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

(57) This steel member has a predetermined chemical composition, in which, when a range of a 1/8 position to a 3/8 position of a thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness in the thickness direction from the surface as a center, is defined as a 1/4 depth position, in a case where, at the 1/4 depth position, with a <011> direction as a rotation axis, among grain boundaries of crystal grains having a body-centered structure, a length of a grain boundary having a rotation angle of 49° to 56° is denoted by L49-56°, a length of a grain boundary having a rotation angle of 64° to 72° is denoted by L64-72°, a length of a grain boundary having a rotation angle of 57° to 63° is denoted by L57-63°, and a length of a grain boundary having a rotation angle of 4° to 12° is denoted by L4-12°, (L49-56° + L64-72°)/(L57-63° + L4-12°) that is a ratio of a sum of the L49-56° and the L64-72° to a sum of the L57-63° and the L4-12° is 1.40 or more, and a tensile strength of the steel member is more than 1,500 MPa.

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Description

TECHNICAL FIELD

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

[0002] Priority is claimed on Japanese Patent Application No. 2023-038695, filed March 13, 2023, the content of which is incorporated herein by reference.

BACKGROUND ART

[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.

[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 warpage, 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. 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.

[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.

[0008] In recent years, countries around the world have set higher CO_2 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 (1,500 MPa)) 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.

[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.

Citation List

Patent Documents

[0010]

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
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.

(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 0.20 mass% of C, and strength after the heat treatment is secured due to this C.

[0014] 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 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 0.26 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.

[0015] 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.

[0016] (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 controlling a ratio between lengths of grain boundaries having specific rotation angles.

[0017] (c) In addition, the present inventors found that the length of the grain boundary having a specific rotation angle changes significantly depending on the state of the presence of W (tungsten) in steel, and the state of the presence of W can be controlled by manufacturing conditions.

[0018] The present inventors have made the present invention 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: 0.26% to 0.65%; Si: 0% to 2.00%; Mn: 0% to 3.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; W: 0.10% to 2.00%; Nb: 0% to 0.10%; Ti: 0% to 0.200%; Cu: 0% to 2.00%; Ni: 0% to 2.00%; Cr: 0% to 1.00%; B: 0% to 0.0200%; Mo: 0% to 1.00%; V: 0% to 1.00%; Ca: 0% to 0.020%; Mg: 0% to 0.010%; Al: 0% to 1.00%; Sn: 0% to 1.00%; Sb: 0% to 1.00%; Zr: 0% to 1.00%; Se: 0% to 1.00%; Bi: 0% to 1.00%; As: 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%; Co: 0% to 1.00%; REM: 0% to 0.30%; and a remainder: Fe and impurities, in which, when a range of a 1/8 position to a 3/8 position of a thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness in the thickness direction from the surface as a center, is defined as a 1/4 depth position, in a case where, at the 1/4 depth position, with a <011> direction as a rotation axis, among grain boundaries of crystal grains having a body-centered structure, a length of a grain boundary having a rotation angle of 49° to 56° is denoted by L49-56°, a length of a grain boundary having a rotation angle of 64° to 72° is denoted by L64-72°, a length of a grain boundary having a rotation angle of 57° to 63° is denoted by L57-63°, and a length of a grain boundary having a rotation angle of 4° to 12° is denoted by L4-12°, (L49-56° + L64-72°)/(L57-63° + L4-12°) that is a ratio of a sum of the L49-56° and the L64-72° to a sum of the L57-63° and the L4-12° is 1.40 or more, and a tensile strength of the steel member is more than 1,500 MPa.

[2] In the steel member according to [1], the chemical composition may contain, by mass%, Nb: 0.01% to 0.10%, a Nb-based precipitate may be present at the 1/4 depth position, and a W concentration of the Nb-based precipitate is 5.0 times or more a W content of the steel member.

[3] In the steel member according to [1] or [2], the surface may have a coating.

[4] In the steel member according to [3], the coating may primarily contain an Fe-Al-based alloy or an Fe-Zn-based

alloy.

[5] A steel sheet according to another aspect of the present invention includes, as a chemical composition, by mass%: C: 0.26% to 0.65%; Si: 0% to 2.00%; Mn: 0% to 3.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; W: 0.10% to 2.00%; Nb: 0% to 0.10%; Ti: 0% to 0.200%; Cu: 0% to 2.00%; Ni: 0% to 2.00%; Cr: 0% to 1.00%; B: 0% to 0.0200%; Mo: 0% to 1.00%; V: 0% to 1.00%; Ca: 0% to 0.020%; Mg: 0% to 0.010%; Al: 0% to 1.00%; Sn: 0% to 1.00%; Sb: 0% to 1.00%; Zr: 0% to 1.00%; Se: 0% to 1.00%; Bi: 0% to 1.00%; As: 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%; Co: 0% to 1.00%; REM: 0% to 0.30%; and a remainder: Fe and impurities, in which, when a range of a 1/8 position to a 3/8 position of a thickness in a thickness direction from a surface of the steel sheet, with respect to a 1/4 position of the thickness in the thickness direction from the surface as a center, is defined as a 1/4 depth position, at the 1/4 depth position, an area fraction of regions that are surrounded by boundaries having a crystal misorientation of 5° or more and that have an average crystal misorientation within the boundaries of 0.4° to 3.0° is 80% or less.

[6] In the steel sheet according to [5], the chemical composition may contain, by mass%, Nb: 0.01% to 0.10%, a Nb-based precipitate may be present at the 1/4 depth position, and a W concentration of the Nb-based precipitate may be 5.0 times or more a W content of the steel sheet.

[7] In the steel sheet according to [5] or [6], the surface may have a coating.

[8] In the steel sheet according to [7], the coating may be an Al-based coating or a Zn-based coating.

Advantageous Effects of Invention

[0019] According to the above aspect of the present invention, it is possible 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.

DESCRIPTION OF EMBODIMENTS

<Steel Member>

[0020] A steel member according to an embodiment of the present invention (a steel member according to the present embodiment) will be described. Hereinafter, a range of a 1/8 position to a 3/8 position of a thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness in the thickness direction from the surface as a center, is referred to as a 1/4 depth position.

[0021] The steel member according to the present embodiment has a predetermined chemical composition, in which (L49-56° + L64-72°)/(L57-63° + L4-12°) is 1.40 or more at a 1/4 depth position, and a tensile strength is more than 1,500 MPa.

[0022] These will be described.

[Chemical Composition]

[0023] Specifically, the chemical composition of the steel member according to the present embodiment includes, by mass%: C: 0.26% to 0.65%; Si: 0% to 2.00%; Mn: 0% to 3.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; W: 0.10% to 2.00%; Nb: 0% to 0.10%; Ti: 0% to 0.200%; Cu: 0% to 2.00%; Ni: 0% to 2.00%; Cr: 0% to 1.00%; B: 0% to 0.0200%; Mo: 0% to 1.00%; V: 0% to 1.00%; Ca: 0% to 0.020%; Mg: 0% to 0.010%; Al: 0% to 1.00%; Sn: 0% to 1.00%; Sb: 0% to 1.00%; Zr: 0% to 1.00%; Se: 0% to 1.00%; Bi: 0% to 1.00%; As: 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%; Co: 0% to 1.00%; REM: 0% to 0.30%; and a remainder: Fe and impurities.

[0024] The reasons for limiting the amount of each element are as follows.

(C: 0.26% to 0.65%)

[0025] C is an element that enhances hardenability of steel and improves strength of the steel member that is obtained after subjecting a steel sheet to quenching such as hot stamping. When a C content is less than 0.26%, 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 0.26% or more. The C content is set to preferably 0.28% or more, and more preferably 0.31% or more or 0.32% 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 0.45% or more.

[0026] On the other hand, when the C content is more than 0.65%, 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 0.65% or less. The C content is set to preferably 0.60% or less, and more preferably 0.56% or less or 0.55%

or less.

(Si: 0% to 2.00%)

[0027] 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 of obtaining the above effects, a Si content is set to preferably 0.10% or more, more preferably 0.20% or more, and even more preferably 0.35% or more.

[0028] On the other hand, when the Si content in steel is more than 2.00%, a heating temperature required for austenitic transformation becomes significantly high during the heat treatment (quenching).

[0029] 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 2.00% or less. The Si content is set to preferably 1.70% or less, more preferably 1.50% or less.

(Mn: 0% to 3.00%)

[0030] 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, more preferably 0.15% or more, and even more preferably 0.25% or more or 0.30% or more.

[0031] 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, more preferably 2.10% or less, and even more preferably 1.50% or less or 1.00% or less.

(P: 0.100% or Less)

[0032] 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 limited to preferably 0.050% or less, and more preferably 0.020% or less.

[0033] 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)

[0034] 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 limited to preferably 0.0050% or less, and more preferably 0.0035% 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)

[0035] 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. The N content is preferably 0.015% or less, 0.010% or less, or 0.006% 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 0.0002% leads to an increase in steelmaking cost and is economically undesirable. Therefore, the N content may be set to 0.0002% or more, 0.0008% or more or 0.001% or more.

(O: 0.010% or Less)

[0036] 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. The O content is preferably 0.007% or less, 0.005% or less, or 0.003% or less. 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 0.0002% leads to an increase in steelmaking cost and is economically

undesirable. Therefore, the O content may be set to 0.0002% or more, 0.0008% or more, or 0.001% or more.

(W: 0.10% to 2.00%)

[0037] W is an important element in the steel member according to the present embodiment. W is an element that is segregated to grain boundaries and is an effective element for promoting the development of the grain boundaries having specific rotation angles described above. In addition, W is an effective element for enhancing the hardenability of the steel and stably securing the strength of the steel member after quenching. Furthermore, W is an element that improves corrosion resistance in a corrosive environment.

[0038] In a case where a W content is less than 0.10%, it is not possible to sufficiently obtain the effect. Therefore, the W content is set to 0.10% or more. The W content is set to preferably 0.20% or more, and more preferably 0.40% or more.

[0039] On the other hand, when the W content is more than 2.00%, the above effect is saturated and the economic efficiency is lowered. Therefore, the W content is set to 2.00% or less. The W content is set to preferably 1.50% or less, more preferably 1.00% or less, and even more preferably 0.80% or less.

(Nb: 0% to 0.10%)

[0040] 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 (W content) higher than a W concentration of a base steel material). Therefore, a Nb content may be 0%, or Nb may be contained.

[0041] In a case of obtaining the above effect, the Nb content is preferably set to 0.01% or more. The Nb content is more preferably 0.02% or more.

[0042] On the other hand, when the Nb content is more than 0.10%, 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 0.10% or less. The Nb content is preferably 0.08% or less.

(Ti: 0% to 0.200%)

[0043] 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 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 not be contained, that is, a Ti content may be 0%, but Ti may be contained.

[0044] In a case of obtaining the above effect, 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.

[0045] 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.

[0046] Accordingly, the Ti content is set to 0.200% or less. The Ti content is set to preferably 0.080% or less, and more preferably 0.050% or less.

(Cu: 0% to 2.00%)

[0047] 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 not be contained, that is, a Cu content may be 0%, but Cu may be contained. In a case of obtaining the above effects, the Cu content is preferably set to 0.10% or more. The Cu content is more preferably 0.20% or more.

[0048] 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. The Cu content is set to preferably 1.50% or less, and more preferably 1.00% or less or 0.60% or less.

(Ni: 0% to 2.00%)

[0049] 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 not be contained, that is, a Ni content may be 0%, but Ni may be contained. In a case of obtaining the above effect, the Ni content is set to preferably 0.10% or more, and more preferably 0.20% or more.

[0050] 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 or 0.10% or less.

(Cr: 0% to 1.00%)

[0051] 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 not be contained, that is, a Cr content may be 0%, but Cr may be contained. In a case of obtaining the above effect, the Cr content is set to preferably 0.03% or more, and more preferably 0.05% or more.

[0052] 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 or 0.10% or less.

(B: 0% to 0.0200%)

[0053] 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 not be contained, that is, a B content may be 0%, but B may be contained. In a case of obtaining the above effects, the B content is set to preferably 0.0005% or more, more preferably 0.0010% or more, and even more preferably 0.0015% or more.

[0054] 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 0.0080% or less, and more preferably 0.0050% or less.

(Mo: 0% to 1.00%)

[0055] 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 not be contained, that is, a Mo content may be 0%, but Mo may be contained. In a case of obtaining the above effect, the Mo content is set to preferably 0.10% or more, and more preferably 0.20% or more.

[0056] On the other hand, Mo is an element having an action of stabilizing iron carbides. When the Mo content is more than 1.00%, there are cases where coarse iron carbides remain undissolved when the steel sheet is heated, and the hydrogen embrittlement resistance of the steel member after quenching decreases. In addition, the cost increase is significant. Therefore, in a case where Mo is contained, the Mo content is set to 1.00% or less. The Mo content is set to preferably 0.80% or less, and more preferably 0.50% or less.

(V: 0% to 1.00%)

[0057] V is an element that forms fine carbides in steel and improves the hydrogen embrittlement resistance of the steel member through a grain refining effect or hydrogen trapping effect of the carbides. Therefore, V may not be contained, that is, a V content may be 0%, but V may be contained. In a case of obtaining the above effect, the V content is set to preferably 0.01% or more, and more preferably 0.10% or more.

[0058] 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. The V content is preferably 0.50% or less or 0.20% or less.

(Ca: 0% to 0.020%)

[0059] 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 not be contained, that is, a Ca content may be 0%, but Ca may be contained. In a case of obtaining the above effect, the Ca content is set to preferably 0.001% or more, and more preferably 0.002% or more.

[0060] On the other hand, in a case where the Ca content is more than 0.020%, the effects are saturated and the cost increases. Accordingly, in a case where Ca is to be contained, the Ca content is set to 0.020% or less. The Ca content is set to preferably 0.005% or less, and more preferably 0.004% or less.

(Mg: 0% to 0.010%)

[0061] 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 not be contained, that is, a Mg content may be 0%, but Mg may be contained. In a case of obtaining the above effect, the Mg content is preferably set to 0.001% or more. The Mg content is more preferably 0.002% or more.

[0062] On the other hand, when the Mg content is more than 0.010%, the effect is saturated and the cost increases. Therefore, in a case where Mg is contained, the Mg content is set to 0.010% or less. The Mg content is preferably 0.005% or less, and more preferably 0.004% or less.

(Al: 0% to 1.00%)

[0063] Al is an element generally used as a steel deoxidizing agent. Therefore, Al may not be contained, that is, an Al content may be 0%, but Al may be contained. In order to obtain the above effect, the Al content is preferably set to 0.01% or more.

[0064] On the other hand, when the Al content is more than 1.00%, the above effect is saturated and the economic efficiency is lowered. Therefore, in a case where Al is contained, the Al content is set to 1.00% or less. The Al content is preferably 0.30% or less, and may be 0.10% or less.

(Sn: 0% to 1.00%)

[0065] Sn is an element that improves the corrosion resistance in a corrosive environment. Therefore, Sn may not be contained, that is, a Sn content may be 0%, but Sn may be contained. In a case of obtaining the above effect, 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.

[0066] On the other hand, when the Sn content is more than 1.00%, a grain boundary strength decreases, and the hydrogen embrittlement resistance of the steel member after quenching decreases. Therefore, in a case where Sn is contained, the Sn content is set to 1.00% or less. The Sn content is preferably 0.30% or less, and may be 0.10% or less.

(Sb: 0% to 1.00%)

[0067] Sb is an element that improves corrosion resistance in a corrosive environment. Therefore, Sb may not be contained, that is, a Sb content may be 0%, but Sb may be contained. In a case of obtaining the above effect, the Sb content is preferably set to 0.01% or more.

[0068] On the other hand, when the Sb content is more than 1.00%, the grain boundary strength decreases, and the hydrogen embrittlement resistance of the steel member after quenching decreases. Therefore, in a case where Sb is contained, the Sb content is set to 1.00% or less. The Sb content is preferably 0.30% or less, and may be 0.10% or less.

(Zr: 0% to 1.00%)

[0069] Zr is an element that improves corrosion resistance in a corrosive environment. Therefore, Zr may not be contained, that is, a Zr content may be 0%, but Zr may be contained. In a case of obtaining the above effect, the Zr content is preferably set to 0.01% or more.

[0070] On the other hand, when the Zr content is more than 1.00%, the grain boundary strength decreases, and the hydrogen embrittlement resistance of the steel member after quenching decreases. Therefore, in a case where Zr is contained, the Zr content is set to 1.00% or less. The Zr content is preferably 0.30% or less.

(Se: 0% to 1.00%)

[0071] Se is an element that improves the hydrogen embrittlement resistance. Therefore, Se may not be contained, that is, a Se content may be 0%, but Se may be contained. In a case of obtaining the above effect, the Se content is preferably set to 0.01% or more.

[0072] 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 is preferably 0.40% or less.

(Bi: 0% to 1.00%)

[0073] Bi is an element that improves the hydrogen embrittlement resistance. Therefore, Bi may not be contained, that is, a Bi content may be 0%, but Bi may be contained. In a case of obtaining the above effect, the Bi content is preferably set to 0.01% or more.

[0074] 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 is preferably 0.30% or less.

(As: 0% to 1.00%)

[0075] As is an element that improves the hydrogen embrittlement resistance. Therefore, As may not be contained, that is, an As content may be 0%, but As may be contained. In a case of obtaining the above effect, the As content is preferably set to 0.01% or more.

[0076] 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 is preferably 0.40% or less.

(Ta: 0% to 1.00%)

[0077] Ta is an element that improves the hydrogen embrittlement resistance. Therefore, Ta may not be contained, that is, a Ta content may be 0%, but Ta may be contained. In a case of obtaining the above effect, the Ta content is preferably set to 0.01% or more.

[0078] 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 is preferably 0.50% or less.

(Re: 0% to 1.00%)

[0079] Re is an element that improves the hydrogen embrittlement resistance. Therefore, Re may not be contained, that is, a Re content may be 0%, but Re may be contained. In a case of obtaining the above effect, the Re content is preferably set to 0.01% or more.

[0080] 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 is preferably 0.40% or less.

(Os: 0% to 1.00%)

[0081] Os is an element that improves the hydrogen embrittlement resistance. Therefore, Os may not be contained, that is, an Os content may be 0%, but Os may be contained. In a case of obtaining the above effect, the Os content is preferably set to 0.01% or more.

[0082] 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 is preferably 0.30% or less.

(Ir: 0% to 1.00%)

[0083] Ir is an element that improves the hydrogen embrittlement resistance. Therefore, Ir may not be contained, that is, an Ir content may be 0%, but Ir may be contained. In a case of obtaining the above effect, the Ir content is preferably set to 0.01% or more.

[0084] 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 is preferably 0.30% or less.

(Tc: 0% to 1.00%)

[0085] Tc is an element that improves the hydrogen embrittlement resistance. Therefore, Tc may not be contained, that is, a Tc content may be 0%, but Tc may be contained. In a case of obtaining the above effect, the Tc content is preferably set to 0.01% or more.

[0086] 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 is preferably 0.40% or less, and more preferably 0.20% or less.

(Co: 0% to 1.00%)

[0087] Co is an element that improves corrosion resistance in a corrosive environment. Therefore, Co may not be contained, that is, a Co content may be 0%, but Co may be contained. In a case of obtaining the above effect, the Co content is preferably set to 0.01% or more.

[0088] On the other hand, when the Co content is more than 1.00%, the above effect is saturated and the economic efficiency is lowered. Therefore, in a case where Co is contained, the Co content is set to 1.00% or less. The Co content is preferably 0.40% or less, and more preferably 0.10% or less.

(REM: 0% to 0.30%)

[0089] 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 not be contained, that is, a REM content may be 0%, but REM may be contained. In a case of obtaining the above effect, the REM content is set to preferably 0.01% or more, and more preferably 0.02% or more.

[0090] On the other hand, when the REM content is more than 0.30%, the effect is saturated and the cost increases. Therefore, in a case where REM is contained, the REM content is set to 0.30% or less. The REM content is preferably set to 0.20% or less.

[0091] 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.

(Remainder: Fe and Impurities)

[0092] In the chemical composition of the steel member according to the present embodiment, elements other than the above-described elements, that is, the remainder is Fe and impurities.

[0093] 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. The impurities may contain Pb.

[0094] The chemical composition of the steel member can be obtained by the following method.

[0095] 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.

[0096] However, since the chemical composition at the 1/4 depth position does not substantially change in the manufacturing process, in a case where an analysis value of a chemical composition in molten steel or a steel sheet is known, the analysis value of the chemical composition in the molten steel or the steel sheet may be used as the chemical composition of the steel member.

[0097] Here, the surface serving as a reference for the 1/4 depth position is the surface of the steel member. However, in a case where the steel member has a coating, that is, in a case where the steel member has a coating on the surface thereof, the surface means a surface of a base steel material excluding the coating.

[Microstructure]

[0098] In the steel member according to the present embodiment, a microstructure at the 1/4 depth position is specified as described below.

[0099] (L49-56° + L64-72°)/(L57-63° + L4-12°): 1.40 or More

Grain boundaries of crystal grains having a body-centered structure primarily include one or two or more of grain boundaries having a rotation angle of 4° to 12°, grain boundaries having a rotation angle of 49° to 56°, grain boundaries having a rotation angle of 57° to 63°, and grain boundaries having a rotation angle of 64° to 72°. In particular, martensite often primarily includes the above four types of grain boundaries.

[0100] Among these, with regard to ductile fracture behavior mediated by hydrogen, which is a fracture behavior of hydrogen embrittlement cracking, when considering the suppression of the occurrence and propagation of ductile cracks, the grain boundaries having a rotation angle of 49° to 56° and the grain boundaries having a rotation angle of 64° to 72° are effective, while the grain boundaries having a rotation angle of 57° to 63° and the grain boundaries having a rotation angle of 4° to 12° are not effective.

[0101] Therefore, in the steel member according to the present embodiment, at the 1/4 depth position, with a <011> direction as a rotation axis, a sum (L49-56° + L64-72°) of lengths (L49-56°) of the grain boundaries having a rotation angle of 49° to 56° and lengths (L64-72°) of the grain boundaries having a rotation angle of 64° to 72° is increased relative to a sum (L57-63° + L4-12°) of lengths (L57-63°) of the grain boundaries having a rotation angle of 57° to 63° and lengths (L4-12°) of the grain boundaries having a rotation angle of 4° to 12°, thereby improving the hydrogen embrittlement resistance.

[0102] When (L49-56° + L64-72°)/(L57-63° + L4-12°) is less than 1.40, a sufficient effect of improving the hydrogen embrittlement resistance cannot be obtained. (L49-56° + L64-72°)/(L57-63° + L4-12°) is preferably 1.60 or more, and more preferably 1.70 or more. An upper limit thereof is not limited, but is substantially 3.00 or less.

[0103] Here, a grain boundary having a rotation angle of A° to B° about the <011> direction as the rotation axis refers to a grain boundary between crystal grains adjacent to each other at which the grain boundaries are in an overlapping relationship when rotated by A° to B° about the <011> direction as the rotation axis.

[0104] (L49-56° + L64-72°)/(L57-63° + L4-12°) can be measured by the following method.

[0105] A sample is cut out from a position 50 mm or more away from an end portion of the steel member so that a cross section perpendicular to the surface (sheet thickness cross section) can be observed. A length of the sample depends on a measurement device, but may be set so that a cross section of about 10 mm in the thickness direction can be observed. The cross section of the cut sample is polished. For example, the cross section of the cut sample is polished using waterproof abrasive paper of #320 to #1200 or more, and then polished using a diamond suspension having a particle size of 3 to 1 μm to obtain a mirror finish. Next, electrolytic polishing is performed to remove strain introduced into a surface layer of the cross section. At the 1/4 depth position, which is a range of the 1/8 position to the 3/8 position in the thickness direction from the surface, with respect to the 1/4 position of the thickness in the thickness direction from the surface of the steel member as the center, a measurement region of 50 μm $\times$ 50 μm is subjected to EBSD analysis at a measurement interval of 0.1 μm to obtain crystal orientation information. Here, the EBSD analysis is performed using, for example, 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) at an analysis speed of 200 to 300 points/second. A scanning electron microscope and an EBSD detector having performance equal to or higher than those described above may be used, but apparatuses manufactured by JEOL Ltd. and TSL are desirable.

[0106] Next, for the obtained crystal orientation information, among the grain boundaries of crystal grains having a body-centered structure, the lengths of the grain boundaries having a rotation angle of 49° to 56°, the lengths of the grain boundaries having a rotation angle of 64° to 72°, the lengths of the grain boundaries having a rotation angle of 57° to 63°, and the lengths of the grain boundaries having a rotation angle of 4° to 12° with the <011> direction as the rotation axis are obtained, and (L49-56° + L64-72°)/(L57-63° + L4-12°) is calculated using each of the results.

[0107] The length of the grain boundary can be easily calculated by using, for example, the "Inverse Pole Figure Map" function and the "Axis Angle" function provided in the software "OIM Analysis (registered trademark)" included in the EBSD analysis apparatus. In these functions, for the grain boundaries of the crystal grains having a body-centered structure, a total length of the grain boundaries can be calculated by designating a specific rotation angle about any direction as the rotation axis.

[0108] The above analysis may be performed on all of the crystal grains included in the measurement region, and the lengths of the above-described four kinds of grain boundaries with the <011> direction as the rotation axis may be calculated. The measurement is performed in five visual fields, and an average value of (L49-56° + L64-72°)/(L57-63° + L4-12°) in each visual field is denoted by (L49-56° + L64-72°)/(L57-63° + L4-12°) in the present embodiment.

[0109] Formation of the grain boundaries having a rotation angle of 57° to 63° and the grain boundaries having a rotation angle of 4° to 12° with the <011> direction as the rotation axis is suppressed by segregation of W to the grain boundaries.

(Preferably, Nb-Based Precipitates Are Present, and W Concentration (Content) of Nb-Based Precipitates Is 5.0 Times or More W Content of Steel Member)

[0110] In order to further enhance the above effect, it is preferable that Nb-based precipitates that dissolve W are present at the 1/4 depth position. However, even in a case where the Nb-based precipitates are present at the 1/4 depth position, the effect cannot be sufficiently obtained when the W concentration is less than 5.0 times the W content in the steel member. Therefore, it is preferable that Nb-based precipitates having a W concentration of 5.0 times or more the W content in the steel member are present. The W concentration of the Nb-based precipitates is preferably 8.0 times or more, and more preferably 10.0 times or more the W content of the steel member. In addition, a size of the Nb-based precipitate is preferably 15 μm or less.

[0111] The Nb-based precipitates to be targeted in the present embodiment are precipitate containing 50 mass% or more of Nb, and are, for example, Nb carbides, Nb carbonitrides, Nb nitrides, NbTi carbides, and NbTi carbonitrides.

[0112] The presence or absence of the Nb-based precipitates and the W concentration (content) of the Nb-based precipitates are obtained by the following methods.

[0113] A sample is collected from a 1/4 width (lateral) position in a width direction from a width-directional end portion of the steel member so that a cross section of the steel member in the thickness direction can be observed. A COMPO image is acquired from the sample using a scanning electron microscope to check the presence of the Nb-based precipitates. Since the Nb-based precipitates contain a large amount of Nb, which is a heavier element than Fe, and therefore appear brighter than a base metal of iron. A W content in the Nb-based precipitates can be obtained by performing spot elemental analysis (beam diameter: 0.5 μm) on the bright Nb-based precipitates using an electron probe microanalyzer (EPMA). During the measurement, the observation is conducted at a magnification at which the Nb-based precipitates can be observed, and the observation continues, changing a visual field, until 10 Nb-based precipitates are found or until a total area of observed visual fields reaches 1,250,000 μm^2.

[0114] In a case where no Nb-based precipitates are observed in any of the observed visual fields of 1,250,000 μm^2, it is determined that no Nb-based precipitates are present at the 1/4 depth position.

[0115] The observed Nb-based precipitates are analyzed individually, and the average value thereof is taken as the W content of the Nb-based precipitates. That is, in a case where 10 Nb-based precipitates are observed, an average of W contents of the 10 Nb-based precipitates is taken as the W content of the Nb-based precipitates, and in a case where the number of the Nb-based precipitates is less than 10, the average of the W contents of the number of the Nb-based precipitates is taken as the W content of the Nb-based precipitates. The Nb-based precipitates may also contain C, N, Ti, Cr, and B.

[0116] During the measurement, Nb-based precipitates having a size of 0.5 μm or more and a Nb concentration of 50 mass% or more are targeted. Most of the Nb-based precipitates in the steel member of the present embodiment have a size of 1.0 to 12.0 μm. Furthermore, the size of the Nb-based precipitates is defined as an average value of a distance between parallel lines that are lines parallel to a horizontal direction and sandwich the second region (horizontal Feret diameter) and a distance between parallel lines that are lines parallel to a vertical direction and sandwich the second region (vertical Feret diameter). The horizontal direction is a longitudinal direction of the steel member, and the vertical direction is a thickness direction perpendicular to the longitudinal direction.

[0117] In the steel member according to the present embodiment, in order to obtain a tensile strength of more than 1.5 GPa, it is preferable that the steel member contains martensite in an area fraction (area%) of 75% or more. In addition, the grain boundaries having a specific rotation angle, which will be described later, are easily controlled in martensite among structures having a body-centered structure. Therefore, it is preferable that the area fraction of martensite is high. A martensite fraction is, by area fraction, more preferably 90% or more. The area fraction of martensite may even be 100%.

[0118] Martensite includes tempered martensite and auto-tempered martensite. The auto-tempered martensite is tempered martensite generated during cooling at the time of quenching without a heat treatment for tempering, and is generated by in-situ tempering of martensite generated due to self-heating associated with martensitic transformation.

[0119] At the 1/4 depth position of the steel member, residual austenite and/or bainite may be contained in addition to martensite. There is no ferrite or pearlite, area fractions of ferrite and pearlite are set to 0%. A total area fraction of martensite, residual austenite, and bainite is preferably 98% or more or 99% or more, and more preferably 100%. The area fraction of martensite is preferably 95% or more or 97% or more, and more preferably 98% or more. An upper limit of the area fraction of martensite is 100%.

[0120] An area fraction of the microstructure of the steel member can be measured by the following method.

[0121] The area fraction of martensite (including fresh martensite, tempered martensite, and auto-tempered martensite) is measured by a transmission electron microscope (TEM) and an electron beam diffractometer attached to the TEM. In the TEM, a structure of a thin film sample in a thickness direction is also observed, and thus a microstructural fraction is originally a volume fraction. However, the steel member of the present embodiment has a structure primarily containing martensite, and a size of the structure identified as martensite is much larger than a thickness of the thin film. Therefore, in a TEM photograph (visual field), there are almost no boundary portions where martensite and a structure other than

martensite (substantially bainite) are mixed in a depth direction of the photograph (visual field), and in a case where a boundary portion is present, the boundary portion is excluded from an observation area. Therefore, in the present embodiment, the area fraction of each structure is calculated by an area ratio of each structure in the TEM photograph (visual field).

[0122] Specifically, a measurement sample including a 1/4 position of a width (1/4 width position) of the steel member from the width-directional end portion of the steel member and the 1/4 depth position of the steel member is cut out, and is used as a thin film sample for TEM observation. A range of 400 μm^2 or more at the 1/4 depth position of the steel member in the thin film sample is observed by TEM.

[0123] By an electron beam diffraction pattern of the thin film sample, martensite and bainite, which have body-centered cubic lattices, and residual austenite, which has a face-centered cubic lattice are distinguished. Then, iron carbides (Fe_3C) in martensite and bainite, which have body-centered cubic lattices, are found from the diffraction pattern, and a precipitation morphology thereof is observed to measure a microstructural fraction of each of martensite and bainite. Specifically, regarding the precipitation morphology, precipitation in three directions is determined to be martensite (tempered martensite), and precipitation limited to one direction is determined to be bainite. A case where precipitation of iron carbides is not observed is also determined to be martensite (fresh martensite). Carbides are observed to distinguish between martensite and bainite, but in the present embodiment, carbides themselves are not included in the area fraction of the structure.

[0124] The area fraction of residual austenite is measured using an X-ray diffraction method. Specifically, a measurement sample is cut out from the 1/4 position of the width of the steel member (1/4 width position) from the width-directional end portion of the steel member, and used as a sample for X-ray diffraction. The cut sample is chemically polished from the surface to a depth of 1/4 of the thickness using hydrofluoric acid and hydrogen peroxide solution. In a case where chemical polishing takes a long time, for example, the surface may be polished using waterproof abrasive paper to about 1/8 of the thickness from the surface, and then chemical polishing can be performed further up to 1/4 of the thickness. As measurement conditions, a Co tube is used and 20 is in a range of 45° to 105°. A diffraction X-ray intensity of the face-centered cubic lattice (residual austenite) contained in the steel member is measured, and the volume fraction of the residual austenite is calculated from an area ratio of a diffraction curve thereof. The volume fraction of residual austenite obtained by the X-ray diffraction is regarded as the area fraction as it is.

[0125] The measurement of the area fractions of martensite, residual austenite, and bainite is complicated. Instead of the measurement of these area fractions, the area fractions of ferrite and pearlite may be measured by the following method, and a value obtained by subtracting a sum of the area fractions from 100% may be regarded as a sum of the area fractions of martensite, residual austenite, and bainite.

[0126] In a case where ferrite or pearlite is present, the presence of ferrite or pearlite can be easily confirmed with an optical microscope or a scanning electron microscope. Specifically, a measurement sample including the 1/4 width position of the steel member and the 1/4 depth position of the steel member is cut out, and is used as a sample for observation. The cut sample is mechanically polished and subsequently mirror-finished. Next, etching is performed on the sample with a nital etching solution to reveal ferrite and pearlite, and a range of 40,000 μm^2 or more by area at the 1/4 depth position of the steel member is observed using a scanning electron microscope to confirm the presence of ferrite or pearlite. A structure in which ferrite and cementite are alternately arranged in layers is determined to be pearlite, and a structure in which cementite is precipitated in particles is determined to be bainite. The microstructural fractions by the scanning electron microscope are area fractions (area%).

[0127] Here, in the present embodiment, the Nb-based precipitates described above are not included in the area fraction of the Nb-based precipitates, but are included in an area fraction of a microstructure around Nb-based inclusions. Therefore, the presence of the Nb-based precipitates is not taken into consideration during the measurement of the area fractions.

[Tensile Strength]

[0128] The steel member according to the present embodiment has a tensile strength of more than 1,500 MPa (1.5 GPa) in order to contribute to the improvement of both fuel efficiency and collision safety by being applied to a vehicle member. The tensile strength is preferably 1,800 MPa or more, and more preferably 2,300 MPa or more.

[0129] On the other hand, the tensile strength is preferably 3,150 MPa or less, and more preferably 2,850 MPa or less in terms of hydrogen embrittlement resistance.

[0130] The tensile strength can be measured in accordance with ASTM E8M-22. Specifically, a tensile test piece of a sub-size test piece (parallel section width: 6.0 $\pm$ 0.1 mm, gauge length: 25.0 $\pm$ 0.1 mm) in Table 1 of ASTM E8M-22 can be collected and subjected to a tensile test to measure the tensile strength (TS). In a case where the steel member is small and the tensile test piece cannot be collected, an average hardness in a sheet thickness direction may be measured by a Vickers hardness test (test force of 9.807 N, HV1) in accordance with JIS Z 2244-1:2020, and a value obtained by converting the obtained average hardness in the sheet thickness direction into a tensile strength using a known hardness

conversion table (for example, SAE J417-1983) may be regarded as the tensile strength of the steel member according to the present embodiment.

[0131] 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, and 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". In addition, the steel member may be a part of a tailored property material having different strengths depending on portions. In this case, the tailored property material is a steel member in which the steel member according to the present embodiment and a steel member other than the present embodiment are combined, and it is not necessary for the entire tailored property material to satisfy the above-described chemical composition, microstructure (here, L49-56° + L64-72°)/(L57-63° + L4-12°), and tensile strength. It is sufficient that at least a part of the tailored property material satisfies the above-described chemical composition, microstructure (here, L49-56° + L64-72°)/(L57-63° + L4-12°), and tensile strength, and there is no need to specify ratios therebetween, and the like. The tailored property material may be a material obtained by joining steel sheets which are different in chemical composition, strength, and sheet thickness, or may be a material obtained by subjecting a part of a steel sheet to a heat treatment. In addition, the steel member may be provided with a decarburized layer or a soft layer in a part of a surface layer.

[Sheet Thickness]

[0132] The thickness of the steel member (in a case where the steel member is a member obtained by processing a steel sheet, the thickness can be said to be a sheet thickness of the steel sheet forming the steel member) is not limited. In a case of a steel member for a vehicle manufactured by hot stamping, the sheet thickness may be 0.6 mm or more or 0.8 mm or more based on a main sheet thickness range in which the steel member is used. For the same reason, the thickness may be set to 4.0 mm or less or 2.5 mm or less.

[Coating]

[0133] A part or the entirety of the surface of the steel member according to the present embodiment may have a coating.

[0134] The coating may be a coating primarily containing an Fe-Al-based alloy or a coating primarily containing an Fe-Zn-based alloy. The coating is also referred to as a film, an alloyed plating layer, or an intermetallic compound layer. It is not necessary to exclude coatings other than the coating primarily containing an Fe-Al-based alloy and the coating primarily containing an Fe-Zn-based alloy, and other coatings, such as a Sn-based coating, a resin coating other than a metal-based coating, or a multilayer thereof may be provided.

[0135] 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. The total of the amounts of the impurities may be 1% or less.

[0136] 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.

[0137] A thickness of the coating is preferably 10 to 100 μm.

[0138] The chemical composition and the thickness of the coating can be obtained by observing a cross section with a scanning electron microscope.

[0139] 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.

[0140] Observation with a BSE image (or a COMPO image) confirms a clear difference in contrast between the coating and the base metal (steel sheet substrate). 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.

[0141] 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: 0.5 μm) 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>

[0142] Next, a 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 on the steel sheet.

[Chemical Composition]

[0143] A 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. The chemical composition of the steel sheet can be measured from a 1/4 depth position (a range of 1/8 to 3/8 of a thickness from a surface of the steel sheet in a sheet thickness direction) in the same manner as in the steel member.

[0144] As described above, since the chemical composition at the 1/4 depth position does not substantially change in the manufacturing process, in a case where an analysis value of a chemical composition in molten steel is known, the analysis value of the chemical composition in the molten steel may be used as the chemical composition of the steel sheet.

[0145] Here, the surface serving as a reference for the 1/4 depth position is the surface of the steel sheet. However, in a case where the steel sheet has a coating, that is, in a case where the steel sheet has a base steel sheet and a coating formed on a surface of the base steel sheet, the surface means the surface of the base steel sheet excluding the coating.

[Microstructure]

[0146] A microstructure at the 1/4 depth position, which is a range of a 1/8 position to a 3/8 position of the thickness in the thickness direction from the surface, with respect to a 1/4 position of the thickness (sheet thickness) in the thickness direction (sheet thickness direction) from the surface as a center, is defined.

(Area Fraction of Regions That are Surrounded by Boundaries Having Crystal Misorientation of 5° or More and That Have Average Crystal Misorientation of 0.4° to 3.0° Within Boundaries: 80% or Less)

[0147] In the steel sheet according to the present embodiment, at the 1/4 depth position, an area fraction of regions (crystal grains) that are surrounded by boundaries having a crystal misorientation of 5° or more and that have an average crystal misorientation within the boundaries of 0.4° to 3.0° is 80% or less. This region is a base metal structure in which the microstructure of the steel member described above is obtained in the heat treatment, which will be described later, and in a case where the area fraction of these regions is more than 80%, (L49-56° + L64-72°)/(L57-63° + L4-12°) in the steel member may be less than 1.40. The area fraction of the regions is preferably 50% or less, more preferably 35% or less, and even more preferably 30% or less. The area fraction of the regions may be 1% or more or 10% or more. When the area fraction of the above regions is 80% or less, the microstructure of the other parts is not limited.

[0148] A method of measuring an area fraction of crystal grains having an average crystal misorientation of 0.4° to 3.0° (hereinafter, referred to as "area ratio of a specific structure") within the crystal grains surrounded by grain boundaries having a crystal misorientation of 5° or more will be described.

[0149] A sample is cut out from a position 50 mm or more away from an end portion of the steel sheet so that a cross section perpendicular to the surface (sheet thickness cross section) can be observed. The sample has a size that allows a cross section to be observed by about 10 mm in the sheet thickness direction, depending on a measurement device. In the cut sample, a measurement region of 100 μm $\times$ 100 μm with respect to the 1/4 position of the sheet thickness from the surface as a center is subjected to EBSD analysis at a measurement interval of 0.2 μm to obtain crystal orientation information. Here, the EBSD analysis is performed using 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) at an analysis speed of 200 to 300 points/second. A scanning electron microscope and an EBSD detector having performance equal to or higher than those described above may be used, but apparatuses manufactured by JEOL Ltd. and TSL are desirable.

[0150] From the obtained crystal orientation information, for example, the area fraction of the specific structure can be easily calculated by using, for example, the "Grain Average Misorientation" function provided in the software "OIM Analysis (registered trademark)" included in the EBSD analysis apparatus. With this function, for crystal grains having a

body-centered structure, it is possible to calculate a misorientation between adjacent measurement points and thereafter obtain an average value of all the measurement within the crystal grains. For the obtained crystal orientation information, a region having a misorientation of 5° or more is defined as a crystal grain, and the area fraction of the region having an average crystal misorientation within the crystal grains of 0.4° to 3.0° to an observation visual field is calculated using the "Grain Average Misorientation" function, thereby obtaining the area fraction of the specific structure. The measurement is performed in five visual fields, and an average value of the area fractions of the specific structures in the visual fields is taken as the area fraction of the specific structure in the present embodiment.

[0151] The area fraction of the microstructure of the steel sheet according to the present embodiment can be determined by the same method as that of the steel member described above.

(Preferably, Nb-Based Precipitates Are Present, and W Concentration of Nb-Based Precipitates Is 5.0 Times or More W Content of Steel Sheet)

[0152] Nb-based precipitates in which W is dissolved have an effect of dragging austenite (γ) grain boundaries during a heat treatment involving heating to a temperature of an Ac3 point or higher. When the Nb-based precipitates are partially dissolved in a state in which the γ grain boundaries are dragged by the Nb-based precipitates in which W is dissolved, the dissolved W segregates to the γ grain boundaries. The grain boundaries to which W segregates promote the generation of lath martensite having a specific crystal orientation during $\gamma \rightarrow \alpha$' (martensite) transformation. As the lath martensite having a specific crystal orientation grows, the laths collide and coalesce with each other, which contributes to the formation of the grain boundaries having the above-described specific rotation angle. The presence of the Nb-based precipitates in which W is concentrated can lead to an increase in the amount of W that segregates to the grain boundaries during the heat treatment.

[0153] In order to obtain the above effect, it is preferable that the Nb-based precipitates in which W is dissolved are present at the 1/4 depth position. However, even in a case where the Nb-based precipitates are present at the 1/4 depth position, the effect cannot be sufficiently obtained when the W concentration thereof is less than 5.0 times the W content of the steel sheet. Therefore, the W concentration of the Nb-based precipitates is preferably set to 5.0 times or more the W content of the steel sheet. The W concentration of the Nb-based precipitates is preferably, 8.0 times or more, and more preferably 10.0 times or more the W content of the steel sheet.

[0154] In addition, a size of the Nb-based precipitate is preferably 15 μm or less.

[0155] In the present embodiment, the Nb-based precipitates are precipitates containing 50 mass% or more of Nb, and are, for example, Nb carbides, Nb carbonitrides, Nb nitrides, NbTi carbides, and NbTi carbonitrides.

[0156] The presence or absence of the Nb-based precipitates and the W concentration of the Nb-based precipitates can be obtained by the same method as the method described for the steel member.

[0157] A shape of the steel sheet according to the present embodiment is not particularly limited. That is, the steel sheet may be a flat sheet, and may be a part of a base sheet of a tailored property material in which steel sheets having different strengths or sheet thicknesses are joined together.

[Sheet Thickness]

[0158] The sheet thickness of the steel sheet according to the present embodiment is not limited. In a case of a steel sheet for hot stamping for a vehicle component, the sheet thickness may be 0.6 mm or more or 0.8 mm or more based on a main sheet thickness range of the steel sheet. For the same reason, the sheet thickness may be set to 4.0 mm or less or 2.5 mm or less.

[Coating]

[0159] 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. It is not necessary to exclude coatings other than the Al-based coating and the Zn-based coating, and other coatings, such as a Sn-based coating, a resin coating other than a metal-based coating, or a plurality of coating layers thereof may be provided. 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. The total of the amounts of the impurities may be 1% or less.

[0160] A thickness of the coating is preferably 10 to 100 μm. The chemical composition and the thickness of the coating of the steel sheet can be obtained by the same method as the method of measuring the chemical composition and the

thickness of the coating of the steel member described above.

<Manufacturing Method of Steel Sheet>

[0161] A manufacturing method of the steel sheet according to the present embodiment suitable as the material of the steel member according to the present embodiment is not limited, and the steel sheet can be manufactured by using, for example, a manufacturing method including the following steps:

(i) a casting step of melting and casting a steel having the above chemical composition to manufacture a slab;
(ii) a hot rolling step of heating the obtained slab and then performing hot rolling on the slab to obtain a hot-rolled steel sheet;
(iii) a coiling step of coiling the hot-rolled steel sheet;
(iv) a hot-rolled sheet annealing step of annealing the hot-rolled steel sheet after the coiling step as necessary;
(v) a cold rolling step of descaling the hot-rolled steel sheet after the coiling step or after the hot-rolled sheet annealing step, and performing cold rolling on the hot-rolled steel sheet to obtain a cold-rolled steel sheet, as necessary;
(vi) an annealing step of annealing the hot-rolled steel sheet or the cold-rolled steel sheet to obtain an annealed steel sheet, as necessary; and
(vii) a coating step of coating the hot-rolled steel sheet, the cold-rolled steel sheet, or the annealed steel sheet to obtain a coated steel sheet, as necessary.

[0162] Hereinafter, preferable conditions for each step will be described. Well-known conditions can be applied to conditions that are not described.

<Casting Step>

[0163] In the casting step, a steel having the above-described chemical composition is melted and cast to manufacture a slab to be subjected to hot rolling. For example, a slab manufactured by melting molten steel having the above chemical composition using a converter or an electric furnace and performing a continuous casting method thereon can be used. Instead of the continuous casting method, an ingot-making method, a thin slab casting method, or the like may also be adopted.

[0164] During the casting, it is necessary for W to be uniformly (macroscopically uniformly) dissolved. However, W is a heavy element having a high melting point and is difficult to dissolve. Therefore, when a casting temperature is lower than a liquidus temperature + 10°C, W is not uniformly dissolved. Therefore, the casting temperature is set to the liquidus temperature + 10°C or higher. An upper limit of the casting temperature is not limited, but is preferably 1,650°C or lower.

[0165] The liquidus temperature is determined by the chemical composition of molten steel and can be obtained by a thermodynamic calculation. A method for the thermodynamic calculation is not particularly limited, but it is preferable to use integrated thermodynamic calculation software: Thermo-Calc.

[0166] In addition, in order to achieve uniform solidification, a casting rate (Vc) is reduced. Specifically, the casting rate is set to 0.9 m/min or slower. In general, a slower casting rate increases a likelihood of cracking during bending and straightening. However, the steel sheet according to the present embodiment contains W in a predetermined amount or more. Since W has an effect of suppressing the precipitation of intergranular ferrite, which causes cracking by segregating to the grain boundaries, there is no problem with cracking even when the casting rate is set. The casting rate is preferably set to 0.5 m/min or slower.

<Hot Rolling Step>

[0167] In the hot rolling step, the slab is heated, subjected to rough rolling, then subjected to descaling as necessary, and finally subjected to finish rolling.

[0168] In a case of obtaining the Nb-based precipitates in which W is concentrated (for example, the W concentration is 5.0 times or more the W content of the base steel sheet), it is preferable to perform hot rolling under the following conditions.

[0169] That is, in the heating performed before the hot rolling, a heating temperature is set to a dissolution temperature of the Nb-based precipitates + 5°C or higher.

[0170] The Nb-based precipitates precipitated in the casting step are coarse and do not contain concentrated W. In order to obtain the Nb-based precipitates in which W is concentrated, it is necessary to once dissolve the Nb-based precipitates and then precipitate the Nb-based precipitates again finely through hot rolling. When the heating temperature is lower than the dissolution temperature of the Nb-based precipitates + 5°C, the coarse Nb-based precipitates precipitated in the casting step cannot be dissolved.

[0171] In addition, in the hot rolling step, in a case of obtaining predetermined Nb-based precipitates, it is preferable that

the time from the end of the rough rolling to the start of the finish rolling is set to 10 seconds or shorter.

[0172] In the steel sheet according to the present embodiment, Nb-based precipitates are precipitated in fine ferrite after finish rolling. In a case of the Nb-based precipitates that are finely dispersed, W is dissolved and the concentration of W increases.

[0173] At the time of the end of the rough rolling, the temperature of the steel sheet is usually in a γ region, and when the time from the end of the rough rolling to the start of the finish rolling exceeds 10 seconds, Nb-based precipitates are precipitated in a γ state, and fine Nb-based precipitates in which W is concentrated cannot be obtained. It is more preferable that the time from the end of the rough rolling to the start of the finish rolling is set to 7 seconds or shorter.

<Coiling Step>

[0174] In the coiling step, for example, the hot-rolled steel sheet after the hot rolling step is coiled in a temperature range of 850°C or lower. When a coiling temperature is higher than 850°C, the hot-rolled steel sheet is coiled while transformation hardly progresses and the transformation progresses in the coil, so that there are cases where a coil shape is defective, which is not preferable. On the other hand, in order to reduce the area fraction of the specific structure in the steel sheet, it is preferable to perform coiling at 450°C or higher, and more preferable to perform coiling at 550°C or higher.

<Hot-Rolled Sheet Annealing Step>

[0175] In the annealing step of the hot-rolled steel sheet, for example, annealing may be performed at 450°C to 950°C for five hours or longer in an atmosphere containing 80 vol% or more of nitrogen or in the air atmosphere as necessary. Hot-rolled sheet annealing softens the hot-rolled steel sheet and makes it possible to reduce a load in the cold rolling step, which is the subsequent step, which is preferable.

<Cold Rolling Step>

[0176] In the cold rolling step, the hot-rolled steel sheet after the hot-rolled sheet annealing step (in a case where the hot-rolled sheet annealing step is not performed, the hot-rolled steel sheet after the coiling step) is subjected to descaling and is cold-rolled to obtain a cold-rolled steel sheet. Descaling and cold rolling do not necessarily have to be performed. However, in a case where cold rolling is performed, a cumulative rolling reduction in the cold rolling is preferably set to 30% or more from the viewpoint of securing good flatness.

[0177] On the other hand, in order to prevent a rolling force from becoming excessive, the cumulative rolling reduction in the cold rolling is preferably set to 80% or less.

[0178] A descaling method is not particularly limited, but pickling is preferable. Furthermore, in a case where pickling is performed, it is preferable to remove only iron scale by pickling with hydrochloric acid or sulfuric acid.

<Annealing Step>

[0179] In a case where annealing is performed before the coating step, the hot-rolled steel sheet or the cold-rolled steel sheet is annealed in a temperature range of 700°C to 950°C to obtain an annealed steel sheet. The annealing step softens the cold-rolled steel sheet and facilitates threading in a plating step, which is the subsequent step, which is preferable.

<Coating Step>

[0180] In a case of forming a coating on the surface, a 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 annealed steel sheet after the annealing step) to obtain a coated steel sheet (a plated steel sheet when the coating is a plating layer). 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.

[0181] Examples of the coating may include an Al-based coating containing Al and a Zn-based coating containing Zn.

[0182] 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.

[0183] In the case of performing hot-dip plating, plating may be performed on the annealed 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 650°C to 750°C, which is close to a plating bath temperature, after annealing without temporarily

performing cooling to room temperature.

[0184] 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>

[0185] A manufacturing method of the steel member according to the present embodiment is not limited, but the steel member according to the present embodiment can be manufactured by using, for example, a manufacturing method including the following steps for the steel sheet according to the present embodiment obtained by the above-described method.

<Heat Treatment Step>

[0186] In a heat treatment step, a heat treatment is performed on the steel sheet according to the present embodiment having the predetermined chemical composition to obtain the steel member. The heat treatment is performed, for example, under conditions in which the steel sheet obtained by a method described later is heated to an Ac3 point to (Ac3 point + 300)°C at an average temperature rising rate of 1.0 to 1,000 °C/s and is cooled to an Ms point or lower at an average cooling rate equal to or faster than an upper critical cooling rate.

[0187] 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.

[0188] Furthermore, when the heat treatment temperature is lower than the Ac3 point (°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 the Ac3 point + 300°C, coarse grains are formed in the structure, and the limit hydrogen amount decreases, which is not preferable.

[0189] The upper critical cooling rate is a minimum cooling rate at which austenite is supercooled to generate martensite without causing precipitation of ferrite and pearlite in the structure. When cooling is performed at a cooling rate slower than the upper critical cooling rate, ferrite and pearlite are generated, resulting in insufficient strength.

[0190] During heating, holding may be performed for 1 to 300 seconds within a range of the heating temperature $\pm$ 10°C.

[0191] In addition, after cooling to a temperature equal to or lower than the Ms point, a tempering treatment may be performed in a temperature range of about 100°C to 600°C in order to adjust the strength of the steel member.

[0192] The Ac3 point, the Ms point, and the upper critical cooling rate are measured by the following method.

[0193] Strip-shaped test pieces each having a width of 30 mm and a length of 200 mm are cut out from the steel sheet according to the present embodiment, and the test pieces are heated to 1,000°C at a temperature rising rate of 10 °C/s in a nitrogen atmosphere, held at the temperature for five minutes, and then cooled to room temperature at various cooling rates. The cooling rates are set at intervals of 10 °C/s (here, 1 °C/s is followed by 10 °C/s) from 1 °C/s to 100 °C/s. By measuring changes in thermal expansion of each of the test pieces during heating and cooling at that time, the Ac3 point and the Ms point are measured.

[0194] Furthermore, among the test pieces cooled at the above cooling rates, the minimum cooling rate at which precipitation of ferrite and pearlite do not occur is defined as the upper critical cooling rate. Furthermore, an Ms point obtained from changes in thermal expansion in the case of cooling the steel member at the upper critical cooling rate or faster is defined as the Ms point of the steel member.

[0195] Here, in the series of heat treatments, hot forming such as hot stamping may be performed simultaneously with a step of heating to a temperature range of the Ac3 point to (Ac3 point + 300)°C and then cooling to the Ms point, that is, cooling at the upper critical cooling rate or faster. As the hot forming, there are bending, drawing, stretching, hole widening, flange forming, and the like. Furthermore, a forming method other than press forming, for example, roll forming, may be applied as long as a cooler for cooling the steel sheet simultaneously with or immediately after forming is provided. In a case where the thermal history described above is followed, hot forming may be repeatedly performed. In addition, the series of heat treatments may be repeated a plurality of times.

[0196] In addition, as the heat treatment described above, hot forming or a heat treatment may be performed on a part of a steel sheet that serves as a material. In this case, a steel member having regions different in strength can be obtained.

[0197] The series of heat treatments can be performed by any method, and, for example, heating may be performed by induction heating, energization heating, infrared heating, or furnace heating. Furthermore, cooling may also be performed by water cooling, die cooling, or the like. As an atmosphere in a heating furnace, city gas or nitrogen gas may be used in addition to the air. In addition, in order to suppress the generation of hydrogen during the heat treatment, a dew point in the heating furnace may be controlled.

Examples

[0198] Hereinafter, the present invention will be described more specifically with reference to examples, but the present invention is not limited to the examples.

<Example 1>

[0199] Steels having the chemical compositions shown in Tables 1-1 and 1-2 (the remainder including Fe and impurities) were melted and continuously cast under the conditions shown in Table 2-1 to obtain slabs for hot rolling.

[0200] The obtained slabs were heated to 1,260°C, which is equal to or higher than the dissolution temperature of the Nb-based precipitates + 5°C, hot-rolled, and coiled at a temperature of 850°C or lower and 450°C or higher to obtain steel sheets (hot-rolled steel sheets) having a thickness of 2.7 mm.

[0201] The hot-rolled steel sheets were pickled and then cold-rolled to obtain steel sheets (cold-rolled steel sheets) having a thickness of 1.6 mm.

[0202] For some of the steel sheets, after the cold rolling, the steel sheets were heated to 760°C, held for 10 seconds to be annealed, and, furthermore, immersed in an A1 plating bath containing 10% of Si and 2% of Fe with a remainder of impurities at 680° to obtain Al-plated steel sheets (coating in Table 2-2: Al). In addition, some of the steel sheets were immersed in a molten zinc bath including Zn and impurities to obtain galvanized steel sheets (coating in Table 2-2: Zn).

[0203] Thicknesses of the coatings were all adjusted to 30 μm.

[Table 1-1]

Steel No.	Chemical composition (mass%)																		
	C	Si	Mn	P	S	N	O	W	Nb	Ti	Cu	Ni	Cr	B	Mo	v	Ca	Mg	Al
A1	0.27	1.25	2.08	0.017	0.0031	0.007	0.006	0.64											
A2	0.56	0.64	0.27	0.002	0.0002	0.002	0.002	0.55	0.02	0.035				0.0025		0.12			
A3	0.34	1.70	0.78	0.010	0.0013	0.003	0.005	0.29											
A4	0.28	0.29	2.50	0.004	0.0005	0.003	0.003	0.50		0.022				0.0018				0.008	
A5	0.28	0.30	0.33	0.051	0.0003	0.002	0.004	0.48	0.06								0.005		0.05
A6	0.29	0.27	0.50	0.005	0.0088	0.003	0.005	0.43			0.59		0.29	0.0030					
A7	0.31	0.45	0.72	0.007	0.0009	0.010	0.003	0.37	0.05										
A8	0.31	0.29	0.43	0.011	0.0011	0.003	0.009	0.40				0.42							
A9	0.35	0.41	0.80	0.009	0.0012	0.004	0.004	0.20		0.034					0.28				
A10	0.44	0.38	0.65	0.012	0.0010	0.004	0.005	1.50						0.0008					0.01
A11	0.50	0.39	0.25	0.007	0.0005	0.003	0.002	0.42	0.03	0.030	0.28	0.07	0.08	0.0025	0.13				0.04
a1	0.20	0.50	0.30	0.042	0.0055	0.006	0.008	0.70											
a2	0.45	0.65	3.28	0.016	0.0019	0.005	0.006	0.28						0.0020					0.44
a3	0.39	0.25	1.00	0.156	0.0014	0.003	0.004	0.44											
a4	0.38	0.72	1.12	0.017	0.0167	0.005	0.004	0.29	0.07									0.006	
a5	0.41	0.55	1.24	0.014	0.0018	0.027	0.004	0.33		0.080			0.44						
a6	0.45	0.57	1.08	0.015	0.0014	0.005	0.020	0.32			0.89			0.0075		0.18			
a7	0.29	0.66	1.88	0.020	0.0025	0.006	0.006	0.02				0.22							

[Table 1-2]

Steel No.	Chemical composition (mass%)													Transformation point (°C)		Upper critical cooling rate (°C/s)
	Sn	Sb	Zr	Se	Bi	As	Ta	Re	Os	Ir	Tc	Co	REM	Ac3	Ms	
A1														855	363	30
A2														829	318	10
A3	0.10		0.27											895	380	20
A4													0.19	777	350	10
A5							0.41							862	432	30
A6				0.34					0.20					800	404	30
A7		0.20			0.25									818	404	30
A8						0.37					0.14			768	408	30
A9										0.24				828	383	30
A10								0.33				0.08		813	354	20
A11	0.01													809	335	20
a1														883	464	40
a2														798	248	10
a3			0.33											890	362	30
a4		0.40												820	358	30
a5														827	334	30
a6									0.22				0.10	800	314	30
a7	0.44			0.25										808	362	20

[0204] In the obtained steel sheet, an area fraction of regions (that is, a specific structure) that were surrounded by boundaries having a crystal misorientation of 5° or more and that have an average crystal misorientation within the boundaries of 0.4° to 3.0° was evaluated by the above-described method. The evaluation results are shown in Table 2-2.

[0205] In addition, in a case where Nb-based precipitates were present in the obtained steel sheet, a ratio of a W concentration of the Nb-based precipitates to a W content of the steel sheet was measured. Results are shown in Table 2-2.

[Table 2-1]

	Symbol	Steel No.	Continuous casting		Hot rolling
			Casting temperature - liquidus temperature (°C)	Casting rate (m/min)	Time from completion of rough rolling to start of finish rolling (s)
Invention Example	B1	A1	28	0.8	9
	B2	A2	19	0.8	9
	B3	A3	23	0.8	9
	B4	A4	22	0.8	9
	B5	A5	30	0.8	9
	B6	A6	26	0.8	9
	B7	A7	27	0.8	9
	B8	A8	21	0.8	9
	B9	A9	28	0.8	9
	B10	A10	26	0.8	9
	B11	A11	25	0.8	9
	B12	A11	30	0.8	6
	B13	A11	21	0.5	9
	B14	A11	22	0.8	18
Comparative Example	b1	a1	28	0.8	9
	b2	a2	22	0.8	9
	b3	a3	27	0.8	9
	b4	a4	28	0.8	9
	b5	a5	23	0.8	9
	b6	a6	29	0.8	9
	b7	a7	21	0.8	9
	b8	A4	7	0.8	9
	b9	A6	28	2.1	9

[Table 2-2]

Symbol	Steel sheet		
	Regions that are surrounded by boundaries having a crystal misorientation of 5° or more and that have an internal crystal misorientation of 0.4° to 3.0° (area%)	W concentration of Nb-based precipitates/W content of steel sheet	Coating
B1	11	-	-
B2	48	11.5	-
B3	28	-	-
B4	46	-	Al

(continued)

Symbol	Steel sheet		
	Regions that are surrounded by boundaries having a crystal misorientation of 5° or more and that have an internal crystal misorientation of 0.4° to 3.0° (area%)	W concentration of Nb-based precipitates/W content of steel sheet	Coating
B5	17	11.7	Al
B6	16	-	Al
B7	18	10.0	Zn
B8	19	-	Zn
B9	25	-	Zn
B10	35	-	-
B11	21	12.3	Al
B12	24	15.0	Al
B13	21	12.3	Al
B14	20	4.0	Al
b1	2	-	-
b2	85	-	-
b3	17	-	Zn
b4	15	9.4	Zn
b5	16	-	Al
b6	17	-	Al
b7	22	-	Al
b8	48	-	Al
b9	19	-	Al

[0206] As shown in Tables 2-1 and 2-2, in Invention Examples B1 to B14 satisfying the ranges of the present invention, steel sheets having a predetermined chemical composition and microstructure were obtained. On the other hand, Comparative Examples b1 to b9 that did not satisfy the ranges of the present invention did not satisfy the chemical composition or the microstructure.

<Example 2>

[0207] The steel sheets (B1 to B14 and b1 to b9) manufactured in Example 1 were subjected to a heat treatment of heating to the heating temperature shown in Table 3-1 at the temperature rising rate shown in Table 3-1, holding in a range of the heating temperature ± 10°C for 90 seconds, and cooling to a temperature equal to or lower than an Ms point at the average cooling rate shown in Table 3-1 to obtain steel members C1 to C14 and c1 to c9.

[0208] For the obtained steel members, an area fraction of martensite and (L49-56° + L64-72°)/(L57-63° + L4-12°) were measured by the above-described methods, and the presence or absence of Nb-based inclusions was checked. In a case where the Nb-based precipitate was present, a ratio of a W concentration thereof to a W content in the chemical composition of the steel member (in a case of having a coating, the chemical composition of the base steel sheet) was measured by the above-described method. Results are shown in Table 3-2.

[0209] Although not shown in the table, the microstructure of the invention examples contained residual austenite and/or bainite in addition to martensite. In addition, the Nb-based precipitates that were present had a size of 0.5 to 15 μm.

[0210] In addition, a tensile strength and a limit hydrogen amount Hc, which is an index of hydrogen embrittlement resistance, were evaluated in the following manner. The evaluation results are shown in Table 3-2.

[0211] In addition, steel members obtained from steel sheets having an Al-based coating had an Fe-Al-based coating on the surface, and steel members obtained from steel sheets having a Zn-based coating had an Fe-Zn-based coating on the surface. The Fe-Al-based coating was a coating containing about 10 mass% of Si, and a remainder including Fe, Al, and 1% or less of impurities. The Fe-Zn-based coating was a coating containing an Fe-Zn alloy and 1% or less of impurities.

<Tensile Strength>

[0212] A tensile test was conducted in accordance with the regulations of ASTM Standard E8M-22. A portion of the steel member avoiding end portions was ground evenly on both sides to a thickness of 1.2 mm, and then a sub-size tensile test piece (gauge length: 25.0 ± 0.1 mm (parallel portion length: 32.0 mm), parallel portion width: 6.0 ± 0.1 mm) in Table 1 of ASTM standard E8M-22 were collected. Then, a strain gauge (gauge length: 5 mm) was attached to a center of a parallel portion of the test piece in width and length directions, a room temperature tensile test was conducted at a strain rate of 3 mm/min, and the tensile strength (TS) was measured. In this example, a case of having a tensile strength of more than 1,500 MPa was evaluated as having high strength.

<Limit Hydrogen Amount Hc>

[0213] The hydrogen embrittlement resistance was evaluated by a limit hydrogen amount Hc at which no cracking had occurred by performing four-point bending on a test piece that had stored hydrogen. Specifically, a strip-shaped test piece having a width of 8 mm and a length of 68 mm was cut out to avoid the end portions of the steel member. Then, a strain gauge (gauge length: 5 mm) similar to that used in the tensile test was attached to a center of a surface of the test piece in the width and length directions, and the test piece was bent with a four-point support jig so that a strain corresponding to a stress of 1/2 of the tensile strength obtained in the tensile test was generated on the surface of the test piece (a four-point bending test piece was used). The presence or absence of cracking was observed in the four-point bending test pieces in which various amounts of hydrogen were stored, and the limit hydrogen amount Hc at which no cracking had occurred was obtained. In a case of an Al-based coating, a hydrogen storage amount was changed by changing a dew point in a furnace during the heat treatment. In addition, in a case of no coating and a Zn-based coating, after four-point bending, the test pieces were immersed in various concentrations of ammonium thiocyanate solution for 72 hours to store hydrogen. A temperature of hydrogen stored in the steel member was raised at 100 °C/hr in thermal hydrogen analysis, and the amount of diffusible hydrogen released up to 250°C was defined as the amount of hydrogen contained in the steel member.

[0214] In this example, the hydrogen embrittlement resistance was evaluated as excellent in a case where Hc is 0.7 mass ppm or more when the tensile strength was 1,500 to less than 2,000 MPa, 0.5 mass ppm or more when the tensile strength was 2,000 to less than 2,500 MPa, and 0.3 mass ppm or more when the tensile strength was 2,500 MPa or more.

[Table 3-1]

	Symbol	Steel No.	Steel sheet No.	Heat treatment		
				Temperature rising rate (°C/s)	Heating temperature (°C)	Cooling rate (°C/s)
Invention Example	C1	A1	B1	3	920	50
	C2	A2	B2	3	920	50
	C3	A3	B3	3	920	50
	C4	A4	B4	3	920	50
	C5	A5	B5	3	920	50
	C6	A6	B6	3	920	50
	C7	A7	B7	3	920	50
	C8	A8	B8	3	920	50
	C9	A9	B9	3	920	50
	C10	A10	B10	3	920	50
	C11	A11	B11	3	920	50
	C12	A11	B12	3	920	50
	C13	A11	B13	3	920	50
	C14	A11	B14	3	920	50
	c1	a1	b1	3	920	50
	c2	a2	b2	3	920	50
	c3	a3	b3	3	920	50

(continued)

	Symbol	Steel No.	Steel sheet No.	Heat treatment		
				Temperature rising rate (°C/s)	Heating temperature (°C)	Cooling rate (°C/s)
Comparative Example	c4	a4	b4	3	920	50
	c5	a5	b5	3	920	50
	c6	a6	b6	3	920	50
	c7	a7	b7	3	920	50
	c8	A4	b8	3	920	50
	c9	A6	b9	3	920	50

[Table 3-2]

Steel Member											
Symbol	Martensite area fraction	Grain boundary length				(L49-56° + L64-72°) /(L57-63° + L4-12°)	W concentration of Nb-based precipitates/W content of steel member	Coating	TS	Hc
		L57-63°	L49-56°	L64-72°	L4-12°					
	%	(μm)	(μm)	(μm)	(μm)				(MPa)	(mass ppm)
C1	98	538	599	1077	597	1.48	-	-	1957	0.8
C2	97	825	1177	1682	535	2.10	11.5	-	2803	0.4
C3	98	590	856	1330	579	1.87	-	-	2137	0.7
C4	98	542	671	1121	593	1.58	-	Fe-Al	2014	0.6
C5	100	529	673	1122	591	1.60	11.7	Fe-Al	1799	1.0
C6	99	545	725	1153	591	1.65	-	Fe-Al	1861	0.9
C7	99	581	764	1236	589	1.71	10.0	Fe-Zn	1963	0.9
C8	99	591	762	1234	587	1.69	-	Fe-Zn	1934	0.9
C9	98	641	842	1311	580	1.76	-	Fe-Zn	2145	0.6
C10	99	692	1067	1619	559	2.15	-	-	2494	0.9
C11	98	812	1143	1643	554	2.04	12.3	Fe-Al	2679	0.7
C12	98	787	1148	1648	537	2.11	15.0	Fe-Al	2679	0.8
C13	98	800	1145	1643	549	2.07	12.3	Fe-Al	2679	0.8
C14	98	829	1122	1633	564	1.98	4.0	Fe-Al	2679	0.6
c1	100	402	458	958	597	1.42	-	-	1421	1.2
c2	96	663	1067	1543	567	2.12	-	-	2849	0.1
c3	99	580	911	1409	578	2.00	-	Fe-Zn	2324	0.1
c4	98	582	911	1410	576	2.00	9.4	Fe-Zn	2321	0.3
c5	98	614	973	1469	568	2.07	-	Fe-Al	2452	0.2
c6	98	660	1068	1545	567	2.13	-	Fe-Al	2587	0.2
c7	99	696	687	1123	693	1.30	-	Fe-Al	2017	0.4
c8	98	689	643	1089	603	1.34	-	Fe-Al	2012	0.4
c9	99	693	652	1105	598	1.36	-	Fe-Al	1861	0.6

[0215] As shown in Tables 3-1 and 3-2, in Invention Examples C1 to C14, the chemical composition and the microstructure satisfied the ranges of the present invention, and good results were shown in both the tensile strength and hydrogen embrittlement resistance. On the other hand, in Comparative Examples c1 to c9, the chemical composition and the microstructure did not satisfy the ranges of the present invention, and at least one of the strength and the hydrogen embrittlement resistance was inferior.

INDUSTRIAL APPLICABILITY

[0216] According to the present invention, it is possible to obtain a steel member and a steel sheet having excellent hydrogen embrittlement resistance and high strength. The steel member according to the present invention is particularly suitable for use as a frame component of a vehicle. Since the steel member of the present invention has high strength and excellent hydrogen embrittlement resistance, the steel member contributes to an improvement in fuel efficiency and collision safety when being applied to a vehicle component.

Claims

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

C: 0.26% to 0.65%;
Si: 0% to 2.00%;
Mn: 0% to 3.00%;
P: 0.100% or less;
S: 0.0100% or less;
N: 0.020% or less;
O: 0.010% or less;
W: 0.10% to 2.00%;
Nb: 0% to 0.10%;
Ti: 0% to 0.200%;
Cu: 0% to 2.00%;
Ni: 0% to 2.00%;
Cr: 0% to 1.00%;
B: 0% to 0.0200%;
Mo: 0% to 1.00%;
V: 0% to 1.00%;
Ca: 0% to 0.020%;
Mg: 0% to 0.010%;
Al: 0% to 1.00%;
Sn: 0% to 1.00%;
Sb: 0% to 1.00%;
Zr: 0% to 1.00%;
Se: 0% to 1.00%;
Bi: 0% to 1.00%;
As: 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%;
Co: 0% to 1.00%;
REM: 0% to 0.30%; and
a remainder: Fe and impurities,
wherein, when a range of a 1/8 position to a 3/8 position of a thickness in a thickness direction from a surface of the steel member, with respect to a 1/4 position of the thickness in the thickness direction from the surface as a center, is defined as a 1/4 depth position,
in a case where, at the 1/4 depth position, with a <011> direction as a rotation axis, among grain boundaries of crystal grains having a body-centered structure, a length of a grain boundary having a rotation angle of 49° to 56° is denoted by L49-56°, a length of a grain boundary having a rotation angle of 64° to 72° is denoted by L64-72°, a

length of a grain boundary having a rotation angle of 57° to 63° is denoted by L57-63°, and a length of a grain boundary having a rotation angle of 4° to 12° is denoted by L4-12°, (L49-56° + L64-72°)/(L57-63° + L4-12°) that is a ratio of a sum of the L49-56° and the L64-72° to a sum of the L57-63° and the L4-12° is 1.40 or more, and a tensile strength of the steel member is more than 1,500 MPa.

2. The steel member according to Claim 1,

wherein the chemical composition contains, by mass%, Nb: 0.01% to 0.10%,
a Nb-based precipitate is present at the 1/4 depth position, and
a W concentration of the Nb-based precipitate is 5.0 times or more a W content of the steel member.

3. The steel member according to Claim 1 or 2,
wherein the surface has a coating.

4. The steel member according to Claim 3,
wherein the coating primarily contains an Fe-Al-based alloy or an Fe-Zn-based alloy.

5. A steel sheet comprising, as a chemical composition, by mass%:

C: 0.26% to 0.65%;
Si: 0% to 2.00%;
Mn: 0% to 3.00%;
P: 0.100% or less;
S: 0.0100% or less;
N: 0.020% or less;
O: 0.010% or less;
W: 0.10% to 2.00%;
Nb: 0% to 0.10%;
Ti: 0% to 0.200%;
Cu: 0% to 2.00%;
Ni: 0% to 2.00%;
Cr: 0% to 1.00%;
B: 0% to 0.0200%;
Mo: 0% to 1.00%;
V: 0% to 1.00%;
Ca: 0% to 0.020%;
Mg: 0% to 0.010%;
Al: 0% to 1.00%;
Sn: 0% to 1.00%;
Sb: 0% to 1.00%;
Zr: 0% to 1.00%;
Se: 0% to 1.00%;
Bi: 0% to 1.00%;
As: 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%;
Co: 0% to 1.00%;
REM: 0% to 0.30%; and
a remainder: Fe and impurities,
wherein, when a range of a 1/8 position to a 3/8 position of a thickness in a thickness direction from a surface of the steel sheet, with respect to a 1/4 position of the thickness in the thickness direction from the surface as a center, is defined as a 1/4 depth position,
at the 1/4 depth position, an area fraction of regions that are surrounded by boundaries having a crystal misorientation of 5° or more and that have an average crystal misorientation within the boundaries of 0.4° to 3.0° is 80% or less.

6. The steel sheet according to Claim 5,

wherein the chemical composition contains, by mass%, Nb: 0.01% to 0.10%,
a Nb-based precipitate is present at the 1/4 depth position, and
a W concentration of the Nb-based precipitate is 5.0 times or more a W content of the steel sheet.

7. The steel sheet according to Claim 5 or 6,
wherein the surface has a coating.

8. The steel sheet according to Claim 7,
wherein the coating is an Al-based coating or a Zn-based coating.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2024/009506

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***B22D 11/00***(2006.01)i; ***C21D 1/18***(2006.01)i; ***C21D 9/00***(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 18/00***(2006.01)i; ***C22C 21/00***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301Z; C22C38/00 301S; C22C38/00 301T; C22C38/60; C21D1/18 C; C21D9/00 A; C21D9/46 G; C21D9/46 J; C22C18/00; C22C21/00 M; B22D11/00 A

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60; C21D1/18; C21D9/00; C21D8/02; C21D9/46; C22C18/00-18/04; C22C21/00-21/14; B22D11/00

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 2019/003541 A1 (JFE STEEL CORP.) 03 January 2019 (2019-01-03) claims	1-8
A	JP 2021-155794 A (NIPPON STEEL CORPORATION) 07 October 2021 (2021-10-07) claims	1-8
A	WO 2021/141103 A1 (NIPPON STEEL CORPORATION) 15 July 2021 (2021-07-15) claims	1-8
A	WO 2020/195009 A1 (NIPPON STEEL CORPORATION) 01 October 2020 (2020-10-01) claims, paragraphs [0043]-[0044]	1-8
A	WO 2020/195012 A1 (NIPPON STEEL CORPORATION) 01 October 2020 (2020-10-01) claims, paragraphs [0053]-[0056]	1-8

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 May 2024	**04 June 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.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2024/009506

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2020/241257 A1 (NIPPON STEEL CORPORATION) 03 December 2020 (2020-12-03) claims	1-8
A	WO 2020/241258 A1 (NIPPON STEEL CORPORATION) 03 December 2020 (2020-12-03) claims	1-8
P, X	WO 2023/095920 A1 (NIPPON STEEL CORPORATION) 01 June 2023 (2023-06-01) claims, paragraphs [0077]-[0078], [0085], tables 1-1 to 3-2	5, 7-8
P, A		1-4, 6

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2024/009506

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2019/003541 A1	03 January 2019	EP 3647447 A1 claims US 2020/0131597 A1 CN 110799662 A	
JP 2021-155794 A	07 October 2021	(Family: none)	
WO 2021/141103 A1	15 July 2021	EP 4089191 A1 claims US 2023/0002874 A1 CN 114829652 A	
WO 2020/195009 A1	01 October 2020	(Family: none)	
WO 2020/195012 A1	01 October 2020	(Family: none)	
WO 2020/241257 A1	03 December 2020	US 2022/0170128 A1 claims CN 113677819 A	
WO 2020/241258 A1	03 December 2020	US 2022/0195567 A1 claims CN 113840936 A	
WO 2023/095920 A1	01 June 2023	(Family: none)	

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2012180594 A **[0010]**
- JP 2012001802 A **[0010]**
- WO 2015182596 A **[0010]**
- WO 2015182591 A **[0010]**