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

(57) A steel member has a predetermined chemical composition. In a case where a position corresponding to a depth of 114 of a thickness from a surface in a thickness direction is defined as a 1/4-depth position, a maximum B content in a range to a depth of 10 μm from the surface in the thickness direction is 5 times or more a B content at the 1/4-depth position. In a case where a C content is measured from the surface in the thickness direction using GDS and the distance from the surface to a position where the C content is equal to a C content at the 1/4-depth position for the first time is defined as a decarburization depth, the decarburization depth is 20 μm or more. The Vickers hardness at the 1/4-depth position is in a range of 310 to 890.

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Description

Technical Field of the Invention

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

[0002] Priority is claimed on Japanese Patent Application No. 2022-055819, filed March 30, 2022, the content of which is incorporated herein by reference.

Related 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, since the press formability of a steel sheet deteriorates with high-strengthening, it is difficult to manufacture a product having a complex shape.

[0004] Specifically, since the ductility of the steel sheet deteriorates with high strengthening, there is a problem in that the steel sheet is fractured at a highly worked portion in the case of being worked into a complex shape. Further, since springback and wall warpage occur due to residual stress after working as the steel sheet is highly strengthened, there is also a problem in that dimensional accuracy deteriorates. Accordingly, 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 work a high strength steel sheet, but the application thereof is limited to components having a uniform cross section in a longitudinal direction thereof.

[0005] Accordingly, in recent years, a hot stamping technique has been employed as a technique for press-forming a material that is difficult to form, such as a high strength steel sheet. The hot stamping technique is a hot forming technique of heating a material to be subjected to forming and then forming the material.

[0006] In this technique, the material is formed after being heated. For this reason, 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, since quenching is performed simultaneously with forming by a press die in the hot stamping technique, a steel member subjected to the forming has sufficient strength.

[0007] For example, Patent Document 1 discloses that the hot stamping technique makes it possible to impart a tensile strength of 1,400 MPa or more to a steel member subjected to forming.

[0008] On the other hand, a vehicle is also required to have collision safety. The collision safety of a vehicle is evaluated on the basis of crushing strength and absorbed energy in a collision test for the entire vehicle body or some members. In particular, since crushing strength largely depends on material strength, the demand for an ultrahigh strength steel member as a vehicle member dramatically increases.

[0009] However, as a steel member is highly strengthened, the fracture toughness and deformability of the steel member generally deteriorate. For this reason, a steel member is fractured early during a crush caused by a collision or is fractured at a portion on which deformation is to be concentrated, so that there are cases where crushing strength corresponding to material strength is not exhibited and sufficient absorbed energy cannot be obtained. Accordingly, in order to improve the collision safety of a vehicle, it is required to improve not only the material strength but also the fracture toughness and deformability, that is, the toughness and bendability of a steel member to be used. Therefore, in order to apply a high strength steel member having a tensile strength of more than 1.0 GPa to a vehicle body, there is a need for a technique for providing a steel member that has toughness and bendability higher than that in the related art and ensures sufficient absorbed energy even in a case where a collision accident occurs.

[0010] Patent Document 2 discloses a press-formed article that is excellent in toughness, has a tensile strength of 1.8 GPa or more, and is hot press-formed. Patent Document 3 discloses steel that has an extremely high tensile strength of 2.0 GPa or more and further has good toughness and good ductility. Patent Document 4 discloses steel that has an extremely high tensile strength of 1.8 GPa or more and further has good toughness. Patent Document 5 discloses steel that has an extremely high tensile strength of 2.0 GPa or more and further has good toughness.

[0011] However, Patent Documents 1 to 5 do not contain any description regarding bendability, and higher demands may not be sufficiently met in a case where high strength steel having a tensile strength of more than 1.0 GPa is used for vehicle members.

[0012] Further, 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 increases in susceptibility to hydrogen embrittlement in a case where the tensile strength of the steel member increases, and there is a case in which hydrogen embrittlement cracking has occurred in bolt steel for which high-strengthening has been progressed ahead of the vehicle field.

[0013] However, there is room for further improvement in the techniques disclosed in Patent Documents 1 to 5 from the viewpoint of hydrogen embrittlement resistance.

Prior Art Document

Patent Document

[0014]

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

Disclosure of the Invention

Problems to be Solved by the Invention

[0015] The present invention has been made in consideration of the above-described problems. An object of the present invention is to provide a steel member that has high strength, excellent bendability, and excellent hydrogen embrittlement resistance (excellent hydrogen embrittlement resistance properties), and a steel sheet that is suitable as a material of the steel member.

Means for Solving the Problem

[0016] The present inventors have conducted studies to obtain excellent bendability and excellent hydrogen embrittlement resistance in a high strength steel member obtained from the hot-stamping of a steel sheet.

[0017] As a result, it was found that excellent bendability and excellent hydrogen embrittlement resistance are obtained in a case where B is concentrated while a decarburized layer is formed in a surface layer of the steel member. Further, it was found that a steel member can be stably obtained in a case where cracks are introduced into scales formed on the surface of a steel sheet (base steel sheet) to be subjected to hot stamping.

[0018] The present invention has been made in consideration of the above-described problems. 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: 0.10% to 0.70%; Si: 3.00% or less; Mn: 0.01% to 3.00%; P: 0.100% or less; S: 0.0100% or less; N: 0.020% or less; O: 0.010% or less; B: 0.0002% to 0.0200%; Ti: 0% to 0.200%; Cr: 0% to 1.00%; Mo: 0% to 1.00%; Ni: 0% to 2.00%; Nb: 0% to 0.10%; Cu: 0% to 2.00%; V: 0% to 1.00%; Ca: 0% to 0.020%; Mg: 0% to 0.020%; Al: 0% to 1.00%; Sn: 0% to 1.00%; W: 0% to 2.00%; 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 a case where a position corresponding to a depth of 1/4 of a thickness from a surface in a thickness direction is defined as a 1/4-depth position, a maximum B content in a range to a depth of 10 μm from the surface in the thickness direction is 5 times or more a B content at the 1/4-depth position. In a case where a C content is measured from the surface in the thickness direction using GDS and the distance from the surface to a position where the C content is equal to a C content at the 1/4-depth position for the first time is defined as a decarburization depth, the decarburization depth is 20 μm or more. The Vickers hardness at the 1/4-depth position is in a range of 310 to 890.

[2] In the steel member according to [1], in a case where a position corresponding to a depth of 0.1 mm from the surface in the thickness direction is defined as a 0.1 mm-depth position, the Vickers hardness at the 0.1 mm-depth position may be 0.95 times or less the Vickers hardness at the 1/4-depth position.

[3] In the steel member according to [2], the Vickers hardness at the 1/4-depth position may be in a range of 310 to 450, and, in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, the maximum principal plastic strain at a center of an outside bend surface layer may be 0.340 or less.

[4] In the steel member according to [2], the Vickers hardness at the 1/4-depth position may be more than 450 and 530 or less, and the Vickers hardness at the 0.1 mm-depth position may be 0.90 times or less the Vickers hardness at the 1/4-depth position. In a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending

angle of 50 degrees, the maximum principal plastic strain at a center of an outside bend surface layer may be 0.310 or less.

[5] In the steel member according to [2], the Vickers hardness at the 1/4-depth position may be more than 530 and 700 or less, and the Vickers hardness at the 0.1 mm-depth position may be 0.88 times or less the Vickers hardness at the 1/4-depth position. In a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, the maximum principal plastic strain at a center of an outside bend surface layer may be 0.280 or less.

[6] In the steel member according to [2], the Vickers hardness at the 1/4-depth position may be more than 700 and 890 or less, and the Vickers hardness at the 0.1 mm-depth position may be 0.86 times or less the Vickers hardness at the 1/4-depth position. In a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, the maximum principal plastic strain at a center of an outside bend surface layer may be 0.260 or less.

[7] In the steel member according to any one of [1] to [6], an alloy layer may be further provided on the surface.

[8] In the steel member according to [7], the alloy layer may be an Fe-Al-based alloy layer.

[9] In the steel member according to [7], the alloy layer may be an Fe-Zn-based alloy layer.

[10] A steel sheet according to another aspect of the present invention includes a base steel sheet and an iron scale that is formed on a surface of the base steel sheet. The base steel sheet contains, as a chemical composition, by mass%, C: 0.10% to 0.70%, Si: 3.00% or less, Mn: 0.01% to 3.00%, P: 0.100% or less, S: 0.0100% or less, N: 0.020% or less, O: 0.010% or less, B: 0.0002% to 0.0200%, Ti: 0% to 0.200%, Cr: 0% to 1.00%, Mo: 0% to 1.00%, Ni: 0% to 2.00%, Nb: 0% to 0.10%, Cu: 0% to 2.00%, V: 0% to 1.00%, Ca: 0% to 0.020%, Mg: 0% to 0.020%, Al: 0% to 1.00%, Sn: 0% to 1.00%, W: 0% to 2.00%, 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. The iron scale includes cracks at a density of 90 pieces/mm^2 or more.

Effects of the Invention

[0019] According to the above-described aspect of the present invention, it is possible to provide a steel member that has high strength, excellent bendability, and excellent hydrogen embrittlement resistance, and a steel sheet that is suitable as a material of the steel member.

Embodiments of the Invention

[0020] A steel member (a steel member according to the present embodiment) and a steel sheet (a steel sheet according to the present embodiment) according to an embodiment of the present invention, and preferred manufacturing methods therefor will be described below.

[0021] In the present embodiment, the steel member also includes a case where a steel member includes an alloy layer on a surface thereof and the steel sheet also includes a case where a steel sheet includes a plating layer (a case where the steel sheet is a plated steel sheet).

(A) Steel member

[0022] In a case where a position corresponding to a depth of 1/4 of a thickness from a surface in a thickness direction is defined as a 1/4-depth position, the maximum B content in a range to a depth of 10 μm from the surface in the thickness direction is 5 times or more the B content at the 1/4-depth position. In a case where the C content is measured from the surface in the thickness direction using GDS and the distance from the surface to a position where the C content is equal to the C content at the 1/4-depth position for the first time is defined as a decarburization depth, the decarburization depth is 20 μm or more, and the Vickers hardness at the 1/4-depth position is in a range of 310 to 890.

[0023] The steel member may have a strength gradient.

[0024] The steel member may include an alloy layer (coating) on the surface thereof. In a case where the steel member includes the alloy layer, the surface of the steel member serving as a reference, such as "a depth of 1/4 of a thickness from a surface in a thickness direction" or "a depth of 10 μm from the surface in the thickness direction", means a surface of a portion excluding the alloy layer (so-called base steel).

[0025] Each requirement will be described in detail below.

(A1) Chemical composition

[0026] The steel member according to the present invention has a chemical composition including, by mass%, C: 0.10% to 0.70%, Si: 3.00% or less, Mn: 0.01% to 3.00%, P: 0.100% or less, S: 0.0100% or less, N: 0.020% or less, O: 0.010% or less, B: 0.0002% to 0.0200%, Ti: 0% to 0.200%; Cr: 0% to 1.00%; Mo: 0% to 1.00%, Ni: 0% to 2.00%, Nb: 0% to 0.10%, Cu: 0% to 2.00%, V: 0% to 1.00%, Ca: 0% to 0.020%, Mg: 0% to 0.020%, Al: 0% to 1.00%, Sn: 0% to 1.00%, W: 0% to 2.00%, 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.

[0027] Here, the chemical composition of the steel member refers to a chemical composition of a portion excluding the vicinity of the surface (for example, a 1/4 position of the thickness from the surface of the steel member in the thickness direction: the 1/4-depth position). Hereinafter, % regarding the content is mass% unless otherwise specified.

[0028] Reasons for limiting the amount of each element are as follows.

C: 0.10% to 0.70%

[0029] C is an element that increases the hardenability of steel and improves the strength of a steel member obtained from the hot stamping of the steel sheet. However, in a case where the C content is less than 0.10%, it is difficult to ensure the sufficient strength (1.0 GPa or more) of the steel member. Accordingly, the C content is set to 0.10% or more. It is preferable that the C content is 0.15% or more.

[0030] On the other hand, in a case where the C content is more than 0.70%, the strength of the steel member is too high. As a result, bendability and hydrogen embrittlement resistance deteriorate significantly. In addition, weldability also deteriorates. Accordingly, the C content is set to 0.70% or less. It is preferable that the C content is 0.60% or less.

Si: 3.00% or less

[0031] Si is an effective element for increasing the hardenability of steel and stably ensuring the strength of the steel member. For this reason, Si may be contained. In a case where the above-described effects are to be obtained, the Si content is preferably set to 0.05% or more and more preferably set to 0.10% or more.

[0032] On the other hand, in a case where the Si content in the steel sheet is more than 3.00%, a heating temperature required for austenite transformation is significantly high in heat treatment. Accordingly, cost required for the heat treatment may be increased. In addition, in a case where the Si content is more than 3.00%, the toughness of a hardened portion deteriorates. Therefore, the Si content is set to 3.00% or less. The Si content is preferably 2.00% or less and more preferably 1.80% or less.

Mn: 0.01% to 3.00%

[0033] Mn is a very effective element for increasing the hardenability of steel and stably ensuring the strength of the steel member. In addition, Mn is an element that lowers Ac3 point and promotes the lowering of a quenching temperature. Since these effects are not sufficient in a case where the Mn content is less than 0.01%, the Mn content is set to 0.01% or more. It is preferable that the Mn content is 0.05% or more.

[0034] On the other hand, in a case where the Mn content is more than 3.00%, the above-described effects are saturated and the toughness, bendability, and hydrogen embrittlement resistance of the hardened portion deteriorate. For this reason, the Mn content is set to 3.00% or less. The Mn content is preferably 2.80% or less and more preferably 2.50% or less.

P: 0.100% or less

[0035] P is an element that causes the toughness and hydrogen embrittlement resistance of the steel member to deteriorate. In particular, in a case where the P content is more than 0.100%, the toughness and the hydrogen embrittlement resistance deteriorate significantly. Accordingly, the P content is limited to 0.100% or less. It is preferable that the P content is limited to 0.050% or less. Since it is preferable that the P content is small, 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

[0036] S is an element that causes the toughness, bendability, and hydrogen embrittlement resistance of the steel member to deteriorate. In particular, in a case where the S content is more than 0.0100%, the toughness, the bendability, and the hydrogen embrittlement resistance deteriorate significantly. Accordingly, the S content is limited to 0.0100% or less. It is preferable that the S content is limited to 0.0050% or less. Since it is preferable that the S content is small, 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

[0037] N is an element that causes the toughness and hydrogen embrittlement resistance of the steel member to deteriorate. In particular, in a case where the N content is more than 0.020%, coarse nitride is formed in steel and the toughness and the hydrogen embrittlement resistance deteriorate significantly. Accordingly, the N content is set to 0.020% or less. A lower limit of the N content does not need to be particularly limited and may be 0%. However, since causing an increase in steelmaking cost, setting the N content to less than 0.0002% is economically undesirable. For this reason, the N content may be set to 0.0002% or more or 0.0008% or more.

O: 0.010% or less

[0038] O is an element that causes the toughness and hydrogen embrittlement resistance of the steel member to deteriorate. In particular, in a case where the O content is more than 0.010%, coarse nitride is formed in steel and the toughness and the hydrogen embrittlement resistance deteriorate significantly. Accordingly, the O content is set to 0.010% or less. The lower limit of the O content does not need to be particularly limited and may be 0%. However, since causing an increase in steelmaking cost, setting the O content to less than 0.0002% is economically undesirable. For this reason, the O content may be set to 0.0002% or more, 0.0008% or more, or 0.001% or more.

B: 0.0002% to 0.0200%

[0039] B is an element that has an action of dramatically increasing the hardenability of steel even with a very small amount. Further, B is an element that strengthens grain boundaries and increases toughness and hydrogen embrittlement resistance by being segregated at the grain boundaries, and is an element that suppresses the growth of austenite grains during the heating of the steel sheet. In addition, B is an effective element for obtaining a surface layer structure that includes tough grain boundaries and includes fine martensite as a main structure by being concentrated in the surface layer as described later. In a case where the B content is less than 0.0002%, these effects are not sufficient. For this reason, the B content is set to 0.0002% or more. The B content is preferably 0.0005% or more and more preferably 0.0010% or more.

[0040] On the other hand, in a case where the B content is more than 0.0200%, a large amount of coarse compounds are precipitated and the toughness and hydrogen embrittlement resistance of the steel member deteriorate. Accordingly, in a case where B is to be contained, the B content is set to 0.0200% or less. The B content is preferably 0.0100% or less.

[0041] The steel member according to the present embodiment may further contain one or more elements selected from Ti, Cr, Mo, Ni, Nb, Cu, V, Ca, Mg, Al, Sn, W, Sb, Zr, Se, Bi, As, Ta, Re, Os, Ir, Tc, Co, and REM in addition to the elements described above, in order to increase the strength, toughness, bendability, corrosion resistance, a deoxidation property, and hydrogen embrittlement resistance. Since these elements are optional elements and do not necessarily need to be contained, lower limits thereof are 0%. These elements may be contained as impurities as long as the amounts of the elements are equal to or less than upper limits to be described later.

Ti: 0% to 0.200%

[0042] Ti is an element having an action of refining austenite grains by suppressing recrystallization and by forming fine carbide to suppress grain growth in a case where the steel sheet is to be heated to a temperature equal to or higher than Ac3 point and subjected to heat treatment. For this reason, an effect of significantly improving the toughness of the steel member is obtained in a case where Ti is contained. In addition, Ti is an element that is preferentially bonded to N contained in steel, suppresses the consumption of B caused by the precipitation of BN and promotes an effect of improving the hardenability caused by B to be described later. For this reason, Ti may be contained. In a case where the above-described effects are to be sufficiently obtained, it is preferable that the Ti content is set to 0.010% or more. The Ti content is more preferably 0.020% or more.

[0043] On the other hand, in a case where the Ti content is more than 0.200%, the amount of TiC to be precipitated is increased and C is consumed. For this reason, the strength of the steel member is reduced. Accordingly, the Ti content is set to 0.200% or less. The Ti content is preferably 0.100% or less.

Cr: 0% to 1.00%

[0044] Cr is an effective element for increasing the hardenability of steel and stably ensuring the strength of the steel member. For this reason, Cr may be contained. In a case where the above-described effects are to be obtained, it is preferable that the Cr content is set to 0.01% or more. The Cr content is more preferably 0.05% or more and still more preferably 0.08% or more.

[0045] On the other hand, in a case where the Cr content is more than 1.00%, the above-described effects are saturated and cost is increased. Further, Cr has an action of stabilizing iron carbide. Accordingly, in a case where the Cr content is more than 1.00%, coarse iron carbide is remains without melting during the heating of the steel sheet, so that the toughness of the steel member may deteriorate. Therefore, in a case where Cr is to be contained, the Cr content is set to 1.00% or less. The Cr content is preferably 0.80% or less.

Mo: 0% to 1.00%

[0046] Mo is an effective element for increasing the hardenability of steel and stably ensuring the strength of the steel member. For this reason, Mo may be contained. In a case where the above-described effects are to be obtained, it is preferable that the Mo content is set to 0.01% or more. The Mo content is more preferably 0.05% or more.

[0047] On the other hand, in a case where the Mo content is more than 1.00%, the above-described effects are saturated and cost is increased. Further, Mo has an action of stabilizing iron carbide. Accordingly, in a case where the Mo content is more than 1.00%, coarse iron carbide is remains without melting during the heating of the steel sheet, so that the toughness of the steel member may deteriorate. Therefore, in a case where Mo is to be contained, the Mo content is set to 1.00% or less. The Mo content is preferably 0.80% or less.

Ni: 0% to 2.00%

[0048] Ni is an effective element for increasing the hardenability of steel and stably ensuring the strength of the steel member. For this reason, Ni may be contained. In a case where the above-described effects are to be obtained, it is preferable that the Ni content is set to 0.01% or more. The Ni content is more preferably 0.10% or more.

[0049] On the other hand, in a case where the Ni content is more than 2.00%, the above-described effects are saturated and economic efficiency is lowered. Accordingly, in a case where Ni is to be contained, the Ni content is set to 2.00% or less. The Ni content is preferably 1.00% or less.

Nb: 0% to 0.10%

[0050] Nb is an element that has actions of forming fine carbide and increasing the toughness of steel with a grain refinement effect thereof. For this reason, Nb may be contained. In a case where the above-described effects are to be sufficiently obtained, it is preferable that the Nb content is set to 0.02% or more. The Nb content is more preferably 0.03% or more.

[0051] On the other hand, in a case where the Nb content is more than 0.10%, carbide coarsens and the toughness of the steel member deteriorates. Accordingly, in a case where Nb is to be contained, the Nb content is set to 0.10% or less. It is preferable that the Nb content is 0.08% or less.

Cu: 0% to 2.00%

[0052] Cu is an effective element for increasing the hardenability of steel and stably ensuring the strength of the steel member. For this reason, Cu may be contained. Further, Cu is an element that has an effect of improving the corrosion resistance of the steel member. In a case where the above-described effects are to be obtained, it is preferable that the Cu content is set to 0.01% or more. The Cu content is more preferably 0.05% or more.

[0053] On the other hand, in a case where the Cu content is more than 2.00%, the above-described effects are saturated and cost is increased. Accordingly, in a case where Cu is to be contained, the Cu content is set to 2.00% or less. The Cu content is preferably 1.00% or less.

V: 0% to 1.00%

[0054] V is an element that forms fine carbide and increases the toughness of steel with a grain refinement effect thereof. For this reason, V may be contained. In a case where the above-described effects are to be obtained, it is preferable that the V content is set to 0.01% or more. The V content is more preferably 0.10% or more.

[0055] On the other hand, in a case where the V content is more than 1.00%, the above-described effects are saturated and economic efficiency is lowered. Accordingly, in a case where V is to be contained, the V content is set to 1.00% or less.

Ca: 0% to 0.020%

[0056] Ca is an element that has effects of refining inclusions contained in steel and improving the toughness of the steel member. For this reason, Ca may be contained. In a case where the above-described effects are to be obtained, it is preferable that the Ca content is set to 0.001% or more. The Ca content is more preferably 0.002% or more.

[0057] On the other hand, in a case where the Ca content is more than 0.020%, the effects are saturated and cost is increased. Accordingly, in a case where Ca is to be contained, the Ca content is set to 0.020% or less. The Ca content is preferably 0.010% or less and more preferably 0.005% or less.

Mg: 0% to 0.020%

[0058] Mg is an element that has effects of refining inclusions contained in steel and improving the toughness of the steel member. For this reason, Mg may be contained. In a case where the above-described effects are to be obtained, it is preferable that the Mg content is set to 0.001% or more. The Mg content is more preferably 0.002% or more.

[0059] On the other hand, in a case where the Mg content is more than 0.020%, the effects are saturated and cost is increased. Accordingly, in a case where Mg is to be contained, the Mg content is set to 0.020% or less. The Mg content is preferably 0.010% or less and more preferably 0.005% or less.

Al: 0% to 1.00%

[0060] Al is an element that is generally used as a deoxidizing agent for steel. For this reason, Al may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Al content is set to 0.01% or more.

[0061] On the other hand, in a case where the Al content is more than 1.00%, the above-described effect is saturated and economic efficiency is lowered. Accordingly, in a case where Al is to be contained, the Al content is set to 1.00% or less. The Al content mentioned here is the total Al content.

Sn: 0% to 1.00%

[0062] Sn is an element that improves corrosion resistance in a corrosive environment. For this reason, Sn may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Sn content is set to 0.01% or more.

[0063] On the other hand, in a case where the Sn content is more than 1.00%, grain boundary strength is reduced and the toughness of the steel member deteriorates. Accordingly, in a case where Sn is to be contained, the Sn content is set to 1.00% or less.

W: 0% to 2.00%

[0064] W is an element that increases the hardenability of steel and makes it possible to stably ensure the strength of the steel member. For this reason, W may be contained. Further, W is an element that improves corrosion resistance in a corrosive environment. In a case where the above-described effects are to be obtained, it is preferable that the W content is set to 0.01% or more.

[0065] On the other hand, in a case where the W content is more than 2.00%, the above-described effects are saturated and economic efficiency is lowered. Accordingly, in a case where W is to be contained, the W content is set to 2.00% or less. The W content is preferably 1.00% or less.

Sb: 0% to 1.00%

[0066] Sb is an element that improves corrosion resistance in a corrosive environment. For this reason, Sb may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Sb content is set to 0.01% or more.

[0067] On the other hand, in a case where the Sb content is more than 1.00%, grain boundary strength is reduced and the toughness of the steel member deteriorates. Accordingly, in a case where Sb is to be contained, the Sb content is set to 1.00% or less.

Zr: 0% to 1.00%

[0068] Zr is an element that improves corrosion resistance in a corrosive environment. For this reason, Zr may be contained. In order to obtain the above-described effect, it is preferable that the Zr content is set to 0.01% or more.

[0069] On the other hand, in a case where the Zr content is more than 1.00%, grain boundary strength is reduced and the hydrogen embrittlement resistance of the steel member is reduced. Accordingly, in a case where Zr is to be contained, the Zr content is set to 1.00% or less.

Se: 0% to 1.00%

[0070] Se is an element that improves hydrogen embrittlement resistance. For this reason, Se may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Se content is set to 0.01% or more.
[0071] On the other hand, in a case where the Se content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where Se is to be contained, the Se content is set to 1.00% or less.

Bi: 0% to 1.00%

[0072] Bi is an element that improves hydrogen embrittlement resistance. For this reason, Bi may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Bi content is set to 0.01% or more.
[0073] On the other hand, in a case where the Bi content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where Bi is to be contained, the Bi content is set to 1.00% or less.

As: 0% to 1.00%

[0074] As is an element that improves hydrogen embrittlement resistance. For this reason, As may be contained. In a case where the above-described effect is to be obtained, it is preferable that the As content be set to 0.01% or more.
[0075] On the other hand, in a case where the As content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where As is to be contained, the As content is set to 1.00% or less.

Ta: 0% to 1.00%

[0076] Ta is an element that improves hydrogen embrittlement resistance. For this reason, Ta may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Ta content be set to 0.01% or more.
[0077] On the other hand, in a case where the Ta content is more than 1.00%, the effect is saturated and the cost is increased. Accordingly, in a case where Ta is to be contained, the Ta content is set to 1.00% or less.

Re: 0% to 1.00%

[0078] Re is an element that improves hydrogen embrittlement resistance. For this reason, Re may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Re content be set to 0.01% or more.
[0079] On the other hand, in a case where the Re content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where Re is to be contained, the Re content is set to 1.00% or less.

Os: 0% to 1.00%

[0080] Os is an element that improves hydrogen embrittlement resistance. For this reason, Os may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Os content be set to 0.01% or more.
[0081] On the other hand, in a case where the Os content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where Os is to be contained, the Os content is set to 1.00% or less.

Ir: 0% to 1.00%

[0082] Ir is an element that improves hydrogen embrittlement resistance. For this reason, Ir may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Ir content be set to 0.01% or more.
[0083] On the other hand, in a case where the Ir content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where Ir is to be contained, the Ir content is set to 1.00% or less.

Tc: 0% to 1.00%

[0084] Tc is an element that improves hydrogen embrittlement resistance. For this reason, Tc may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Tc content be set to 0.01% or more.
[0085] On the other hand, in a case where the Tc content is more than 1.00%, the effect is saturated and cost is increased. Accordingly, in a case where Tc is to be contained, the Tc content is set to 1.00% or less.

Co: 0% to 1.00%

[0086] Co is an element that improves corrosion resistance in a corrosive environment. For this reason, Co may be contained. In a case where the above-described effect is to be obtained, it is preferable that the Co content be set to 0.01% or more.

[0087] On the other hand, in a case where the Co content is more than 1.00%, the above-described effect is saturated and economic efficiency is lowered. Accordingly, in a case where Co is to be contained, the Co content is set to 1.00% or less.

REM: 0% to 0.30%

[0088] REM is an element that has effects of refining inclusions contained in steel and improving the toughness of the steel member, as with Ca. For this reason, REM may be contained. In a case where the above-described effects are to be obtained, it is preferable that the REM content is set to 0.01% or more. The REM content is more preferably 0.02% or more.

[0089] On the other hand, in a case where the REM content is more than 0.30%, the effects are saturated and cost is increased. Accordingly, in a case where REM is to be contained, the REM content is set to 0.30% or less. The REM content is preferably 0.20% or less.

[0090] Here, REM refers to a total of 17 elements of Sc, Y, and lanthanoids, such as La 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, La, Nd, Ce, and Pr.

[0091] In the chemical composition of the steel member according to the present embodiment, an element other than the above-described elements, that is, the remainder includes Fe and impurities.

[0092] Here, the "impurities" are elements that are incorporated due to various factors including raw materials, such as ore and scrap, and a manufacturing step in a case where 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. A method of industrially manufacturing the steel sheet is a blast furnace steelmaking method or an electric furnace steelmaking method, and also includes a level (impurity level) of impurities to be incorporated in a case where the steel sheet is manufactured by any of the methods.

[0093] The chemical composition of the steel member can be obtained by the following method.

[0094] The chemical composition of the steel member is obtained in a case where an analysis sample is cut out from the steel member and element analysis, such as inductively coupled plasma (ICP) atomic emission spectrometry, is performed. 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-nondispersive infrared absorption method.

[0095] As described in JIS G 0417: 1999, the analysis sample is collected from a 1/4 position of the thickness from the surface of a base steel sheet in a thickness direction while avoiding a width-direction end portion of the base steel sheet so that the average chemical composition of the steel member over the entire thickness is obtained.

[0096] The C content and the B content obtained here are the C content and the B content at the 1/4-depth position to be described later. However, since the chemical composition is generally uniform in the steel member according to the present embodiment, it can be said that the C content and the B content obtained here are also the average chemical composition of the entire steel member except for a decarburized layer or the surface layer in which B is concentrated.

(A2) Structure of steel member

[0097] Hereinafter, a position corresponding to a depth of 1/4 of the thickness from the surface in the thickness direction will be described as a 1/4-depth position, and a position corresponding to a depth of 0.1 mm from the surface in the thickness direction will be described as a 0.1 mm-depth position. Further, in a case where the C content is measured from the surface in the thickness direction using GDS, the distance from the surface to a position where the C content is equal to equal to the C content at the 1/4-depth position for the first time (a position closest to the surface among positions where the C content is equal to the C content at the 1/4-depth position) will be described as a decarburization depth.

[0098] In the structure of the surface layer of the steel member according to the present embodiment, the maximum B content in a range to a depth of 10 μm from the surface is 5 times or more the B content at the 1/4-depth position and a decarburization depth is 20 μm or more.

[0099] In the steel member, decarburizing and softening the surface layer are extremely effective to improve bendability. Since stress and strain to be generated are larger at an outer portion of the bent surface layer with regard to bending deformation, bendability can be improved in a case where the surface layer is softened to improve a fracture limit. In a case where the decarburization depth of the steel member is 20 μm or more, bendability is improved. For this reason, the decarburization depth is set to 20 μm or more.

[0100] As described above, decarburizing and softening the surface layer are effective with regard to the bendability of the steel member. On the other hand, since carbon is an element that is segregated at grain boundaries and strengthens the grain boundaries, it is not preferable that the amount of carbon at the grain boundaries is reduced. Since carbon is an element that is segregated at grain boundaries and strengthens the grain boundaries, hydrogen embrittlement resistance and toughness may be reduced in a case where the amount of carbon at the grain boundaries is reduced and grain boundary strength is reduced.

[0101] Further, it is effective to decarburize and soften the surface layer, but it is not preferable that the surface has a ferrite-based structure. The reason for this is that, since ferrite is coarser and softer than the dense martensite-based structure of the base steel, there is a large mismatch between the ferrite-based structure of the surface layer and the martensite-based structure of the base steel, which causes deterioration in bendability, hydrogen embrittlement resistance, and toughness.

[0102] Accordingly, in the steel member according to the present embodiment, the surface layer is decarburized and B is concentrated in the surface layer. B is an element that is segregated at grain boundaries and strengthens the grain boundaries as with carbon and improves hardenability. For this reason, in a case where B is concentrated in the surface layer, it is possible to obtain a martensite-based structure in which grain boundaries are tough and fine. Since having been decarburized, the martensite-based structure of the surface layer is softer than the martensite-based structure of the base steel and is obtained with a high level of bendability, hydrogen embrittlement resistance, and toughness.

[0103] Specifically, in a case where the maximum B content in a range to a depth of 10 μm from the surface of the steel member is 5 times or more the B content at the 1/4-depth position, bendability and hydrogen embrittlement resistance are improved.

[0104] Further, the steel member according to the present embodiment has a hardness (Vickers hardness (HV)) of 310 to 890 at the 1/4-depth position. The fact that the steel member has this Vickers hardness corresponds to the fact that the tensile strength of the steel member is in a range of 1.0 GPa to 3.1 GPa, and contributes to a reduction in the weight of a vehicle body and the improvement of collision safety thereof in a case where the steel member is applied to a vehicle component. A relationship between hardness and tensile strength is described in, for example, SAE J 417.

[0105] It is preferable that the surface layer of the steel member according to the present embodiment is decarburized and softened and a strength gradient thereof is controlled from the surface layer toward the inside within the following range. In this case, bendability is further improved. The reason for this is considered as follows: The maximum strain and stress are applied to the outside bend surface as described above with regard to bending deformation and cracking is to progress from the surface to the inside. However, in a case where an appropriate strength gradient is present, there is an effect of suppressing the development of strain on the surface.

[0106] In order to obtain the above-described effect in the steel member, it is preferable that the Vickers hardness at a position corresponding to a depth of 0.1 mm from the surface in the thickness direction (0.1 mm-depth position) is controlled within an appropriate range according to the Vickers hardness at the 1/4-depth position that has a high correlation with the tensile strength of the steel member.

[0107] Specifically, it is preferable that the Vickers hardness at the 0.1 mm-depth position is 0.95 times or less the Vickers hardness at the 1/4-depth position.

[0108] Further, it is more preferable to further control the above-described hardness ratio according to the Vickers hardness at the 1/4-depth position and to control the maximum principal plastic strain at the center of the outside bend surface layer in a predetermined range.

[0109] In a case where the Vickers hardness at the 1/4-depth position is more than 700 and 890 or less (corresponding to a case where tensile strength is more than 2.4 GPa and 3.1 GPa or less), it is preferable that the Vickers hardness at the 0.1 mm-depth position is 0.86 times or less the Vickers hardness at the 1/4-depth position. In addition, in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, it is preferable that the maximum principal plastic strain at the center of the outside bend surface layer is 0.260 or less.

[0110] In a case of a steel member having a sheet thickness other than 1.6 mm, a bending angle is adjusted so that the same deformation as in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees is obtained.

[0111] Specifically, the steel member is deformed up to a bending angle that satisfies the following equation.

$$\text{Bending angle} = 6 \times (\text{sheet thickness})^2 - 32 \times (\text{sheet thickness}) + 86$$

[0112] For example, in a case where a sheet thickness is 1.0 mm, the maximum principal plastic strain at a bending outer center when a steel member is deformed up to a bending angle of 60 degrees is evaluated. In a case where a sheet thickness is 2.3 mm, the maximum principal plastic strain at a bending outer center when a steel member is deformed up to a bending angle of 44 degrees is evaluated. The sheet thickness is not limited, but it is preferable that the sheet thickness is in a range of 0.6 mm to 4.0 mm.

[0113] Further, in a case where the Vickers hardness at the 1/4-depth position is more than 530 and 700 or less (corresponding to a case where tensile strength is more than 1.8 GPa and 2.4 GPa or less), it is preferable that the Vickers hardness at the 0.1 mm-depth position is 0.88 times or less the Vickers hardness at the 1/4-depth position. In addition, in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, it is preferable that the maximum principal plastic strain at the center of the outside bend surface layer is 0.280 or less.

[0114] Furthermore, in a case where the Vickers hardness at the 1/4-depth position is more than 450 and 530 or less (corresponding to a case where tensile strength is more than 1.5 GPa and 1.8 GPa or less), it is preferable that the Vickers hardness at the 0.1 mm-depth position is 0.90 times or less the Vickers hardness at the 1/4-depth position. In a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, it is preferable that the maximum principal plastic strain at the center of the outside bend surface layer is 0.310 or less.

[0115] In addition, in a case where the Vickers hardness at the 1/4-depth position is in a range of 310 to 450 (corresponding to a case where tensile strength is in a range of 1.0 GPa to 1.5 GPa), it is preferable that the Vickers hardness at the 0.1 mm-depth position is 0.95 times or less the Vickers hardness at the 1/4-depth position. In addition, in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, it is preferable that the maximum principal plastic strain at the center of the outside bend surface layer is 0.340 or less.

[0116] It is preferable that the Vickers hardness at the 0.1 mm-depth position is 0.70 times or more the Vickers hardness at the 1/4-depth position in any case.

[0117] The degree of concentration of B in the surface layer (B concentration ratio: a ratio of the maximum B content in a range to a depth of 10 μm to the B content at the 1/4-depth position) and the decarburization depth can be obtained using GDS by the following methods.

[0118] At a 1/4 position of a sheet width (short side) from a width-direction end portion of the steel member, GDS (glow discharge spectrometry) is performed at a pitch of 50 nm or less from the outermost surface of the steel member (the surface of a scale in a case where the steel member includes the scale on the surface thereof, and the surface of an alloy layer in a case where the steel member includes an alloy layer on the surface thereof) in the sheet thickness direction to measure the B content, the C content, and the Fe content. As a result of the measurement, a position where the Fe content becomes 95 mass% or more for the first time is defined as the surface.

[0119] Further, the maximum value among values of the B content in a range to a depth of 10 μm from the surface described above, which are obtained from the GDS analysis, is defined as the maximum B content. However, in a case where the steel member includes an Fe-Al-based alloy layer to be described later on the surface thereof, the maximum value among values of the B content in a range to a depth of 10 μm from a position where a total amount of Fe and Al becomes 70 mass% or more for the first time is defined as the maximum B content. In a case where the steel member includes an Fe-Zn-based alloy layer to be described later on the surface thereof, the maximum value among values of the B content in a range to a depth of 10 μm from a position where a total amount of Fe and Zn becomes 70 mass% or more for the first time is defined as the maximum B content. A case where the steel member includes an Fe-Al-based alloy layer is a case where the Al content in an alloy layer region on the surface of the steel member, which is obtained from the GDS analysis, is 25 mass% or more. Further, a case where the steel member includes an Fe-Zn-based alloy layer is a case where the Zn content in an alloy layer region on the surface of the steel member, which is obtained from the GDS analysis, is 25 mass% or more.

[0120] The degree of concentration of B in the surface layer is calculated from the maximum B content and the B content at the 1/4-depth position that is obtained by the method described above.

[0121] Furthermore, a position where the C content obtained from the same GDS analysis becomes equal to the C content at the 1/4-depth position described above for the first time is defined as an end of the decarburization depth, and the distance from the surface to this end is defined as the decarburization depth.

[0122] However, the above-described measurement using GDS is performed five times at different points, and an average value of values obtained from the five times of measurement is used.

[0123] The hardness at the 1/4-depth position and the hardness at the 0.1 mm-depth position are obtained by the following methods.

[0124] A sample for the observation of a cross section is collected from a 1/4 position of the width (short side) from the width-direction end portion of the steel member, and the Vickers hardness is measured at target depth positions (a 1/4-depth position and a 0.1 mm-depth position) according to JIS Z 2244-1 :2020. A test force is set to 100 gf. The measurement is performed five times at each depth, and the average value of measured values is used as hardness at that position.

[0125] The maximum principal plastic strain at the center of the outside bend surface layer in a case where the steel member is deformed up to a predetermined bending angle is obtained by the following method.

[0126] A steel member having a strength gradient on the surface thereof is modeled using a finite element method. The modeled steel member is set such that a range from the surface to a depth of 50 μm, a range having a depth of 50 μm to 100 μm, and a range having a depth of 100 μm to 250 μm respect to the entire sheet thickness have the same hardness as a steel member to be evaluated.

[0127] Further, a test jig used to perform a bending test of VDA238-100 is modeled. On the basis of standards, for example, a punch diameter R is set to 0.4 mm, a roller diameter is set to 30 mmφ, and the distance between the rollers is set to 2 × sheet thickness + 0.05.

[0128] Pressing (simulation) is performed up to a predetermined bending angle using the modeled steel member and the modeled test jig. The maximum principal plastic strain at the predetermined bending angle is output, and the maximum principal plastic strain at the center of the outside bend surface layer (a point where the maximum principal plastic strain on a bending ridge is maximum) is obtained.

[0129] Software for analysis using a finite element method is not limited, and for example, Marc manufactured by MSC Software Corporation is used. The mesh size is set to 5 μm, and a friction coefficient μ of a contact section between the steel member and the test jig is set to 0.05.

[0130] The microstructure (internal structure) of the steel member according to the present embodiment at the 1/4-depth position is not limited, and it is preferable that the microstructure is a structure containing 80% or more of martensite by volume fraction. In a case where the steel member has the above-described chemical composition and the volume fraction of martensite is set to 80% or more, the Vickers hardness at the 1/4-depth position can be set to 310 or more (corresponding to a tensile strength of 1.0 GPa or more). Preferably, martensite occupies 90% or more by volume fraction. More preferably, martensite occupies 95% or more. Martensite may occupy 100%. In a case where the volume fraction of martensite is small, it is difficult to obtain a tensile strength of 1.0 GPa or more.

[0131] The microstructure of the steel member at the 1/4-depth position may contain residual austenite, bainite, ferrite, and/or pearlite as the remainder other than martensite.

[0132] Martensite includes not only so-called fresh martensite but also tempered martensite and auto-tempered martensite. The auto-tempered martensite is tempered martensite generated during cooling at the time of quenching without heat treatment for tempering, and is generated by in-situ tempering of martensite generated due to self-heating associated with martensitic transformation.

[0133] Microstructural fractions of the microstructure of the steel member at the 1/4-depth position can be measured by the following method.

[0134] 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 TEM.

[0135] Specifically, a measurement sample including a 1/4 position of the width of the steel member from a width-direction end portion of the steel member (1/4-width position) and the 1/4-depth position of the steel member is cut out, and is used as a thin film sample for TEM observation. The range of this thin film sample, which includes the 1/4-width position and the 1/4-depth position and has an area of 400 μm^2 or more, is observed with TEM.

[0136] Martensite and bainite, which have body-centered cubic lattices, and residual austenite, which has face-centered cubic lattices, are distinguished using an electron beam diffraction pattern of the thin film sample. Then, iron carbide (Fe_3C) contained in martensite and bainite is found using the diffraction pattern, and a precipitation form thereof is observed to measure the microstructural fraction of each of martensite and bainite. Specifically, a structure is determined to be martensite (tempered martensite) in a case where the precipitation form is precipitation in three directions, and a structure is determined to be bainite in a case where the precipitation form is precipitation limited to one direction. Even in a case where precipitation of iron carbide is not observed, a structure is also determined to be martensite (fresh martensite).

[0137] The microstructural fractions of martensite and bainite to be measured by TEM are measured in area%. However, since the microstructure of the steel member according to the present embodiment has isotropy, a value of an area fraction can be replaced with a volume fraction as it is. Carbide is observed to distinguish between martensite and bainite, but carbide is not included in the volume fraction of the structure in the present embodiment.

[0138] In a case where ferrite or pearlite is present as the remainder in microstructure, the ferrite or the pearlite can be easily confirmed using 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 etchant to reveal ferrite and pearlite, and a range having an area of 40,000 μm^2 or more 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 a granular form is determined to be bainite.

(A3) Alloy layer

[0139] The steel member according to the present embodiment may include an alloy layer on at least a part of the surface (or the entire surface) thereof.

[0140] The alloy layer may be an Fe-Al-based alloy layer or an Fe-Zn-based alloy layer.

[0141] The Fe-Al-based alloy layer is an alloy layer containing 70 mass% or more of Fe and Al in total, and the Fe-Zn-based alloy layer is an alloy layer containing 70 mass% or more of Fe and Zn in total.

[0142] Since the steel member has corrosion resistance in a case where the steel member includes the alloy layer, an effect of improving hydrogen embrittlement resistance can be obtained in a case where the steel member is used for a vehicle.

[0143] It is preferable that the thickness of the alloy layer is in a range of 5 μm to 100 μm.

[0144] In a case where the alloy layer is formed on the surface of the steel member as described above, a surface serving as a reference at each depth position is the surface of a portion (base steel) excluding the alloy layer.

[0145] A cross section taken in the thickness direction is observed using a scanning electron microscope, so that the thickness of the alloy layer can be obtained.

[0146] Specifically, a measurement sample is cut out from a 1/2 portion of the steel member in a longitudinal direction (a position corresponding to 1/2 of a length from a longitudinal-direction end portion in the longitudinal direction) and a 1/4 portion of a width (a 1/4 position of the width from a width-direction end portion in the width direction) and is observed. An observation range of the microscope is set to, for example, a range having an area of 40,000 μm^2 or more at 400-fold magnification. The cut sample is mechanically polished and subsequently mirror-finished. Next, the thicknesses of the alloy layer in ten arbitrary visual fields are measured, and an average value thereof is used as the thickness of the alloy layer. In a case where the measurement sample is observed using a BSE image (or a COMPO image), a clear contrast difference between the alloy layer and base steel (steel sheet substrate) is confirmed. For this reason, it is possible to measure the thickness of the alloy layer by measuring a thickness from an outermost surface to a position where contrast is changed. The measurement is performed at 20 points arranged at regular intervals in an observation photograph, and the distance between the measurement points is set to 6.5 μm. Further, observation is performed in five visual fields in the above-described manner in the measurement, and the average value of measured values is used as the thickness of the alloy layer.

[0147] Furthermore, with regard to the chemical composition of the alloy layer, spot element analysis (a beam diameter of 1 μm or less) can be performed in the same observation range as described above using an electron probe microanalyzer (EPMA) to obtain the amounts of Fe, Al, Zn, and the like contained in the alloy layer. The alloy layer is analyzed at a total of 10 points in ten arbitrary visual fields, and the average value of obtained values is used as the amount of each of Fe, Al, and Zn contained in the alloy layer. Even in a case where an element other than Fe, Al, and Zn is contained, the amount of the element is obtained using the same method.

(A4) Shape of steel member

[0148] The 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 that is a steel sheet formed in a predetermined shape. A hot-formed steel member is often a formed body, and a case of a formed body and a case of a flat sheet are collectively referred to as a "steel member" in the present embodiment. Further, the steel member may be a tailored property material having different strengths depending on points. In this case, it is preferable that at least a part of the steel member has a tensile strength of 1.0 GPa (1000 MPa) or more. The tailored property material may be a material in which steel sheets having different chemical compositions, different strengths, or different sheet thicknesses are joined, or may be a material in which a part of a steel sheet is subjected to heat treatment.

(B) Steel sheet

[0149] Next, a steel sheet (which may be referred to as a steel sheet according to the present embodiment) that serves as a material of the steel member according to the present embodiment will be described. Heat treatment to be described later is performed on the steel sheet to be described below, so that the steel member can be obtained.

[0150] The steel sheet according to the present embodiment includes a base steel sheet and an iron scale that is formed on a surface of the base steel sheet.

[0151] The steel sheet according to the present embodiment may include a plating layer on the iron scale (a surface of the iron scale).

(B 1) Chemical composition of steel sheet

[0152] A range of the chemical composition of a base steel sheet included in the steel sheet according to the present embodiment is the same as the range of the chemical composition of the steel member according to the present embodiment described above, and reasons for limiting the range are also the same as described above.

[0153] For example, a 1/4 position of a sheet thickness from the surface of the base steel sheet in a sheet thickness direction (1/4-depth position) is set as a representative position and element analysis is performed at this position with a general method, such as ICP, so that the chemical composition of the base steel sheet is obtained.

(B2) Scale of steel sheet

[0154] The scale included in the steel sheet according to the present embodiment includes cracks at a density of 90 pieces/mm^2 or more.

[0155] The base steel sheet of the steel sheet according to the present embodiment is decarburized using O that is contained in the scale formed on the surface of the base steel sheet by hot rolling or the like as described later. In a case where decarburization is performed by annealing in a coil shape (box annealing), the discharge of CO, which is a decarbonizing reaction, does not proceed since sheets more closely adhere to each other and are more sealed to each other at an inner portion of a coil. For this reason, decarburization uniform in a longitudinal direction and a width direction of the coil is not obtained. In contrast, since discharge passages for CO are formed in a case where cracks are introduced into the scale, a decarbonizing reaction promptly and uniformly proceeds. In order to obtain the above-described effects, the crack density of the scale is controlled in the steel sheet according to the present embodiment.

[0156] The crack density of the scale can be obtained from the SEM observation of the surface.

[0157] A sample having a size of about 15 mm is collected while avoiding an end portion (for example, within 50 mm from the end portion) of the steel sheet. At this time, attention is paid so that the scale is not peeled off, and a sample having a size of 15 mm^2 or more is cut out as necessary. The surface on which the scale is formed is observed with SEM, a BSE image is acquired, and the crack density is counted up using a cutting method. In the SEM observation, while avoiding an end portion (for example, within 2 mm from the end portion) of the sample, the sample is observed at 500-fold magnification so that an observed area has 50,000 μm^2 or more /per one visual field. In a case where the sample is observed using a BSE image (or a COMPO image), a clear contrast difference between the scale and cracks are confirmed. The obtained BSE image (or COMPO image) is cut into 10 vertical divisions and 10 horizontal divisions, the number of cracks overlapping with cutting-plane lines is counted and converted into a number density. Ten arbitrary visual fields are observed, and the average value of values of the crack density in the respective visual fields is used as the crack density of the scale.

(B3) Plating layer of steel sheet

[0158] The steel sheet according to the present embodiment may include a plating layer (coating) on a part of the surface (or the entire surface) thereof. The plating layer may be an Al-based plating layer that mainly contains Al or a Zn-based plating layer that mainly contains Zn. The Al-based plating layer is a plating layer containing 70 mass% or more of Al, and the Zn-based plating layer is a plating layer containing 70 mass% or more of Zn.

(B4) Shape of steel sheet

[0159] The shape of the steel sheet according to the present embodiment is not particularly limited. That is, the steel sheet may be a flat sheet, or may be a tailored property material in which steel sheets having different strengths or different sheet thicknesses are joined.

(C) Manufacturing method for steel sheet

[0160] Effects can be obtained as long as the steel sheet according to the present embodiment has the above-described characteristics regardless of a manufacturing method. However, since the steel sheet can be stably manufactured in a case where a manufacturing method including the following steps is used, it is preferable that the manufacturing method including the following steps is used.

(I) A steel piece manufacturing step of manufacturing a steel piece having a predetermined chemical composition
(II) A hot rolling step of heating and hot-rolling the steel piece to obtain a hot-rolled steel sheet
(III) A coiling step of coiling the hot-rolled steel sheet
(IV) A light rolling reduction step of performing light rolling reduction on the hot-rolled steel sheet subjected to the coiling step

[0161] Each step will be described below. Steps or conditions not described below can be performed by publicly known methods as appropriate.

(I) Steel piece manufacturing step

[0162] In the steel piece manufacturing step, a steel piece, such as a slab, having the preferable chemical composition of the steel sheet according to the present embodiment described above is manufactured.

[0163] Molten steel of which the chemical composition is adjusted to a predetermined chemical composition may be made into a steel piece by continuous casting or the like under publicly known conditions.

(II) Hot rolling step

[0164] In the hot rolling step, the obtained steel piece is heated and hot-rolled to obtain a hot-rolled steel sheet. In the hot rolling step, an iron scale (hot-roll scale) is formed on the surface of the steel sheet.

[0165] Hot rolling conditions are not particularly limited, and may be appropriately set within a publicly known condition range according to characteristics of the steel sheet to be required.

(III) Coiling step

[0166] In the coiling step, the hot-rolled steel sheet obtained in the hot rolling step is coiled in a coil shape.

[0167] A condition, such as a coiling temperature, is not particularly limited.

(IV) Light rolling reduction step

[0168] In the light rolling reduction step, the hot-rolled steel sheet on which the hot-roll scale is formed on the surface is subjected to uncoiling and light rolling reduction. By performing a light rolling reduction having a rolling reduction of 0.2% or more, scale cracks described above can be introduced. The upper limit of the rolling reduction is not particularly limited. However, since the scale may be peeled off in a case where the rolling reduction is 10.0% or more, it is not preferable that the rolling reduction is 10.0% or more. The rolling reduction is preferably less than 5.0%, less than 2.0%, or less than 1.0%. As a method of introducing the above-described amount of scale cracks, shot blasting may be performed on the hot-rolled steel sheet together with or instead of light rolling reduction.

[0169] Accordingly, a steel sheet, which includes a base steel sheet having a predetermined chemical composition and an iron scale formed on the surface of the base steel sheet and in which the iron scale includes cracks at a predetermined density, is obtained.

[0170] In the related art, there has been a case in which temper rolling is performed before pickling as a case in which light rolling reduction is performed on a hot-rolled sheet. However, a purpose thereof is generally to facilitate pickling. That is, performing light rolling reduction on a hot-rolled sheet, for which the next step is not a pickling step, is not usually performed since also causing an increase in the number of steps.

[0171] In contrast, in the manufacturing method for the steel sheet according to the present embodiment, light rolling reduction is performed on a steel sheet to be subjected to hot-rolled sheet annealing without the removal of a scale (in a so-called mill scale state) as described later. Accordingly, effects that have not been expected in the related art can be obtained.

(D) Manufacturing method for steel member

[0172] A manufacturing method for the steel member according to the present embodiment is not limited, and the steel member can be manufactured by using, for example, a manufacturing method including the following steps for the above-described steel sheet.

(V) A hot-rolled sheet annealing step of annealing the hot-rolled steel sheet subjected to the light rolling reduction step
(VI) A pickling step of pickling the hot-rolled steel sheet subjected to the hot-rolled sheet annealing step as necessary
(VII) A cold rolling step of cold-rolling the hot-rolled steel sheet subjected to the pickling step as necessary to obtain a cold-rolled steel sheet
(VIII) An annealing step of annealing the cold-rolled steel sheet subjected to the cold rolling step as necessary
(IX) A plating step of performing plating on the cold-rolled steel sheet subjected to the annealing step as necessary
(X) A heat treatment step of performing heat treatment on the hot-rolled steel sheet after the hot-rolled sheet annealing step or on the cold-rolled steel sheet after the cold rolling step, the annealing step, or the plating step to obtain a steel member

(V) Hot-rolled sheet annealing step

[0173] In the hot-rolled sheet annealing step, box annealing (BAF) is performed on the steel sheet according to the present embodiment (the steel sheet in which the hot-roll scale including cracks is formed on the surface thereof) in a coiled state without the removal of a scale (in a so-called mill scale state).

[0174] In the annealing, an annealing atmosphere is set to an inert gas atmosphere (an N_2 atmosphere, an H_2 atmosphere, or the like), and the steel sheet is annealed at a temperature of 650°C to 950°C for 4 to 30 hours.

[0175] In the present embodiment, by performing annealing on the hot-rolled steel sheet to which the hot-roll scale is attached, so that decarburization is performed using O contained in the scale as a decarburization source. Specifically, C of the outermost layer of the base steel sheet reacts with O contained in the scale to form CO gas, so that decarburization occurs. Subsequently, C that is insufficient is supplied from the inside of the base steel sheet to the outermost layer and becomes CO gas, so that a decarbonizing reaction further proceeds.

[0176] However, in a case where an annealing temperature is lower than 650°C or an annealing time is shorter than 4 hours, decarburization does not proceed sufficiently. On the other hand, in a case where an annealing temperature is higher than 950°C or an annealing time is longer than 30 hours, the reduction reaction of the scale is completed and the supply of C from the inside of the steel sheet to the surface layer continues thereafter. Therefore, decarburization becomes shallow.

[0177] Further, in a case where the coiled hot-rolled steel sheet is subjected to box annealing, sheets are more sealed to each other at an inner portion of a coil and the discharge of CO gas is suppressed. Accordingly, decarburization uniform in a longitudinal direction and a width direction of the coil is not obtained. Accordingly, it is possible to promptly and uniformly obtain a decarburized layer at any position by introducing the above-described scale cracks. It is desirable that a hot-rolled steel sheet to be supplied to the hot-rolled sheet annealing step has a sheet thickness of 9 mm or less, a sheet width of 2,100 mm or less, an outer diameter of 2,000 mm or less in the case of a coil, and a weight of 30 tons or less per coil.

(VI) Pickling Step

[0178] In the pickling step, pickling is performed on the hot-rolled steel sheet subjected to the hot-rolled sheet annealing step. Publicly known hydrochloric acid or sulfuric acid may be used as pickling liquid. However, in a case where the scale is not sufficiently peeled off during pickling, shot blasting may be performed before pickling to promote the mechanical peeling of the scale. For example, #60 may be applied as a shot size number. The pickling step may be omitted.

(VII) Cold rolling step

[0179] In the cold rolling step, cold rolling is performed on the steel sheet after the pickling step. A rolling reduction is not particularly limited. However, from the viewpoint of ensuring good flatness, it is preferable that a cumulative rolling reduction in the cold rolling is set to 30% or more. On the other hand, in order to avoid an excessive rolling force, it is preferable that a cumulative rolling reduction in the cold rolling is set to 80% or less. The cold rolling step may be omitted.

(VIII) Annealing step

[0180] In the annealing step, annealing is performed on the cold-rolled sheet. The annealing is performed in a temperature range of 700°C to 950°C under a moist hydrogen atmosphere in which a dew point has become high due to humidification as an annealing atmosphere. For example, in a two-stage heating furnace including a direct fire burner and a radiant tube, the steel sheet is heated to a temperature of 560°C to 650°C at an air-fuel ratio of 0.9 to 1.2 and is then heated to a temperature of 700°C to 950°C under an atmosphere in which an oxygen potential is -1.5 or more, a hydrogen concentration is in a range of 1 mass% to 20 mass%, and a dew point is in a range of - 10°C to +30°C. It is preferable that the steel sheet is retained at a temperature of 700°C or higher for 30 seconds or longer under an atmosphere in which hydrogen is contained and a dew point is high.

[0181] However, the annealing step may be omitted or may be performed under conditions other than the above-described conditions.

(IX) Plating step

[0182] In the plating step, a coating is formed on the surface of the steel sheet to obtain a coated steel sheet. A method for forming the coating is not particularly limited, and a hot-dip plating method, an electro plating method, a vacuum vapor deposition method, a cladding method, a thermal spraying method, and the like can be used. The hot-dip plating method is the most popular in the industry.

[0183] Examples of the coating include Al-based plating containing Al, Zn-based plating containing Zn, and the like.

[0184] The plating step may be omitted.

[0185] In a case where an Al-based plating layer is formed by hot-dip plating, Fe is often contained in a plating bath as an impurity in addition to Al. Further, Si, Ni, Mg, Ti, Zn, Sb, Sn, Cu, Co, In, Bi, Ca, mischmetal, and the like may be contained in the plating bath in addition to the above-described elements as long as 70 mass% or more of Al is contained.

[0186] In a case where hot-dip plating is to be performed, the steel sheet after the annealing step may be cooled to room temperature, then heated again, and subjected to plating, or may be cooled to a temperature of 650°C to 750°C near the temperature of the plating bath (that is, not cooled to room temperature) after being retained in the annealing step and then subjected to hot-dip plating.

[0187] Pretreatment and post-treatment of the plating are not particularly limited, and precoating, solvent coating, alloying treatment, temper rolling, and the like can be performed. For example, retaining the steel sheet at 450°C to 800°C can also be applied as the alloying treatment. Further, as the 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%.

(X) Heat treatment step

[0188] In the heat treatment step, heat treatment is performed on the steel sheet, which has been subjected to the above-described steps and has a predetermined chemical composition, to obtain a steel member. The heat treatment is performed under conditions in which, for example, a steel sheet obtained by a method described above is heated to a temperature of 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 Ms point or lower at an average cooling rate equal to or higher than an upper critical cooling rate.

[0189] In a case where the temperature rising rate is lower than 1.0 °C/s, the productivity of the heat treatment deteriorates. For this reason, it is not preferable that the temperature rising rate is lower than 1.0 °C/s. On the other hand, in a case where the temperature rising rate is higher than 1,000 °C/s, a duplex grain structure is formed and bendability deteriorates. For this reason, it is not preferable that the temperature rising rate is higher than 1,000 °C/s.

[0190] Further, in a case where a heat treatment temperature is lower than Ac3 point (°C), ferrite remains after cooling and the strength is insufficient. For this reason, it is not preferable that a heat treatment temperature is lower than the Ac3 point (°C). On the other hand, in a case where a heat treatment temperature is higher than (Ac3 point + 300)°C, a structure becomes coarse and hydrogen embrittlement resistance deteriorates. For this reason, it is not preferable that a heat treatment temperature is higher than (Ac3 point + 300)°C.

[0191] The upper critical cooling rate is a minimum cooling rate at which austenite is supercooled to generate martensite without causing the precipitation of ferrite or pearlite in the structure. In a case where cooling is performed at a cooling rate lower than the upper critical cooling rate, ferrite or pearlite is generated and strength is insufficient.

[0192] During heating, the steel sheet may be retained for 1 to 300 seconds within a range of the heating temperature ± 10°C.

[0193] Furthermore, after the steel sheet is cooled to a temperature equal to or lower than Ms point, tempering treatment may be performed in a temperature range of about 100°C to 600°C in order to adjust the strength of a steel member.

[0194] Ac3 point, Ms point, and the upper critical cooling rate are measured by the following methods.

[0195] Strip-shaped test pieces having a width of 30 mm and a length of 200 mm are cut out from the steel sheet according to the present embodiment, are heated to a temperature of 1,000°C at a temperature rising rate of 10 °C/s in a nitrogen atmosphere, are retained at that temperature for five minutes, and are 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. The thermal expansion changes of the test piece, which is being heated and cooled, are measured to measure Ac3 point and Ms point.

[0196] Further, the minimum cooling rate at which the precipitation of ferrite does not occur in the respective test pieces cooled at the above-described cooling rates is defined as the upper critical cooling rate. Furthermore, Ms point obtained from a thermal expansion change in a case where the test piece is cooled at a cooling rate equal to or higher than the upper critical cooling rate is used as Ms point of the steel member.

[0197] Here, in the series of heat treatment, hot forming, such as hot stamping, may be performed while the steel sheet is cooled to a temperature equal to or lower than Ms point, that is, simultaneously with a step of cooling the steel sheet at a cooling rate equal to or higher than the upper critical cooling rate, after the steel sheet is heated to a temperature range of Ac3 point to (Ac3 point + 300)°C. Examples of the hot forming include bending, drawing, stretching, hole expansion, flange forming, and the like. Further, in a case where means for cooling the steel sheet simultaneously with or immediately after forming is provided, the present invention may be applied to a forming method other than press forming, for example, roll forming. As long as the thermal history is as to described above, hot forming may be repeatedly performed. Furthermore, the series of heat treatment may be repeated a plurality of times.

[0198] As described above, the steel member according to the present embodiment includes both a formed body that is a steel sheet subjected to hot forming and a flat sheet that is subjected to only heat treatment.

[0199] Further, hot forming or heat treatment may be performed on a part of a steel sheet, which serves as a material, to obtain a steel member, which includes regions having different strengths, as the steel member according to the present embodiment.

[0200] The series of heat treatment can be performed by any method, and, for example, heating may be performed by high-frequency heating, energization heating, infrared heating, or furnace heating. Further, cooling may also be performed by water cooling, die cooling, or the like. City gas or nitrogen gas may be used for an atmosphere in a heating furnace in addition to the air. Furthermore, a dew point in the heating furnace may be controlled in order to suppress the generation of hydrogen during the heat treatment.

Examples

[0201] Steels having chemical compositions shown in Table 1A and Table 1B were melted to obtain slabs.

[0202] After hot rolling was performed on the obtained slabs to obtain hot-rolled steel sheets having a thickness of 3.2 mm and a sheet width of 1,000 mm, the hot-rolled steel sheets were coiled at a temperature of 800°C or lower to obtain hot-rolled coils having an outer diameter of 1,700 mm and a weight of 14 tons.

[0203] Light rolling reduction was performed on the obtained hot-rolled coils with rolling reductions shown in Table 2.

Table 1A]

Steel No.	Chemical composition (mass%) Remainder: Fe and impurities														
	C	Si	Mn	P	s	N	O	Ti	B	Cr	Mo	Ni	Nb	Cu	V	Ca
A1	0.12	1.41	2.22	0.041	0.0055	0.010	0.006		0.0054							
A2	0.60	0.33	0.15	0.002	0.0002	0.002	0.002	0.025	0.0023				0.02			
A3	0.45	2.51	0.89	0.011	0.0013	0.003	0.005		0.0012	0.20		0.20		0.45		
A4	0.42	0.51	0.08	0.014	0.0017	0.004	0.005		0.0021		0.18					
A5	0.28	0.28	2.53	0.003	0.0003	0.003	0.003	0.034	0.0005							
A6	0.28	0.28	0.56	0.078	0.0004	0.002	0.004		0.0023		0.22	0.04				
A7	0.30	0.30	0.58	0.006	0.0083	0.003	0.004	0.035	0.0003							
A8	0.29	0.45	0.82	0.007	0.0010	0.015	0.003		0.0033						0.16	
A9	0.31	0.29	0.48	0.011	0.0013	0.004	0.008		0.0034			0.06				
A10	0.14	0.08	2.10	0.018	0.0024	0.005	0.004	0.032	0.0024	0.18						
A11	0.21	0.21	1.32	0.015	0.0018	0.004	0.005	0.032	0.0022	0.21						
A12	0.30	0.21	1.22	0.005	0.0005	0.003	0.004	0.037	0.0020	0.42		0.01	0.05			
A13	0.34	0.39	0.66	0.008	0.0004	0.004	0.003	0.035	0.0026	0.09	0.18	0.08	0.04	0.28		
A14	0.34	0.52	0.62	0.008	0.0007	0.004	0.005	0.024	0.0021	0.38	0.21	0.40	0.05			
A15	0.33	0.22	1.20	0.005	0.0010	0.003	0.003	0.032	0.0022	0.22			0.05		0.02	
A16	0.49	0.40	0.28	0.008	0.0004	0.003	0.003	0.030	0.0024	0.11	0.19	0.07	0.03	0.35		
A17	0.48	0.43	0.41	0.006	0.0006	0.003	0.004	0.028	0.0022	0.32	0.21	0.06	0.02			0.005
a1	0.07	0.20	0.26	0.028	0.0044	0.006	0.006		0.0082							
a2	0.82	0.40	1.40	0.011	0.0012	0.005	0.004			0.28		0.01				
a3	0.15	0.15		0.015	0.0019	0.004	0.005									0.006
a4	0.41	0.65	3.44	0.016	0.0020	0.005	0.005	0.046			0.33					
as	0.38	0.72	1.12	0.017	0.0176	0.005	0.004									

[Table 1B]

Steel No.	Chemical composition (mass%) Remainder: Fe and impurities																Transformation point (°C)		Upper critical cooling rate (°C/s)
	Mg	Al	Sn	w	Sb	Zr	Se	Bi	As	Ta	Re	Os	Ir	Tc	Co	REM	Ac3	Ms	
A1																	902	421	30
A2																	784	316	10
A3						0.27									0.02		903	323	30
A4			0.05										0.13				831	388	30
A5	0.001	0.03		0.52												0.19	791	358	10
A6										0.41							860	423	30
A7							0.34					0.18					818	422	30
A8								0.25									825	417	30
A9												0.21		0.14			816	414	30
A10		003															812	435	20
A11		0.04															831	430	20
A12		0.03													0.01		794	386	20
A13		0.04															822	395	20
A14		0.04															826	384	10
A15		0.03	0.01														788	383	20
A16		0.03		0.41													801	337	20
A17																0.02	809	342	30
a1																	892	529	40
a2									0.55								659	168	10
a3																	848	508	100
a4		0.52									0.54						828	268	10
as	0.006				0.32												814	366	30

[Table 2]

	Steel sheet No.	Steel No.	Light rolling reduction	Steel sheet
			Rolling reduction	Crack density of scale
			(%)	(pieces/mm^2)
Invention Example	B1	A1	0.5	124
	B2	A2	0.7	138
	B3	A3	0.4	111
	B4	A4	0.4	114
	B5	A5	0.6	131
	B6	A6	0.6	134
	B7	A7	0.7	136
	B8	A8	0.5	123
	B9	A9	0.5	118
	B10	A10	0.5	120
	B11	A11	0.5	119
	B12	A12	0.5	127
	B13	A13	0.3	102
	B14	A13	0.5	129
	B15	A13	1.0	140
	B16	A14	0.6	126
	B17	A15	0.6	132
	B18	A16	0.3	102
	B19	A16	0.6	130
	B20	A16	1.2	139
	B21	A17	0.5	123
Comparative Example	b1	a1	1.0	143
	b2	a2	0.8	137
	b3	a3	2.6	141
	b4	a4	0.6	130
	b5	a5	0.6	127
	b6	A1	0.0	65
	b7	A2	0.0	52
	b8	A3	0.0	48
	b9	A4	0.0	67
	b10	A5	0.0	60
	b11	A6	0.1	75
	b12	A7	0.1	79
	b13	A8	0.1	82
	b14	A9	0.1	80
	b15	A1	14.5	

[0204] Steel sheets (blanks) having a predetermined size were cut out from the obtained coils having been subjected to light rolling reduction and were observed with SEM in the above-described manner, and the crack density of the scale of each steel sheet was evaluated.

[0205] Further, as a result of measuring the chemical compositions of the steel sheets at the 1/4-depth positions, the measured chemical compositions were the same as the chemical compositions of the slabs.

[0206] As shown in Table 2, steel sheets, each of which includes a base steel sheet having a predetermined chemical composition and a scale having a predetermined crack density, were obtained as steel sheets B1 to B21 satisfying the ranges of the present invention. On the other hand, results in which Comparative Examples b1 to b15 not satisfying the ranges of the present invention did not satisfy the chemical composition or the crack density of the scale were obtained.

[0207] Hot-rolled sheet annealing was performed on the steel sheets shown in Table 2 under conditions shown in Table 3A.

[0208] Further, pickling and cold rolling were performed on some steel sheets (C2 to C30 and c2 to c16) among the steel sheets subjected to the hot-rolled sheet annealing to obtain cold-rolled steel sheets having a thickness of 1.6 mm. Furthermore, hot-dip A1 plating or hot-dip Zn plating was performed on some (C4 to C22, C24 to C30, and c5 to c16) of the cold-rolled steel sheets.

[0209] Heat treatment was performed under the conditions shown in Table 3A on the hot-rolled steel sheets that were subjected to the hot-rolled sheet annealing, the cold-rolled steel sheets that were subjected to pickling, cold rolling, and annealing, or the cold-rolled steel sheets that were subjected to pickling, cold rolling, and annealing and subjected to plating during annealing (a cooling process after retaining). As a result, steel members were obtained. An Fe-Al-based alloy layer containing 70 mass% or more of Fe and Al in total or an Fe-Zn-based alloy layer containing 70 mass% or more of Fe and Zn in total were formed on the surfaces of the steel members, which were obtained in a case where the heat treatment was performed on the plated steel sheets, to have a thickness of 5 to 100 μm.

[0210] The obtained steel members were cut out, and GDS (glow discharge spectrometry) was performed in the above-described manner to obtain B concentration ratios and decarburization depths. Further, martensite volume percentages at the 1/4-depth position were measured. Results are shown in Table 3B.

[0211] Furthermore, a hardness test, a tensile test, and a bending test were performed for the obtained steel members and coated steel members by the following methods to evaluate the Vickers hardness, tensile strength, bendability, and hydrogen embrittlement resistance. Results are shown in Table 3B.

<Vickers hardness>

[0212] A sample for the observation of a cross section was collected from a 1/4 position of the width (short side) from a width-direction end portion of the steel member, and the Vickers hardness was measured at each of a 1/4-depth position and a 0.1 mm-depth position according to JIS Z 2244-1 :2020. A test force was set to 100 gf. The measurement was performed five times at each depth, and an average value of measured values was used as hardness at that position.

<Tensile strength>

[0213] A tensile test was performed according to the regulation of ASTM Standard E8. After a soaked portion of the steel member is ground to a thickness of 1.2 mm, a half-sized sheet-shaped test piece (the length of a parallel portion: 32 mm, a sheet width of the parallel portion: 6.25 mm) of ASTM standard E8 was collected such that a test direction was parallel to a rolling direction. Then, a strain gauge (gauge length: 5 mm, for example, FLAB-5 manufactured by Tokyo Measuring Instruments Laboratory Co., Ltd.) was attached to the center of the parallel portion of the test piece in a width direction and a length direction, and a room temperature-tensile test was performed at a strain rate of 3 mm/min to measure tensile strength (maximum strength).

[0214] In the present example, the test piece was evaluated to have high strength in a case where the test piece had a tensile strength of 1,000 MPa or more.

<Bendability>

[0215] A bending test piece having a length of 60 mm in a direction parallel to the rolling direction and a length of 30 mm in a direction perpendicular to the rolling direction was collected from a soaked portion of the steel member, and a bending test was performed for this test piece according to the regulation of DA238-100.

[0216] In the test, a bending punch was aligned perpendicular to the rolling direction and a bending angle at the maximum load was measured.

[0217] A bending angle has a correlation with strength. Accordingly, in the present example, the test piece was evaluated as more excellent in bendability than that in the related art in each tensile strength, specifically, in a case where the test piece had a bending angle of more than 70 degrees at a tensile strength of less than 1,500 MPa, in a case where the test piece had a bending angle of more than 55 degrees at a tensile strength of 1,500 MPa or more and less than 2,100

MPa, and in a case where the test piece had a bending angle of more than 45 degrees at a tensile strength of 2,100 MPa or more.

<Hydrogen embrittlement resistance>

[0218] A four-point bending test was performed for a test piece, and hydrogen embrittlement resistance was evaluated on the basis of the amount Hc of hydrogen that could be stored in the test piece until a limit where no cracking occurred. Specifically, a strip-shaped test piece having a width of 8 mm and a length of 68 mm was cut out as a test piece while avoiding an end portion of the steel member to be evaluated. Then, after the same strain gauge (gauge length: 5 mm, for example, FLAB-5 manufactured by Tokyo Measuring Instruments Laboratory Co., Ltd.) as that used in the tensile test was attached to the center of the surface of the test piece in a width direction and a length direction, the test piece was bent along the longitudinal direction of the test piece with a four-point support jig until strain corresponding to 3/5 of the tensile strength measured in the above-described tensile test for the steel member to be evaluated. A jig in which an interval between inner pins (two load application points provided on the inside) was 10 mm and an interval between outer pins (two fulcrums provided on the outside) was 60 mm was used as the jig.

[0219] For a plurality of test pieces in which the amounts of stored hydrogen (the amounts of hydrogen storage) were different, the presence or absence of cracking was observed and the maximum (limit) amount Hc of hydrogen (mass ppm) at which no cracking occurred was obtained. In a case of a steel member including an Fe-Al-based coating, the amount of hydrogen storage was changed by changing a dew point in the furnace in the heat treatment step and whether or not cracking occurred within 72 hours after a four-point bending test was observed. Further, in a case of a steel member without a coating or a steel member including an Fe-Zn-based coating, a plurality of test pieces were immersed in ammonium thiocyanate solutions having different concentrations after a four-point bending test to store hydrogen, and whether or not cracking occurred within 72 hours after the immersion was observed. The 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.

[0220] In the present example, the steel member was evaluated as excellent in hydrogen embrittlement resistance in a case where the amount Hc of hydrogen was 0.7 mass ppm or more in a steel member having a tensile strength equal to or higher than 1,500 and less than 2,000 MPa, in a case where the amount Hc of hydrogen was 0.5 mass ppm or more in a steel member having a tensile strength equal to or higher than 2,000 and less than 2,500 MPa, and in a case where the amount Hc of hydrogen was 0.3 mass ppm or more in a steel member having a tensile strength of 2,500 MPa or more.

[0221] In addition, the maximum principal plastic strain at the center of the outside bend surface layer was obtained using a finite element method in the above-described manner.

[Table 3A]

		Steel sheet			Hot-rolled sheet annealing			Annealing					Heat treatment				
	Symbol	Steel No.	Steel sheet No.	Crack density of scale	Atmosphere	Annealing temperature	Retention time	Oxygen potential of atmosphere	Oxygen concentration of atmosphere	Dew point of atmosphere	Annealing temperature	Retention time	Temperature rising rate	Heating temperature	Retention time	Cooling rate	Cooling stop temperature
				(pieces/mm^2)	-	(°C)	(hr)	-	(mass%)	(°C)	(°C)	(sec.)	(°C/s)	(°C)	(sec.)	(°C/s)	(°C)
Invention Example	C1	A1	B1	124	nitrogen	700	10	-	-	-	-	-	3	920	30	50	50
	C2	A2	B2	138	nitrogen	700	10	-	-	-	-	-	3	920	30	50	50
	C3	A3	B3	111	nitrogen	700	10	-	-	-	-	-	3	920	30	50	50
	C4	A4	B4	114	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	C5	A5	B5	131	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	C6	A6	B6	134	hydrogen	700	10	-3.71	10	-50	770	15	3	920	10	50	50
	C7	A7	B7	136	hydrogen	700	10	-3.71	10	-50	770	15	3	920	10	50	50
	C8	A8	B8	123	hydrogen	700	10	-3.71	10	-50	770	15	3	920	10	50	50
	C9	A9	B9	138	hydrogen	700	10	-3.71	10	-50	770	15	3	920	10	50	50
	C10	A10	B10	120	nitrogen	700	10	-3.71	10	-50	770	15	3	920	120	50	50
	C11	A11	B11	119	nitrogen	700	10	-3.71	10	-50	770	15	3	920	120	50	50
	C12	A12	B12	127	nitrogen	700	10	-3.71	10	-50	770	15	3	920	120	50	50
	C13	A13	B13	102	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C14	A13	B14	129	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C15	A13	B15	140	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C16	A13	B15	140	nitrogen	700	10	-1.22	10	0	770	60	3	920	90	50	50
	C17	A14	B16	126	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C18	A15	B17	132	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C19	A16	B18	102	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C20	A16	B19	130	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C21	A16	B20	139	nitrogen	700	10	-3.71	10	-50	770	15	3	920	90	50	50
	C22	A16	B20	139	nitrogen	700	10	-1.22	10	0	770	60	3	920	90	50	50
	C23	A17	B21	123	nitrogen	700	10	-	-	-	-	-	3	920	90	50	50
	C24	A13	B15	140	nitrogen	670	25	-3.71	10	-50	770	15	3	920	90	50	50
	C25	A13	B15	140	nitrogen	890	6	-3.71	10	-50	770	15	3	920	90	50	50
	C26	A16	B20	139	nitrogen	670	25	-3.71	10	-50	770	15	3	920	90	50	50
	C27	A16	B20	139	nitrogen	890	6	-3.71	10	-50	770	15	3	920	90	50	50
	C28	A13	B15	140	nitrogen	700	10	-1.22	20	10	770	60	3	920	90	50	50
	C29	A13	B15	140	nitrogen	700	10	-0.70	3	0	740	60	3	920	90	50	50
	C30	A13	B15	140	nitrogen	700	10	-1.07	3	-10	820	30	3	920	90	50	50
Comparative Example	c1	a1	b1	143	nitrogen	700	10	-	-	-	-	-	3	920	5	50	50
	c2	a2	b2	137	nitrogen	700	10	-	-	-	-	-	3	920	5	50	50
	c3	a3	b3	141	nitrogen	700	10	-	-	-	-	-	3	920	5	50	50
	c4	a4	b4	130	nitrogen	700	10	-	-	-	-	-	3	920	5	50	50
	c5	a5	b5	127	hydrogen	700	10	-3.71	10	-50	770	15	3	920	240	50	50
	c6	A1	b6	65	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	c7	A2	b7	52	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	c8	A3	b8	48	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	c9	A4	b9	67	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	c10	A5	b10	60	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	c11	A6	b11	75	hydrogen	700	10	-3.71	10	-50	770	15	3	920	0	50	50
	c12	A7	b12	79	hydrogen	700	10	-3.71	10	-50	770	15	3	920	0	50	50
	c13	A8	b13	82	hydrogen	700	10	-3.71	10	-50	770	15	3	920	0	50	50
	c14	A9	b14	80	hydrogen	700	10	-3.71	10	-50	770	15	3	920	0	50	50
	c15	A1	b15	-	nitrogen	700	10	-3.71	10	-50	770	15	3	920	30	50	50
	c16	A2	b7	52	nitrogen	-	-	-3.71	10	-50	770	15	3	920	30	50	50

[Table 3B]

Symbol	Steel member											
	Maximum B content in surface layer	B concentration ratio	Decarburization depth	Alloy layer (coating)	Volume percentage of martensite at 1/4-depth position (%)	The maximum principal plastic strain at center of outside bend surface layer	Hardness at 0.1 mm-depth position (HV)	Hardness at 1/4-depth position (HV)	Hardness at 0.1 mm-depth position/ Hardness at 1/4-depth position	Tensile strength	Bending angle	Hc
	(%)		(µm)							(MPa)	(°)	(mass ppm)
C1	0.0432	8	132	-	100	0.337	352	403	0.87	1344	112	1.2
C2	0.0207	9	149	-	90	0.249	695	862	0.81	2993	49	0.4
C3	0.0084	7	110	-	95	0.251	612	765	0.80	2635	54	0.5
C4	0.0252	12	64	Fe-Al	98	0.275	588	692	0.85	2382	64	0.9
C5	0.0070	14	85	Fe-Al	94	0.276	511	597	0.86	2035	64	0.7
C6	0.0322	14	82	Fe-Al	98	0.275	461	539	0.86	1831	70	0.8
C7	0.0039	13	83	Fe-Al	97	0.275	480	564	0.85	1908	67	0.8
C8	0.0429	13	75	Fe-Zn	97	0.275	479	559	0.86	1903	70	0.8
C9	0.0442	13	91	Fe-Zn	96	0.276	492	573	0.86	1948	72	0.8
C10	0.0312	13	72	Fe-Al	98	0.329	379	416	0.91	1380	109	1.0
C11	0.0264	12	70	Fe-Al	96	0.302	418	476	0.88	1609	95	1.2
C12	0.0280	14	77	Fe-Al	98	0.273	498	581	0.86	1971	74	0.8
C13	0.0312	12	70	Fe-Al	99	0.270	528	614	0.86	2094	66	0.9
C14	0.0338	13	138	Fe-Al	99	0.268	512	610	0.84	2085	80	1.0
C15	0.0390	15	151	Fe-Al	99	0.266	504	607	0.83	2072	90	1.2
C16	0.0390	15	178	Fe-Al	99	0.265	495	607	0.82	2066	93	1.2
C17	0.0252	12	81	Fe-Al	99	0.272	526	613	0.86	2080	69	0.7
C18	0.0308	14	86	Fe-Zn	100	0.270	520	617	0.84	2100	71	0.7
C19	0.0264	11	72	Fe-Al	96	0.254	642	779	0.82	2671	50	0.5
C20	0.0288	12	140	Fe-Al	96	0.253	623	767	0.81	2620	57	0.6
C21	0.0336	14	150	Fe-Al	96	0.253	613	754	0.81	2598	66	0.7
C22	0.0336	14	172	Fe-Al	96	0.252	597	754	0.79	2581	70	0.8
C23	0.0154	7	250	-	95	0.251	575	770	0.75	2652	60	0.6
C24	0.0340	13	139	Fe-Al	99	0.268	515	609	0.85	2086	81	1.0
C25	0.0364	14	143	Fe-Al	99	0.267	510	609	0.84	2084	83	1.0
C26	0.0288	12	141	Fe-Al	96	0.253	622	760	0.82	2609	59	0.6
C27	0.0314	13	143	Fe-Al	96	0.253	620	760	0.82	2608	60	0.6
C28	0.0390	15	178	Fe-Al	99	0.265	495	607	0.82	2066	93	1.2
C29	0.0390	15	180	Fe-Al	99	0.265	495	607	0.82	2066	93	1.2
C30	0.0390	15	175	Fe-Al	99	0.265	497	607	0.82	2070	92	1.2
c1	0.0738	9	150	-	100	0.373	82	263	0.31	834	125	1.2
c2	-	-	142	-	89	0.256	780	926	0.84	3221	32	0.0
c3	-	-	151	-	48	0.378	70	225	0.31	698	125	1.2
c4	-	-	139	-	94	0.251	633	780	0.81	2697	39	0.1
c5	-	-	70	Fe-Al	99	0.277	582	674	0.86	2315	42	0.3
c6	0.0108	2	10	Fe-Al	100	0.348	400	402	1.00	1334	62	1.2
c7	0.0046	2	3	Fe-Al	90	0.271	860	862	1.00	2993	15	0.1
c8	0.0012	1	0	Fe-Al	95	0.273	763	763	1.00	2638	21	0.2
c9	0.0021	1	4	Fe-Zn	98	0.295	690	693	1.00	2384	28	0.4
c10	0.0005	1	4	Fe-Zn	94	0.297	590	596	0.99	2040	39	0.4
c11	0.0046	2	8	Fe-Zn	98	0.288	530	539	0.98	1830	44	0.5
c12	0.0003	1	8	Fe-Zn	97	0.289	555	561	0.99	1908	40	0.6
c13	0.0066	2	10	Fe-Zn	97	0.292	558	560	1.00	1905	40	0.6
c14	0.0034	1	8	Fe-Zn	96	0.291	560	570	0.98	1939	41	0.5
c15	0.0054	1	0	Fe-Al	100	0.350	400	402	1.00	1336	60	1.2
c16	0.0023	1	0	Fe-Al	90	0.273	862	862	1.00	2993	15	0.1

[0222] As shown in Tables 1 to 3B, the invention examples C1 to C30 satisfying the ranges of the present invention had good results in both a structure and characteristics, and had high strength, excellent bendability, and excellent hydrogen embrittlement resistance. On the other hand, Comparative examples c1 to c16 not satisfying the ranges of the present invention are insufficient in terms of a chemical composition and the formation of a structure and were inferior in at least one of strength, bendability, or hydrogen embrittlement resistance, or any combination thereof were inferior.

Industrial Applicability

[0223] According to the present invention, it is possible to obtain a steel member and a steel sheet that have high strength and excellent collision characteristics. The steel member according to the present invention is particularly suitable to be used as a frame component of a vehicle.

Claims

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

   C: 0.10% to 0.70%;
   Si: 3.00% or less;
   Mn: 0.01% to 3.00%;
   P: 0.100% or less;
   S: 0.0100% or less;
   N: 0.020% or less;
   O: 0.010% or less;
   B: 0.0002% to 0.0200%;
   Ti: 0% to 0.200%;
   Cr: 0% to 1.00%;
   Mo: 0% to 1.00%;
   Ni: 0% to 2.00%;
   Nb: 0% to 0.10%;
   Cu: 0% to 2.00%;
   V: 0% to 1.00%;
   Ca: 0% to 0.020%;
   Mg: 0% to 0.020%;
   Al: 0% to 1.00%;
   Sn: 0% to 1.00%;
   W: 0% to 2.00%;
   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, in a case where a position corresponding to a depth of 1/4 of a thickness from a surface in a thickness direction is defined as a 1/4-depth position, a maximum B content in a range to a depth of 10 μm from the surface in the thickness direction is 5 times or more a B content at the 1/4-depth position,
   in a case where a C content is measured from the surface in the thickness direction using GDS and a distance from the surface to a position where the C content is equal to a C content at the 1/4-depth position for the first time is defined as a decarburization depth, the decarburization depth is 20 μm or more, and
   a Vickers hardness at the 1/4-depth position is in a range of 310 to 890.

2. The steel member according to claim 1,
   wherein, in a case where a position corresponding to a depth of 0.1 mm from the surface in the thickness direction is defined as a 0.1 mm-depth position, Vickers hardness at the 0.1 mm-depth position is 0.95 times or less the Vickers hardness at the 1/4-depth position.

3. The steel member according to claim 2,

   wherein the Vickers hardness at the 1/4-depth position is in a range of 310 to 450, and
   in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, a maximum principal plastic strain at a center of an outside bend surface layer is 0.340 or less.

4. The steel member according to claim 2,

wherein the Vickers hardness at the 1/4-depth position is more than 450 and 530 or less, and the Vickers hardness at the 0.1 mm-depth position is 0.90 times or less the Vickers hardness at the 1/4-depth position, and
in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, a maximum principal plastic strain at a center of an outside bend surface layer is 0.310 or less.

5. The steel member according to claim 2,

wherein the Vickers hardness at the 1/4-depth position is more than 530 and 700 or less, and the Vickers hardness at the 0.1 mm-depth position is 0.88 times or less the Vickers hardness at the 1/4-depth position, and
in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, a maximum principal plastic strain at a center of an outside bend surface layer is 0.280 or less.

6. The steel member according to claim 2,

wherein the Vickers hardness at the 1/4-depth position is more than 700 and 890 or less, and the Vickers hardness at the 0.1 mm-depth position is 0.86 times or less the Vickers hardness at the 1/4-depth position, and
in a case where a steel member having a sheet thickness of 1.6 mm is deformed up to a bending angle of 50 degrees, a maximum principal plastic strain at a center of an outside bend surface layer is 0.260 or less.

7. The steel member according to any one of claims 1 to 6,
wherein an alloy layer is further provided on the surface.

8. The steel member according to claim 7,
wherein the alloy layer is an Fe-Al-based alloy layer.

9. The steel member according to claim 7,
wherein the alloy layer is an Fe-Zn-based alloy layer.

10. A steel sheet comprising:

a base steel sheet; and
an iron scale that is formed on a surface of the base steel sheet,
wherein the base steel sheet contains, as a chemical composition, by mass%,

C: 0.10% to 0.70%,
Si: 3.00% or less,
Mn: 0.01% to 3.00%,
P: 0.100% or less,
S: 0.0100% or less,
N: 0.020% or less,
O: 0.010% or less,
B: 0.0002% to 0.0200%,
Ti: 0% to 0.200%,
Cr: 0% to 1.00%,
Mo: 0% to 1.00%,
Ni: 0% to 2.00%,
Nb: 0% to 0.10%,
Cu: 0% to 2.00%,
V: 0% to 1.00%,
Ca: 0% to 0.020%,
Mg: 0% to 0.020%,
Al: 0% to 1.00%,
Sn: 0% to 1.00%,
W: 0% to 2.00%,
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, and

the iron scale includes cracks at a density of 90 pieces/mm^2 or more.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/013175

A. CLASSIFICATION OF SUBJECT MATTER

C21D 9/00(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/60***(2006.01)i; ***C21D 1/18***(2006.01)i
FI: C22C38/00 301Z; C22C38/00 301S; C22C38/00 301W; C22C38/60; C21D9/46 T; C21D9/46 G; C21D9/00 A; C21D1/18 C; C22C38/00 301A

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)

C21D9/00; C21D9/46; C22C38/00-38/60; C21D1/18

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

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021/117989 A1 (HYUNDAI STEEL COMPANY) 17 June 2021 (2021-06-17) paragraphs [0131]-[0153]	10
Y		10
A		1-9
Y	JP 2011-202231 A (NISSHIN STEEL CO LTD) 13 October 2011 (2011-10-13) paragraphs [0002]-[0005]	10
Y	JP 2014-136824 A (NISSHIN STEEL CO LTD) 28 July 2014 (2014-07-28) paragraphs [0002]-[0003]	10
A	JP 2004-346416 A (KOBE STEEL LTD) 09 December 2004 (2004-12-09) entire text	10
A	JP 2013-237101 A (KOBE STEEL LTD) 28 November 2013 (2013-11-28) entire text	10

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search **24 May 2023**	Date of mailing of the international search report **06 June 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/013175

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2011-236483 A (SUMITOMO METAL IND LTD) 24 November 2011 (2011-11-24) entire text	10
A	JP 2006-161064 A (SUMITOMO METAL IND LTD) 22 June 2006 (2006-06-22) entire text	1-10
A	WO 2021/255858 A1 (NIPPON STEEL CORPORATION) 23 December 2021 (2021-12-23) entire text	1-10
A	WO 2021/019947 A1 (JFE STEEL CORPORATION) 04 February 2021 (2021-02-04) entire text	1-10
A	JP 2012-514133 A (POSCO) 21 June 2012 (2012-06-21) entire text	1-10
A	JP 2021-155790 A (NIPPON STEEL CORPORATION) 07 October 2021 (2021-10-07) entire text	1-10

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/013175

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

The common matter between the inventions in claims 1-9 and the invention in claim 10 is only a component composition. However, the component composition is disclosed in WO 2021/117989 A1 or the like and thus is not a special technical feature. Thus, the number of inventions included in claims is two as below.

The invention in claims 1-9 satisfies all matters specifying claim 1, and are thus classified as invention 1.

The invention in claim 10 does not have any specific matters of claim 1 other than the component composition and is thus classified as invention 2.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☑ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/013175

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