% or less.

[0067] Here, REM refers to a total of 17 elements including Sc, Y, and lanthanoids such as La, Ce, and Nd, and the REM content means the total amount of these elements. REM is added to molten steel using, for example, an Fe-Si-REM alloy, and this alloy contains, for example, Sc, Y, La, Ce, Pr, and Nd.

Sb: 0% to 1.00%

[0068] Sb is an element that improves corrosion resistance in a corrosive environment. Therefore, Sb may be contained. A Sb content may be 0%, but in a case where the above effects are obtained, the Sb content is preferably set to 0.01% or more.

[0069] On the other hand, when the Sb content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Sb is contained, the Sb content is set to 1.00% or less. The Sb content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Sn: 0% to 1.00%

[0070] Sn is an element that contributes to an increase in the strength of the steel member. When a Sn content is less than 0.01%, these effects are not sufficient. Therefore, the Sn content may be 0%, but in a case where Sn is contained, the Sn content is preferably set to 0.01% or more. The Sn content is set to more preferably 0.03% or more, and even more

preferably 0.05% or more.

[0071] On the other hand, when the Sn content is more than 1.00%, the effects are saturated and the cost increases. Therefore, in a case where Sn is contained, the Sn content is set to 1.00% or less. The Sn content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Zr: 0% to 1.00%

[0072] Zr is an element that improves corrosion resistance in a corrosive environment. Therefore, Zr may be contained. A Zr content may be 0%, but in a case where the above effects are obtained, the Zr content is preferably set to 0.01% or more.

[0073] On the other hand, when the Zr content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Zr is contained, the Zr content is set to 1.00% or less. The Zr content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

As: 0% to 1.00%

[0074] As is an element that improves the hydrogen embrittlement resistance. Therefore, As may be contained. The As content may be 0%, but in a case where the above effects are obtained, the As content is preferably set to 0.01% or more.

[0075] On the other hand, when the As content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where As is contained, the As content is set to 1.00% or less. The As content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Se: 0% to 1.00%

[0076] Se is an element that improves the hydrogen embrittlement resistance. Therefore, Se may be contained. A Se content may be 0%, but in a case where the above effects are obtained, the Se content is preferably set to 0.01% or more.

[0077] On the other hand, when the Se content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Se is contained, the Se content is set to 1.00% or less. The Se content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Bi: 0% to 1.00%

[0078] Bi is an element that improves the hydrogen embrittlement resistance. Therefore, Bi may be contained. The Bi content may be 0%, but in a case where the above effects are obtained, the Bi content is preferably set to 0.01% or more.

[0079] On the other hand, when the Bi content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Bi is contained, the Bi content is set to 1.00% or less. The Bi content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Ta: 0% to 1.00%

[0080] Ta is an element that improves the hydrogen embrittlement resistance. Therefore, Ta may be contained. A Ta content may be 0%, but in a case where the above effects are obtained, the Ta content is preferably set to 0.01% or more.

[0081] On the other hand, when the Ta content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Ta is contained, the Ta content is set to 1.00% or less. The Ta content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Re: 0% to 1.00%

[0082] Re is an element that improves the hydrogen embrittlement resistance. Therefore, Re may be contained. A Re content may be 0%, but in a case where the above effects are obtained, the Re content is preferably set to 0.01% or more.

[0083] On the other hand, when the Re content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Re is contained, the Re content is set to 1.00% or less. The Re content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Os: 0% to 1.00%

[0084] Os is an element that improves the hydrogen embrittlement resistance. Therefore, Os may be contained. An Os content may be 0%, but in a case where the above effects are obtained, the Os content is preferably set to 0.01% or more.

[0085] On the other hand, when the Os content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Os is contained, the Os content is set to 1.00% or less. The Os content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Ir: 0% to 1.00%

[0086] Ir is an element that improves the hydrogen embrittlement resistance. Therefore, Ir may be contained. An Ir content may be 0%, but in a case where the above effects are obtained, the Ir content is preferably set to 0.01% or more.

[0087] On the other hand, when the Ir content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Ir is contained, the Ir content is set to 1.00% or less. The Ir content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

Tc: 0% to 1.00%

[0088] Tc is an element that improves the hydrogen embrittlement resistance. Therefore, Tc may be contained. The Tc content may be 0%, but in a case where the above effects are obtained, the Tc content is preferably set to 0.01% or more.

[0089] On the other hand, when the Tc content is more than 1.00%, the effect is saturated and the cost increases. Therefore, in a case where Tc is contained, the Tc content is set to 1.00% or less. The Tc content may be set to 0.50% or less, 0.20% or less, 0.10% or less, or 0.05% or less as necessary.

P: 0.100% or Less

[0090] P is an element that decreases the hydrogen embrittlement resistance of the steel member after quenching. In particular, when a P content is more than 0.100%, the decrease in the hydrogen embrittlement resistance becomes significant. Therefore, the P content is limited to 0.100% or less. The P content is preferably limited to 0.050% or less or 0.020% or less.

[0091] Since the P content is preferably as small as possible, the P content may be 0%. However, from the viewpoint of cost, the P content may be set to 0.001% or more.

S: 0.0100% or Less

[0092] S is an element that decreases the hydrogen embrittlement resistance of the steel member after quenching. In particular, when a S content is more than 0.0100%, the decrease in the hydrogen embrittlement resistance becomes significant. Therefore, the S content is limited to 0.0100% or less. The S content is preferably limited to 0.0050% or less.

Since the S content is preferably as small as possible, the S content may be 0%. However, from the viewpoint of cost, the S content may be set to 0.0001% or more.

N: 0.020% or Less

[0093] N is an element that decreases the hydrogen embrittlement resistance of the steel member after quenching. In particular, when a N content is more than 0.020%, coarse nitrides are formed in steel, and the hydrogen embrittlement resistance significantly decreases. Accordingly, the N content is set to 0.020% or less. A lower limit of the N content does not need to be particularly limited and may be 0%. However, setting the N content to less than 0.001% leads to an increase in steelmaking cost and is economically undesirable. Therefore, the N content may be set to 0.001 % or more, 0.002% or more, 0.008% or more, or 0.010% or more.

O: 0.010% or Less

[0094] O is an element that decreases the hydrogen embrittlement resistance of the steel member after quenching. In particular, when an O content is more than 0.010%, coarse nitrides are formed in steel, and the hydrogen embrittlement resistance significantly decreases. Therefore, the O content is set to 0.010% or less.

[0095] A lower limit of the O content does not need to be particularly limited and may be 0%. However, setting the O content to less than 0.001% leads to an increase in steelmaking cost and is economically undesirable. Therefore, the O content may be set to 0.0001% or more, 0.002% or more, 0.0008% or more, or 0.001% or more.

(Remainder: Fe and Impurities)

[0096] In the chemical composition of the steel member according to the present embodiment, the addition or inclusion

of elements other than the above-described elements is not excluded as long as the effects of the present embodiment are achieved. However, the addition or inclusion of elements other than the above-described elements may not be permitted as necessary. In the chemical composition of the steel member according to the present embodiment, the remainder including elements other than the above-described elements includes at least Fe and impurities. The remainder may

[0097] Here, the "impurities" are elements that are incorporated due to various factors including raw materials such as ore and scrap and a manufacturing process when the steel sheet is industrially manufactured, and are acceptable in a range without adversely affecting the properties of the steel member according to the present embodiment. An industrial manufacturing method is a blast furnace steelmaking method or an electric furnace steelmaking method, and includes a level (impurity level) incorporated during manufacturing by any of the methods. Examples of the impurities include Pb and Zn.

[0098] Since the total of the amounts of the impurities is usually 1.0% or less, the total of the amounts of the impurities may be set to 1.0% or less. The total of the amounts of the impurities may be set to 0.5% or less, 0.2% or less, 0.1 % or less, or 0.05% or less as necessary. For various reasons such as reducing raw material costs, raw materials that contain relatively large amounts of elements other than the above-mentioned elements may be intentionally used. Therefore, in the present embodiment, these elements are all regarded as impurity elements, regardless of whether these elements are mixed in or intentionally used. Therefore, the total of the concentrations of these elements may be set to 1.0% or less as described above.

[0099] The chemical composition of the steel member can be obtained by the following method.

[0100] The chemical composition can be obtained by performing elemental analysis on the 1/4 depth position of the steel member (a range of 1/8 to 3/8 of the thickness from the surface in the thickness direction) using a general method such as ICP-AES. For elements, which are difficult to measure using ICP-AES, C and S may be measured using a combustion-infrared absorption method, N may be measured using an inert gas fusion-thermal conductivity method, and O may be measured using an inert gas fusion-non-dispersive infrared absorption method. In a case where a chemical composition of the steel sheet that is a material of the steel member or ladle analysis values of molten steel are known, the chemical composition of the steel sheet or the ladle analysis values of the molten steel may be used as the chemical composition of the steel member.

<Microstructure>

[0101] In the steel member according to the present embodiment, the microstructure at the 1/4 depth position includes, by area ratio, martensite, bainite, and tempered martensite: 90% or more in total.

[0102] Martensite, bainite, and tempered martensite are structures (phases) that contribute to the high-strengthening of the steel member, and it is difficult to obtain sufficient strength in the steel member when the total of the area ratios of these structures is less than 90%. Hereinafter, martensite, bainite, and tempered martensite may be collectively referred to as a hard structure.

[0103] The total area ratio of martensite, bainite, and tempered martensite may be 95% or more, 98% or more, or 100% (an area ratio of a remainder in microstructure excluding the hard structure may be 0%), but the remainder in microstructure may include one or more of pearlite, bainite, ferrite, cementite, and residual austenite.

[0104] The area ratio of each structure can be measured by the following method.

[0105] A test piece is collected from any position (a position avoiding an end portion in a case where the sample cannot be collected from this position) 50 mm or more away from an end surface of the steel member so that the microstructure at the 1/4 depth position can be observed in a cross section parallel to a rolling direction and parallel to the sheet thickness direction.

[0106] The cross section of the test piece is polished using #600 to #1500 silicon carbide paper and is thereafter mirror-finished using a liquid obtained by dispersing a diamond powder having a particle size of 1 to 6 μm in a diluted solution such as alcohol or in pure water. Next, the cross section of the test piece is polished at room temperature using colloidal silica containing no alkaline solution to remove strain introduced into a surface layer of the sample.

[0107] At any position in a longitudinal direction (rolling direction) of the cross section of the test piece after the polishing, a region extending 200 μm in the longitudinal direction and extending from a 1/8 position of a thickness from a surface to a 3/8 position of the thickness from the surface with respect to a 1/4 position of the thickness from the surface as a center is set as an observation region. Then, the observation region is measured by an electron backscatter diffraction method at a measurement interval of 0.1 μm to obtain crystal orientation information. For the measurement, an apparatus including a thermal field-emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.) and an EBSD detector (DVC5 type detector manufactured by TSL) is used. In this case, the degree of vacuum in the apparatus is set to 9.6×10^{-5} Pa or less, an accelerating voltage is set to 15 kv, an irradiation current level is set to 13, and an irradiation level of an electron beam is set to 62. In addition, during the measurement, "iron- α " and "iron- γ " are set as Phases, and the measurement is performed.

[0108] In addition, the same region as the measurement region in EBSD (EBSD measurement region) is observed at a magnification of 1,000-fold or more using the thermal field-emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.)

[0109] In order to observe the same region, Vickers indentations are stamped at three points among four corners of the EBSD measurement region in a range of 100 μm or less from the four corners of the EBSD measurement region so that observation positions can be specified. Thereafter, foreign matter or the like adhering to a surface layer is polished away to leave a structure of an observed section, followed by nital etching. When the Vickers indentation is used as a mark, the same region as the EBSD measurement region can be observed. In a case where foreign matter adheres to the surface of the sample, the foreign matter is removed as necessary by a method such as buffing using alumina particles having a secondary particle size of 0.1 μm or less, polishing using colloidal silica not containing an alkaline solution at room temperature, or Ar ion sputtering.

[0110] An image obtained by the observation with the thermal field-emission scanning electron microscope (FE-SEM) is subjected to image analysis, and particles having a higher brightness than that of a primary phase structure, a particle size (circle equivalent diameter) of 0.3 μm or more and 2.0 μm or less, and an aspect ratio R_l/R_s , which is a ratio between a minor axis R_s and a major axis R_l of a particle, of less than 2.5 (spherical), or plate-like particles having an aspect ratio R_l/R_s of 2.5 or more are determined to be cementite. A region in which these spherical cementite particles are present at a density of 3.0 ($1/\mu\text{m}^2$) or more per unit area or a region in which plate-like cementite particles are distributed in a lamellar form, is determined to be pearlite. The plate-like cementite may have a deformed and curved shape due to rolling. In addition, the lamellar form means a form in which, for three or more of the above plate-like cementite particles, an interior angle at an intersection point where long sides of adjacent particles intersect is within 15° (including cases where the particles are parallel and do not intersect), and the closest distance between the adjacent plate-like cementite particles is 2 μm or less.

[0111] Next, the crystal orientation information obtained by the EBSD measurement is used to calculate the area ratio of the residual austenite by using the "Phase Map" function provided in the software "OIM Analysis (registered trademark)" included in the EBSD analysis apparatus. In the calculation of the area ratio, a region having an fcc crystal structure is determined to be residual austenite.

[0112] In addition, for a region having a bcc crystal structure, the "Grain Average Misorientation" function provided in the software "OIM Analysis (registered trademark)" included in the EBSD analysis apparatus is used to determine whether the region is cementite, pearlite, ferrite, bainite, martensite, or tempered martensite, and an area ratio of the region is measured.

[0113] Specifically, under the condition in which a boundary having a crystal misorientation of 15° or more is defined as a grain boundary (15° grain boundary), a region in which a Grain Average Misorientation value (GAM value) is 3.0° or less is determined to be ferrite.

[0114] In addition, a region where the GAM value is more than 3.0° is determined to be martensite, bainite, or tempered martensite. Furthermore, the EBSD measurement results and the structure image obtained by the FE-SEM observation are superimposed using the Vickers indentation as a mark, and for regions determined to be cementite and pearlite from the structure image of the FE-SEM observation, these regions are determined to be cementite and pearlite regardless of the classification of the structure determined by the "Phase Map" function and the "Grain Average Misorientation" function. At this time, positions of cementite and pearlite may be specified by comparison between a grain boundary MAP using the 15° grain boundary and a position of the Vickers indentation.

[0115] In a case where the rolling direction of the steel member is unknown, the rolling direction can be determined by the following method.

[0116] A test piece is collected from any position 50 mm or more away from the end portion of the steel member (a position avoiding the end portion in a case where the test piece cannot be collected from this position) so that a cross section in the sheet thickness direction can be observed.

[0117] The cross section of the collected test piece is finished by mirror polishing, and then observed at each of magnifications of 100-fold, 200-fold, 500-fold, and 1,000-fold using an optical microscope. An observation result at an appropriate magnification at which dimensions of inclusions can be measured is selected according to the dimensions of the inclusions. The observation range is set to a range of 500 μm or more in width and across the overall sheet thickness, and a region having a low brightness is determined to be an inclusion. The observation may be performed in a plurality of visual fields.

[0118] Next, using a cross section that is first observed by the above method as a reference, a cross section parallel to a cross section obtained by rotating the test piece around the sheet thickness direction as an axis in 5° increments within a range of 0° to 180° is observed. An average value of lengths of major axes of a plurality of inclusions in each of the obtained cross sections is calculated for each cross section, and a direction parallel to a major axis direction of the inclusions in a cross section in which the average value of the lengths of the major axes of the inclusions is maximum is determined to be the rolling direction.

[0119] In a case where the rolling direction of the steel member can be identified, for example, in a case of a steel member

that is manufactured using a steel sheet directly collected from a steel strip or the like, and in which a lengthwise direction (that is, rolling direction) of the steel strip in the steel member can be identified, the above method does not need to be used.

<Texture>

[0120] As a result of the studies by the present inventors, it was found that the resistance to hydrogen embrittlement differs depending on the crystal orientation of the crystal grains. In particular, it was found that the crystal orientations of $\{111\}<011>$, $\{111\}<112>$, $\{100\}<011>$, and $\{100\}<001>$ have a significant influence on the hydrogen embrittlement resistance. Therefore, in the steel member according to the present embodiment, a probability of the presence of the crystal grains having the above-described crystal orientations is controlled (the development degree of the crystal grains having the specific crystal orientation is controlled) to improve the hydrogen embrittlement resistance.

[0121] Crystal grains having the crystal orientations of $\{111\}<011>$ and $\{100\}<011>$ have a particularly large adverse effect on the hydrogen embrittlement resistance, and crystal grains having the crystal orientations of $\{111\}<112>$ and $\{100\}<001>$ have a particularly large effect on improving the hydrogen embrittlement resistance.

[0122] Therefore, in the steel member according to the present embodiment, at the 1/4 depth position, when a random intensity ratio of $\{111\}<011>$ is denoted by I1, a random intensity ratio of $\{111\}<112>$ is denoted by I2, a random intensity ratio of $\{100\}<011>$ is denoted by I3, and a random intensity ratio of $\{100\}<001>$ is denoted by I4, a texture is provided in which I1, I2, I3, and I4 satisfy Expression (1).

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1)$$

[0123] In a case where $(I1 + I3)/(I2 + I4)$ is more than 1.20, the hydrogen embrittlement resistance decreases. Preferably, $(I1 + I3)/(I2 + I4)$ is 1.15 or less, 1.00 or less, or 0.90 or less.

[0124] The random intensity ratios (values of I1, I2, I3, and I4) are measured by the following method.

[0125] A test piece is collected from any position (a position avoiding an end portion in a case where the test piece cannot be collected from this position) 50 mm or more away from an end surface of the steel member so that the microstructure at the 1/4 depth position can be observed in a cross section parallel to the rolling direction and parallel to the sheet thickness direction.

[0126] The cross section of the test piece is polished using #600 to #1500 silicon carbide paper and is thereafter mirror-finished using a liquid obtained by dispersing a diamond powder having a particle size of 1 to 6 μm in a diluted solution such as alcohol or in pure water. Next, the cross section of the test piece is polished at room temperature using colloidal silica containing no alkaline solution to remove strain introduced into a surface layer of the test piece.

[0127] At any position in the longitudinal direction (rolling direction) of the cross section of the obtained test piece, measurement is performed by the electron backscatter diffraction (EBSD) method in a range of 300 μm (an entire range of 1/8 to 3/8 of the thickness from the surface in a case where the thickness is less than 1.2 mm) in the thickness direction at the 1/4 depth position, with a measurement interval of 4 μm and a measurement area of 150,000 μm^2 or more to obtain crystal orientation information. For the measurement, an apparatus including a thermal field-emission scanning electron microscope (JSM-7001F manufactured by JEOL Ltd.) and an EBSD detector (DVC5 type detector manufactured by TSL) is used. In this case, the degree of vacuum in the apparatus is set to 9.6×10^{-5} Pa or less, an accelerating voltage is set to 15 kV, an irradiation current level is set to 13, and an irradiation level of an electron beam is set to 62.

[0128] The obtained crystal orientation information is calculated using spherical harmonic functions using OIM Analysis (registered trademark) manufactured by TSL, and the random intensity ratio of each orientation is obtained from the crystal orientation distribution function (ODF) that displays the calculated three-dimensional texture.

[0129] In the analysis, "sample symmetry" is set to "orthorhombic", the ODF is created for a range of ϕ_1 (ϕ_1) = 0° to 90° and Φ (Φ) = 0° to 90° in a cross section of ϕ_2 (ϕ_2) = 45° at "Bunge Euler angles" and the random intensity ratio of each orientation is calculated. Since there is a measurement error due to the processing of the test piece and the setting of the sample, maximum values are adopted for the random intensity ratio I1 of $\{111\}<011>$ (in a range of $\Phi = 50^\circ$ to 60° and $\phi_1 = 0^\circ$ to 10°), the random intensity ratio I2 of $\{111\}<112>$ (in a range of $\Phi = 50^\circ$ to 60° and $\phi_1 = 25^\circ$ to 35°), the random intensity ratio I3 of $\{100\}<011>$ (in a range of $\Phi = 0^\circ$ to 10° and $\phi_1 = 0^\circ$ to 10°), and the random intensity ratio I4 of $\{100\}<001>$ (in a range of $\Phi = 0^\circ$ to 10° and $\phi_1 = 40^\circ$ to 50°). The above-described ϕ_1 (ϕ_1) and Φ (Φ) are defined in the ODF drawing function of the analysis software (OIM Analysis).

<Properties>

[0130] A tensile (maximum) strength TS of the steel member according to the present embodiment is preferably more than 1,500 MPa. The tensile strength is more preferably 1,800 MPa or more, and even more preferably 2,300 MPa or more. The tensile strength may be set to 3,000 MPa or less or 2,700 MPa or less as necessary. There is a correlation between the tensile strength and a Vickers hardness, and in the present embodiment, a value obtained by multiplying the Vickers

hardness by 3.33 can be regarded as the tensile (maximum) strength TS. Therefore, in the steel member according to the present embodiment, the Vickers hardness (HV1) at a test force of 9.807 N (load 1 kgf) is preferably 450 or more. The Vickers hardness (HV1) is more preferably 470 or more, 510 or more, or 540 or more, and even more preferably 600 or more or 690 or more. The Vickers hardness (HV1) may be set to 900 or less, 860 or less, or 820 or less as necessary.

[0131] The Vickers hardness can be obtained by the following method.

[0132] A sample is cut out from any position 50 mm or more away from the end surface of the steel member so that a cross section (thickness direction cross section) perpendicular to the surface can be observed. A size of the sample depends on a measurement device, but may be set so that a size of about 10 mm can be observed in the rolling direction. The cross section of the sample is polished using #600 to #1500 silicon carbide paper and thereafter mirror-finished using a liquid obtained by dispersing a diamond powder having a particle size of 1 to 6 μm in a diluted solution such as alcohol or pure water. For the cross section mirror-finished, the Vickers hardness (HV1) is obtained by measuring the hardness at 20 points in total at intervals of three or more times the indentation with a test force of 9.807 N in accordance with JIS Z 2244-1:2020 in a direction parallel to a sheet surface at the 1/4 depth position of the base steel sheet using a micro-Vickers hardness tester, and calculating an average value thereof.

[0133] In addition, in the steel member according to the present embodiment, the chemical composition, the micro-structure, and the texture are controlled as described above, so that the hydrogen embrittlement resistance is excellent.

[Coating]

[0134] A part or the entirety of the surface of the steel member according to the present embodiment may have a coating.

[0135] The coating may be a coating primarily containing an Fe-Al-based alloy (Fe-Al-based coating) or a coating primarily containing an Fe-Zn-based alloy (Fe-Zn-based coating). The coating is also referred to as a film, an alloyed plating layer, or an intermetallic compound layer.

[0136] The coating primarily containing an Fe-Al-based alloy is a coating containing 70 mass% or more of Fe and Al in total, and the coating primarily containing an Fe-Zn-based alloy is a coating containing 70 mass% or more of Fe and Zn in total. The coating primarily containing an Fe-Al-based alloy may further contain, in addition to Fe and Al, Si, Mg, Ca, Sr, Ni, Cu, Mo, Mn, Cr, C, Nb, Ti, B, V, Sn, W, Sb, Zn, Co, In, Bi, Zr, Se, As, and REM, and a remainder including impurities. The coating primarily containing an Fe-Zn-based alloy may further contain, in addition to Fe and Zn, Si, Mg, Ca, Sr, Ni, Cu, Mo, Mn, Cr, C, Nb, Ti, B, V, Sn, W, Sb, Al, Co, In, Bi, Zr, Se, As, and REM, and a remainder including impurities.

[0137] By including the coating, corrosion resistance is obtained, so that an effect of improving the hydrogen embrittlement resistance in use in a vehicle can be obtained.

[0138] A thickness of the coating is preferably 10 to 100 μm .

[0139] The chemical composition and the thickness of the coating can be obtained by observing a cross section with a scanning electron microscope.

[0140] Specifically, a measurement sample is cut out from a 1/2 portion of the steel member in a longitudinal direction (a 1/2 position of a length in the longitudinal direction from a longitudinal end portion) and a 1/4 width portion (a 1/4 position of the width in the width direction from the width-directional end portion) and is observed. An observation range of the microscope is set to, for example, a range of 40,000 μm^2 or more in terms of area at a magnification of 400-fold. The cut sample is mechanically polished and subsequently mirror-finished. Next, the thickness of the coating is measured in any 10 visual fields, and an average value thereof is used as the thickness of the coating.

[0141] By observation with a BSE image (or a COMPO image) a clear difference in contrast between the coating and the base metal (steel sheet substrate) is confirmed. Therefore, the thickness of the coating can be measured by measuring a thickness from an outermost surface to a position where the contrast changes. Measurement is performed at 20 points at equal intervals in an observation photograph, and a distance between the measurement points is set to 6.5 μm . During the measurement, observation is performed in five visual fields in the above-described manner, and an average value thereof is used as the thickness of the coating.

[0142] In addition, as the chemical composition of the coating, the amounts of Fe, Al, and Zn contained in the coating can be obtained by performing spot elemental analysis (beam diameter: 1.0 μm or less) on the observation range described above using an electron probe micro-analyzer (EPMA). A total of 10 points are analyzed in the coating in 10 random visual fields, and average values thereof are regarded as the amounts of Fe, Al, and Zn contained in coating. Even in a case where an element other than Fe, Al, and Zn is contained, the amount thereof is obtained using the same method.

[Steel Sheet]

[0143] Next, the steel sheet according to the present embodiment will be described. The steel sheet according to the present embodiment can be used as a material for the steel member according to the present embodiment, since the steel member according to the present embodiment can be obtained by performing a heat treatment such as hot stamping on the steel sheet.

[0144] Hereinafter, when a range between a 1/8 position of a sheet thickness in a sheet thickness direction from a surface of the steel sheet and a 3/8 position of the sheet thickness in the sheet thickness direction from the surface is defined as a 1/4 depth position.

[0145] The steel sheet according to the present embodiment has a predetermined chemical composition, and, at the 1/4 depth position, when a random intensity ratio of $\{111\}<011>$ is denoted by I1, a random intensity ratio of $\{111\}<112>$ is denoted by I2, a random intensity ratio of $\{100\}<011>$ is denoted by I3, and a random intensity ratio of $\{100\}<001>$ is denoted by I4, has a texture in which I1, I2, I3, and I4 satisfy Expression (1).

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1)$$

[0146] The steel sheet according to the present embodiment may be coated on the surface. Even in that case, since the coating is not a steel sheet, the chemical composition, a microstructure, the texture, and the like of the steel sheet are a chemical composition, a microstructure, a texture, and the like of a part excluding the coating (this part is sometimes referred to as a "base steel sheet" or "base metal steel sheet").

[0147] In a case where the surface of the steel sheet according to the present embodiment is coated, that is, the surface of the steel sheet according to the present embodiment serving as a reference for the 1/4 depth position is a surface of the part excluding the coating (base steel sheet), that is, a boundary between the base steel sheet and the coating. Therefore, for example, in a case where front and back surfaces of the steel sheet are coated, a thickness t_1' of the steel sheet including the coating is measured, a thickness t_2' of the coating is then measured by a method described later, and a thickness (thickness of the base steel sheet) $t_3' = t_1' - 2 \times t_2'$ of the steel sheet is calculated. Thereafter, a range separated by $t_3'/8$ to $(3 \times t_3')/8$ in the thickness direction from a center of the thickness t_1' of the steel member including the coating can be set as the 1/4 depth position.

[0148] These will be described.

<Chemical Composition>

[0149] The chemical composition of the steel sheet according to the present embodiment needs to be set to obtain preferable properties for the steel member after the heat treatment. However, since the chemical composition does not substantially change due to the heat treatment, the chemical composition of the steel sheet according to the present embodiment may be the same as the chemical composition of the steel member according to the present embodiment.

[0150] The chemical composition of the steel sheet can be obtained by the following method.

[0151] The chemical composition can be obtained by performing elemental analysis on the 1/4 depth position of the steel sheet (a range of 1/8 to 3/8 of the thickness from the surface in the thickness direction) using a general method such as ICP-AES. For elements, which are difficult to measure using ICP-AES, C and S may be measured using a combustion-infrared absorption method, N may be measured using an inert gas fusion thermal conductivity method, and O may be measured using an inert gas fusion-non-dispersive infrared absorption method. In a case where ladle analysis values of molten steel or a chemical composition of a slab at the 1/4 depth position is known, the ladle analysis values of molten steel or the chemical composition of the slab at the 1/4 depth position may be used as the chemical composition of the steel sheet.

<Microstructure>

[0152] The microstructure of the steel sheet according to the present embodiment is not limited, but in terms of workability, the microstructure at the 1/4 depth position preferably contains, by area ratio, ferrite: 5% or more and less than 90%, pearlite: more than 10% and 95% or less, and a remainder in microstructure including one or more of bainite, martensite, cementite, and residual austenite.

[0153] Ferrite is a structure having low strength and excellent ductility. When ferrite is contained in less than 5%, cold rolling properties are poor, and there is a concern that defects in a shape of the steel sheet are incurred. Therefore, the area ratio of ferrite is preferably 5% or more. An upper limit of the area ratio of ferrite is not particularly limited. However, in a case where the C content is 0.260% or more, it is difficult to control ferrite to 90% or more. Therefore, the area ratio of ferrite may be set to less than 90%. The area ratio of ferrite may be set to 85% or less as necessary.

[0154] Pearlite contains fine lamellar cementite within a structure, and is an important structure that shares austenite nucleation sites during heating. The area ratio is preferably more than 10% from the viewpoint of suppressing coarsening of prior γ grains of the steel member. On the other hand, when the area ratio of pearlite is more than 95%, the cold rolling properties become poor, and defects in the shape of the steel sheet are incurred. Therefore, an upper limit thereof is preferably set to 95% or less.

[0155] The remainder includes one or more of bainite, martensite, cementite, and residual austenite. It is preferable that the total of the area ratios of ferrite and pearlite is 50% or more, and the area ratio of the remainder is 50% or less. The total of ferrite and pearlite is more preferably 80% or more.

[0156] Microstructural fractions in the microstructure of the steel sheet at the 1/4 depth position can be measured in the same manner as for the steel member. In a case where a rolling direction of the steel sheet is unknown, the rolling direction can be determined in the same manner as for the steel member.

<Texture>

[0157] In the steel sheet according to the present embodiment, at the 1/4 depth position, when a random intensity ratio of { 111 }<011 > is denoted by I1, a random intensity ratio of { 111 }<112> is denoted by I2, a random intensity ratio of {100}<011> is denoted by I3, and a random intensity ratio of {100}<001> is denoted by I4, a texture is provided in which I1, I2, I3, and I4 satisfy Expression (1).

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1)$$

[0158] This texture is retained even after a heat treatment such as hot stamping under predetermined conditions is performed. Therefore, by controlling the steel sheet to have a texture satisfying Expression (1) at a stage of the steel sheet, a steel member obtained by performing a heat treatment including quenching on this steel sheet also has a texture satisfying Expression (1).

[0159] The random intensity ratios (values of I1, I2, I3, and I4) of the steel sheet can be measured in the same manner as for the steel member.

[0160] The sheet thickness of the steel sheet in the present embodiment is not limited, but may be set to 0.4 to 5.0 mm from the viewpoint of forming into a component.

[Coating]

[0161] A part of the surface of the steel sheet according to the present embodiment may have a coating. The coating may be a coating primarily containing Al (Al-based coating) or a coating primarily containing Zn (Zn-based coating). The coating is also referred to as a film or a plating layer. The coating primarily containing Al is a coating containing 70 mass% or more of Al, and the coating primarily containing Zn is a coating containing 70 mass% or more of Zn. The coating primarily containing Al may further contain, in addition to Al, Si, Mg, Ca, Sr, Ni, Cu, Mo, Mn, Cr, C, Nb, Ti, B, V, Sn, W, Sb, Zn, Co, In, Bi, Zr, Se, As, and REM, and a remainder including impurities. The coating primarily containing Zn may further contain, in addition to Zn, Si, Mg, Ca, Sr, Ni, Cu, Mo, Mn, Cr, C, Nb, Ti, B, V, Sn, W, Sb, Al, Co, In, Bi, Zr, Se, As, and REM, and a remainder including impurities. A chemical composition and a thickness of the coating can be measured in the same manner as for the steel member.

[Manufacturing Method]

[0162] Details of manufacturing methods of the steel member according to the present embodiment and the steel sheet according to the present embodiment will be described below, but the steel member and the steel sheet can be manufactured according to a manufacturing method including the following steps.

[0163] Specifically, the steel sheet according to the present embodiment can be manufactured by a manufacturing method including the following steps:

- (I) a casting step of obtaining a slab having a predetermined chemical composition by casting;
- (II) a heating step of heating the slab to a temperature range of 1,200°C or higher and holding the slab for 20 minutes or longer;
- (III) a hot rolling step of performing hot rolling on the slab after the heating step to obtain a hot-rolled steel sheet;
- (IV) a cooling step of cooling the hot-rolled steel sheet to T1 - 150°C or lower;
- (V) a coiling step of coiling the hot-rolled steel sheet after the cooling step at a coiling temperature of T1 - 150°C to 450°C; and
- (VI) a cold rolling step of performing cold rolling on the hot-rolled steel sheet after the coiling step at a rolling reduction of 15% to 60% to obtain a steel sheet (cold-rolled steel sheet).

[0164] In addition, the manufacturing method of the steel sheet according to the present embodiment may further include any or both of the following steps:

- (VII) an annealing step of heating the steel sheet after the cold rolling step to an annealing temperature (maximum attainment temperature) of 680°C to 950°C and holding the steel sheet in a temperature range of 680°C to 950°C for 5 to 1,200 seconds; and

(VIII) a coating forming step of forming a coating on a surface of the steel sheet.

[0165] In addition, the steel member according to the present embodiment can be manufactured by a manufacturing method including the following step using the steel sheet according to the present embodiment obtained through the above steps:

(IX) a heat treatment step of heating the steel sheet according to the present embodiment to a temperature range of Ac_3 to $Ac_3 + 300^\circ C$ at an average heating rate of 1 to $1,000^\circ C/s$, holding the steel sheet in the temperature range for 60 to 600 seconds, and then cooling the steel sheet to a temperature range of $300^\circ C$ or lower at an average cooling rate of $20^\circ C/s$ or faster.

[0166] Each step will be described.

[0167] The temperature of the slab and the temperature of the steel sheet in the present embodiment refer to a center temperature of the slab and a surface temperature of the steel sheet.

[Manufacturing Method of Steel Sheet]

<Casting Step>

[0168] In the casting step, a slab having a predetermined chemical composition is obtained by casting. The chemical composition of the slab may be the same as the steel sheet according to the present embodiment.

[0169] Molten steel having the same chemical composition as the steel sheet according to the present embodiment is melted by a normal melting method such as a converter or an electric furnace, and cast into a slab by casting such as a continuous casting method. In addition to the continuous casting method, an ingot-making method, a thin slab casting method, or the like may also be adopted to manufacture the steel slab.

<Heating Step>

[0170] In the heating step, the slab is heated such that a center portion of the slab reaches $1,200^\circ C$ or higher prior to the hot rolling, and held at $1,200^\circ C$ or higher for 20 minutes or longer. When a heating temperature (the temperature of the center portion of the slab) is lower than $1,200^\circ C$ or a holding time is shorter than 20 minutes, sufficient uniformity of crystal grains cannot be obtained in the subsequent steps, and an effect of sufficient uniformity of crystal grains cannot be obtained in the subsequent rough rolling step.

[0171] The temperature of the center portion of the slab can be obtained by actually measuring a surface temperature of the slab with a radiation-type thermometer and performing heat transfer calculations.

<Hot Rolling Step>

[0172] In the hot rolling step, the heated slab is hot-rolled to obtain a hot-rolled steel sheet, and the hot-rolled steel sheet is cooled to a coiling temperature. It is preferable that the hot rolling includes rough rolling and finish rolling, and conditions of each of the rough rolling and the finish rolling are preferably as follows. The temperatures controlled in the following steps are all surface temperatures of the steel sheet.

<<Rough Rolling>>

[0173] In the rough rolling, it is preferable to perform rolling two or more times at a rolling reduction of 30% or more and complete the rough rolling in a temperature range of $T_1 + 50^\circ C$ or higher. By performing the rolling two or more times at a rolling reduction of 30% or more, uniformity of the microstructure can be increased, and a predetermined texture can be obtained.

[0174] In addition, when the temperature (the temperature on an outlet side of a final pass of the rough rolling) at which the rough rolling is completed is denoted by Tr , in a case where Tr is lower than $T_1 + 50^\circ C$, recrystallization before the start of the finish rolling becomes non-uniform, austenite grain sizes become non-uniform, and the microstructure during the finish rolling becomes non-uniform, so that a predetermined texture cannot be obtained. Therefore, the rough rolling completion temperature Tr is set to $T_1 + 50^\circ C$ or higher.

[0175] In addition, in the rough rolling, the time from the final pass where rolling is performed at a rolling reduction of 30% or more to the start of the finish rolling is denoted by trs (sec), and trs , Tr , and T_1 ($^\circ C$) obtained by Expression (3) are set to satisfy Expression (2).

$$trs \geq 60 \times (Tr/T_1) \dots (2)$$

<<Finish Rolling>>

[0176] After the rough rolling, finish rolling is performed. In the finish rolling, a finish rolling start temperature T_s is set to be equal to or higher than T_1 (°C) obtained by Expression (3), and a finish rolling completion temperature is set to $T_1 - 20^\circ\text{C}$ or lower.

$$T_1 (\text{°C}) = 907 + 168 \times \text{Ti} + 1325 \times \text{Nb} + 120 \times \text{Mo} + 4500 \times \text{B} \dots (3)$$

[0177] Here, the element symbols in the expression are the amounts of the elements in the steel sheet by mass%.

[0178] By setting a total rolling reduction (cumulative rolling reduction) at T_1 to $T_1 + 150^\circ\text{C}$ to 80% or more and the total rolling reduction at lower than T_1 °C to 10% to 50%, a predetermined texture is developed.

[0179] In a case where the total rolling reduction (cumulative rolling reduction) at T_1 to $T_1 + 150^\circ\text{C}$ is less than 80%, or the total rolling reduction at lower than T_1 °C is less than 10% or more than 50%, a predetermined texture does not develop, or a texture in an undesirable orientation develops.

[0180] When the finish rolling completion temperature is higher than $T_1 - 20^\circ\text{C}$, the uniformity of the microstructure decreases, and a predetermined texture cannot be obtained.

[0181] On the other hand, when the finish rolling completion temperature is lower than $T_1 - 100^\circ\text{C}$, a predetermined texture cannot be obtained, which is not preferable. Therefore, the finish rolling completion temperature is preferably set to $T_1 - 100^\circ\text{C}$ or higher.

[0182] Here, the total rolling reduction (%) in each temperature range is calculated by (start thickness - final thickness) / start thickness $\times 100$, and is calculated for each rolling in each temperature range. Therefore, the sum of the total rolling reductions in each temperature range may simply exceed 100%.

<Cooling Step>

[0183] In the cooling step, the hot-rolled steel sheet after the finish rolling is cooled. The time until the start of the cooling step after the finish rolling and the average cooling rate in a predetermined temperature range affect the formation of the texture of the steel sheet. Therefore, the elapsed time from the completion of the finish rolling to the start of cooling is set to shorter than 2.5 seconds, and the steel sheet is cooled to a temperature of $T_1 - 150^\circ\text{C}$ or lower at an average cooling rate of faster than 50°C/s and 150°C/s or slower.

[0184] In a case where the elapsed time from the completion of the finish rolling to the start of the cooling is 2.5 seconds or longer, or the average cooling rate up to $T_1 - 150^\circ\text{C}$ or lower is 50°C/s or slower, the predetermined texture does not develop.

[0185] On the other hand, when the average cooling rate to $T_1 - 150^\circ\text{C}$ or lower is faster than 150°C/s , temperature control becomes difficult, the material becomes non-uniform, and cold rolling properties deteriorate, which causes defects in the shape of the steel sheet. Therefore, the average cooling rate to $T_1 - 150^\circ\text{C}$ or lower is preferably set to 150°C/s or slower.

[0186] A cooling stop temperature is preferably set to 450°C or higher in order to secure the coiling temperature.

<Coiling Step>

[0187] In the coiling step, the hot-rolled steel sheet after the cooling step is coiled at a temperature of $T_1 - 150^\circ\text{C}$ to 450°C .

[0188] When the coiling temperature is higher than $T_1 - 150^\circ\text{C}$, the steel sheet is coiled while transformation hardly progresses, and transformation progresses in the coil, so that defects in a shape of a coil are incurred, which is not preferable. The coiling temperature is more preferably $T_1 - 150^\circ\text{C}$ or lower and 800°C or lower.

[0189] On the other hand, when the coiling temperature is lower than 450°C , bainite is excessively generated, the cold rolling properties of the steel sheet deteriorate, and defects in the shape of the steel sheet are incurred. Therefore, the coiling temperature is preferably 450°C or higher.

<Cold Rolling Step>

[0190] In the cold rolling step, the hot-rolled steel sheet after the coiling step is cold-rolled at a rolling reduction (cumulative rolling reduction) of 15% to 60% to obtain a steel sheet (cold-rolled steel sheet).

[0191] A predetermined texture can be developed at a rolling reduction of 15% or more. When the rolling reduction is less than 15%, the development of the texture cannot be sufficiently achieved.

[0192] On the other hand, when the rolling reduction is more than 60%, a texture in an undesirable orientation develops.

<Annealing Step>

[0193] The steel sheet after the cold rolling step may be annealed for the purpose of softening. This annealing may be a heat treatment for the purpose of softening by reducing a carbon concentration in the surface layer in addition to softening by microstructure control of a sheet thickness center portion of the steel sheet.

[0194] The annealing is preferably performed under the conditions in which the annealing temperature (maximum attainment temperature) is 680°C to 950°C and the holding time in a temperature range of 680°C to 950°C is 5 to 1,200 seconds. The holding time referred to here means the time from when the steel sheet temperature rises and reaches 680°C to when the steel sheet temperature decreases and reaches 680°C after being held at 680°C to 950°C.

<Coating Formation Step>

[0195] In a case where a coating is formed on the surface, the coating is formed on the surface of the steel sheet (the hot-rolled steel sheet after the coiling step, the hot-rolled steel sheet after the hot-rolled sheet annealing step, the cold-rolled steel sheet after the cold rolling step, or the cold-rolled steel sheet after the annealing step) to obtain a coated steel sheet. A method for forming the coating is not particularly limited, and a hot-dip plating method, an electro plating method, a vacuum vapor deposition method, a cladding method, a thermal spraying method, and the like can be used. The hot-dip plating method is the most popular in the industry.

[0196] Examples of the coating may include an Al-based coating containing Al and a Zn-based coating containing Zn.

[0197] In a case where the Al-based coating is formed by hot-dip plating, in addition to Al, Fe is mixed in a plating bath as an impurity in many cases. Furthermore, in addition to the above elements, Si, Mg, Ca, Sr, Ni, Cu, Mo, Mn, Cr, C, Nb, Ti, B, V, Sn, W, Sb, Zn, Co, In, Bi, Zr, Se, As, and mischmetal may be contained in the plating bath as long as 70 mass% or more of Al is contained.

[0198] In the case of performing hot-dip plating, plating may be performed after the steel sheet after the annealing step is cooled to room temperature and is then heated again, or hot-dip plating may be performed after performing cooling to 450°C to 750°C, which is close to a plating bath temperature, after annealing without temporarily performing cooling to room temperature.

[0199] In a case where no coating is to be formed, this step does not need to be performed.

[0200] Pretreatments and post-treatments of the coating are not particularly limited, and precoating, solvent coating, an alloying treatment, temper rolling, or the like can be performed. As the alloying treatment, for example, annealing at 450°C to 800°C can be performed. Furthermore, as a post-treatment, temper rolling is useful for shape adjustment and the like, and can achieve, for example, a rolling reduction of 0.1% to 0.5%.

[Manufacturing Method of Steel Member]

<Heat Treatment Step>

[0201] In the heat treatment step, the steel sheet according to the present embodiment is heated to a temperature range of Ac_3 to $Ac_3 + 300^\circ C$ at an average heating rate of 1.0 to 1,000 °C/s, held in the temperature range for 60 to 600 seconds, and then cooled to a temperature range of 300°C or lower at an average cooling rate of 20 °C/s or faster.

[0202] When the temperature rising rate is slower than 1.0 °C/s, productivity of the heat treatment decreases, which is not preferable. On the other hand, when the temperature rising rate is faster than 1,000 °C/s, a duplex grain structure is formed and the limit hydrogen amount decreases, which is not preferable. The average heating rate referred to here is a value obtained by dividing a temperature difference between the surface temperature of the steel sheet at the time of the start of the heating and the holding temperature by a time difference from the start of the heating to the time when the holding temperature is reached.

[0203] Furthermore, when the heat treatment temperature is lower than Ac_3 (°C), ferrite remains after cooling and the strength is insufficient, which is not preferable. On the other hand, when the heat treatment temperature is higher than $Ac_3 + 300^\circ C$, grains become coarse in the structure, and the limit hydrogen amount decreases, which is not preferable.

[0204] When the average cooling rate to 300°C or lower is slower than 20 °C/s, the area ratio of ferrite or pearlite becomes 10% or more, resulting in insufficient strength.

[0205] During heating, holding may be performed for 1 to 300 seconds within a range of the heating temperature $\pm 10^\circ C$.

[0206] In addition, after cooling to a temperature equal to or lower than 300°C, a tempering treatment may be performed in a temperature range of about 150°C to 600°C in order to adjust the strength of the steel member. In addition, a part of the hotstamping formed body may be tempered by, for example, laser irradiation to partially provide a softened region.

[0207] The heat treatment is, for example, hot stamping.

[0208] Ac_3 (°C) is calculated from Expression (4) using the amount (mass%) of each element in the chemical composition of the steel sheet (steel sheet for hot stamping).

$$Ac3 = 854 \times 179 \times C + 44 \times Si - 14 \times Mn - 18 \times Ni - 2 \times Cr \dots (4)$$

[0209] Here, the element symbols in the expression are the amounts of the elements in the steel sheet by mass%.

5 Examples

[0210] Slabs having the chemical compositions (ladle analysis values) shown in Tables 1-1 to 1-10 were obtained by casting.

10 [0211] The slabs were heated until a temperature of a slab center portion reached the temperature shown in "Heating temperature (°C)" in Tables 2-1 to 2-6, and were controlled to be held at a temperature of 1,200°C or higher for "Holding time (min)" shown in Tables 2-1 to 2-6.

15 [0212] The slabs after the heating were subjected to hot rolling (rough rolling and finish rolling) to obtain hot-rolled steel sheets. In the rough rolling, rough rolling was performed at a rolling reduction of 30% or more in rolling passes including a final stage of the rough rolling for the number of times shown in "Number of rolling passes at rolling reduction of 30% or more (times)" in Tables 2-1 to 2-6, and the rolling was performed so that the rolling was completed at the temperature of "Rough rolling completion temperature (°C)". A sheet thickness of the rough-rolled sheet was controlled in a range of 25 to 50 mm.

[0213] After the completion of the rough rolling, no reduction was performed until the start of finish rolling for the time shown in "Time from completion of rough rolling to start of finish rolling trs (sec)" in Tables 2-1 to 2-6.

20 [0214] In the finish rolling, rolling was started at "Finish rolling start temperature T1 (°C)", and rolling was performed so that "Total rolling reduction at T1 to T1 + 150°C (%)" and "Total rolling reduction at lower than T1°C (%)" were the values in Tables 2-1 to 2-6, and the rolling was completed at "Finish rolling completion temperature (°C)".

[0215] The sheet thickness after the finish rolling was set to 4.5 to 2.0 mm.

25 [0216] After the finish rolling was completed, cooling was started after "Time until start of cooling (sec)" shown in Tables 2-7 to 2-12 had elapsed. Cooling to "Cooling stop temperature (°C)" was performed at "Average cooling rate (°C/s)" in Tables 2-7 to 2-12, followed by coiling into coils at "Coiling temperature (°C)", and air cooling to room temperature.

30 [0217] Next, the obtained hot-rolled steel sheets were cold-rolled at "Rolling reduction (%)" in Tables 2-7 to 2-12 to obtain cold-rolled steel sheets. In addition, some of the cold-rolled steel sheets were further annealed at "Annealing temperature (°C)" for "Annealing holding time (sec)" shown in Tables 2-7 to 2-12. In addition, in some examples, after the annealing, coating (plating) was performed by hot-dip galvanizing (GI), hot-dip galvannealing (GA), or Al plating (Al). The plating was performed by a known method. For GA, heating to a temperature range of 500°C to 570°C was performed after hot-dip galvanizing to promote alloying. In addition, some of the examples were subjected to temper rolling at an elongation rate of 0.2% after the annealing.

35 [0218] The microstructures at the 1/4 depth positions of the obtained steel sheets were observed in the above-described manner. The area ratios of ferrite and pearlite are shown in Tables 2-7 to 2-12. The remainder of the microstructure was not shown in the table, but included one or more of bainite, martensite, cementite, and residual austenite.

[0219] In addition, for the obtained steel sheets, a ratio $(I1 + I3)/(I2 + I4)$ between the random intensity ratio I1 of {111}<011>, the random intensity ratio I2 of {111}<112>, the random intensity ratio I3 of {100}<011>, and the random intensity ratio I4 of {100}<001> was measured.

40 [0220] The results are shown in Tables 2-7 to 2-12.

[0221] In addition, the steel sheets were subjected to a heat treatment of heating to "Heating temperature (°C)" shown in Tables 3-1 to 3-6 at "Average heating rate (°C/s)", holding for "Heating holding time (sec)", and then cooling to "Cooling completion temperature (°C)" at "Average cooling rate (°C/s)" to obtain steel members.

[0222] In some examples, after the heat treatment, tempering was further performed at 150°C for 25 minutes.

45 [0223] The microstructure at the 1/4 depth position was observed in the above-described manner for the obtained steel members. The area ratio of the hard structure (the total area ratio of martensite, bainite, and tempered martensite) is shown in Tables 3-1 to 3-6.

[0224] In addition, for the obtained steel members, the Vickers hardness was measured as an alternative index of tensile strength.

50 [0225] Specifically, a sample is cut out from a position 50 mm or more away from the end surface of the steel member so that a cross section (sheet thickness cross section) perpendicular to the surface could be observed. The sample was set to a size that allowed observation of 10 mm in the rolling direction. The cross section of the sample was polished using #600 to #1500 silicon carbide paper and thereafter mirror-finished using a liquid obtained by dispersing a diamond powder having a particle size of 1 to 6 μm in a diluted solution such as alcohol or pure water. For the cross section mirror-finished, the hardness was measured in a direction parallel to the sheet surface at the 1/4 depth position of the sheet thickness from the surface of the base steel sheet using a micro-Vickers hardness tester with a test force of 9.807 N at intervals of three or more times the indentation. A total of 20 points were measured, and the average value thereof was taken as the Vickers hardness (M_{HV}) of the steel member.

55

[0226] The results are shown in Tables 3-1 to 3-6.

[0227] In a case where the Vickers hardness (HV1) was 450 or more, it was determined that the steel sheet had sufficient strength (tensile strength).

[0228] In addition, the hydrogen embrittlement resistance of the obtained steel members was evaluated by a slow strain rate tensile test (slow strain rate technique (SSRT)).

[0229] Specifically, a sample was cut out from a flat part 50 mm or more away from the end surface of the steel member, front and back surfaces were reduced in thickness by the same amount by polishing up to a thickness of 1.2 mm, and a test piece having a width of 9.0 mm and a length of 120 mm was collected. In this test piece, a length of a parallel portion was set to 20 mm, a width of the parallel portion was set to 2.0 mm, and U-notches having a notch depth of 0.35 mm and a notch bottom radius of 0.1 mm were provided on both sides of the parallel portion.

[0230] The test piece provided with the U-notches was immersed in a 3% NaCl solution, and using a galvanostat as a power source, a current density at the immersed part of the surface of the test piece was controlled to 0.1 mA/cm² to perform hydrogen charging for 24 hours. Next, a low strain rate tensile test was conducted on the test piece subjected to the hydrogen charging at a tensile rate of 0.0060 mm/min, and a stress (SSRT TS (MPa)) at the time of fracture was investigated. The same test was conducted three times for the same manufacturing No., and an average value of the three fracture loads in such a hydrogen environment was obtained.

[0231] In a case where a relationship between the SSRT TS and the Vickers hardness (M_{HV}) of the steel member satisfied the following expression, the steel member was determined to have excellent hydrogen embrittlement resistance (GOOD in the table).

$$\text{SSRT TS} \geq 2240 - 2.64 \times M_{\text{HV}}$$

[0232] The results are shown in Tables 3-1 to 3-6.

[Table 1-1]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)											
		C	Si	Mn	Al	Nb	Ti	Cr	B	P	S	N	O
1	A	0.289	0.081	1.28	0.047	0.012	0.031	0.11	0.0018	0.010	0.0010	0.005	0.009
2	B	0.277	0.250	0.69	0.027	0.003	0.021	0.17	0.0015	0.009	0.0008	0.006	0.003
3	B	0.277	0.250	0.69	0.027	0.003	0.021	0.17	0.0015	0.009	0.0008	0.006	0.003
4	B	0.277	0.250	0.69	0.027	0.003	0.021	0.17	0.0015	0.009	0.0008	0.006	0.003
5	C	0.281	1.730	0.62	0.044	0.013	0.042	0.36	0.0025	0.007	0.0010	0.004	0.004
6	D	0.281	0.830	0.35	0.031	0.014	0.042	0.35	0.0029	0.007	0.0009	0.006	0.008
7	E	0.295	0.520	2.73	0.046	0.025	0.041	0.01	0.0033	0.012	0.0006	0.005	0.008
8	F	0.270	0.530	1.02	0.830	0.020	0.024	0.36	0.0026	0.009	0.0012	0.004	0.004
9	G	0.279	0.700	0.83	0.029	0.020	0.030	0.35	0.0023	0.012	0.0007	0.005	0.004
10	H	0.274	0.310	0.98	0.054	0.083	0.039	0.39	0.0034	0.011	0.0012	0.005	0.009
11	I	0.266	0.920	1.27	0.035	0.041	0.009	0.20	0.0013	0.014	0.0011	0.004	0.008
12	I	0.306	0.920	1.27	0.035	0.041	0.009	0.20	0.0013	0.014	0.0011	0.004	0.008
13	J	0.272	0.280	0.98	0.053	0.026	0.135	0.15	0.0035	0.011	0.0012	0.006	0.006
14	K	0.271	0.800	0.70	0.030	0.018	0.042	0.04	0.0023	0.013	0.0007	0.006	0.007
15	K	0.301	0.800	0.70	0.030	0.018	0.042	0.04	0.0023	0.013	0.0007	0.006	0.007
16	L	0.279	0.900	0.60	0.039	0.007	0.037	0.71	0.0022	0.013	0.0008	0.004	0.009
17	M	0.278	0.920	1.11	0.040	0.023	0.044	0.14	0.0086	0.014	0.0008	0.006	0.001
18	N	0.274	0.620	1.19	0.035	0.032	0.043	0.19	0.0040	0.014	0.0012	0.006	0.001
19	O	0.273	0.740	0.68	0.054	0.003	0.037	0.19	0.0025	0.012	0.0007	0.004	0.003
20	P	0.288	0.770	0.87	0.036	0.020	0.040	0.32	0.0034	0.014	0.0008	0.005	0.002
21	Q	0.299	0.260	0.81	0.044	0.016	0.026	0.25	0.0025	0.008	0.0011	0.005	0.005
22	R	0.266	0.240	1.21	0.031	0.022	0.025	0.03	0.0022	0.006	0.0004	0.004	0.005
23	S	0.281	0.530	0.63	0.041	0.006	0.037	0.23	0.0022	0.012	0.0008	0.004	0.005
24	T	0.279	0.590	0.21	0.042	0.040	0.043	0.22	0.0033	0.007	0.0010	0.005	0.005
25	U	0.276	0.860	1.32	0.046	0.008	0.039	0.38	0.0028	0.012	0.0005	0.006	0.003
26	V	0.277	0.580	0.99	0.028	0.021	0.017	0.13	0.0022	0.014	0.0015	0.004	0.006
27	W	0.273	0.550	0.99	0.025	0.020	0.039	0.17	0.0026	0.012	0.0010	0.006	0.007
28	X	0.281	0.860	0.21	0.041	0.021	0.029	0.18	0.0020	0.009	0.0012	0.006	0.002
29	Y	0.279	0.280	1.03	0.024	0.049	0.028	0.13	0.0026	0.007	0.0005	0.005	0.005
30	Z	0.287	0.400	0.34	0.039	0.023	0.045	0.33	0.0030	0.007	0.0006	0.004	0.002
31	AA	0.277	0.770	1.03	0.025	0.015	0.035	0.14	0.0019	0.009	0.0013	0.004	0.009
32	AB	0.274	0.650	1.09	0.027	0.015	0.016	0.19	0.0024	0.013	0.0008	0.005	0.005
33	AC	0.292	0.630	1.08	0.048	0.030	0.041	0.23	0.0021	0.014	0.0009	0.004	0.006
34	AD	0.270	0.600	0.97	0.028	0.005	0.018	0.19	0.0022	0.008	0.0012	0.004	0.009
35	AE	0.279	0.610	0.81	0.027	0.018	0.038	0.13	0.0022	0.012	0.0009	0.005	0.002
36	AF	0.263	0.790	0.57	0.028	0.023	0.037	0.18	0.0040	0.008	0.0011	0.004	0.002

The underlines indicate values outside the ranges of the present invention.

[Table 1-2]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)											
		C	Si	Mn	Al	Nb	Ti	Cr	B	P	S	N	O
37	AG	0.273	0.530	0.99	0.028	0.020	0.028	0.21	0.0027	0.009	0.0012	0.005	0.008
38	AH	0.269	0.650	0.92	0.021	0.029	0.042	0.15	0.0025	0.011	0.0009	0.005	0.006
39	AI	0.271	0.590	0.56	0.026	0.038	0.062	0.38	0.0016	0.008	0.0012	0.005	0.003
40	AJ	0.274	0.640	0.92	0.036	0.031	0.023	0.31	0.0014	0.014	0.0011	0.004	0.008
41	AK	0.275	0.520	1.07	0.028	0.004	0.042	0.19	0.0023	0.010	0.0014	0.004	0.005
42	AL	0.263	0.510	0.96	0.027	0.004	0.014	0.19	0.0025	0.012	0.0010	0.004	0.007
43	AM	0.291	0.700	1.10	0.044	0.011	0.034	0.28	0.0016	0.009	0.0015	0.004	0.008
44	AN	0.278	0.610	0.99	0.020	0.004	0.036	0.16	0.0024	0.007	0.0008	0.004	0.006
45	AO	0.275	0.700	1.07	0.028	0.030	0.023	0.18	0.0027	0.013	0.0007	0.004	0.003
46	AP	0.285	0.920	1.10	0.027	0.027	0.023	0.18	0.0039	0.009	0.0009	0.005	0.006
47	AQ	0.272	0.680	0.91	0.020	0.023	0.014	0.14	0.0025	0.007	0.0008	0.004	0.005
48	AR	0.286	0.410	1.09	0.042	0.021	0.043	0.36	0.0040	0.014	0.0015	0.004	0.005
49	AS	0.268	0.630	0.83	0.022	0.025	0.033	0.15	0.0023	0.011	0.0013	0.004	0.005
50	AT	0.288	0.800	0.67	0.028	0.029	0.027	0.18	0.0029	0.009	0.0007	0.005	0.005
51	AU	0.273	0.520	1.01	0.021	0.008	0.041	0.20	0.0027	0.008	0.0012	0.004	0.004
52	AV	0.281	0.710	0.91	0.041	0.010	0.029	0.29	0.0025	0.008	0.0008	0.004	0.007
53	AW	0.264	0.660	0.97	0.020	0.011	0.039	0.17	0.0022	0.008	0.0010	0.005	0.007
54	AX	0.263	0.570	1.23	0.037	0.008	0.019	0.20	0.0028	0.009	0.0012	0.004	0.005
55	AY	0.283	0.540	0.82	0.026	0.007	0.029	0.20	0.0020	0.009	0.0014	0.005	0.003
56	AZ	0.293	0.400	1.26	0.036	0.026	0.040	0.37	0.0037	0.012	0.0010	0.004	0.002
57	BA	0.263	0.560	0.95	0.026	0.031	0.027	0.15	0.0027	0.015	0.0009	0.005	0.002
58	BB	0.276	0.670	0.80	0.054	0.023	0.025	0.23	0.0021	0.008	0.0013	0.005	0.007
59	BC	0.266	0.570	0.85	0.022	0.030	0.019	0.20	0.0024	0.014	0.0009	0.005	0.006
60	BD	0.281	0.670	0.41	0.031	0.018	0.022	0.12	0.0025	0.011	0.0012	0.004	0.005
61	BE	0.263	0.460	0.53	0.027	0.025	0.018	0.23	0.0031	0.012	0.0009	0.005	0.007
62	BF	0.281	1.030	0.80	0.036	0.034	0.027	0.29	0.0035	0.150	0.0009	0.005	0.008
63	BG	0.301	0.460	1.26	0.042	0.019	0.033	0.16	0.0024	0.013	0.0130	0.004	0.001
64	BH	0.291	0.780	1.01	0.048	0.035	0.031	0.17	0.0011	0.012	0.0006	0.031	0.003
65	BI	0.281	0.520	0.81	0.036	0.027	0.023	0.36	0.0038	0.008	0.0011	0.006	0.019
66	BJ	0.311	0.220	1.60	0.031	0.075	0.023	0.17	0.0038	0.009	0.0009	0.004	0.007
67	BJ	0.311	0.220	1.60	0.031	0.075	0.023	0.17	0.0038	0.009	0.0009	0.004	0.007
68	BK	0.343	0.220	1.34	0.044	0.047	0.025	0.25	0.0018	0.007	0.0009	0.006	0.001
69	BK	0.343	0.220	1.34	0.044	0.047	0.025	0.25	0.0018	0.007	0.0009	0.006	0.001
70	BK	0.343	0.220	1.34	0.044	0.047	0.025	0.25	0.0018	0.007	0.0009	0.006	0.001
71	BK	0.343	0.220	1.34	0.044	0.047	0.025	0.25	0.0018	0.007	0.0009	0.006	0.001
72	BK	0.343	0.220	1.34	0.044	0.047	0.025	0.25	0.0018	0.007	0.0009	0.006	0.001

The underlines indicate values outside the ranges of the present invention.

[Table 1-3]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)											
		C	Si	Mn	Al	Nb	Ti	Cr	B	P	S	N	O
73	BL	0.321	0.070	1.12	0.038	0.039	0.021	0.19	0.0025	0.007	0.0011	0.004	0.007
74	BM	0.404	1.480	0.52	0.038	0.045	0.069	0.38	0.0035	0.012	0.0006	0.004	0.006
75	BN	0.365	0.170	0.11	0.037	0.043	0.058	0.32	0.0014	0.008	0.0005	0.006	0.009
76	BO	0.358	0.230	2.67	0.028	0.042	0.097	0.02	0.0020	0.013	0.0012	0.004	0.005
77	BO	0.358	0.230	2.67	0.028	0.042	0.097	0.02	0.0020	0.013	0.0012	0.004	0.005
78	BP	0.342	0.390	0.73	0.710	0.048	0.074	0.30	0.0026	0.010	0.0005	0.004	0.007
79	BQ	0.391	0.180	0.93	0.034	0.009	0.093	0.22	0.0011	0.012	0.0006	0.006	0.004
80	BQ	0.391	0.180	0.93	0.034	0.009	0.093	0.22	0.0011	0.012	0.0006	0.006	0.004
81	BR	0.335	0.430	0.62	0.017	0.081	0.031	0.30	0.0040	0.010	0.0007	0.005	0.004
82	BR	0.335	0.430	0.62	0.017	0.081	0.031	0.30	0.0040	0.010	0.0007	0.005	0.004
83	BS	0.355	0.640	0.48	0.025	0.045	0.009	0.25	0.0037	0.009	0.0012	0.006	0.005
84	BS	0.355	0.640	0.48	0.025	0.045	0.009	0.25	0.0037	0.009	0.0012	0.006	0.005
85	BS	0.355	0.640	0.48	0.025	0.045	0.009	0.25	0.0037	0.009	0.0012	0.006	0.005
86	BT	0.398	0.460	0.97	0.017	0.039	0.181	0.35	0.0022	0.012	0.0011	0.005	0.009
87	BT	0.398	0.460	0.97	0.017	0.039	0.181	0.35	0.0022	0.012	0.0011	0.005	0.009
88	BT	0.398	0.460	0.97	0.017	0.039	0.181	0.35	0.0022	0.012	0.0011	0.005	0.009
89	BU	0.375	0.190	0.92	0.017	0.039	0.021	0.02	0.0040	0.011	0.0010	0.005	0.007
90	BU	0.375	0.190	0.92	0.017	0.039	0.021	0.02	0.0040	0.011	0.0010	0.005	0.007
91	BU	0.375	0.190	0.92	0.017	0.039	0.021	0.02	0.0040	0.011	0.0010	0.005	0.007
92	BV	0.395	0.900	0.21	0.020	0.028	0.035	0.86	0.0021	0.009	0.0006	0.005	0.004
93	BV	0.395	0.900	0.21	0.020	0.028	0.035	0.86	0.0021	0.009	0.0006	0.005	0.004
94	BW	0.382	0.620	0.70	0.018	0.042	0.065	0.26	0.0091	0.011	0.0008	0.006	0.007
95	BW	0.382	0.620	0.70	0.018	0.042	0.065	0.26	0.0091	0.011	0.0008	0.006	0.007
96	BW	0.382	0.620	0.70	0.018	0.042	0.065	0.26	0.0091	0.011	0.0008	0.006	0.007
97	BX	0.478	1.290	0.80	0.042	0.021	0.045	0.25	0.0018	0.007	0.0009	0.004	0.008
98	BY	0.502	0.190	0.11	0.030	0.048	0.058	0.38	0.0021	0.011	0.0005	0.004	0.002
99	BY	0.502	0.190	0.11	0.030	0.048	0.058	0.38	0.0021	0.011	0.0005	0.004	0.002
100	BZ	0.526	0.720	2.51	0.018	0.025	0.044	0.18	0.0039	0.010	0.0009	0.006	0.004
101	CA	0.476	0.620	0.48	0.021	0.009	0.081	0.32	0.0035	0.007	0.0007	0.005	0.002
102	CB	0.489	0.190	1.06	0.023	0.081	0.021	0.36	0.0037	0.013	0.0011	0.005	0.008
103	CB	0.489	0.190	1.06	0.023	0.081	0.021	0.36	0.0037	0.013	0.0011	0.005	0.008
104	CC	0.362	0.450	0.68	0.031	0.046	0.091	0.16	0.0015	0.013	0.0006	0.004	0.007
105	CD	0.319	0.450	0.98	0.028	0.040	0.060	0.20	0.0018	0.012	0.0009	0.005	0.009
106	CE	0.395	0.160	0.41	0.043	0.042	0.037	0.03	0.0035	0.011	0.0008	0.004	0.008
107	CF	0.451	0.410	0.42	0.031	0.021	0.020	0.32	0.0025	0.013	0.0011	0.005	0.007
108	CG	0.532	0.420	0.36	0.030	0.025	0.024	0.13	0.0026	0.011	0.0005	0.005	0.009

[Table 1-4]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)											
		C	Si	Mn	Al	Nb	Ti	Cr	B	P	S	N	O
109	CG	0.532	0.420	0.36	0.030	0.025	0.024	0.13	0.0026	0.011	0.0005	0.005	0.009
110	CH	0.502	0.310	0.02	0.026	0.029	0.049	0.02	0.0019	0.013	0.0010	0.004	0.009
111	CI	0.324	0.660	0.72	0.040	0.025	0.048	0.29	0.0015	0.008	0.0011	0.006	0.005
112	CJ	0.343	0.230	1.09	0.037	0.035	0.022	0.21	0.0021	0.010	0.0008	0.005	0.009
113	CK	0.388	0.550	0.84	0.026	0.039	0.053	0.21	0.0022	0.014	0.0011	0.006	0.007
114	CL	0.492	0.270	0.67	0.020	0.032	0.089	0.29	0.0035	0.009	0.0006	0.004	0.003
115	CM	0.500	0.410	0.21	0.022	0.021	0.023	0.01	0.0025	0.009	0.0006	0.004	0.005
116	CN	0.467	0.660	0.54	0.037	0.022	0.075	0.22	0.0023	0.011	0.0011	0.004	0.006
117	CO	0.499	0.410	0.21	0.035	0.025	0.025	0.08	0.0025	0.009	0.0015	0.005	0.002
118	CP	0.483	0.440	0.08	0.031	0.015	0.019	0.04	0.0022	0.009	0.0006	0.004	0.005
119	CQ	0.476	0.230	0.41	0.027	0.022	0.045	0.34	0.0028	0.011	0.0006	0.004	0.007
120	CR	0.356	0.430	0.76	0.029	0.060	0.080	0.40	0.0037	0.010	0.0012	0.005	0.007
121	CS	0.306	0.370	0.79	0.021	0.080	0.046	0.10	0.0016	0.015	0.0014	0.004	0.003
122	CT	0.319	0.230	0.98	0.021	0.040	0.120	0.48	0.0013	0.014	0.0014	0.004	0.006
123	CU	0.517	0.870	0.46	0.041	0.025	0.074	0.18	0.0028	0.011	0.0005	0.004	0.005
124	CV	0.407	0.220	0.36	0.036	0.037	0.052	0.15	0.0019	0.009	0.0013	0.005	0.008
125	CW	0.309	0.720	0.98	0.027	0.080	0.100	0.29	0.0014	0.012	0.0012	0.004	0.003
126	CX	0.314	0.930	1.13	0.024	0.070	0.074	0.49	0.0021	0.014	0.0014	0.005	0.004
127	CY	0.350	0.940	0.52	0.026	0.032	0.081	0.36	0.0035	0.012	0.0007	0.005	0.006
128	CZ	0.523	0.410	0.42	0.032	0.021	0.024	0.10	0.0022	0.009	0.0014	0.006	0.005
129	DA	0.331	0.280	1.12	0.031	0.025	0.043	0.11	0.0028	0.008	0.0012	0.005	0.003
130	DB	0.481	0.820	1.20	0.072	0.020	0.054	0.43	0.0020	0.010	0.0013	0.005	0.003
131	DC	0.510	0.420	0.37	0.021	0.028	0.022	0.09	0.0025	0.013	0.0015	0.005	0.006
132	DD	0.530	0.810	0.24	0.032	0.031	0.029	0.02	0.0019	0.013	0.0010	0.005	0.008
133	DE	0.385	0.320	0.54	0.034	0.041	0.036	0.18	0.0017	0.009	0.0014	0.004	0.007
134	DF	0.327	0.810	0.95	0.021	0.050	0.055	0.30	0.0015	0.009	0.0014	0.004	0.001
135	DG	0.317	0.360	0.60	0.021	0.051	0.057	0.33	0.0016	0.009	0.0007	0.004	0.009
136	DH	0.522	0.490	0.59	0.030	0.031	0.088	0.33	0.0019	0.007	0.0010	0.005	0.006
137	DI	0.499	0.410	0.52	0.076	0.100	0.035	0.16	0.0021	0.015	0.0015	0.005	0.002
138	DJ	0.347	0.640	0.98	0.035	0.045	0.048	0.36	0.0039	0.011	0.0006	0.005	0.006
139	DK	0.391	0.800	0.93	0.040	0.031	0.050	0.34	0.0015	0.012	0.0009	0.005	0.002
140	DL	0.323	0.350	1.10	0.045	0.050	0.042	0.31	0.0020	0.008	0.0009	0.004	0.003
141	DM	0.304	0.250	1.30	0.059	0.080	0.057	0.48	0.0016	0.008	0.0008	0.004	0.003
142	DN	0.405	0.200	0.76	0.026	0.028	0.069	0.22	0.0027	0.010	0.0015	0.006	0.004
143	DO	0.317	0.280	1.07	0.049	0.060	0.061	0.06	0.0017	0.007	0.0013	0.005	0.003
144	DP	0.327	0.450	0.97	0.021	0.047	0.065	0.38	0.0011	0.013	0.0012	0.004	0.007

[Table 1-5]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)											
		C	Si	Mn	Al	Nb	Ti	Cr	B	P	S	N	O
145	DQ	0.315	0.230	1.19	0.033	0.076	0.048	0.24	0.0015	0.009	0.0014	0.005	0.008
146	DR	0.359	0.800	0.98	0.035	0.032	0.068	0.18	0.0014	0.007	0.0015	0.004	0.009
147	DS	0.314	0.820	0.57	0.025	0.030	0.035	0.12	0.0014	0.015	0.0014	0.005	0.003
148	DT	0.300	0.240	0.77	0.099	0.010	0.042	0.13	0.0012	0.009	0.0012	0.006	0.002
149	DU	0.300	0.220	0.59	0.064	0.010	0.061	0.20	0.0012	0.009	0.0014	0.006	0.003
150	DV	0.355	0.440	0.98	0.030	0.036	0.038	0.32	0.0035	0.010	0.0015	0.004	0.002
151	DW	0.333	0.920	1.12	0.025	0.050	0.039	0.14	0.0013	0.010	0.0009	0.005	0.008
152	DX	0.347	0.590	0.51	0.033	0.028	0.075	0.34	0.0030	0.012	0.0011	0.004	0.008
153	DY	0.323	0.850	1.09	0.070	0.040	0.035	0.12	0.0018	0.012	0.0009	0.005	0.009
154	DZ	0.334	0.380	0.33	0.024	0.038	0.048	0.18	0.0013	0.007	0.0014	0.006	0.003
155	EA	0.321	0.970	1.25	0.036	0.090	0.048	0.35	0.0020	0.010	0.0014	0.005	0.005
156	EB	0.305	0.450	0.50	0.027	0.022	0.090	0.37	0.0031	0.011	0.0009	0.006	0.002
157	EC	0.314	0.540	0.62	0.020	0.090	0.036	0.13	0.0015	0.011	0.0008	0.005	0.005
158	ED	0.327	0.740	0.31	0.023	0.039	0.029	0.22	0.0037	0.010	0.0014	0.004	0.002
159	EF	0.306	0.790	0.81	0.037	0.070	0.064	0.32	0.0021	0.015	0.0008	0.005	0.009
160	EG	0.371	0.850	0.67	0.016	0.027	0.020	0.17	0.0016	0.009	0.0015	0.004	0.007
161	EH	0.330	0.740	0.80	0.055	0.024	0.063	0.26	0.0020	0.011	0.0007	0.005	0.002
162	EI	0.408	0.930	0.90	0.041	0.039	0.032	0.27	0.0030	0.213	0.0011	0.006	0.007
163	EJ	0.386	0.770	1.02	0.041	0.033	0.042	0.39	0.0032	0.014	0.0280	0.005	0.002
164	EK	0.387	0.930	0.48	0.039	0.025	0.021	0.17	0.0016	0.012	0.0011	0.055	0.004
165	EL	0.352	0.940	1.07	0.040	0.022	0.040	0.77	0.0038	0.014	0.0008	0.005	0.074
166	EM	0.210	1.210	1.41	0.025	0.021	0.035	0.28	0.0027	0.008	0.0011	0.003	0.005
167	EN	0.750	0.660	0.54	0.037	0.022	0.075	0.22	0.0023	0.010	0.0014	0.004	0.004
168	EO	0.310	2.810	0.41	0.025	0.020	0.039	0.11	0.0026	0.008	0.0013	0.003	0.003
169	EP	0.332	0.220	3.15	0.032	0.022	0.025	0.01	0.0015	0.010	0.0012	0.003	0.005
170	EQ	0.421	0.480	1.21	0.032	0.110	0.025	0.11	0.0025	0.015	0.0014	0.004	0.003
171	ER	0.365	0.510	0.84	0.034	0.031	0.281	0.08	0.0031	0.011	0.0008	0.003	0.004
172	ES	0.391	0.710	0.84	0.031	0.028	0.031	1.28	0.0027	0.008	0.0008	0.004	0.003
173	ET	0.338	0.610	0.73	0.028	0.022	0.026	0.11	0.0250	0.012	0.0011	0.003	0.003
174	EU	0.371	0.410	1.67	0.031	0.021	0.035	0.51	0.0001	0.009	0.0010	0.003	0.004
175	EV	0.392	0.190	0.91	0.030	0.028	0.032	0.10	0.0026	0.010	0.0010	0.006	0.004
176	EW	0.330	0.280	1.11	0.039	0.060	0.042	0.06	0.0020	0.007	0.0010	0.005	0.003
177	EX	0.356	0.450	0.89	0.028	0.016	0.020	0.15	0.0020	0.009	0.0012	0.004	0.007
178	EY	0.331	0.510	0.55	0.019	0.022	0.035	0.13	0.0021	0.007	0.0010	0.003	0.003

The underlines indicate values outside the ranges of the present invention.

[Table 1-6]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)																				T1 (°C)	Ac3 (°C)
		Mo	W	Co	Ni	Cu	V	Ca	Mg	REM	Sb	Sn	Zr	As	Se	Bi	Ta	Re	Os	Ir	Tc		
1	A																					936	788
2	B																					921	805
3	B																					921	805
4	B																					921	805
5	C																					943	870
6	D																					946	835
7	E																					962	786
8	F																					949	814
9	G																					949	823
10	H																					1039	804
11	I																					969	829
12	I																					969	822
13	J																					980	804
14	K																					948	831
15	K																					948	825
16	L																					932	834
17	M																					984	829
18	N	0.06																				982	815
19	O	0.23																				956	828
20	P	0.84																				1056	824
21	Q		0.08																			944	800
22	R		0.41																			950	800
23	S		1.67																			931	818
24	T		0.41		0.51	0.95																982	817
25	U			0.05																		937	823
26	V			0.41																		948	816
27	W			0.83																		952	815
28	X			0.44	0.71																	949	825
29	Y			0.21		0.38																988	802
30	Z				0.06																	959	814
31	AA				0.29																	941	818
32	AB				0.79																	940	804
33	AC					0.07																963	814
34	AD					0.21																927	818
35	AE					1.57																947	819
36	AF						0.07															962	833

[Table 1-7]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)																				T1 (°C)	Ac3 (°C)
		Mo	W	Co	Ni	Cu	V	Ca	Mg	REM	Sb	Sn	Zr	As	Se	Bi	Ta	Re	Os	Ir	Tc		
37	AG						0.15															950	814
38	AH						0.84															964	821
39	AI						0.31		0.12			0.15										975	823
40	AJ							0.042														958	820
41	AK							0.081														930	812
42	AL							0.170														926	816
43	AM								0.04													934	817
44	AN								0.11													929	817
45	AO								0.16													963	820
46	AP									0.020												964	828
47	AQ									0.180												951	822
48	AR										0.05											960	805
49	AS										0.67											956	822
50	AT											0.07										963	828
51	AU											0.81										937	813
52	AV												0.05									936	822
53	AW												0.91									938	822
54	AX																	0.07				933	814
55	AY																	0.93				930	815
56	AZ																		0.06			965	801
57	BA																		0.72			965	818
58	BB																			0.06		951	822
59	BC																			0.76		961	819
60	BD																				0.08	946	827
61	BE																				0.57	957	819
62	BF																					972	837
63	BG																					949	802
64	BH																					964	822
65	BI																					964	815
66	BJ																					1027	785
67	BJ																					1027	785
68	BK																					982	783
69	BK																					982	783
70	BK																					982	783
71	BK																					982	783
72	BK																					982	783

[Table 1-8]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)																			T1 (°C)	Ac3 (°C)
		Mo	W	Co	Ni	Cu	V	Ca	Mg	REM	Sb	Sn	Zr	As	Se	Bi	Ta	Re	Os	Ir	Tc	
73	BL																				973	784
74	BM																				994	839
75	BN																				980	794
76	BO																				988	763
77	BO																				988	763
78	BP																				995	799
79	BQ																				939	778
80	BQ																				939	778
81	BR																				1038	804
82	BR																				1038	804
83	BS																				985	811
84	BS																				985	811
85	BS																				985	811
86	BT																				999	789
87	BT																				999	789
88	BT																				999	789
89	BU																				980	782
90	BU																				980	782
91	BU																				980	782
92	BV																				959	818
93	BV																				959	818
94	BW																				1015	803
95	BW																				1015	803
96	BW																				1015	803
97	BX																				950	813
98	BY																				990	770
99	BY																				990	770
100	BZ																				965	756
101	CA																				948	789
102	CB																				1035	759
103	CB																				1035	759
104	CC	0.07																			998	799
105	CD	0.21																			1003	803
106	CE	0.71																			1070	785
107	CF	0.21																			975	785
108	CG	0.18			0.06	0.21															977	771

[Table 1-9]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)																				T1 (°C)	Ac3 (°C)
		Mo	W	Co	Ni	Cu	V	Ca	Mg	REM	Sb	Sn	Zr	As	Se	Bi	Ta	Re	Os	Ir	Tc		
109	CG	0.18			0.06	0.21																977	771
110	CH	0.81																				1059	777
111	CI		0.07																			955	814
112	CJ		0.31																			967	787
113	CK		1.21																			977	797
114	CL		0.06																			980	768
115	CM		0.29																			950	780
116	CN		0.24		0.05	0.41																959	791
117	CO	0.21	0.41		0.07	0.19																981	778
118	CP		1.11																			940	786
119	CQ		0.41				0.31															956	772
120	CR			0.08																		1017	798
121	CS			0.45																		1028	804
122	CT			0.84																		986	792
123	CU			0.46																		965	793
124	CV				0.07																	973	784
125	CW				0.64																	1036	805
126	CX				1.35																	1022	798
127	CY				0.31				0.11													979	819
128	CZ				0.07	0.19																949	771
129	DA	0.18			0.08	0.31																982	790
130	DB				0.04	0.15																952	786
131	DC	0.21			0.06	0.22																984	775
132	DD	0.43			0.05	0.19																1013	790
133	DE					0.03																975	791
134	DF					0.28																989	817
135	DG					1.11																991	804
136	DH					0.02																971	773
137	DI					0.46																1055	775
138	DJ					0.31	0.28															992	806
139	DK						0.07															963	806
140	DL						0.12															989	796
141	DM						0.75															1030	791
142	DN							0.051														968	779
143	DO							0.171														1004	794
144	DP								0.02													985	801

[Table 1-10]

Manufacturing No.	Kind of steel	Chemical composition (unit: mass%, remainder includes Fe and impurities)																				T1 (°C)	Ac3 (°C)
		Mo	W	Co	Ni	Cu	V	Ca	Mg	REM	Sb	Sn	Zr	As	Se	Bi	Ta	Re	Os	Ir	Tc		
145	DQ								0.15													1023	791
146	DR									0.010												967	811
147	DS									0.220												959	826
148	DT										0.02											933	800
149	DU										0.74											936	801
150	DV											0.05										977	795
151	DW											0.86										986	819
152	DX												0.07									970	810
153	DY												0.83									974	818
154	DZ																	0.04				971	806
155	EA																	0.77				1043	821
156	EB																		0.03			965	811
157	EC																	0.67				1039	813
158	ED																			0.06		980	823
159	EF																			0.91		1020	822
160	EG																				0.04	953	815
161	EH																				0.88	958	816
162	EI																					978	809
163	EJ																					972	804
164	EK																					951	819
165	EL																					960	816
166	EM																					953	849
167	EN																					959	741
168	EO																					952	916
169	EP																					947	760
170	EQ																					1068	783
171	ER																					1009	799
172	ES																					961	801
173	ET																					1053	810
174	EU																					941	781
175	EV													0.23								961	779
176	EW														0.31							1003	792
177	EX															0.48						941	797
178	EY																0.41					951	809

[Table 2-1]

Manufacturing No.	Kind of steel	Heating		Rough rolling		Rough rolling to finish rolling	Finish rolling			
		Heating temperature (°C)	Holding time (min)	Rough rolling completion temperature Tr (°C)	Number of rolling passes at rolling reduction of 30% or more (times)	Time from completion of rough rolling to start of finish rolling trs (sec)	Finish rolling start temperature Ts (°C)	Finish rolling completion temperature (°C)	Total rolling reduction at T1 to T1 + 150°C (%)	Total rolling reduction at lower than T1°C (%)
1	A	1237	27	1127	3	77	1052	902	85	27
2	B	1249	26	1129	2	96	1025	890	87	25
3	B	1245	35	1133	3	95	1015	892	87	24
4	B	1246	54	1131	2	89	1028	890	88	25
5	C	1262	27	1171	4	80	1076	921	88	11
6	D	1211	36	1096	3	75	1077	905	85	26
7	E	1289	33	1195	2	98	1047	921	87	29
8	F	1204	39	1087	3	101	980	902	83	33
9	G	1220	36	1109	4	133	1016	904	85	30
10	H	1272	65	1161	3	76	1072	981	80	47
11	I	1289	37	1208	3	76	1066	907	80	49
12	I	1278	45	1210	3	80	1060	910	81	46
13	J	1278	71	1173	4	93	1025	910	83	42
14	K	1256	38	1162	4	102	960	894	80	46
15	K	1246	60	1156	3	80	980	903	82	45
16	L	1247	38	1159	3	93	965	884	85	29
17	M	1282	30	1167	4	138	986	930	80	38
18	N	1251	26	1145	4	152	1007	929	80	43
19	O	1274	26	1195	3	87	1078	922	89	28
20	P	1268	24	1171	3	75	1081	989	80	49
21	Q	1245	32	1151	2	117	1004	909	85	24
22	R	1225	24	1124	4	114	986	909	82	42
23	S	1232	32	1119	4	83	1044	901	88	23
24	T	1249	25	1160	4	108	1029	934	82	34
25	U	1212	39	1120	4	84	1056	899	85	31
26	V	1277	26	1166	2	110	986	901	84	31
27	W	1205	33	1096	3	81	1056	927	87	22
28	X	1277	30	1195	2	111	1024	911	81	40
29	Y	1204	35	1112	3	95	1042	945	82	29
30	Z	1241	36	1134	3	91	1069	912	85	36

[Table 2-2]

Manufacturing No.	Kind of steel	Heating		Rough rolling		Rough rolling to finish rolling	Finish rolling			
		Heating temperature (°C)	Holding time (min)	Rough rolling completion temperature Tr (°C)	Number of rolling passes at rolling reduction of 30% or more (times)	Time from completion of rough rolling to start of finish rolling trs (sec)	Finish rolling start temperature Ts (°C)	Finish rolling completion temperature (°C)	Total rolling reduction at T1 to T1 + 150°C (%)	Total rolling reduction at lower than T1°C (%)
31	AA	1239	38	1157	3	144	960	908	88	26
32	AB	1205	25	1085	3	72	1052	904	85	21
33	AC	1242	32	1123	2	156	986	928	89	25
34	AD	1210	29	1115	3	75	1010	902	82	42
35	AE	1221	37	1101	4	93	1026	893	85	29
36	AF	1255	35	1155	3	144	968	927	86	27
37	AG	1255	31	1150	2	157	965	901	80	39
38	AH	1203	68	1109	3	79	1023	907	80	44
39	AI	1218	28	1121	4	117	993	918	81	43
40	AJ	1277	36	1157	2	99	1080	916	82	31
41	AK	1223	31	1136	4	129	977	897	80	46
42	AL	1223	38	1142	2	83	1009	899	89	26
43	AM	1235	36	1121	4	159	961	906	80	41
44	AN	1244	34	1165	4	110	999	902	87	28
45	AO	1238	34	1116	2	84	1062	929	87	22
46	AP	1220	30	1128	2	75	1072	932	82	43
47	AQ	1230	24	1125	2	72	1066	914	86	27
48	AR	1259	30	1172	3	83	1053	932	82	39
49	AS	1267	37	1151	3	127	1000	931	82	37
50	AT	1246	35	1151	4	133	978	925	87	27
51	AU	1205	26	1093	4	120	976	912	81	42
52	AV	1249	35	1131	3	91	1049	903	86	28
53	AW	1287	37	1201	2	121	990	911	80	38
54	AX	1267	31	1170	4	154	960	901	87	28
55	AY	1204	32	1095	3	104	997	901	88	24
56	AZ	1220	36	1109	2	80	1031	919	85	31
57	BA	1238	27	1125	2	76	1038	920	82	34
58	BB	1248	38	1139	4	75	1038	915	88	21
59	BC	1231	27	1131	3	78	1061	912	81	43
60	BD	1234	32	1112	3	83	1024	899	82	31

[Table 2-3]

Manufacturing No.	Kind of steel	Heating		Rough rolling		Rough rolling to finish rolling	Finish rolling			
		Heating temperature (°C)	Holding time (min)	Rough rolling completion temperature Tr (°C)	Number of rolling passes at rolling reduction of 30% or more (times)	Time from completion of rough rolling to start of finish rolling trs (sec)	Finish rolling start temperature Ts (°C)	Finish rolling completion temperature (°C)	Total rolling reduction at T1 to T1 + 150°C (%)	Total rolling reduction at lower than T1°C (%)
61	BF	1205	24	1111	3	150	993	931	81	38
62	BF	1228	32	1109	2	74	1057	944	82	46
63	BG	1245	35	1166	3	107	995	918	86	29
64	BH	1237	27	1154	4	96	1067	925	85	27
65	BI	1273	32	1159	3	92	997	918	82	34
66	BJ	1216	38	1100	3	76	1038	981	83	34
67	BJ	1252	29	1162	4	85	1086	969	82	41
68	BK	1292	37	1176	2	77	1015	945	85	43
69	BK	1278	41	1156	3	75	1025	935	80	41
70	BK	1132	37	1033	3	77	990	920	80	47
71	BK	1236	45	1145	2	55	1025	953	84	28
72	BK	1232	25	1123	3	120	1045	921	87	26
73	BL	1283	26	1189	3	96	1016	942	88	25
74	BM	1204	37	1114	4	81	1015	941	81	46
75	BN	1239	25	1160	4	90	1042	935	83	29
76	BO	1247	26	1131	2	73	1051	946	86	21
77	BO	1215	35	1131	3	85	1044	943	87	25
78	BP	1270	25	1187	2	131	1024	941	83	30
79	BQ	1209	24	1126	4	94	1065	913	88	26
80	BQ	1211	36	1125	3	88	1028	915	88	25
81	BR	1257	37	1157	2	87	1075	979	82	45
82	BR	1275	45	1168	1	85	1081	985	80	45
83	BS	1256	32	1150	4	72	1078	945	87	24
84	BS	1224	40	1155	3	75	1065	925	86	25
85	BS	1245	29	1167	2	75	1069	971	86	11
86	BT	1276	55	1196	4	152	1040	951	83	34
87	BT	1203	10	1103	2	115	1008	933	82	46
88	BT	1203	40	1044	3	80	1005	956	81	45
89	BU	1218	34	1117	4	85	1033	923	81	45
90	BU	1243	25	1140	3	80	1028	910	80	43

[Table 2-4]

Manufacturing No.	Kind of steel	Heating		Rough rolling		Rough rolling to finish rolling	Finish rolling			
		Heating temperature (°C)	Holding time (min)	Rough rolling completion temperature Tr (°C)	Number of rolling passes at rolling reduction of 30% or more (times)	Time from completion of rough rolling to start of finish rolling trs (sec)	Finish rolling start temperature Ts (°C)	Finish rolling completion temperature (°C)	Total rolling reduction at T1 to T1 + 150°C (%)	Total rolling reduction at lower than T1°C (%)
91	BU	1222	36	1112	3	86	1036	865	81	44
92	BV	1242	37	1139	4	82	1026	921	88	20
93	BV	1205	29	1104	3	79	1012	899	81	55
94	BW	1268	37	1149	3	99	1037	967	82	35
95	BW	1244	42	1134	2	85	1051	967	78	47
96	BW	1258	35	1144	2	101	1033	971	88	8
97	BX	1267	29	1177	2	76	1067	922	89	27
98	BY	1252	27	1161	2	71	1045	956	88	25
99	BY	1245	30	1151	2	72	1043	955	87	26
100	BZ	1273	30	1190	3	78	1073	922	85	30
101	CA	1294	37	1201	3	89	1020	925	82	40
102	CB	1237	34	1121	2	98	1064	978	80	46
103	CB	1221	35	1142	2	95	1044	965	80	46
104	CC	1211	33	1125	4	84	1024	948	80	43
105	CD	1217	37	1138	3	99	1032	952	81	41
106	CE	1227	64	1148	2	96	1101	998	82	42
107	CF	1250	28	1156	3	99	1011	932	85	32
108	CG	1234	35	1155	3	91	1031	921	83	43
109	CG	1215	32	1145	3	90	1023	915	80	42
110	CH	1269	31	1183	2	75	1071	992	81	41
111	CI	1295	39	1177	2	112	974	924	89	27
112	CJ	1230	40	1127	4	76	1035	910	82	42
113	CK	1246	33	1136	4	111	999	930	85	30
114	CL	1264	27	1166	2	98	1011	954	80	38
115	CM	1228	24	1120	3	141	966	904	84	29
116	CN	1286	29	1203	2	81	1069	937	81	38
117	CO	1267	32	1161	3	84	1076	941	88	21
118	CP	1257	37	1154	4	80	1044	863	80	44
119	CQ	1236	31	1129	4	113	979	900	82	43
120	CR	1254	25	1173	4	87	1052	961	80	43

[Table 2-5]

Manufacturing No.	Kind of steel	Heating		Rough rolling		Rough rolling to finish rolling	Finish rolling			
		Heating temperature (°C)	Holding time (min)	Rough rolling completion temperature Tr (°C)	Number of rolling passes at reduction of 30% or more (times)	Time from completion of rough rolling to start of finish rolling trs (sec)	Finish rolling start temperature Ts (°C)	Finish rolling completion temperature (°C)	Total rolling reduction at T1 to T1 + 150°C (%)	Total rolling reduction at lower than T1°C (%)
121	CS	1276	39	1181	2	88	1078	973	81	39
122	CT	1220	34	1125	4	93	1033	931	80	45
123	CU	1231	27	1125	3	81	1060	927	87	20
124	CV	1220	33	1141	4	153	993	940	88	29
125	CW	1260	26	1138	4	93	1051	979	81	41
126	CX	1206	36	1123	4	93	1051	965	82	42
127	CY	1257	32	1161	4	80	1024	923	80	41
128	CZ	1209	33	1127	2	131	1008	919	88	25
129	DA	1235	36	1137	3	80	1066	959	85	25
130	DB	1284	32	1203	4	89	1064	925	82	46
131	DC	1295	38	1195	4	95	1005	924	81	44
132	DD	1247	35	1153	2	87	1026	954	80	44
133	DE	1271	29	1157	4	100	1043	918	80	47
134	DF	1239	30	1136	3	153	1012	933	82	45
135	DG	1205	40	1122	2	119	1008	928	80	45
136	DH	1281	36	1197	2	156	1002	950	86	11
137	DI	1295	34	1185	4	98	1073	987	81	44
138	DJ	1208	34	1096	4	107	1035	938	82	41
139	DK	1222	29	1109	4	124	1024	889	82	40
140	DL	1227	24	1136	2	82	1038	922	81	47
141	DM	1252	36	1167	3	79	1042	965	81	45
142	DN	1237	27	1146	4	73	1072	921	84	36
143	DO	1286	31	1183	2	87	1038	938	80	46
144	DP	1209	36	1102	3	83	1066	936	81	38
145	DQ	1283	34	1197	4	81	1064	966	81	43
146	DR	1218	32	1134	3	115	992	936	89	26
147	DS	1276	31	1169	3	160	981	912	85	36
148	DT	1221	40	1133	2	83	1064	911	88	12
149	DU	1290	28	1171	3	89	1046	902	88	20
150	DV	1217	27	1111	4	102	1015	945	83	37

[Table 2-6]

Manufacturing No.	Kind of steel	Heating		Rough rolling		Rough rolling to finish rolling	Finish rolling			
		Heating temperature (°C)	Holding time (min)	Rough rolling completion temperature Tr (°C)	Number of rolling passes at reduction of 30% or more (times)	Time from completion of rough rolling to start of finish rolling trs (sec)	Finish rolling start temperature Ts (°C)	Finish rolling completion temperature (°C)	Total rolling reduction at T1 to T1 + 150°C (%)	Total rolling reduction at lower than T1°C (%)
151	DW	1205	38	1120	3	139	997	930	81	39
152	DX	1223	28	1115	4	79	1061	918	82	41
153	DY	1228	24	1105	3	90	1072	915	81	46
154	DZ	1271	37	1179	2	141	982	907	80	45
155	EA	1284	28	1193	2	78	1067	979	80	45
156	EB	1210	37	1101	2	99	1039	942	88	12
157	EC	1259	28	1153	3	76	1060	987	80	41
158	ED	1254	34	1131	2	77	1051	953	87	27
159	EF	1224	28	1135	3	80	1052	956	81	45
160	EG	1214	36	1132	4	86	1032	901	81	40
161	EH	1224	32	1133	3	81	1078	907	82	38
162	EI	1255	38	1166	2	152	1004	932	83	34
163	EJ	1246	32	1127	3	95	987	911	82	41
164	EK	1210	30	1095	2	121	1010	909	86	22
165	EL	1239	39	1128	2	86	1049	932	83	41
166	EM	1222	39	1109	4	91	1077	911	82	36
167	EN	1253	38	1160	3	90	1070	913	83	34
168	EO	1254	32	1144	4	98	1080	914	88	25
169	EP	1237	40	1117	4	144	967	902	84	31
170	EQ	1261	37	1157	2	72	1098	998	81	45
171	ER	1211	37	1116	4	72	1043	954	81	44
172	ES	1244	31	1135	3	77	1044	937	87	12
173	ET	1280	38	1195	4	74	1079	982	80	45
174	EU	1251	31	1129	3	78	1055	905	85	25
175	EV	1241	26	1148	3	80	1070	915	85	35
176	EW	1254	33	1179	2	86	1043	921	81	45
177	EX	1224	35	1141	2	88	1036	908	83	41
178	EY	1244	36	1189	3	132	999	904	81	43

[Table 2-7]

Manufacturing No.	Kind of steel	Cooling			Coiling	Cold rolling	Annealing		Coating formation	Other manufacturing conditions	Microstructure of steel sheet		
		Time until start of cooling (sec)	Average cooling rate (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Rolling reduction (%)	Annealing temperature (°C)	Holding time (sec)	Kind of plating		Ferrite (area%)	Pearlite (area%)	(I1 + I3)/(I2 + I4)
1	A	1.7	108	675	620	37					73	22	0.99
2	B	1.8	98	768	760	36					83	9	1.04
3	B	2.1	76	672	630	41	750	100	GI		30	57	1.03
4	B	2.3	98	770	760	36	755	110	GA		46	42	1.09
5	C	2.1	85	604	510	44					68	23	1.07
6	D	2.1	106	667	610	35					68	26	1.12
7	E	1.3	64	678	620	45					68	25	0.99
8	F	1.0	82	598	480	18					62	25	1.04
9	G	1.1	141	660	610	46					71	24	1.01
10	H	0.9	106	664	580	35					70	21	0.95
11	I	0.8	78	593	550	36					73	21	1.08
12	I	1.2	70	595	540	35	760	100			25	61	1.10
13	J	0.8	96	652	610	41					68	26	0.92
14	K	0.8	101	597	540	30					70	24	1.02
15	K	1.3	90	608	550	32	720	70	Al		15	70	0.99
16	L	1.6	85	634	590	34					73	18	0.93
17	M	0.9	101	654	600	34					74	21	0.92
18	N	0.7	87	556	500	33					70	21	0.95
19	O	2.0	79	569	510	40					69	23	0.97
20	P	1.4	80	586	530	34					67	28	1.04
21	Q	1.8	87	658	600	35					71	20	0.86
22	R	1.6	100	663	620	52					70	21	0.82
23	S	1.2	93	663	620	33					72	20	0.81
24	T	0.8	95	556	500	33					66	28	0.84
25	U	2.2	81	645	600	30					74	19	0.94
26	V	0.8	107	678	630	41					74	18	1.03
27	W	1.8	100	659	610	30					70	24	1.01
28	X	0.8	99	629	580	35					65	29	1.04
29	Y	2.2	105	627	570	41					68	23	1.04
30	Z	1.3	92	590	540	46					68	26	1.01

[Table 2-8]

Manufacturing No.	Kind of steel	Cooling			Coiling	Cold rolling	Annealing		Coating formation	Other manufacturing conditions	Microstructure of steel sheet		
		Time until start of cooling (sec)	Average cooling rate (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Rolling reduction (%)	Annealing temperature (°C)	Holding time (sec)	Kind of plating		Ferrite (area%)	Pearlite (area%)	(I1 + I3)/(I2 + I4)
31	AA	1.2	108	562	520	40					73	20	1.09
32	AB	2.4	93	569	520	36					70	21	1.05
33	AC	2.4	94	636	580	44					71	23	1.09
34	AD	2.4	84	689	640	33					71	21	1.07
35	AE	1.9	96	665	620	31					70	25	1.05
36	AF	2.2	85	687	640	38					70	21	0.99
37	AG	1.9	98	565	510	46					64	31	0.95
38	AH	0.8	98	550	500	36					67	24	1.06
39	AI	1.6	87	551	510	46					70	25	1.01
40	AJ	0.9	84	628	570	30					68	26	0.93
41	AK	2.0	87	531	480	33					62	22	1.02
42	AL	2.4	85	679	620	41					71	24	0.96
43	AM	1.0	90	627	580	31					68	25	1.01
44	AN	2.2	92	686	630	43					70	24	1.08
45	AO	0.7	106	631	590	30					68	23	1.01
46	AP	1.4	90	587	530	40					70	24	1.11
47	AQ	1.2	92	763	710	36					83	11	1.02
48	AR	0.7	84	606	550	33					67	25	0.92
49	AS	1.4	85	569	520	37					69	24	1.10
50	AT	1.4	102	599	540	39					70	21	1.01
51	AU	2.1	99	695	640	39					74	17	0.97
52	AV	1.1	109	563	510	39					67	28	1.12
53	AW	1.5	86	662	620	44					69	22	0.96
54	AX	1.6	94	604	550	45					67	24	0.94
55	AY	2.3	107	674	620	33					70	21	1.04
56	AZ	0.8	96	567	510	44					70	22	1.05
57	BA	1.7	106	691	640	36					68	23	1.08
58	BB	0.9	105	713	660	46					74	17	1.12
59	BC	1.2	87	646	600	39					71	20	1.04
60	BD	0.7	104	639	580	32					72	22	1.07

[Table 2-9]

Manufacturing No.	Kind of steel	Cooling			Coiling temperature (°C)	Cold rolling reduction (%)	Annealing		Coating formation	Kind of plating	Other manufacturing conditions	Microstructure of steel sheet		
		Time until start of cooling (sec)	Average cooling rate (°C/s)	Cooling stop temperature (°C)			Annealing temperature (°C)	Holding time (sec)				Ferrite (area%)	Pearlite (area%)	(I1 + I3)/(I2 + I4)
61	BE	1.1	91	635	590	30						69	24	0.95
62	BF	0.9	89	570	520	34						65	26	1.11
63	BG	1.6	95	605	550	37						68	27	1.08
64	BH	1.3	91	692	640	44						71	24	1.10
65	BI	1.2	82	654	600	46						70	23	0.94
66	BJ	0.5	92	542	500	39						56	41	1.00
67	BJ	1.6	90	577	520	63						52	44	<u>1.31</u>
68	BK	0.5	78	589	530	36						16	69	0.93
69	BK	1.5	78	589	530	40						19	67	0.93
70	BK	1.3	85	606	560	35						19	72	<u>1.28</u>
71	BK	1.2	75	591	550	41						18	71	<u>1.22</u>
72	BK	3.3	56	605	550	45						16	69	<u>1.23</u>
73	BL	1.2	96	661	610	42						28	59	1.04
74	BM	2.3	93	576	520	19						18	70	0.93
75	BN	2.1	65	676	620	42						37	50	0.96
76	BO	0.5	95	663	610	46						32	56	1.02
77	BO	1.2	88	599	540	10						35	50	<u>1.22</u>
78	BP	2.4	103	661	610	44						37	53	1.04
79	BQ	2.0	103	561	510	46						26	63	0.94
80	BQ	2.0	35	776	720	41						35	54	<u>1.23</u>
81	BR	0.5	105	681	630	41						36	51	0.92
82	BR	1.1	80	753	705	35						36	53	<u>1.24</u>
83	BS	2.0	144	618	570	36						23	63	1.03
84	BS	2.0	110	609	550	35	770	40	Al			18	67	0.95
85	BS	1.5	120	609	550	41						23	63	<u>1.24</u>
86	BT	0.6	103	577	520	35						17	68	1.01
87	BT	1.2	90	603	550	41						15	73	<u>1.28</u>
88	BT	1.0	90	621	580	39						16	76	<u>1.26</u>
89	BU	2.4	90	637	590	30						23	67	1.04
90	BU	3.1	100	586	530	35	750	80	G1			20	69	1.01

The underlines indicate values outside the ranges of the present invention.

[Table 2-10]

Manufacturing No.	Kind of steel	Cooling			Coiling	Cold rolling	Annealing		Coating formation	Other manufacturing conditions	Microstructure of steel sheet		
		Time until start of cooling (sec)	Average cooling rate (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Rolling reduction (%)	Annealing temperature (°C)	Holding time (sec)	Kind of plating		Ferrite (area%)	Pearlite (area%)	(11 + 13)/ (12 + 14)
91	BU	1.8	90	593	550	35					23	67	<u>1.26</u>
92	BV	0.7	101	541	500	43					21	67	0.93
93	BV	1.1	95	588	530	41					22	65	<u>1.24</u>
94	BW	2.1	78	679	620	39					37	51	0.93
95	BW	1.5	95	650	600	45					35	52	<u>1.25</u>
96	BW	1.8	66	631	580	35					37	55	<u>1.25</u>
97	BX	2.3	88	704	650	38					12	77	0.93
98	BY	2.2	86	576	530	51					6	79	0.96
99	BY	2.3	80	608	550	45	780	60		0.2% temper rolling	17	74	0.97
100	BZ	1.4	83	673	630	30					14	72	1.02
101	CA	2.4	97	593	540	33					9	81	0.98
102	CB	1.3	83	809	760	32					25	58	1.02
103	CB	1.4	86	798	750	40	780	120			51	36	0.98
104	CC	0.4	79	635	590	39					32	55	0.98
105	CD	1.7	83	576	520	42					25	63	1.01
106	CE	0.6	105	671	620	31					32	58	1.06
107	CF	0.5	83	606	550	42					6	80	1.02
108	CG	0.9	87	581	530	40					6	79	1.12
109	CG	1.1	85	595	540	40	800	90	GA		26	59	0.94
110	CH	2.1	98	529	475	31					9	44	0.97
111	CI	1.5	84	672	630	32					38	47	0.88
112	CJ	1.4	95	591	550	31					20	66	0.87
113	CK	2.2	80	673	630	39					29	62	0.81
114	CL	1.4	89	610	560	32					6	82	0.88
115	CM	0.8	86	577	530	46					7	81	0.88
116	CN	2.3	101	632	590	43					16	73	0.86
117	CO	1.7	96	591	550	33					9	81	0.85
118	CP	1.1	97	557	510	32					9	78	0.82
119	CQ	1.3	97	647	590	42					9	82	0.84
120	CR	1.0	96	664	610	37					33	52	0.98

The underlines indicate values outside the ranges of the present invention.

[Table 2-11]

Manufacturing No.	Kind of steel	Cooling			Coiling		Cold rolling		Annealing		Coating formation		Other manufacturing conditions		Microstructure of steel sheet		
		Time until start of cooling (sec)	Average cooling rate (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Rolling reduction (%)	Annealing temperature (°C)	Holding time (sec)	Kind of plating	Kind of plating	Kind of plating	Kind of plating	Kind of plating	Kind of plating	Ferrite (area%)	Pearlite (area%)	(I1 + I3)/ (I2 + I4)
121	CS	1.6	97	582	540	41									20	66	0.92
122	CT	1.1	81	652	600	33									42	44	0.99
123	CU	2.2	102	684	630	34									29	61	0.94
124	CV	2.3	84	636	590	33									24	62	0.92
125	CW	1.1	89	680	630	46									43	42	1.10
126	CX	1.4	78	671	630	32									37	54	0.98
127	CY	1.6	109	599	550	33									22	66	1.02
128	CZ	2.3	106	661	620	30									35	52	1.05
129	DA	2.1	89	592	540	39									19	68	1.06
130	DB	0.5	98	638	580	33									21	68	1.12
131	DC	1.8	109	671	630	41									15	74	0.96
132	DD	2.4	78	692	640	35									14	73	0.95
133	DE	2.4	107	542	500	34									17	74	1.02
134	DF	1.8	90	665	620	38									40	47	1.09
135	DG	0.4	83	676	630	32									41	47	0.92
136	DH	2.3	80	616	570	39									13	73	1.07
137	DI	1.7	106	649	600	36									13	75	0.92
138	DJ	2.3	104	647	590	40									26	61	1.05
139	DK	0.7	109	662	610	35									38	47	1.12
140	DL	2.4	90	522	480	37									17	39	0.92
141	DM	1.1	95	598	540	41									18	70	1.02
142	DN	2.2	82	559	510	45									16	71	1.10
143	DO	1.9	98	664	620	32									30	56	1.04
144	DP	0.4	85	595	540	40									20	66	1.08
145	DQ	2.4	97	578	530	46									25	65	0.98
146	DR	0.9	82	574	530	44									19	69	0.93
147	DS	0.9	82	552	500	46									22	69	1.08
148	DT	2.2	103	664	620	34									39	52	1.11
149	DU	0.6	80	560	510	44									21	64	1.12
150	DV	0.4	97	635	590	42									24	65	1.10

[Table 2-12]

Manufacturing No.	Kind of steel	Cooling			Coiling	Cold rolling	Annealing		Coating formation	Other manufacturing conditions	Microstructure of steel sheet		
		Time until start of cooling (sec)	Average cooling rate (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Rolling reduction (%)	Annealing temperature (°C)	Holding time (sec)	Kind of plating		Ferrite (area%)	Pearlite (area%)	(I1 + I3)/ (I2 + I4)
151	DW	0.5	104	621	580	36					15	70	1.01
152	DX	2.4	78	693	640	32					31	54	0.93
153	DY	0.7	99	745	700	34					49	39	1.06
154	DZ	1.5	103	562	520	32					22	65	1.02
155	EA	1.6	84	666	610	32					31	59	1.02
156	EB	0.6	98	613	570	45					17	68	0.99
157	EC	1.9	80	676	630	37					29	61	0.94
158	ED	2.1	86	575	530	41					18	71	0.93
159	EF	1.0	81	616	570	46					26	59	1.01
160	EG	0.8	81	678	620	44					28	59	0.92
161	EH	1.6	105	626	580	41					20	71	1.06
162	EI	1.4	99	661	610	34					43	48	1.04
163	EJ	1.1	86	605	550	37					21	70	0.99
164	EK	1.2	84	577	520	41					23	65	1.08
165	EL	2.3	83	610	560	44					15	76	1.01
166	EM	2.4	93	657	600	35					42	44	0.92
167	EN	2.3	99	597	550	43					25	62	0.98
168	EO	0.4	109	638	580	40					26	65	0.96
169	EP	2.3	96	616	570	35					16	71	1.04
170	EQ	2.1	103	653	610	33					39	47	1.10
171	ER	1.3	95	638	590	39					21	69	1.04
172	ES	1.1	101	547	500	37					23	68	1.06
173	ET	1.3	81	628	580	31					25	61	1.08
174	EU	1.1	90	634	590	40					30	61	1.05
175	EV	2.1	79	589	530	44					17	71	1.09
176	EW	1.8	99	652	610	33					34	57	1.05
177	EX	0.9	82	646	590	43					27	61	0.99
178	EY	1.4	102	580	530	33					24	65	1.04

[Table 3-1]

Manufacturing No.	Kind of steel	Heat treatment					Tempering	Microstructure of steel member		Vickers hardness (HV1)	Hydrogen embrittlement resistance	Remark
		Heating temperature (°C)	Average heating rate (°C/s)	Holding time (sec)	Average cooling rate (°C/s)	Cooling completion temperature (°C)	Temperature (°C) and time (min)	Hard structure (area%)	(I1 + I3)/(I2 + I4)			
1	A	900	6.7	80	60	36		99	0.99	485	Good	Present Invention Example
2	B	900	7.3	100	65	33		98	1.04	467	Good	Present Invention Example
3	B	900	7.2	133	39	35		100	1.03	595	Good	Present Invention Example
4	B	910	6.5	93	30	48		100	1.12	617	Good	Present Invention Example
5	C	930	10.0	115	36	45		98	1.08	532	Good	Present Invention Example
6	D	960	3.0	144	47	40		98	1.15	530	Good	Present Invention Example
7	E	900	3.0	113	51	50		100	1.01	489	Good	Present Invention Example
8	F	910	6.1	65	40	31		99	1.06	482	Good	Present Invention Example
9	G	890	9.7	124	42	110		98	1.01	508	Good	Present Invention Example
10	H	890	4.6	95	49	40		100	0.97	466	Good	Present Invention Example
11	I	910	4.6	119	42	53		99	1.08	485	Good	Present Invention Example
12	I	910	5.2	79	33	53		99	1.12	591	Good	Present Invention Example
13	J	910	10.0	95	56	37		99	0.94	483	Good	Present Invention Example
14	K	960	6.3	83	51	40		98	1.02	469	Good	Present Invention Example
15	K	960	6.3	126	39	53		100	0.99	590	Good	Present Invention Example
16	L	880	4.6	115	52	44		99	0.95	563	Good	Present Invention Example
17	M	930	4.7	86	51	156		100	0.93	467	Good	Present Invention Example
18	N	940	5.9	65	52	52		98	0.97	462	Good	Present Invention Example
19	O	950	9.4	98	49	44		99	0.98	549	Good	Present Invention Example
20	P	890	9.1	76	44	37		99	1.07	486	Good	Present Invention Example
21	Q	880	4.0	119	36	48		98	0.86	472	Good	Present Invention Example
22	R	920	3.8	127	47	37		100	0.85	482	Good	Present Invention Example
23	S	900	10.0	64	67	38		98	0.83	474	Good	Present Invention Example
24	T	920	4.2	82	48	110		100	0.85	512	Good	Present Invention Example
25	U	940	2.9	95	40	49		99	0.97	494	Good	Present Invention Example
26	V	880	9.5	61	51	41		98	1.04	461	Good	Present Invention Example
27	W	900	9.3	73	55	31		99	1.03	485	Good	Present Invention Example
28	X	880	8.9	84	55	40		100	1.06	478	Good	Present Invention Example
29	Y	890	3.2	82	51	39		99	1.06	485	Good	Present Invention Example
30	Z	880	6.7	62	44	39		98	1.02	459	Good	Present Invention Example

[Table 3-2]

Manufacturing No.	Kind of steel	Heat treatment					Tempering Temperature (°C) and time (min)	Microstructure of steel member		Vickers hardness (HV1)	Hydrogen embrittlement resistance	Remark
		Heating temperature (°C)	Average heating rate (°C/s)	Holding time (sec)	Average cooling rate (°C/s)	Cooling completion temperature (°C)		Hard structure (area%)	(I1 + I3)/(I2 + I4)			
31	AA	910	3.8	104	59	34		99	1.12	465	Good	Present Invention Example
32	AB	880	3.5	66	42	33		99	1.05	465	Good	Present Invention Example
33	AC	960	6.2	138	39	49		100	1.10	464	Good	Present Invention Example
34	AD	960	5.2	125	32	43		99	1.09	481	Good	Present Invention Example
35	AE	930	5.3	107	57	36		98	1.07	478	Good	Present Invention Example
36	AF	930	5.1	99	65	36		100	1.00	475	Good	Present Invention Example
37	AG	940	7.1	113	58	34		100	0.98	494	Good	Present Invention Example
38	AH	880	5.5	84	29	49		98	1.08	464	Good	Present Invention Example
39	AI	900	9.3	95	62	32		98	1.03	470	Good	Present Invention Example
40	AJ	920	3.6	98	32	55		98	0.93	455	Good	Present Invention Example
41	AK	890	8.5	69	32	36		100	1.03	477	Good	Present Invention Example
42	AL	900	5.5	134	30	42		98	0.97	460	Good	Present Invention Example
43	AM	900	6.4	114	34	44		100	1.01	463	Good	Present Invention Example
44	AN	920	5.6	105	40	41		98	1.11	480	Good	Present Invention Example
45	AO	960	6.0	111	47	30		100	1.02	473	Good	Present Invention Example
46	AP	880	4.6	94	41	80		99	1.11	458	Good	Present Invention Example
47	AQ	920	8.9	96	65	46		100	1.05	498	Good	Present Invention Example
48	AR	900	6.9	128	34	45		100	0.95	477	Good	Present Invention Example
49	AS	920	9.4	78	67	39		99	1.13	479	Good	Present Invention Example
50	AT	880	7.1	100	33	64		99	1.04	480	Good	Present Invention Example
51	AU	900	5.3	135	68	45		100	0.99	468	Good	Present Invention Example
52	AV	880	7.6	87	60	54		98	1.12	487	Good	Present Invention Example
53	AW	910	8.8	104	48	39		98	0.99	457	Good	Present Invention Example
54	AX	930	4.8	86	50	30		100	0.97	492	Good	Present Invention Example
55	AY	960	8.7	132	57	50		98	1.04	467	Good	Present Invention Example
56	AZ	950	6.0	105	54	50		99	1.07	484	Good	Present Invention Example
57	BA	940	2.9	94	48	55		99	1.11	464	Good	Present Invention Example
58	BB	920	5.5	68	38	53		99	1.15	462	Good	Present Invention Example
59	BC	880	8.5	94	45	34		100	1.04	481	Good	Present Invention Example
60	BD	900	8.7	111	35	49		99	1.07	495	Good	Present Invention Example

[Table 3-3]

Manufacturing No.	Kind of steel	Heat treatment					Tempering Temperature (°C) and time (min)	Microstructure of steel member		Vickers hardness (HV1)	Hydrogen embrittlement resistance	Remark
		Heating temperature (°C)	Average heating rate (°C/s)	Holding time (sec)	Average cooling rate (°C/s)	Cooling completion temperature (°C)		Hard structure (area%)	(I1 + I3)/(I2 + I4)			
61	BF	890	4.8	64	57	81		100	0.95	456	Good	Present Invention Example
62	BF	910	2.9	114	57	46		98	1.11	477	Bad	Comparative Example
63	BG	920	3.8	94	47	50		98	1.10	459	Bad	Comparative Example
64	BH	930	6.1	99	40	35		100	1.12	472	Bad	Comparative Example
65	BI	960	9.1	71	31	53		98	0.94	451	Bad	Comparative Example
66	BJ	910	8.3	68	41	34		100	1.00	486	Good	Present Invention Example
67	BJ	900	7.6	65	43	41		100	<u>1.28</u>	603	Bad	Comparative Example
68	BK	910	6.3	69	59	31		100	0.94	512	Good	Present Invention Example
69	BK	905	5.5	75	55	28	150°C × 25 min	99	0.96	568	Good	Present Invention Example
70	BK	900	5.6	65	50	28		99	<u>1.26</u>	594	Bad	Comparative Example
71	BK	900	5.5	70	55	41		99	<u>1.21</u>	634	Bad	Comparative Example
72	BK	900	5.5	60	36	44		100	<u>1.21</u>	700	Bad	Comparative Example
73	BL	950	4.5	96	64	167		99	1.05	494	Good	Present Invention Example
74	BM	920	7.3	90	48	43		98	0.94	487	Good	Present Invention Example
75	BN	900	9.8	107	66	47		100	0.98	558	Good	Present Invention Example
76	BO	950	6.5	95	47	52		100	1.05	585	Good	Present Invention Example
77	BO	890	5.2	65	32	40		99	<u>1.22</u>	695	Bad	Comparative Example
78	BP	900	7.4	63	55	110		100	1.05	615	Good	Present Invention Example
79	BQ	910	7.2	62	40	54		98	0.97	562	Good	Present Invention Example
80	BQ	890	5.6	65	35	54		98	<u>1.23</u>	633	Bad	Comparative Example
81	BR	880	9.7	81	60	54		100	0.93	638	Good	Present Invention Example
82	BR	900	6.5	75	60	40		100	<u>1.22</u>	654	Bad	Comparative Example
83	BS	920	2.9	88	61	80		100	1.03	613	Good	Present Invention Example
84	BS	900	3.5	88	64	39		98	0.95	588	Good	Present Invention Example
85	BS	900	4.3	75	55	80		100	<u>1.22</u>	966	Bad	Comparative Example
86	BT	890	8.9	62	42	39		99	1.04	612	Good	Present Invention Example
87	BT	900	7.2	65	35	30		99	<u>1.25</u>	681	Bad	Comparative Example
88	BT	900	5.6	60	40	45		99	<u>1.24</u>	668	Bad	Comparative Example
89	BU	890	5.6	90	43	44		100	1.04	586	Good	Present Invention Example
90	BU	900	5.5	116	57	32		99	1.03	590	Good	Present Invention Example

The underlines indicate values outside the ranges of the present invention.

[Table 3-4]

Manufacturing No.	Kind of steel	Heat treatment					Tempering Temperature (°C) and time (min)	Microstructure of steel member		Vickers hardness (HV1)	Hydrogen embrittlement resistance	Remark
		Heating temperature (°C)	Average heating rate (°C/s)	Holding time (sec)	Average cooling rate (°C/s)	Cooling completion temperature (°C)		Hard structure (area%)	(I1 + I3)/(I2 + I4)			
91	BU	900	5.5	66	45	44		100	<u>1.24</u>	410	Bad	Comparative Example
92	BV	890	3.3	140	57	51		100	0.94	678	Good	Present Invention Example
93	BV	900	4.4	110	55	45		99	<u>1.23</u>	604	Bad	Comparative Example
94	BW	890	8.2	102	68	66		99	0.94	635	Good	Present Invention Example
95	BW	910	4.5	68	55	45		100	<u>1.22</u>	448	Bad	Comparative Example
96	BW	900	4.5	65	45	41		100	<u>1.22</u>	633	Bad	Comparative Example
97	BX	960	7.8	85	46	33		99	0.94	634	Good	Present Invention Example
98	BY	880	5.3	62	32	51		98	0.97	618	Good	Present Invention Example
99	BY	900	4.5	60	35	35		100	1.00	642	Good	Present Invention Example
100	BZ	880	4.8	71	41	40		100	1.03	607	Good	Present Invention Example
101	CA	960	9.0	101	58	49		100	1.00	660	Good	Present Invention Example
102	CB	960	7.0	146	51	44		100	1.04	644	Good	Present Invention Example
103	CB	920	7.0	79	61	41		100	0.99	575	Good	Present Invention Example
104	CC	880	9.7	123	63	49		100	0.99	605	Good	Present Invention Example
105	CD	940	9.8	102	32	31		98	1.04	604	Good	Present Invention Example
106	CE	910	6.9	67	50	49		99	1.06	621	Good	Present Invention Example
107	CF	940	5.0	86	45	51		98	1.02	625	Good	Present Invention Example
108	CG	900	5.8	128	60	42		98	1.13	632	Good	Present Invention Example
109	CG	900	5.8	67	45	54		98	0.97	563	Good	Present Invention Example
110	CH	920	6.0	72	61	50		98	0.97	672	Good	Present Invention Example
111	CI	940	8.4	73	33	33		98	0.88	691	Good	Present Invention Example
112	CJ	900	8.9	74	51	34		100	0.88	677	Good	Present Invention Example
113	CK	950	7.7	88	46	42		100	0.84	647	Good	Present Invention Example
114	CL	920	4.4	121	53	51		99	0.90	641	Good	Present Invention Example
115	CM	940	9.7	73	53	48		99	0.88	635	Good	Present Invention Example
116	CN	950	4.0	109	30	37		98	0.87	685	Good	Present Invention Example
117	CO	890	8.3	101	40	53		99	0.88	633	Good	Present Invention Example
118	CP	930	5.3	93	45	38		99	0.83	659	Good	Present Invention Example
119	CQ	880	2.9	140	45	36		99	0.85	633	Good	Present Invention Example
120	CR	890	8.8	109	40	41		99	1.01	764	Good	Present Invention Example

The underlines indicate values outside the ranges of the present invention.

[Table 3-5]

Manufacturing No.	Kind of steel	Heat treatment					Tempering Temperature (°C) and time (min)	Microstructure of steel member		Vickers hardness (HV1)	Hydrogen embrittlement resistance	Remark
		Heating temperature (°C)	Average heating rate (°C/s)	Holding time (sec)	Average cooling rate (°C/s)	Cooling completion temperature (°C)		Hard structure (area%)	(I1 + I3)/(I2 + I4)			
121	CS	950	5.0	115	65	42		100	0.95	793	Good	Present Invention Example
122	CT	910	3.3	137	32	30		98	1.02	791	Good	Present Invention Example
123	CU	960	7.0	91	40	33		99	0.97	836	Good	Present Invention Example
124	CV	960	3.1	128	45	49		98	0.95	767	Good	Present Invention Example
125	CW	910	7.7	65	54	50		98	1.13	781	Good	Present Invention Example
126	CX	930	6.8	125	45	32		100	0.99	783	Good	Present Invention Example
127	CY	960	5.6	119	56	50		100	1.03	628	Good	Present Invention Example
128	CZ	910	7.1	123	29	34		100	1.06	586	Good	Present Invention Example
129	DA	900	5.1	100	63	41		98	1.08	687	Good	Present Invention Example
130	DB	880	4.0	140	37	53		100	1.15	735	Good	Present Invention Example
131	DC	930	3.7	108	44	43		98	0.98	829	Good	Present Invention Example
132	DD	890	8.9	74	68	31		98	0.97	832	Good	Present Invention Example
133	DE	960	3.6	150	49	47		98	1.03	808	Good	Present Invention Example
134	DF	920	7.0	106	34	48		100	1.12	591	Good	Present Invention Example
135	DG	940	9.6	65	31	38		99	0.92	608	Good	Present Invention Example
136	DH	920	10.0	76	66	54		98	1.10	662	Good	Present Invention Example
137	DI	890	5.9	127	58	47		99	0.93	783	Good	Present Invention Example
138	DJ	940	6.6	116	64	32		99	1.06	789	Good	Present Invention Example
139	DK	880	5.3	128	55	46		99	1.12	755	Good	Present Invention Example
140	DL	880	9.4	114	39	44		100	0.92	785	Good	Present Invention Example
141	DM	920	4.4	116	32	53		100	1.05	769	Good	Present Invention Example
142	DN	900	8.5	63	58	88		98	1.10	764	Good	Present Invention Example
143	DO	890	5.1	126	47	32		100	1.06	627	Good	Present Invention Example
144	DP	900	5.1	69	63	50		99	1.10	553	Good	Present Invention Example
145	DQ	900	7.2	132	36	54		99	1.00	572	Good	Present Invention Example
146	DR	900	5.6	130	39	33		98	0.96	798	Good	Present Invention Example
147	DS	960	8.6	132	31	30		98	1.10	673	Good	Present Invention Example
148	DT	960	9.4	133	49	43		99	1.12	576	Good	Present Invention Example
149	DU	950	7.0	107	30	36		98	1.14	577	Good	Present Invention Example
150	DV	910	2.7	127	61	55		99	1.10	618	Good	Present Invention Example

[Table 3-6]

Manufacturing No.	Kind of steel	Heat treatment					Tempering Temperature (°C) and time (min)	Microstructure of steel member		Vickers hardness (HV1)	Hydrogen embrittlement resistance	Remark
		Heating temperature (°C)	Average heating rate (°C/s)	Holding time (sec)	Average cooling rate (°C/s)	Cooling completion temperature (°C)		Hard structure (area%)	(I1 + I3)/(I2 + I4)			
151	DW	960	5.8	74	68	51		98	1.04	816	Good	Present Invention Example
152	DX	890	3.7	125	31	47		98	0.95	601	Good	Present Invention Example
153	DY	900	7.9	63	47	30		100	1.08	778	Good	Present Invention Example
154	DZ	950	3.4	89	53	55		100	1.05	806	Good	Present Invention Example
155	EA	900	8.6	64	53	39		100	1.02	835	Good	Present Invention Example
156	EB	930	4.4	69	41	40		100	1.02	656	Good	Present Invention Example
157	EC	950	2.8	142	44	32		99	0.96	590	Good	Present Invention Example
158	ED	930	7.6	127	47	39		99	0.95	583	Good	Present Invention Example
159	EF	890	3.2	107	36	30		98	1.02	822	Good	Present Invention Example
160	EG	890	8.0	64	31	46		99	0.93	788	Good	Present Invention Example
161	EI	930	3.6	128	37	34		98	1.07	622	Good	Present Invention Example
162	EJ	940	3.7	135	41	30		99	1.06	667	Bad	Comparative Example
163	EJ	940	5.0	91	59	32		99	0.99	591	Bad	Comparative Example
164	EK	960	9.4	65	37	52		99	1.10	570	Bad	Comparative Example
165	EL	910	2.7	96	54	34		100	1.04	679	Bad	Comparative Example
166	EM	930	6.1	93	65	52		100	0.93	425	Good	Comparative Example
167	EN	890	2.6	160	32	32		100	0.98	599	Bad	Comparative Example
168	EO	920	7.7	62	53	23		81	0.98	448	Good	Comparative Example
169	EP	890	8.8	89	36	32		100	1.05	622	Bad	Comparative Example
170	EQ	930	8.9	79	57	32		98	1.10	573	Bad	Comparative Example
171	ER	920	3.4	131	37	33		99	1.04	555	Bad	Comparative Example
172	ES	960	7.8	107	43	34		100	1.08	561	Bad	Comparative Example
173	ET	960	9.6	82	41	50		98	1.08	622	Bad	Comparative Example
174	EU	915	9.8	93	45	28		100	1.02	606	Good	Present Invention Example
175	EV	910	3.6	60	45	67		99	1.04	711	Good	Present Invention Example
176	EW	900	3.1	126	41	35		100	1.07	616	Good	Present Invention Example
177	EX	900	4.2	67	35	65		100	0.97	676	Good	Present Invention Example
178	EY	910	3.5	90	45	51		100	1.03	700	Good	Present Invention Example

The underlines indicate values outside the ranges of the present invention.

[0233] As can be seen from Tables 1-1 to 3-6, in the steel members of the present invention examples, the chemical composition, the microstructure (area ratio of each phase), and the texture were within predetermined ranges, and as a result, the Vickers hardness was high (that is, the tensile strength was high) and the hydrogen embrittlement resistance was excellent.

[0234] Contrary to this, in the steel members of the comparative examples, one or more of the chemical composition, the microstructure (area ratio of each phase), and the texture were outside the ranges of the present invention. As a result, the Vickers hardness and the hydrogen embrittlement resistance of the steel member were both or either inferior.

INDUSTRIAL APPLICABILITY

[0235] According to the present invention, it is possible to provide a steel member having a high tensile strength and excellent hydrogen embrittlement resistance, and a steel sheet which is a material for the steel member. Therefore, high industrial applicability is achieved.

Claims

1. A steel member comprising, as a chemical composition, by mass%:

C: 0.260% to 0.700%;

Si: 0% to 2.000%;
Mn: 0% to 3.00%;
Al: 0% to 1.000%;
Nb: 0% to 0.100%;
5 Ti: 0% to 0.200%;
Cr: 0% to 1.00%;
B: 0% to 0.0200%;
Mo: 0% to 1.00%;
10 W: 0% to 2.00%;
Co: 0% to 1.00%;
Ni: 0% to 2.00%;
Cu: 0% to 2.00%;
V: 0% to 1.00%;
Ca: 0% to 0.200%;
15 Mg: 0% to 0.20%;
REM: 0% to 0.300%;
Sb: 0% to 1.00%;
Sn: 0% to 1.00%;
Zr: 0% to 1.00%;
20 As: 0% to 1.00%;
Se: 0% to 1.00%;
Bi: 0% to 1.00%;
Ta: 0% to 1.00%;
Re: 0% to 1.00%;
25 Os: 0% to 1.00%;
Ir: 0% to 1.00%;
Tc: 0% to 1.00%;
P: 0.100% or less;
S: 0.0100% or less;
30 N: 0.020% or less;
O: 0.010% or less; and
a remainder: Fe and impurities,

wherein, when a range between a 1/8 position of a thickness and a 3/8 position of the thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness from the surface as a center, is defined as a 1/4 depth position,
35 a microstructure at the 1/4 depth position includes, by area ratio, martensite, bainite, and tempered martensite: 90% or more in total, and at the 1/4 depth position, when a random intensity ratio of $\{111\}<011>$ is denoted by I1, a random intensity ratio of $\{111\}<112>$ is denoted by I2, a random intensity ratio of $\{100\}<011>$ is denoted by I3, and a random intensity ratio of $\{100\}<001>$ is denoted by I4, the steel member has a texture in which the I1, the I2, the I3, and the I4 satisfy Expression (1),
40

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1).$$

2. The steel member according to Claim 1,

wherein the chemical composition contains one or more selected from the group consisting of, by mass%,
Nb: 0.005% to 0.100%,
50 Ti: 0.005% to 0.200%,
Cr: 0.01% to 1.00%,
B: 0.0010% to 0.0200%,
Mo: 0.01% to 1.00%,
W: 0.001% to 2.00%,
55 Co: 0.01% to 1.00%,
Ni: 0.01% to 2.00%,
Cu: 0.01% to 2.00%,
V: 0.01% to 1.00%,

Ca: 0.001% to 0.200%,
Mg: 0.01% to 0.20%,
REM: 0.001% to 0.300%,
Sb: 0.01% to 1.00%,
Sn: 0.01% to 1.00%,
Zr: 0.01% to 1.00%,
As: 0.01% to 1.00%,
Se: 0.01% to 1.00%,
Bi: 0.01% to 1.00%,
Ta: 0.01% to 1.00%,
Re: 0.01% to 1.00%,
Os: 0.01% to 1.00%,
Ir: 0.01% to 1.00%, and
Tc: 0.01% to 1.00%.

3. The steel member according to Claim 1 or 2, wherein a Vickers hardness at the 1/4 depth position is 450 or more.
4. The steel member according to any one of Claims 1 to 3, wherein the surface of the steel member has a coating.
5. The steel member according to Claim 4, wherein the coating is an Fe-Al-based coating or an Fe-Zn-based coating.
6. A steel sheet comprising, as a chemical composition, by mass%:

C: 0.260% to 0.700%;
Si: 0% to 2.000%;
Mn: 0% to 3.00%;
Al: 0% to 1.000%;
Nb: 0% to 0.100%;
Ti: 0% to 0.200%;
Cr: 0% to 1.00%;
B: 0% to 0.0200%;
Mo: 0% to 1.00%;
W: 0% to 2.00%;
Co: 0% to 1.00%;
Ni: 0% to 2.00%;
Cu: 0% to 2.00%;
V: 0% to 1.00%;
Ca: 0% to 0.200%;
Mg: 0% to 0.20%;
REM: 0% to 0.300%;
Sb: 0% to 1.00%;
Sn: 0% to 1.00%;
Zr: 0% to 1.00%;
As: 0% to 1.00%;
Se: 0% to 1.00%;
Bi: 0% to 1.00%;
Ta: 0% to 1.00%;
Re: 0% to 1.00%;
Os: 0% to 1.00%;
Ir: 0% to 1.00%;
Tc: 0% to 1.00%;
P: 0.100% or less;
S: 0.0100% or less;
N: 0.020% or less;
O: 0.010% or less; and

a remainder: Fe and impurities,
wherein, when a range between a 1/8 position of a sheet thickness and a 3/8 position of the sheet thickness in a sheet thickness direction from a surface of the steel sheet, with respect to a 1/4 position of the sheet thickness

from the surface as a center, is defined as a 1/4 depth position,
at the 1/4 depth position, when a random intensity ratio of $\{111\}<011>$ is denoted by I1, a random intensity ratio of $\{111\}<112>$ is denoted by I2, a random intensity ratio of $\{100\}<011>$ is denoted by I3, and a random intensity ratio of $\{100\}<001>$ is denoted by I4, the steel sheet has a texture in which the I1, the I2, the I3, and the I4 satisfy Expression (1),

$$(I1 + I3)/(I2 + I4) \leq 1.20 \dots (1).$$

7. The steel sheet according to Claim 6,

wherein the chemical composition contains one or more selected from the group consisting of, by mass%,
Nb: 0.005% to 0.100%,
Ti: 0.005% to 0.200%,
Cr: 0.01% to 1.00%,
B: 0.0010% to 0.0200%,
Mo: 0.01% to 1.00%,
W: 0.001% to 2.00%,
Co: 0.01% to 1.00%,
Ni: 0.01% to 2.00%,
Cu: 0.01% to 2.00%,
V: 0.01% to 1.00%,
Ca: 0.001% to 0.200%,
Mg: 0.01% to 0.20%,
REM: 0.001% to 0.300%,
Sb: 0.01% to 1.00%,
Sn: 0.01% to 1.00%,
Zr: 0.01% to 1.00%,
As: 0.01% to 1.00%,
Se: 0.01% to 1.00%,
Bi: 0.01% to 1.00%,
Ta: 0.01% to 1.00%,
Re: 0.01% to 1.00%,
Os: 0.01% to 1.00%,
Ir: 0.01% to 1.00%, and
Tc: 0.01% to 1.00%.

8. The steel sheet according to Claim 6 or 7, wherein the surface of the steel sheet has a coating.

9. The steel sheet according to Claim 8, wherein the coating is an Al-based coating or a Zn-based coating.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/008038

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; *C21D 1/18*(2006.01)i; *C21D 9/00*(2006.01)i; *C21D 9/46*(2006.01)i; *C22C 38/60*(2006.01)i;
C22C 21/00(2006.01)n

FI: C22C38/00 301Z; C22C38/00 301S; C22C38/00 301T; C22C38/60; C21D9/46 J; C21D1/18 C; C21D9/00 A; C22C21/00 Z

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; C21D1/18; C21D9/00; C21D9/46; C22C38/60; C22C21/00

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 1971-2024
 Registered utility model specifications of Japan 1996-2024
 Published registered utility model applications of Japan 1994-2024

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	WO 2019/186930 A1 (NIPPON STEEL CORPORATION) 03 October 2019 (2019-10-03)	1-9
A	JP 2015-151600 A (NIPPON STEEL & SUMITOMO METAL CORP.) 24 August 2015 (2015-08-24)	1-9
A	JP 2012-172159 A (NIPPON STEEL CORP.) 10 September 2012 (2012-09-10)	1-9
A	JP 2007-284776 A (NIPPON STEEL CORP.) 01 November 2007 (2007-11-01)	1-9

☐ 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

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“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 08 May 2024	Date of mailing of the international search report 21 May 2024
Name and mailing address of the ISA/JP Japan Patent Office (ISA/JP) 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915 Japan	Authorized officer Telephone No.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2024/008038

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO	2019/186930	A1	03 October 2019	US 2021/0010118 A1 EP 3778951 A1 CN 111655885 A KR 10-2020-0121872 A	
JP	2015-151600	A	24 August 2015	(Family: none)	
JP	2012-172159	A	10 September 2012	(Family: none)	
JP	2007-284776	A	01 November 2007	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2023038696 A [0002]
- JP 2002102980 A [0010]
- JP 2012180594 A [0010]
- JP 2012001802 A [0010]
- WO 2015182596 A [0010]
- WO 2015182591 A [0010]