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(54) **STEEL SHEET AND METHOD FOR PRODUCING SAME**

(57) This steel sheet has a predetermined chemical composition, a tensile strength is 780 MPa or greater, a total of the area ratio of ferrite and an area ratio of bainite is 10% or greater and 90% or less, a total of an area ratio of martensite and an area ratio of tempered martensite is 10% or greater and 90% or less, and a total of an area ratio of pearlite and an area ratio of residual austenite is 0% or greater and 10% or less, a number proportion of crystal grains of ferrite and bainite having an area of 6 μm^2 or less is 40% or greater to a total number of crystal grains of the ferrite and the bainite, and a number proportion of crystal grains of ferrite and bainite having an area of 50 μm^2 or greater is 5% or less to the total number of crystal grains of the ferrite and the bainite, and a maximum Mn content in a region up to 0.5 pm from an interface between the ferrite and the martensite or the tempered martensite, in a direction perpendicular to the interface and toward an inside of the ferrite grains, is 0.30 mass% or more lower than an average Mn content of the steel sheet

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Description

[Technical Field of the Invention]

[0001] The present invention relates to a steel sheet and a method for producing the steel sheet.
[0002] Priority is claimed on Japanese Patent Application No. 2021-122923, filed on July 28, 2021, the content of which is incorporated herein by reference.

[Related Art]

[0003] In recent years, vehicle manufacturers have also actively developed techniques for reducing the weight of vehicle bodies for the purpose of reducing fuel consumption. In a case where the weight of steel to be used is reduced, for example, by reducing the sheet thickness of a steel sheet, it is possible to easily reduce the weight of vehicle bodies. However, for vehicles, improving collision resistance is also emphasized in order to secure occupant's safety. Accordingly, reducing the weight of vehicle bodies by simply reducing the weight of steel used cannot be adopted, and therefore it is not easy to reduce the weight of vehicle bodies. Therefore, studies are underway to reduce thickness of members using high strength steel sheets in order to satisfy both weight reduction in vehicle bodies and collision resistance. Meanwhile, steel sheets to be applied to vehicle components are formed into component shapes. However, in a case where the steel sheets have an increased strength, their formability usually deteriorates. Therefore, steel sheets to be applied to vehicle components are strongly desired to have both a high strength and excellent formability.
[0004] As such a high strength steel sheet, for example, Patent Document 1 discloses a high strength TRIP steel sheet that is a steel sheet having excellent elongation, hole expansibility, bending workability, and delayed fracture resistance property, the steel sheet including, as a composition, by mass%, C: 0.15% to 0.25%, Si: 1.00% to 2.20%, Mn: 2.00% to 3.50%, P: 0.05% or less, S: 0.005% or less, Al: 0.01% to 0.50%, N: 0.010% or less, B: 0.0003% to 0.0050%, one or more selected from Ti: 0.005% to 0.05%, Cu: 0.003% to 0.50%, Ni: 0.003% to 0.50%, Sn: 0.003% to 0.50%, Co: 0.003% to 0.05%, and Mo: 0.003% to 0.50%, and a remainder consisting of Fe and unavoidable impurities, in which a microstructure contains 15% or less (including 0%) of ferrite having an average grain size of 2 μm or less by volume fraction, 2% to 15% of residual austenite having an average grain size of 2 μm or less by volume fraction, 10% or less (including 0%) of martensite having an average grain size of 3 μm or less by volume fraction, a remainder consisting of bainite and tempered martensite having an average grain size of 6 μm or less, and on average, 10 or more cementite grains having a grain size of 0.04 μm or greater are contained in bainite and tempered martensite grains.
[0005] Patent Document 2 discloses a high strength cold-rolled steel sheet that is a steel sheet having both a high strength of 980 MPa or greater in terms of tensile strength (TS) and excellent bendability, the steel sheet having a specific composition and a specific steel structure in which the area ratio of ferrite is 30% or greater and 70% or less, the area ratio of martensite is 30% or greater and 70% or less, the average grain size of ferrite grains is 3.5 μm or less, a standard deviation of grain sizes of the ferrite grains is 1.5 μm or less, the average aspect ratio of the ferrite grains is 1.8 or less, the average grain size of martensite grains is 3.0 μm or less, and the average aspect ratio of the martensite grains is 2.5 or less, in which a tensile strength is 980 MPa or greater.
[0006] Patent Document 3 discloses a high strength steel sheet that is a steel sheet that has a yield strength (YS) of 780 MPa or greater and a tensile strength (TS) of 1,180 MPa or greater, and is excellent in spot weldability, ductility, and bending workability, in which a C content is 0.15% or less, the area ratio of ferrite is 8% to 45%, the area ratio of martensite is 55% to 85%, a ratio of martensite adjacent only to ferrite is 15% or less in a total structure, the average grain size of ferrite and martensite is 10 μm or less, and the area ratio of ferrite having a grain size of 10 μm or greater is less than 5% in ferrite present in a range from a depth of 20 μm to a depth of 100 μm from a steel sheet surface.
[0007] Patent Document 4 discloses a high strength cold-rolled steel sheet that is a steel sheet having a small variation in mechanical properties (strength and ductility in particular), the steel sheet including, as a composition, by mass%, C: 0.10% to 0.25%, Si: 0.5% to 2.0%, Mn: 1.0% to 3.0%, P: 0.1% or less, S: 0.01% or less, Al: 0.01% to 0.05%, N: 0.01% or less, and a remainder consisting of iron and unavoidable impurities, in which a structure containing, by area ratio, 20% to 50% of ferrite as a soft first phase, and a remainder consisting of tempered martensite and/or tempered bainite as a hard second phase is provided, a total area of ferrite grains having an average grain size of 10 to 25 μm occupies 80% or greater of a total area of all the ferrite grains, the number of cementite grains dispersed, that are present in all the ferrite grains and have a circle equivalent diameter of 0.3 μm or greater, is greater than 0.15 and 1.0 or less per 1 μm^2 of the ferrite, and a tensile strength is 980 MPa or greater.

[Prior Art Document]

[Patent Document]

[0008]

[Patent Document 1] PCT International Publication No. WO2017/179372
[Patent Document 2] PCT International Publication No. WO2016/194272
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2015-117404
[Patent Document 4] Japanese Unexamined Patent Application, First Publication No. 2013-245397

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0009] In many cases, steel sheets to be used for vehicle components or the like are formed by pressing, punching, or the like when being formed into components.
[0010] In recent years, press forming conditions have become stricter, and a strain amount exceeding uniform elongation is often introduced to a forming part. Although Patent Documents 1 to 4 mention increasing the strength and having good ductility and bendability, there is no mention about the suppression of crack occurrence in a case where press forming is performed under such strict conditions, and there is room for improvement.
[0011] Therefore, an object of the present invention is to provide a steel sheet in which it is possible to suppress crack occurrence during press forming (excellent fracture resistance) even in a case where a strain amount exceeding uniform elongation is introduced and a method for producing the steel sheet.

[Means for Solving the Problem]

[0012] The present inventors have conducted studies on a method of suppressing crack occurrence (of obtaining excellent fracture resistance) in a case where a strain amount exceeding uniform elongation is introduced to a steel sheet containing: ferrite and/or bainite; and martensite and/or tempered martensite. As a result, it has been found that it is possible to suppress crack occurrence during press forming as long as a state in which the true stress is high can be maintained even with a strain amount equal to or greater than uniform elongation.
[0013] The present invention has been contrived in view of the above problems. The gist of the present invention is as follows.

[1] A steel sheet according to an aspect of the present invention includes, as a chemical composition, by mass%: C: 0.07% to 0.15%; Si: 0.01% to 2.00%; Mn: 1.5% to 3.0%; P: 0% to 0.020%; S: 0% to 0.0200%; Al: 0.001% to 1.000%; N: 0% to 0.0200%; O: 0% to 0.0200%; Co: 0% to 0.500%; Ni: 0% to 1.000%; Cu: 0% to 0.500%; Mo: 0% to 1.000%; Cr: 0% to 2.000%; Ti: 0% to 0.5000%; Nb: 0% to 0.50%; V: 0% to 0.500%; W: 0% to 0.100%; Ta: 0% to 0.100%; B: 0% to 0.0100%; Mg: 0% to 0.050%; Ca: 0% to 0.050%; Zr: 0% to 0.050%; REM: 0% to 0.100%; Sn: 0% to 0.050%; Sb: 0% to 0.050%; As: 0% to 0.050%; and a remainder: Fe and impurities, a tensile strength is 780 MPa or greater, in a microstructure, an area ratio of ferrite is 5% or greater, a total of the area ratio of ferrite and an area ratio of bainite is 10% or greater and 90% or less, a total of an area ratio of martensite and an area ratio of tempered martensite is 10% or greater and 90% or less, and a total of an area ratio of pearlite and an area ratio of residual austenite is 0% or greater and 10% or less, a number proportion of crystal grains of ferrite and bainite having an area of 6 μm^2 or less is 40% or greater to a total number of crystal grains of the ferrite and the bainite, and a number proportion of crystal grains of ferrite and bainite having an area of 50 μm^2 or greater is 5% or less to the total number of crystal grains of the ferrite and the bainite, and a maximum Mn content in a region up to 0.5 μm from an interface between the ferrite and the martensite or the tempered martensite, in a direction perpendicular to the interface and toward an inside of the ferrite grains, is 0.30 mass% or more lower than an average Mn content of the steel sheet.
[2] In the steel sheet according to [1], the average aspect ratio of the crystal grains of the ferrite and the bainite having an area of 6 μm^2 or less may be 1.0 or greater and 2.0 or less.
[3] In the steel sheet according to [1] or [2], a coating layer containing zinc, aluminum, magnesium, or an alloy of these metals may be provided on a surface.
[4] A method for producing a steel sheet according to another aspect of the present invention includes: hot-rolling a slab to obtain a hot-rolled steel sheet, the slab including, as a chemical composition, by mass%, C: 0.07% to 0.15%, Si: 0.01% to 2.00%, Mn: 1.5% to 3.0%, P: 0% to 0.020%, S: 0% to 0.0200%, Al: 0.001% to 1.000%, N: 0%

to 0.0200%, O: 0% to 0.0200%, Co: 0% to 0.500%, Ni: 0% to 1.000%, Cu: 0% to 0.500%, Mo: 0% to 1.000%, Cr: 0% to 2.000%, Ti: 0% to 0.5000%, Nb: 0% to 0.50%, V: 0% to 0.500%, W: 0% to 0.100%, Ta: 0% to 0.100%, B: 0% to 0.0100%, Mg: 0% to 0.050%, Ca: 0% to 0.050%, Zr: 0% to 0.050%, REM: 0% to 0.100%, Sn: 0% to 0.050%, Sb: 0% to 0.050%, As: 0% to 0.050%, and a remainder: Fe and impurities; cooling the hot-rolled steel sheet to a coiling temperature of 650°C or lower and 450°C or higher at an average cooling rate of 30 °C/sec or higher, and coiling the hot-rolled steel sheet at the coiling temperature; holding the hot-rolled steel sheet after the coiling so that a holding time in a temperature range from the coiling temperature to the coiling temperature - 50°C is 2 to 8 hours; cooling the hot-rolled steel sheet after the holding to a temperature of 300°C or lower at an average cooling rate of 0.1 °C/sec or higher; cold-rolling the hot-rolled steel sheet after the cooling at a ratio of sheet thickness reduction of 20% to 80% to obtain a cold-rolled steel sheet; and annealing the cold-rolled steel sheet by heating the cold-rolled steel sheet to an annealing temperature of 740°C to 900°C at an average temperature rising rate of 5 °C/sec or higher and holding the cold-rolled steel sheet at the annealing temperature for 60 to 300 seconds, and in the hot rolling, finish rolling is performed using a rolling mill having four or more stands, and in a case where an initial stand is defined as a first stand and a final stand is defined as an n-th stand, a ratio of sheet thickness reduction in each of stands ranging from an (n-3)-th stand to the n-th stand is set to 30% or greater, and a rolling temperature in the n-th stand is set to 900°C or lower.

[5] In the method for producing a steel sheet according to [4], in the annealing, a coating layer containing zinc, aluminum, magnesium, or an alloy of these metals may be formed on a surface of the steel sheet.

[Effects of the Invention]

[0014] According to the aspects of the present invention, it is possible to provide a steel sheet having excellent fracture resistance and a method for producing the steel sheet.

[Brief Description of the Drawings]

[0015] FIG. 1 is a diagram explaining a method of obtaining $\Delta\sigma$.

[Embodiments of the Invention]

[0016] Hereinafter, a steel sheet according to an embodiment of the present invention (a steel sheet according to the present embodiment) and a method for producing the steel sheet will be described.

<Steel Sheet>

[0017] A steel sheet according to the present embodiment has a predetermined chemical composition to be described below, a tensile strength is 780 MPa or greater, in a microstructure, the area ratio of ferrite is 5% or greater, the total of the area ratio of ferrite and an area ratio of bainite is 10% or greater and 90% or less, the total of the area ratio of martensite and an area ratio of tempered martensite is 10% or greater and 90% or less, and the total of an area ratio of pearlite and the area ratio of residual austenite is 0% or greater and 10% or less, the number proportion of crystal grains of ferrite and bainite having an area of 6 μm^2 or less is 40% or greater to a total number of crystal grains of the ferrite and the bainite, and a number proportion of crystal grains of ferrite and bainite having an area of 50 μm^2 or greater is 5% or less to the total number of crystal grains of the ferrite and the bainite, and the maximum Mn content in a region up to 0.5 μm from an interface between the ferrite and the martensite or the tempered martensite in a direction perpendicular to the interface and toward the inside of the ferrite grains is 0.30 mass% or more lower than the average Mn content of the steel sheet.

[Chemical Composition]

[0018] The amount of each element constituting the chemical composition and the reason for the limitation will be described. In the present embodiment, the symbol % indicating the amount of each element means mass%. In addition, numerical values at both ends of a range, with "to" in between, are included as a lower limit and an upper limit. For example, "0.07% to 0.15%" indicates "0.07% or greater and 0.15% or less".

C: 0.07% to 0.15%

[0019] C is an element necessary to secure a predetermined amount of martensite and to improve the strength of the steel sheet. In a case where the C content is less than 0.07%, it is difficult to obtain a predetermined amount of martensite, and a tensile strength of 780 MPa or greater cannot be secured. Therefore, the C content is set to 0.07% or greater. The C content is preferably 0.09% or greater.

[0020] On the other hand, in a case where the C content is greater than 0.15%, the formation of ferrite is suppressed, resulting in a decrease in elongation and a deterioration in ductility of a punched end surface. Therefore, the C content is set to 0.15% or less. The C content is preferably 0.13% or less.

Si: 0.01% to 2.00%

[0021] Si has a function of increasing the strength of the steel sheet as a solid solution strengthening element, and is an effective element for obtaining a structure containing martensite, bainite, residual γ, and the like. In order to obtain the above effects, the Si content is set to 0.01% or greater. The Si content may be set to 0.10% or greater.

[0022] On the other hand, in a case where the Si content is greater than 2.00%, the press formability deteriorates, the chemical convertibility decreases, or the ductility of a punched end surface deteriorates. Therefore, the Si content is set to 2.00% or less. In a case where hot-dip galvanizing is performed, problems such as a decrease in plating adhesion and a decrease in productivity due to a delay of alloying reaction occur. Therefore, the Si content is preferably set to 1.20% or less.

Mn: 1.5% to 3.0%

[0023] Mn is an element that contributes to an improvement in strength of the steel sheet. In addition, Mn is an element acting to suppress ferritic transformation that occurs during a heat treatment in a continuous annealing facility or a continuous hot-dip galvanizing facility. In a case where the Mn content is less than 1.5%, these effects are not sufficiently exhibited, whereby ferrite exceeding a required area ratio is formed and a tensile strength of 780 MPa or greater cannot be obtained. Therefore, the Mn content is set to 1.5% or greater. The Mn content is preferably 1.7% or greater, and more preferably 1.9% or greater.

[0024] On the other hand, in a case where the Mn content is greater than 3.0%, ferritic transformation is excessively suppressed, it is not possible to secure a predetermined amount of ferrite, and the elongation decreases. Therefore, the Mn content is set to 3.0% or less. The Mn content is preferably 2.7% or less.

P: 0% to 0.020%

[0025] P is an impurity element, and is an element that segregates in a sheet thickness center part of the steel sheet and causes a decrease in toughness. In addition, P is an element that causes embrittlement of a welded part in a case where the steel sheet is welded. In a case where the P content is greater than 0.020%, the strength of a welded part, the hole expansibility, and the ductility of a punched end surface significantly decrease. Therefore, the P content is set to 0.020% or less. The P content is preferably 0.010% or less.

[0026] The P content is preferably as small as possible and may be 0%. However, in a case where the P content is reduced to less than 0.0001 % in a practical steel sheet, the production cost increases significantly, which is economically disadvantageous. Therefore, the P content may be set to 0.0001% or greater.

S: 0% to 0.0200%

[0027] S is an impurity element, and is an element that decreases weldability and also decreases producibility during casting and hot rolling. In addition, S is also an element that forms coarse MnS, thereby decreasing hole expansibility. In a case where the S content is greater than 0.0200%, the weldability, the hole expansibility, and the ductility of a punched end surface significantly decrease. Therefore, the S content is set to 0.0200% or less. The S content is preferably 0.0050% or less. The S content is preferably as small as possible and may be 0%. However, in a case where the S content is reduced to less than 0.0001 % in a practical steel sheet, the production cost increases significantly, which is economically disadvantageous. Therefore, the S content may be set to 0.0001% or greater.

Al: 0.001% to 1.000%

[0028] Al is an element that acts as a deoxidizing agent for steel and stabilizes ferrite. In order to obtain these effects, the Al content is set to 0.001% or greater.

[0029] On the other hand, in a case where the Al content is greater than 1.000%, a coarse Al oxide is formed, and the ductility decreases. Therefore, the content is set to 1.000% or less. The Al content is preferably 0.500% or less.

N: 0% to 0.0200%

[0030] N is an element that forms a coarse nitride and decreases bendability and hole expansibility. In addition, N is an element that causes the generation of blowholes during welding. In a case where the N content is greater than 0.0200%, a coarse nitride is formed, and thus a decrease in formability and the generation of blowholes become significant. Therefore, the N content is set to 0.0200% or less. The N content is preferably as small as possible and may be 0%. However, in a case where the N content is reduced to less than 0.0005% in a practical steel sheet, the production cost increases significantly, which is economically disadvantageous. Therefore, the N content may be set to 0.0005% or greater.

O: 0% to 0.0200%

[0031] O is an element that forms a coarse oxide and deteriorates formability and fracture resistance. In addition, O is an element that causes the generation of blowholes during welding. In a case where the O content is greater than 0.0200%, due to the presence of a coarse oxide, the formability and ductility of a punched end surface significantly deteriorate, and the generation of blowholes also becomes significant. Therefore, the O content is set to 0.0200% or less. The O content is preferably as small as possible and may be 0%. However, in a case where the O content is reduced to less than 0.0001% in a practical steel sheet, the production cost increases significantly, which is economically disadvantageous. Therefore, the O content may be set to 0.0001% or greater.

Co: 0% to 0.500%

[0032] Co is an effective element for increasing the strength of the steel sheet. The Co content may be 0%, but in a case where the above effects are obtained, the Co content is preferably 0.001% or greater, and more preferably 0.010% or greater.
[0033] On the other hand, in a case where the Co content is too high, there is a concern that the ductility of the steel sheet may decrease and the formability may decrease. Therefore, the Co content is 0.500% or less.

Ni: 0% to 1.000%

[0034] Similar to Co, Ni is an effective element for increasing the strength of the steel sheet. The Ni content may be 0%, but in a case where the above effects are obtained, the Ni content is preferably 0.001% or greater, and more preferably 0.010% or greater.
[0035] On the other hand, in a case where the Ni content is too high, there is a concern that the ductility of the steel sheet may decrease and the formability may decrease. Therefore, the Ni content is 1.000% or less.

Cu: 0% to 0.500%

[0036] Cu is an element that contributes to an improvement in strength of the steel sheet. The Cu content may be 0%, but in a case where the above effects are obtained, the Cu content is preferably 0.001% or greater.
[0037] On the other hand, in a case where the Cu content is excessive, there is a concern that the productivity in hot rolling may decrease due to hot shortness. Therefore, the Cu content is 0.500% or less.

Mo: 0% to 1.000%

[0038] Similar to Mn, Mo is an element that contributes to high-strengthening of the steel sheet. The Mo content may be 0%, but in a case where the above effects are obtained, the Mo content is preferably 0.010% or greater.
[0039] On the other hand, in a case where the Mo content is greater than 1.000%, there is a concern that a coarse Mo carbide may be formed, and the cold formability of the steel sheet may decrease. Therefore, the Mo content is 1.000% or less.

Cr: 0% to 2.000%

[0040] Similar to Mn and Mo, Cr is an element that contributes to high-strengthening of the steel sheet. The Cr content may be 0%, but in a case where the above effects are obtained, the Cr content is preferably 0.001% or greater, and more preferably 0.100% or greater.
[0041] On the other hand, in a case where the Cr content is greater than 2.000%, there is a concern that a coarse Cr nitride may be formed, and the cold formability of the steel sheet may decrease. Therefore, the Cr content is 2.000% or less.

Ti: 0% to 0.5000%

[0042] Ti is an effective element for strengthening ferrite. In addition, Ti is an effective element for controlling the morphology of carbide, and is also an effective element for improving the toughness of the steel sheet by refining the structure. The Ti content may be 0%, but in a case where the above effects are obtained, the Ti content is preferably 0.0001% or greater, and more preferably 0.0010% or greater.
[0043] On the other hand, in a case where the Ti content is excessive, there is a concern that a coarse Ti oxide or TiN may be formed, and the formability of the steel sheet may decrease. Therefore, from the viewpoint of securing the formability of the steel sheet, the Ti content is 0.5000% or less.

Nb: 0% to 0.50%

[0044] Similar to Ti, Nb is an effective element for controlling the morphology of carbide and is also an effective element for improving the toughness of steel sheet by refining the structure. The Nb content may be 0%, but in a case where the above effects are obtained, the Nb content is preferably 0.001% or greater, and more preferably 0.01% or greater.
[0045] On the other hand, in a case where the Nb content is excessive, there is a concern that a large number of fine and hard Nb carbides may be precipitated, the ductility may significantly deteriorate with an increasing strength of the steel sheet, and the formability of the steel sheet may decrease. Therefore, the Nb content is 0.50% or less.

V: 0% to 0.500%

[0046] Similar to Ti and Nb, V is also an effective element for controlling the morphology of carbide and is also an effective element for improving the toughness of steel sheet by refining the structure. The V content may be 0%, but in a case where the above effects are obtained, the V content is preferably 0.001% or greater.
[0047] On the other hand, in a case where the V content is excessive, there is a concern that due to the precipitation of a large number of fine V carbides, the ductility may decrease with an increasing strength of the steel, and the formability of the steel sheet may decrease. Therefore, the V content is 0.500% or less.

W: 0% to 0.100%

[0048] Similar to Nb and V, W is also an effective element for controlling the morphology of carbide. W is also an effective element for improving the strength of the steel sheet. The W content may be 0%, but in order to obtain the above effects, the W content is preferably 0.001% or greater.
[0049] On the other hand, in a case where the W content is too high, there is a concern that due to the precipitation of a large number of fine W carbides, the strength of the steel sheet may increase, and thus the ductility may decrease and the cold workability of the steel sheet may decrease. Therefore, the W content is 0.100% or less.

Ta: 0% to 0.100%

[0050] Similar to W, Ta is also an effective element for controlling the morphology of carbide and improving the strength of the steel sheet. The Ta content may be 0%, but in a case where the above effects are obtained, the Ta content is preferably 0.001% or greater.
[0051] On the other hand, in a case where the Ta content is excessive, there is a concern that due to the precipitation of a large number of fine Ta carbides, the strength of the steel sheet may increase, and thus the ductility may decrease and the cold workability of the steel sheet may decrease. Therefore, the Ta content is 0.100% or less. The Ta content is preferably 0.020% or less, and more preferably 0.010% or less.

B: 0% to 0.0100%

[0052] B is an element that suppresses the formation of ferrite and pearlite in a cooling process from an austenite temperature range and accelerates the formation of a low temperature transformation structure such as bainite or martensite. In addition, B is an effective element for high-strengthening of steel. The B content may be 0%, but in a case where the above effects are obtained, the B content is preferably 0.0001% or greater.
[0053] On the other hand, in a case where the B content is too high, there is a concern that a coarse B oxide may be formed, which becomes a starting point of the occurrence of voids during press forming, and the formability of the steel sheet may decrease. Therefore, the B content is 0.0100% or less.

Mg: 0% to 0.050%

[0054] Mg is an element that controls the morphologies of sulfide and oxide and contributes to an improvement in bendability of the steel sheet. The Mg content may be 0%, but in a case where the above effects are obtained, the Mg content is preferably 0.0001 % or greater, and more preferably 0.001% or greater.
[0055] On the other hand, in a case where the Mg content is too high, there is a concern that the cold formability may decrease due to the formation of coarse inclusions. Therefore, the Mg content is 0.050% or less. The Mg content is preferably 0.040% or less.

Ca: 0% to 0.050%

[0056] Similar to Mg, Ca is an element capable of controlling the morphology of sulfide with a trace amount. The Ca content may be 0%, but in order to obtain the above effect, the Ca content is preferably 0.001% or greater.
[0057] On the other hand, in a case where the Ca content is too high, a coarse Ca oxide is formed. The coarse Ca oxide may serve as a starting point of crack occurrence during cold forming. Therefore, the Ca content is 0.050% or less. The Ca content is preferably 0.030% or less.

Zr: 0% to 0.050%

[0058] Similar to Mg and Ca, Zr is an element capable of controlling the morphology of sulfide with a trace amount. The Zr content may be 0%, but in a case where the above effects are obtained, the Zr content is preferably 0.001% or greater.
[0059] On the other hand, in a case where the Zr content is excessive, there is a concern that the cold formability may decrease due to the formation of a coarse Zr oxide. Therefore, the Zr content is 0.050% or less. The Zr content is preferably 0.040% or less.

REM: 0% to 0.100%

[0060] REM is an effective element for controlling the morphology of sulfide with a trace amount. The REM content may be 0%, but in order to obtain the above effects, the REM content is preferably 0.001% or greater.
[0061] On the other hand, in a case where the REM content is too high, there is a concern that workability and fracture resistance may decrease due to the formation of a coarse REM oxide. Therefore, the REM content is 0.100% or less. The REM content is preferably 0.050% or less.
[0062] Here, REM represents a rare earth metal (rare earth element) and is a general term for 17 elements, including 2 elements of scandium (Sc) and yttrium (Y) and 15 elements (lanthanoids) ranging from lanthanum (La) to lutetium (Lu). In the present embodiment, the term "REM" is composed of one or more selected from these rare earth elements, and the term "REM content" is a total amount of the rare earth elements. REM is often added as mischmetal and contains, in addition to La and Ce, the above-described lanthanoid-series element in complex in some cases. Even in a case where these lanthanoid-series elements other than La and Ce are contained as the impurities, the effects of the present embodiment are exhibited. Even in a case where the metal La or Ce is added, the effects of the present embodiment are exhibited.

Sn: 0% to 0.050%

[0063] Sn is an element that can be contained in the steel sheet in a case where a scrap is used as a raw material of the steel sheet. In addition, Sn is an element that may cause a decrease in cold formability of the steel sheet attributed to the embrittlement of ferrite. In a case where the Sn content is greater than 0.050%, adverse effects thereof are significant. Therefore, the Sn content is 0.050% or less. The Sn content is preferably 0.040% or less.
[0064] The Sn content is preferably as small as possible and may thus be 0%. However, the reduction of the Sn content to less than 0.001% leads to an excessive increase in refining cost. Therefore, the Sn content may be set to 0.001% or greater.

Sb: 0% to 0.050%

[0065] Similar to Sn, Sb is an element that can be contained in the steel sheet in a case where a scrap is used as a raw material of the steel sheet. Sb is an element that may be strongly segregated in grain boundaries and may cause the embrittlement of grain boundaries, a decrease in ductility, and a decrease in cold formability. In a case where the Sb content is greater than 0.050%, adverse effects thereof are significant. Therefore, the Sb content is 0.050% or less.

The Sb content is preferably 0.040% or less.

[0066] The Sb content is preferably as small as possible and may thus be 0%. However, the reduction of the Sb content to less than 0.001% leads to an excessive increase in refining cost. Therefore, the Sb content may be set to 0.001% or greater.

As: 0% to 0.050%

[0067] Similar to Sn and Sb, As is an element that can be contained in the steel sheet in a case where a scrap is used as a raw material of the steel sheet. As is an element that is strongly segregated in grain boundaries and may cause a decrease in cold formability. In a case where the As content is greater than 0.050%, adverse effects thereof are significant. Therefore, the As content is 0.050% or less. The As content is preferably 0.040% or less.

[0068] The As content is preferably as small as possible and may thus be 0%. However, the reduction of the As content to less than 0.001% leads to an excessive increase in refining cost. Therefore, the As content may be set to 0.001% or greater.

[0069] In the chemical composition of the steel sheet according to the present embodiment, a remainder except the above-described elements consists of Fe and impurities. Impurities are elements that are incorporated from steel raw materials and/or in a steelmaking process, and are allowed within the range that does not impair the properties of the steel sheet according to the present embodiment, and are elements that are not components intentionally added to the steel sheet.

[0070] The above-described chemical composition can be measured using, for example, a spark discharge emission analysis method (Spark-OES, commonly known as Quantovac) or an ICP emission spectroscopic/mass analysis device (ICP-OES/ICP-MS). Those measured by this method are the average content in the steel sheet.

<Microstructure>

[0071] The microstructure (metallographic structure) of the steel sheet according to the present embodiment will be described. Hereinafter, since a microstructural fraction is expressed by area ratio, the unit "%" of the microstructural fraction means area%.

[0072] In addition, in the steel sheet according to the present embodiment, at least a microstructure in a range of 1/8 to 3/8 of the thickness, centered at a position that is at a depth of 1/4 of the sheet thickness from the surface of the steel sheet, is as follows. The reason why the microstructure is regulated in this range is that it is a representative structure of the steel sheet and has a high correlation with the properties.

(Total of Area Ratio of Ferrite and Area Ratio of Bainite: 10% or Greater and 90% or Less)

(Area Ratio of Ferrite: 5% or Greater)

[0073] Ferrite and bainite are soft structures and are thus easily deformed, which contribute to an improvement in fracture resistance. In a case where the sum of ferrite and bainite is 10% or greater, sufficient elongation can be obtained and the formability is improved. Therefore, the sum of the area ratios of ferrite and bainite is set to 10% or greater. The sum of the area ratios of ferrite and bainite is preferably 20% or greater, and more preferably 25% or greater.

[0074] In order to secure a predetermined tensile strength, the sum of the area ratios of ferrite and bainite is set to 90% or less. The sum of the area ratios of ferrite and bainite is preferably 70% or less, and more preferably 50% or less.

[0075] In addition, ferrite is softer and more excellent in ductility than bainite, and thus contributes to an improvement in fracture resistance more than bainite. For this reason, the area ratio of ferrite is set to 5% or greater. The area ratio of ferrite is preferably greater than 5%, more preferably 7% or greater, and even more preferably 10% or greater.

(Total of Area Ratio of Martensite and Area Ratio of Tempered martensite: 10% or Greater and 90% or Less)

[0076] Martensite (so-called fresh martensite) and tempered martensite are hard structures and thus contribute to an improvement in tensile strength. In a case where the sum of martensite and tempered martensite is set to 10% or greater, high-strengthening can be achieved, and it becomes easy to secure a tensile strength of 780 MPa or greater. In a case where a higher tensile strength is secured, it is preferable to increase the sum of the area ratios of martensite and tempered martensite. For example, in a case where a tensile strength of 900 MPa or greater is secured, the sum of the area ratios of martensite and tempered martensite is preferably 45% or greater, more preferably 50% or greater, and even more preferably 55% or greater. In addition, in a case where a tensile strength of 1,100 MPa or greater is secured, the sum of the area ratios of martensite and tempered martensite is preferably 70% or greater, and more preferably 80% or greater.

[0077] On the other hand, in a case where the sum of the area ratios of martensite and tempered martensite is greater than 90%, sufficient elongation cannot be obtained and the formability deteriorates. Therefore, the sum of the area ratios is set to 90% or less. From the viewpoint of formability, the sum of the area ratios of martensite and tempered martensite is preferably 85% or less, and more preferably 80% or less.

(Total of Area Ratio of Pearlite and Area Ratio of Residual Austenite: 0% or Greater and 10% or Less)

[0078] Pearlite, that is a structure containing hard cementite, becomes a starting point of the occurrence of voids during press forming, thereby deteriorating fracture resistance.
[0079] Residual austenite is a structure that contributes to an improvement in elongation by transformation induced plasticity (TRIP). However, martensite that is formed by transformation induced plasticity of the residual austenite is extremely hard, and becomes a starting point of the occurrence of voids, thereby deteriorating fracture resistance.
[0080] Therefore, the sum of the area ratios of pearlite and residual austenite is set to 10% or less. The sum of the area ratios is preferably 5% or less. The area ratio of residual austenite is preferably 5% or less, and more preferably less than 3%. The steel sheet according to the present embodiment may not include pearlite and residual austenite. That is, the sum of the area ratios may be 0%.
[0081] Identification of ferrite, bainite, martensite, tempered martensite, pearlite, and residual austenite, and calculation of the areas and the area ratios will be described.
[0082] The identification of each microstructure structure and the calculation of the area and the area ratio can be performed by using a scanning electron microscope by electron back scattering diffraction (EBSD), an X-ray diffraction method, or by observing a region of 100 μm $\times$ 100 μm on a cross section of the steel sheet that is parallel to the rolling direction and perpendicular to the sheet surface which is etched using a Nital reagent or a LePera reagent at a magnification of 1,000 to 50,000 times, according to the target structure. In the measurement of the area ratio of any structure, three measurement points are set and the average value thereof is calculated.
[0083] The area and area ratio of crystal grains of ferrite can be measured by the following method. That is, a range of 1/8 to 3/8 of the sheet thickness from the surface, centered at a position that is at a depth of 1/4 of the sheet thickness from the surface of the steel sheet, is measured at intervals of 0.2 μm (pitch) by EBSD attached to a scanning electron microscope. The value of grain average misorientation (GAM) is calculated from the measured data. Then, a region where the value of grain average misorientation is less than 0.5° is defined as ferrite, and the area and area ratio thereof are measured. Here, the grain average misorientation is a value obtained by: calculating an orientation difference between adjacent measurement points in a region surrounded by grain boundaries having a crystal orientation difference of 5° or greater; and averaging the orientation differences among all measurement points in the crystal grains.
[0084] Regarding the area and area ratio of crystal grains of bainite, a sample is collected so that a cross section in the sheet thickness direction that is parallel to the rolling direction of the steel sheet serves as an observation surface, the observation surface is polished and etched with a Nital reagent, a range of 1/8 to 3/8 of the sheet thickness from the surface, centered at a position that is at a depth of 1/4 of the sheet thickness from the surface, is observed by a field emission scanning electron microscope (FE-SEM), and the calculation is performed using known image analysis software. Using, for example, "ImageJ" as the image analysis software, the area ratio can be calculated. Here, "ImageJ" is open source and public domain image processing software, and is widely used by those skilled in the art.
[0085] In the observation by the FE-SEM, for example, the structure in the square observation surface having a side of 100 μm is distinguished as follows. Bainite is an aggregate of lath-shaped crystal grains and does not contain therein an iron-based carbide having a major axis of 20 nm or greater, or contains therein an iron-based carbide having a major axis of 20 nm or greater where the carbide belongs to a single variant, that is, an iron-based carbide group elongated in the same direction. Here, the iron-based carbide group stretched in the same direction means a group in which a difference in stretching direction of the iron-based carbide group is within 5°. The bainite surrounded by grain boundaries having an orientation difference of 15° or greater is counted as one bainite crystal grain.
[0086] The area ratios of martensite and tempered martensite can be calculated as follows: a sample is collected so that a cross section in the sheet thickness direction that is parallel to the rolling direction of the steel sheet serves as an observation surface, the observation surface is polished and etched with a LePera reagent, a range of 1/8 to 3/8 of the sheet thickness from the surface, centered at a position that is at a depth of 1/4 of the sheet thickness from the surface, is observed and photographed by a FE-SEM, and the area ratio of residual austenite measured using X-rays to be described later (to be described in detail) is subtracted from the area ratio of an uncorroded region. The observation range in the observation surface is, for example, a square range having a side of 100 μm.
[0087] Regarding the area ratio of residual austenite, the thickness is reduced by electrolytic polishing or chemical polishing up to a position that is at a depth of 1/8 to 3/8 of the sheet thickness from the surface. The polished surface is subjected to X-ray diffraction using MoKα rays as characteristic X-rays, and from the integrated intensity ratios of the diffraction peaks of (200) and (211) of the bcc phase and (200), (220), and (311) of the fcc phase obtained, the area ratio of residual austenite is calculated and set as the value at the position that is at a depth of 1/4 of the sheet thickness.

[0088] The area ratio of pearlite is obtained as follows: a sample is collected so that a cross section in the sheet thickness direction that is parallel to the rolling direction of the steel sheet serves as an observation surface, the observation surface is polished and etched with a Nital reagent, and a range of 1/8 to 3/8 of the thickness, centered at a position that is at a depth of 1/4 of the sheet thickness from the surface of the steel sheet, is observed using a secondary electron image obtained by a scanning electron microscope. The region photographed with high contrast in the secondary electron image is defined as pearlite, and the area ratio thereof is calculated using the above-described image analysis software "ImageJ". The observation range in the observation surface is, for example, a square range having a side of 100 μm.

(Number Proportion of Crystal Grains of Ferrite and Bainite Having Area of 6 μm^2 or Less to Total Number of Crystal Grains of Ferrite and Bainite is 40% or Greater To Total Number of Crystal Grains of Ferrite and Bainite)

[0089] The ratio (N_6/N_T) of the number (N_6) of crystal grains of ferrite and bainite having an area of 6 μm^2 or less to the total number (N_T) of crystal grains of ferrite and bainite is one index having a great influence on the fracture resistance of the steel sheet according to the present embodiment.

[0090] In a case where the ratio (N_6/N_T) of the number of crystal grains (fine grains) having an area of 6 μm^2 or less to the total number of crystal grains of ferrite and bainite increases, voids are less likely to occur in the vicinity of a forming part during forming. In addition, the occurred voids are less likely to be connected to each other, and the fracture resistance is thus improved. Specifically, by setting the ratio (N_6/N_T) of the number of crystal grains having an area of 6 μm^2 or less in the ferrite and bainite to 40% or greater, the fracture resistance becomes higher than that of a vehicle component having the same level of strength. Therefore, the ratio (N_6/N_T) of the number of crystal grains having an area of 6 μm^2 or less is set to 40% or greater. (N_6/N_T) is preferably 50% or greater, and more preferably 55% or greater.

[0091] The ratio of the number of crystal grains having an area of 6 μm^2 or less in the ferrite and bainite may be set to 90% or less from the viewpoint of suppressing yield point elongation.

(Number Proportion of Crystal Grains of Ferrite and Bainite Having Area of 50 μm^2 or Greater to Total Number of Crystal Grains of Ferrite and Bainite is 5% or Less To Total Number of Crystal Grains of Ferrite and Bainite)

[0092] The ratio (N_{50}/N_T) of the number (N_{50}) of crystal grains of ferrite and bainite having an area of greater than 50 μm^2 to the total number (N_T) of crystal grains of ferrite and bainite is one index having a great influence on the fracture resistance of the steel sheet according to the present embodiment.

[0093] In a case where the number proportion of crystal grains having an area of greater than 50 μm^2 in the ferrite and bainite increases, voids are likely to occur in the vicinity of a forming part during forming. In addition, the occurred voids are likely to be connected to each other, and the fracture resistance is thus decreased. Therefore, the ratio (N_{50}/N_T) of the number of crystal grains having an area of greater than 50 μm^2 is set to 5% or less. (N_{50}/N_T) is preferably 3% or less. Since (N_{50}/N_T) is preferably as small as possible, the lower limit thereof is not particularly set. However, from the viewpoint of suppressing an increase in production cost due to fine control, (N_{50}/N_T) may be set to 1 % or greater.

[0094] The grain sizes and the number proportions of crystal grains of ferrite and bainite are calculated from the results of image analysis obtained in the same visual field using the above-described "EBSD" and "ImageJ".

(Maximum Mn content in Region up to 0.5 μm from Interface Between Ferrite and Martensite or Tempered Martensite in Direction Perpendicular to Interface and Toward Inside of Ferrite Grains is 0.30 mass% or More Lower Than Average Mn Content of Steel Sheet)

[0095] The present inventors have found that in a steel sheet containing soft ferrite and hard martensite and tempered martensite, in a case where the Mn content in the ferrite near the interface between ferrite and martensite or tempered martensite (the interface between ferrite and martensite and the interface between ferrite and tempered martensite) is high, the fracture resistance decreases. Therefore, in the steel sheet according to the present embodiment, the maximum Mn content in a region up to 0.5 μm from the interface between ferrite and martensite or tempered martensite in a direction perpendicular to the interface (in a case where the interface is not a straight line, a direction perpendicular to a tangent to the interface at the position, and the same shall apply hereinafter) and toward the inside of the ferrite grains (that is, a range extending 0.5 μm from the interface in the ferrite) is set to be 0.30 mass% or more lower than the average Mn content of the steel sheet.

[0096] In a case where the maximum Mn content in the above region is larger than (average Mn content of steel sheet - 0.30 mass%), a sufficient fracture resistance improvement effect cannot be obtained.

[0097] Whether the maximum Mn content in the region up to 0.5 μm from the interface between ferrite and martensite or tempered martensite in a direction perpendicular to the interface and toward the inside of the ferrite grains is 0.30 mass% or more lower than the average Mn content of the steel sheet is determined by the following method.

[0098] That is, after identifying the ferrite, martensite, and tempered martensite using the above-described method, the range extending 0.5 μm or greater from the interface between two, i.e., ferrite and martensite or ferrite and tempered martensite facing each other at a distance of 3.0 μm or less in a direction perpendicular to the interface and toward the inside of the ferrite grains is subjected to linear analysis using an EPMA. The difference between the maximum Mn content in the ferrite in the range extending 0.5 μm from the interface obtained by the linear analysis and the average Mn content of the steel sheet (average Mn content of steel sheet - maximum Mn content in range extending 0.5 μm from interface) is denoted by ΔMn. The linear analysis is performed at 10 points, and in a case where the average of ΔMn at the 10 points is 0.30 (mass%) or greater, the Mn content in the region up to 0.5 μm from the interface between ferrite and martensite or tempered martensite in a direction perpendicular to the interface and toward the inside of the ferrite grains is determined to be 0.30 mass% or more lower than the average Mn content of the steel sheet (ΔMn ≥ 0.30).

(Preferably, Average Aspect Ratio of Crystal Grains of Ferrite and Bainite Having Area of 6 μm^2 or Less is 1.0 or Greater and 2.0 or Less)

[0099] The average aspect ratio of crystal grains of ferrite and bainite having an area of 6 μm^2 or less is also one index having an influence on the fracture resistance. In general, the smaller the aspect ratio and the more equiaxial the grains, the less likely it is for stress concentration to occur at the interface. Therefore, in a case where more excellent fracture resistance is obtained, the average aspect ratio of crystal grains of ferrite and bainite is preferably set to 1.0 or greater and 2.0 or less. In a case where the average aspect ratio is greater than 2.0, it is difficult to obtain the above effect. The average aspect ratio is more preferably 1.0 or greater and 1.5 or less.

[0100] In the present embodiment, the aspect ratio refers to the ratio of the longest diameter (major axis) of the ferrite crystal grain to the longest diameter (minor axis) among the diameters of the ferrite orthogonal thereto. The same applies to the aspect ratio of the bainite crystal grain.

[0101] Crystal grains having an area of greater than 6 μm^2 are not particularly limited since the contribution thereof to void connection is relatively small. However, since it is preferable that the crystal grains be stretched grains from the viewpoint of reducing the stress concentration at the interface, the average aspect ratio may be greater than 2.0 and 5.0 or less.

<Mechanical Properties>

[Tensile Strength: 780 MPa or Greater]

[0102] In the steel sheet according to the present embodiment, the tensile strength is set to 780 MPa or greater in consideration of contribution to the weight reduction of a vehicle by application of the steel sheet to a vehicle component.

[0103] In consideration of contribution to the weight reduction of a vehicle, the tensile strength is preferably 980 MPa or greater, and more preferably 1,180 MPa or greater.

[0104] Although it is not necessary to limit the upper limit of the tensile strength, an increase in tensile strength may cause a decrease in elongation, hole expansibility, and the like. Therefore, the tensile strength may be set to 1,500 MPa or less.

[Δσ That is Difference (σ1 - σ2) Between Stress α2 at Uniform Elongation + 1.0% and Tensile Strength σ1 is 50 MPa or Less]

[0105] In order to suppress crack occurrence during press forming, it is important to maintain a state in which the true stress is high with a strain amount equal to or greater than uniform elongation. In particular, in the stress-strain curve as shown in FIG. 1 in which a stress at a position where the stress is maximum is denoted by σ1, elongation at that time is referred to as uniform elongation (u-El), and a stress at uniform elongation + 1.0% (a stress on the strain amount (horizontal axis) when the elongation is uniform elongation + 1.0%) is denoted by σ2, in a case where Δσ that is (σ1 - σ2) is 50 MPa or less, the fracture resistance is improved.

[0106] The reason for this is considered to be that Δσ is an index indicating the amount of voids formed, that reduce true stress, and has a good correlation with the crack occurrence during press forming.

[0107] Therefore, in the steel sheet according to the present embodiment, target Δσ is 50 MPa or less. Δσ is more preferably 40 MPa or less.

[0108] The tensile strength σ1 of the steel sheet and the stress σ2 at uniform elongation + 1.0% are obtained by performing a tensile test according to JIS Z 2241: 2011 using a No. 5 test piece of JIS Z 2241: 2011.

[0109] The steel sheet according to the present embodiment described above may have a coating layer containing zinc, aluminum, magnesium, or an alloy of these metals on its surface. Due to the presence of the coating layer on the surface of the steel sheet, corrosion resistance is improved. The coating layer may be a known coating layer.

[0110] For example, in a case where the steel sheet is used under an environment where it corrodes, perforation or the like may occur, and thus it may not be possible to reduce the thickness to a certain sheet thickness or less even in a case where the strength is increased. One purpose of high-strengthening of the steel sheet is to reduce the weight by making the steel sheet thinner. Accordingly, even in a case where a high strength steel sheet is developed, the site where the steel sheet is to be applied is limited in a case where the steel sheet has low corrosion resistance. It is preferable that a coating layer containing zinc, aluminum, magnesium, or an alloy of these metals be provided on the surface since the corrosion resistance is improved and the range where the steel sheet is applicable is widened.
[0111] In a case where the steel sheet has a coating layer (for example, a plating layer) on its surface, the term "surface" in the "range of 1/8 to 3/8 of the thickness, centered at a position that is at a depth of 1/4 of the sheet thickness from the surface of the steel sheet, means a base metal surface excluding the coating layer.
[0112] The sheet thickness of the steel sheet according to the present embodiment is not limited to a specific range, but is preferably 0.3 to 6.0 mm in consideration of strength, versatility, and producibility.

<Producing Method>

[0113] The method for producing the steel sheet according to the present embodiment is not particularly limited, but the steel sheet can be obtained by a producing method including the following steps:

(I) a hot rolling step of hot-rolling a slab having a predetermined chemical composition to obtain a hot-rolled steel sheet,
(II) a coiling step of cooling the hot-rolled steel sheet to a coiling temperature of 650°C or lower and 450°C or higher at an average cooling rate of 30 °C/sec or higher and coiling the hot-rolled steel sheet at the coiling temperature,
(III) a holding step of holding the hot-rolled steel sheet after the coiling step so that a holding time in a temperature range from the coiling temperature to the coiling temperature - 50°C is 2 to 8 hours,
(IV) a cooling step of cooling the hot-rolled steel sheet after the holding step to a temperature of 300°C or lower at an average cooling rate of 0.1 °C/sec or higher,
(V) a cold rolling step of cold-rolling the hot-rolled steel sheet after the cooling step at a ratio of sheet thickness reduction of 20% to 80% to obtain a cold-rolled steel sheet, and
(VI) an annealing step of heating the cold-rolled steel sheet to an annealing temperature of 740°C to 900°C at an average temperature rising rate of 5 °C/sec or higher and holding the cold-rolled steel sheet at the annealing temperature for 60 to 300 seconds.

[0114] Hereinafter, preferable conditions for each step will be described.

[Hot Rolling Step]

[0115] In the hot rolling step, a slab having a predetermined chemical composition (in a case where the steel sheet according to the present embodiment is obtained, the same chemical composition as the steel sheet according to the present embodiment) is heated and hot-rolled to obtain a hot-rolled steel sheet.
[0116] The slab to be heated may be a slab obtained by continuous casting or casting and blooming or may also be a slab obtained by additionally performing hot working or cold working on the above-described slab.
[0117] The heating temperature is not limited. However, in a case where the temperature is lower than 1,100°C, a carbide or sulfide formed during casting does not form a solid solution and becomes coarse, whereby press formability may deteriorate. Therefore, the heating temperature is preferably 1,100°C or higher, and more preferably 1,150°C or higher.
[0118] In addition, in the hot rolling step, finish rolling is performed using a rolling mill having four or more stands, and in a case where an initial stand is defined as a first stand and a final stand is defined as an n-th stand, the ratio of sheet thickness reduction in each of stands ranging from an (n-3)-th stand to the n-th stand is set to 30% or greater, and the rolling temperature in the final stand (the n-th stand) is set to 900°C or lower. That is, for example, in a rolling mill having seven stands, the ratio of sheet thickness reduction in each of a fourth stand, a fifth stand, a sixth stand, and a seventh stand is set to 30% or greater, and the rolling temperature in the seventh stand is set to 900°C or lower. In this finish rolling, the austenite grain size is refined by recrystallization during rolling, and by introducing a large amount of strain into the austenite, sites where ferrite nuclei are generated are increased and the crystal grains of the hot-rolled steel sheet are refined.
[0119] In a case where the ratio of sheet thickness reduction is less than 30% in even one of the stands, or the rolling temperature in the n-th stand is higher than 900°C, the hot-rolled structure becomes coarse and duplex grain sized, and the structure after the annealing step to be described later also becomes coarse. In a case where the hot rolling completion temperature is lower than 830°C, the rolling counterforce increases and it becomes difficult to stably obtain a target sheet thickness. Therefore, the rolling temperature in the final stand is preferably 830°C or higher. In addition, even in

a case where the rolling reduction is set to be larger than 50%, the grain refining effect is saturated and the equipment load excessively increases due to an increase of the rolling force. Therefore, the ratio of sheet thickness reduction in each of the (n-3)- to n-th stands is preferably set to 50% or less.

[0120] In addition, since the finish rolling is continuous rolling in which the interpass time between final four passes for rolling is short, the finish rolling is performed using a rolling mill having four or more stands. This is because, in a case where the interpass time is long, the strain is recovered between the passes and does not sufficiently accumulate even in a case where the reduction is performed at a large ratio of sheet thickness reduction.

[0121] In the past, reduction with three or more passes at a rolling reduction of 20% or greater was performed for the sole purpose of refining the crystal grains. However, in the present embodiment, reduction with final four passes (in the (n-3)- to n-th stands) at a ratio of sheet thickness reduction of 30% or greater is performed as described above for the purpose of concentrating Mn to cementite, which is not an object in the past. Even in a case where the reduction with three or more passes at a rolling reduction of 20% or greater is performed, performing the reduction with final four passes at a ratio of sheet thickness reduction of 30% or greater is usually not done since this leads to not only saturation of the crystal grain refining effect, but also a decrease in productivity and the risk of equipment troubles due to the concentration of rolling load on the four stands in the latter stage.

[Coiling Step]

[0122] In the coiling step, the hot-rolled steel sheet after the hot rolling step is cooled to a coiling temperature of 650°C or lower and 450°C or higher at an average cooling rate of 30 °C/sec or higher and coiled at the coiling temperature.

[0123] By rapid cooling after hot rolling, transformation into ferrite or pearlite at high temperature is suppressed and ferritic transformation is caused at low temperature at which the driving force of transformation is high, whereby a structure having fine ferrite and fine cementite formed at grain boundaries of the ferrite can be obtained.

[0124] In a case where the average cooling rate is lower than 30 °C/sec or the cooling stop temperature (coiling temperature) is higher than 650°C, coarse ferrite and pearlite including a coarse carbide are formed non-uniformly. Since the coarse carbide is not easily dissolved in the annealing step, the structure after annealing becomes coarse and duplex grain sized.

[0125] Meanwhile, in a case where the coiling temperature is lower than 450°C, the strength of the hot-rolled steel sheet becomes excessive, the cold rolling load increases, and the productivity deteriorates. The average cooling rate is preferably 100 °C/sec or lower in order to stably obtain a target cooling stop temperature.

[Holding Step]

[0126] In the holding step, the steel sheet after the coiling step is held so that a holding time in a temperature range from the coiling temperature to the coiling temperature - 50°C is 2 to 8 hours.

[0127] During the holding, Mn mainly diffuses at ferrite grain boundaries and is concentrated in cementite. By refining the ferrite grains as described above, the number of diffusion paths is increased, and the concentration of Mn to cementite is promoted (for example, the Mn content in cementite becomes greater than 3.0%). In addition, in a case where Mn is concentrated to cementite, a Mn-deficient layer having a low Mn content is formed in the vicinity of the part where Mn is concentrated.

[0128] However, in a case where the holding time in a temperature range from the coiling temperature to (the coiling temperature- 50)°C is longer than 8 hours, the cementite becomes coarse. The coarse carbide is not easily dissolved in the annealing step. Accordingly, in a case where the carbide becomes coarse, the structure after annealing becomes coarse and duplex grain sized. Therefore, the holding time is set to 8 hours or shorter. In order to sufficiently concentrate Mn to cementite, the holding time in a temperature range from the coiling temperature to the coiling temperature-50°C is 2 hours or longer.

[Cooling Step]

[0129] In the cooling step, the hot-rolled steel sheet after the holding step is cooled to a temperature of 300°C or lower at an average cooling rate of 0.1 °C/sec or higher.

[0130] In a case where the average cooling rate after the holding step until the cooling stop temperature of 300°C or lower is lower than 0.1 °C/sec, there is a concern that cementite may become coarse. In a case where the average cooling rate is high, hard martensite is likely to be formed in a case where untransformed γ remains. In this case, there is a concern that the strength of the hot-rolled sheet may increase and the cold rolling load may increase. Therefore, the average cooling rate is preferably 12.0 °C/sec or lower.

[Cold Rolling Step]

[0131] In the cold rolling step, the hot-rolled steel sheet after the cooling step is cold-rolled at a ratio of sheet thickness reduction of 20% to 80% to obtain a cold-rolled steel sheet.
[0132] In a case where the ratio of sheet thickness reduction is less than 20%, the strain does not sufficiently accumulate in the steel sheet, and sites where austenite nuclei are generated become non-uniform. In this case, the grain size becomes coarse or duplex grain sized are formed in the subsequent annealing step, whereby the number proportion of the crystal grains of ferrite and bainite having an area of 6 μm^2 or less and the number proportion of the crystal grains of ferrite and bainite having an area of 50 μm^2 or greater to the total number of crystal grains of the ferrite and the bainite are not within a desired range. In addition, the aspect ratio of the crystal grains also increases. As a result, the fracture resistance deteriorates.
[0133] On the other hand, in a case where the ratio of sheet thickness reduction is greater than 80%, the cold rolling load becomes excessive, and the productivity deteriorates.
[0134] Therefore, the ratio of sheet thickness reduction is set to 20% or greater and 80% or less. The ratio of sheet thickness reduction is preferably 30% or greater and 80% or less. The cold rolling method is not limited, and the number of rolling passes and the rolling reduction per pass may be set as appropriate.
[0135] Pickling may be performed under known conditions before the cold rolling.

[Annealing Step]

[0136] In the annealing step, the cold-rolled steel sheet is heated to an annealing temperature of 740°C to 900°C at an average temperature rising rate of 5 °C/sec or higher and held at the annealing temperature (740°C to 900°C) for 60 seconds or longer.
[0137] In a case where the average temperature rising rate is lower than 5 °C/sec, there is a concern that Mn concentrated to cementite (0) in the hot-rolled steel sheet may diffuse to the Mn-deficient layer having a low Mn content and the Mn-deficient layer may disappear. Therefore, the average temperature rising rate until the annealing temperature is set to 5 °C/sec or higher. In particular, since the diffusion of Mn is likely to occur at higher than 550°C, it is preferable that the average temperature rising rate in a temperature range of 550°C or higher be set to 5 °C/sec or higher. In order to control the average temperature rising rate to exceed 50 °C/sec, a great capital investment is required. Therefore, the average temperature rising rate is preferably 50 °C/sec or lower from the viewpoint of economic efficiency.
[0138] In addition, in a case where the annealing temperature is lower than 740°C, the amount of austenite is small, the area ratio of martensite and tempered martensite after annealing becomes less than 10%, and the tensile strength becomes less than 780 MPa.
[0139] On the other hand, in a case where the annealing temperature is higher than 900°C, the microstructure structure becomes coarse and the fracture resistance deteriorates.
[0140] Therefore, the annealing temperature is set to 740°C or higher and 900°C or lower. The annealing temperature is preferably 780°C or higher and 850°C or lower.
[0141] In a case where the holding time (retention time) at the annealing temperature is shorter than 60 seconds, austenite is not sufficiently formed, the area ratio of martensite and tempered martensite after annealing becomes less than 10%, and the tensile strength becomes less than 780 MPa. Therefore, the holding time at the annealing temperature is set to 60 seconds or longer. The holding time is preferably 70 seconds or longer, and more preferably 80 seconds or longer.
[0142] Meanwhile, in a case where the annealing time is longer than 300 seconds, the crystal grains become coarse. Therefore, the annealing time is set to 300 seconds or shorter.
[0143] The cooling rate after heating in the annealing step is not limited. However, the steel sheet is slowly cooled to achieve a desired ferrite fraction, and then rapidly cooled to form martensite. A holding step or a step of increasing the temperature again may be included in order to temper the martensite.
[0144] It is considered that in a case where the hot-rolled steel sheet having a Mn-deficient layer and fine cementite at the ferrite grain boundaries is annealed under the above-described conditions after cold rolling, the Mn-deficient layer having a low Mn content becomes ferrite after annealing, the fine cementite is dissolved and becomes martensite (or residual austenite) having a high Mn content, and thus the structure of the steel sheet according to the present embodiment is obtained.
[0145] In the annealing step, a coating layer such as a plating layer containing zinc, aluminum, magnesium, or an alloy of these metals may be formed on the surface of the steel sheet from the viewpoint of increasing the corrosion resistance of the steel sheet. For example, the steel sheet may be immersed in a plating bath during cooling after holding to form a hot-dip plating. In addition, the hot-dip plating may be heated to a predetermined temperature and alloyed to obtain an alloyed hot-dip plating. In addition, the plating layer may further contain Fe, Al, Mg, Mn, Si, Cr, Ni, Cu, and the like. For the plating layer for increasing the corrosion resistance, any of the above-described methods may be adopted.

As the plating conditions and alloying conditions, known conditions may be applied depending on the composition of the plating.

[Examples]

[0146] Hereinafter, the present invention will be described in greater detail with examples, but is not limited to these examples.

[0147] Various slabs having chemical compositions shown in Tables 1-1 and 1-2 (subsequent to 1-1) were prepared by casting. In Tables 1-1 and 1-2, the blank space indicates that the corresponding element was not added intentionally. In addition, the unit of each slab component was mass%, and the remainder of the slab was Fe and impurities.

[0148] The slabs were heated to a temperature range of 1,150°C to 1,250°C, and hot-rolled under conditions shown in Tables 2-1 and 2-2 to obtain hot-rolled steel sheets. The hot-rolled steel sheets were cooled to a coiling temperature under conditions shown in Tables 2- 3 and 2-4, and coiled. In the hot rolling, a rolling mill having four or more stands was used for finish rolling.

[0149] After the coiled hot-rolled steel sheets were held so that a holding time in a temperature range from the coiling temperature to the coiling temperature - 50°C was as shown in Tables 2-3 and 2-4, the hot-rolled steel sheets were cooled to a temperature range of 300°C or lower.

[0150] The hot-rolled steel sheets after cooling were pickled, and then cold-rolled at a ratio of sheet thickness reduction shown in Tables 2-3 and 2-4, and cold-rolled steel sheets having a sheet thickness of 1.4 mm were obtained.

[0151] The obtained cold-rolled steel sheets were annealed under conditions shown in Tables 2-5 and 2-6. Some steel sheets were immersed in a galvanizing bath during cooling in the annealing to form a hot-dip galvanized layer on their surfaces. In addition, among the plated steel sheets, some steel sheets were further subjected to an alloying treatment to turn the hot-dip galvanized layer into a hot-dip galvannealed layer. In Tables 2-5 and 2-6, the phrase "Presence or Absence of Plating" indicates whether hot-dip galvanizing was performed in the continuous annealing step, and the phrase "Presence or Absence of Alloying" indicates whether the alloying treatment was performed after hot-dip galvanizing.

[0152] In addition, after annealing, the cooling rate was adjusted in order to set the area ratios of ferrite, martensite, and tempered martensite within preferable ranges.

[0153] In the manner described above, cold-rolled steel sheets having test Nos. 1 to 51 and 53 to 58 were obtained. In No. 52, the test was stopped since cold rolling could not be performed due to excessive cold rolling load.

[Table 1-1]

Component	Chemical Composition (mass%), Remainder: Fe and Impurities												
	C	Si	Mn	P	S	Al	N	O	Co	Ni	Cu	Mo	Cr	Ti
a	0.12	0.48	2.2	0.010	0.0030	0.030	0.0039	0.0033				0.076		0.0238
b	0.14	0.17	2.9	0.013	0.0046	0.060	0.0029	0.0047					0.224	0.0345
c	0.07	0.10	1.7	0.012	0.0049	0.190	0.0021	0.0011				0.011		
d	0.14	0.47	2.6	0.016	0.0073	0.180	0.0044	0.0035						0.0200
e	0.14	0.20	2.4	0.016	0.0070	0.170	0.0032	0.0035						
f	0.07	0.20	2.1	0.015	0.0012	0.120	0.0024	0.0032	0.114			0.109		
g	0.10	0.40	2.3	0.007	0.0047	0.190	0.0014	0.0011						
h	0.12	0.45	2.6	0.012	0.0025	0.300	0.0024	0.0032				0.064		0.0120
i	0.11	0.19	2.8	0.015	0.0079	0.100	0.0016	0.0024		0.240	0.216			
j	0.10	0.18	1.9	0.015	0.0066	0.140	0.0028	0.0011				0.864		0.4280
k	0.14	0.83	2.9	0.016	0.0066	0.170	0.0034	0.0022						
l	0.10	0.11	2.0	0.007	0.0039	0.110	0.0026	0.0046			0.115		0.348	0.0228
m	0.12	0.21	2.8	0.007	0.0024	0.160	0.0045	0.0035						
n	0.09	0.12	2.2	0.013	0.0073	0.040	0.0050	0.0011			0.480			
o	0.11	0.31	2.7	0.012	0.0007	0.140	0.0039	0.0011					0.550	
p	0.08	0.45	2.2	0.010	0.0011	0.020	0.0036	0.0023					0.345	
q	0.11	0.12	1.7	0.008	0.0066	0.030	0.0043	0.0022						
r	0.09	0.14	2.3	0.006	0.0053	0.090	0.0023	0.0012		0.117			1.560	0.1090
s	0.08	0.32	2.1	0.016	0.0063	0.040	0.0025	0.0012						
t	0.09	0.12	1.6	0.015	0.0007	0.090	0.0031	0.0012				0.106		
u	0.14	0.21	2.4	0.007	0.0024	0.030	0.0039	0.0022					0.342	0.0200
v	0.11	1.00	1.8	0.006	0.0035	0.160	0.0050	0.0024						
w	0.07	0.91	3.0	0.016	0.0074	0.850	0.0043	0.0012		0.192				0.0238
x	0.07	0.30	2.0	0.011	0.0065	0.020	0.0044	0.0012						

(continued)

Component	Chemical Composition (mass%), Remainder: Fe and Impurities													
	C	Si	Mn	P	S	Al	N	O	Co	Ni	Cu	Mo	Cr	Ti
y	0.13	0.18	2.6	0.014	0.0079	0.160	0.0036	0.0011				0.228		0.0238
z	0.15	0.20	2.1	0.011	0.0068	0.020	0.0039	0.0023	0.120	0.054			1.962	0.0238
aa	0.12	1.66	2.2	0.014	0.0042	0.080	0.0014	0.0023				0.012	0.436	0.0212
ab	0.15	0.37	1.9	0.007	0.0009	0.010	0.0027	0.0012					0.452	
ac	0.08	0.19	2.5	0.008	0.0075	0.120	0.0038	0.0014		0.070				
ad	0.02	0.80	2.5	0.017	0.0021	0.027	0.0037	0.0012						
ae	0.19	0.80	2.2	0.006	0.0075	0.067	0.0018	0.0014						
af	0.12	2.30	2.4	0.002	0.0066	0.082	0.0044	0.0014						
ag	0.07	0.60	0.6	0.013	0.0045	0.013	0.0054	0.0021						
ah	0.12	0.60	3.5	0.014	0.0096	0.056	0.0053	0.0012						
ai	0.09	0.40	2.3	0.030	0.0076	0.055	0.0014	0.0025						
aj	0.12	0.60	2.5	0.008	0.0600	0.083	0.0032	0.0016						
ak	0.14	0.20	2.8	0.018	0.0088	1.800	0.0018	0.0050						
al	0.12	0.60	2.5	0.017	0.0140	0.800	0.0600	0.0017						
am	0.08	0.60	2.5	0.020	0.0180	0.021	0.0014	0.0400						

[Table 1-2]

Component	Chemical Composition (mass%), Remainder: Fe and Impurities												Remarks
	Nb	V	W	Ta	B	Mg	Ca	Zr	REM	Sn	Sb	As	
a	0.01				0.0012								Invention Steel
b	0.02			0.011	0.0010			0.011			0.001		
c		0.354											
d		0.120			0.0012								
e													
f								0.032		0.002			
g				0.023									
h	0.05				0.0012								
i													
j				0.012			0.047				0.003		
k	0.03				0.0024		0.030			0.004			
l					0.0023								
m	0.45				0.0025							0.005	
n					0.0011			0.030					
o	0.03												
p													
g													
r		0.110	0.011			0.011	0.010						
s													
t													
u	0.02				0.0011						0.002		
v													
w					0.0022								
x	0.04												

(continued)

Component	Chemical Composition (mass%), Remainder: Fe and Impurities												Remarks
	Nb	V	W	Ta	B	Mg	Ca	Zr	REM	Sn	Sb	As	
y					0.0022								
z		0.234		0.093	0.0024	0.043	0.002	0.023	0.011	0.002	0.001		
aa			0.011				0.003		0.059	0.005			
ab													
ac					0.0011		0.003					0.002	
ad													Comparative Steel
ae													
af													
ag													
ah													
ai													
aj													
ak													
al													
am													

[Table 2-1]

Test No.	Component	Hot Rolling Step				
		Ratio of Sheet Thickness Reduction at (n-3)-th Stand (%)	Ratio of Sheet Thickness Reduction at (n-2)-th Stand (%)	Ratio of Sheet Thickness Reduction at (n-1)-th Stand (%)	Ratio of Sheet Thickness Reduction at Final Stand (n-th Stand) (%)	Rolling Temperature at Final Stand (°C)
1	a	34	42	41	34	859
2	a	35	48	38	41	889
3	a	41	49	37	35	880
4	b	48	41	49	32	842
5	c	44	40	43	33	869
6	c	43	32	30	34	883
7	d	35	42	34	39	863
8	d	32	37	39	38	893
9	e	31	34	34	44	838
10	f	31	40	35	42	877
11	9	38	48	32	32	843
12	h	40	32	49	37	885
13	h	48	36	35	32	853
14	h	34	37	46	35	896
15	i	31	41	38	40	840
16	j	37	31	48	33	865
17	k	37	48	40	35	881
18	l	46	39	32	50	832
19	m	38	44	45	42	888
20	n	41	32	47	39	877
21	o	32	45	48	47	862
22	p	30	35	40	31	845
23	p	36	47	37	48	877
24	p	34	33	33	45	850
25	q	45	40	31	45	846
26	r	49	41	41	47	862
27	s	49	33	33	43	847
28	t	32	35	42	42	837
29	u	33	35	44	46	896
30	v	33	43	40	42	894
31	w	32	31	36	44	874
32	x	43	33	46	36	887
33	y	38	36	32	32	835
34	z	46	31	45	31	896

(continued)

Test No.	Component	Hot Rolling Step				
		Ratio of Sheet Thickness Reduction at (n-3)-th Stand (%)	Ratio of Sheet Thickness Reduction at (n-2)-th Stand (%)	Ratio of Sheet Thickness Reduction at (n-1)-th Stand (%)	Ratio of Sheet Thickness Reduction at Final Stand (n-th Stand) (%)	Rolling Temperature at Final Stand (°C)
35	aa	31	35	35	38	837
36	ab	40	48	41	49	873
37	ac	32	40	30	38	863

[Table 2-2]

Test No.	Component	Hot Rolling Step				
		Ratio of Sheet Thickness Reduction at (n-3)-th Stand (%)	Ratio of Sheet Thickness Reduction at (n-2)-th Stand (%)	Ratio of Sheet Thickness Reduction at (n-1)-th Stand (%)	Ratio of Sheet Thickness Reduction at Final Stand (n-th Stand) (%)	Rolling Temperature at Final Stand (°C)
38	ad	37	44	47	47	836
39	ae	40	45	38	35	870
40	at	42	38	48	45	880
41	ag	39	38	43	41	870
42	ah	38	39	47	40	840
43	ai	37	46	37	44	856
44	aj	42	36	42	31	857
45	ak	35	47	35	33	842
46	al	44	44	38	47	859
47	am	48	31	43	37	869
48	b	49	36	49	48	950
49	b	46	41	38	12	880
50	b	18	28	25	48	869
51	b	36	36	45	36	886
52	m	32	44	34	43	855
53	m	40	39	31	41	891
54	k	41	35	33	35	863
55	k	37	34	39	40	894
56	u	44	33	41	43	884
57	u	42	46	44	48	885
58	aa	31	35	35	38	837

[Table 2-3]

Test No.	Coiling Step		Holding Step	Cooling Step	Cold Rolling Step
	Average Cooling Rate After Hot Rolling Step (°C/sec)	Coiling Temperature (°C)	Holding Time (hr)	Average Cooling Rate until Temperature of 300°C or Lower (°C/s)	Ratio of Sheet Thickness Reduction (%)
1	59	640	4	1.5	77
2	63	606	6	8.0	76
3	78	558	5	9.6	54
4	36	481	5	1.3	72
5	36	550	2	7.8	73
6	68	505	4	2.7	64
7	58	494	7	4.2	76
8	93	539	5	8.6	76
9	82	504	2	10.5	73
10	42	604	4	4.5	75
11	89	576	6	3.0	43
12	56	635	6	11.0	75
13	76	489	2	2.9	45
14	42	562	6	7.1	75
15	87	584	7	3.7	54
16	56	528	5	6.3	44
17	73	600	2	3.4	76
18	66	640	3	8.5	75
19	85	553	7	11.5	24
20	50	459	4	7.1	76
21	44	507	3	5.5	55
22	40	520	7	6.9	76
23	49	488	3	7.8	70
24	41	612	3	5.3	70
25	85	632	4	10.1	65
26	47	561	6	8.9	76
27	55	583	3	5.7	73
28	52	516	7	3.4	39
29	79	466	5	10.7	46
30	66	539	2	5.6	44
31	50	595	6	2.2	74
32	61	555	2	11.3	67
33	71	540	7	9.2	59
34	87	558	6	10.1	37
35	31	635	5	0.7	57

(continued)

Test No.	Coiling Step		Holding Step	Cooling Step	Cold Rolling Step
	Average Cooling Rate After Hot Rolling Step (°C/sec)	Coiling Temperature (°C)	Holding Time (hr)	Average Cooling Rate until Temperature of 300°C or Lower (°C/s)	Ratio of Sheet Thickness Reduction (%)
36	42	573	2	2.0	44
37	34	600	5	1.0	75

[Table 2-4]

Test No.	Coiling Step		Holding Step	Cooling Step	Cold Rolling Step
	Average Cooling Rate After Hot Rolling Step (°C/sec)	Coiling Temperature (°C)	Holding Time (hr)	Average Cooling Rate until Temperature of 300°C or Lower (°C/s)	Ratio of Sheet Thickness Reduction (%)
38	39	517	7	0.9	76
39	96	463	6	6.6	76
40	91	585	3	2.5	77
41	92	609	3	1.6	77
42	79	613	4	5.2	50
43	71	462	7	2.3	76
44	82	597	4	9.9	73
45	88	618	6	5.4	77
46	62	528	7	3.8	30
47	36	626	8	6.4	74
48	75	516	4	4.7	32
49	48	593	6	10.8	70
50	81	540	4	2.4	39
51	<u>17</u>	620	5	7.7	75
52	34	<u>370</u>	6	6.5	-
53	87	488	<u>1</u>	16.0	73
54	71	456	4	8.1	<u>18</u>
55	96	623	2	9.7	64
56	74	478	3	1.0	32
57	66	509	2	10.8	74
58	31	635	5	0.7	57

[Table 2-5]

(continued)

Test No.	Annealing Step						Remarks
	Average Temperature Rising Rate until Annealing Temperature (°C/sec)	Average Temperature Rising Rate at 550°C or Higher (°C/sec)	Annealing Temperature (°C)	Holding Time (sec)	Presence or Absence of Plating	Presence or Absence of Alloying	

(continued)

Test No.	Annealing Step						Remarks
	Average Temperature Rising Rate until Annealing Temperature (°C/sec)	Average Temperature Rising Rate at 550°C or Higher (°C/sec)	Annealing Temperature (°C)	Holding Time (sec)	Presence or Absence of Plating	Presence or Absence of Alloying	
1	8	6	860	220	Presence	Presence	Invention Example
2	9	6	839	102	Presence	Absence	
3	15	15	811	82	Absence	Absence	
4	9	6	890	87	Presence	Presence	
5	14	4	794	263	Absence	Absence	
6	10	8	895	89	Presence	Absence	
7	10	8	877	248	Absence	Absence	
8	7	6	805	111	Presence	Presence	
9	9	4	883	80	Absence	Absence	
10	9	8	804	102	Presence	Presence	
11	16	15	866	280	Absence	Absence	
12	19	17	815	78	Presence	Presence	
13	22	15	826	241	Presence	Presence	
14	12	9	830	122	Presence	Absence	
15	12	10	745	258	Absence	Absence	
16	8	7	763	91	Presence	Presence	
17	8	8	806	79	Absence	Absence	
18	17	17	779	80	Absence	Absence	
19	20	18	798	191	Presence	Presence	
20	8	4	834	145	Presence	Presence	
21	15	11	819	114	Absence	Absence	
22	10	2	805	79	Absence	Absence	
23	9	4	837	74	Presence	Presence	
24	9	4	822	80	Presence	Presence	
25	22	16	820	80	Absence	Absence	
26	8	6	801	82	Presence	Presence	
27	8	6	885	80	Absence	Absence	
28	11	11	856	78	Absence	Absence	
29	9	8	823	86	Presence	Presence	
30	10	2	847	75	Presence	Presence	
31	10	10	837	84	Presence	Presence	
32	13	3	824	76	Presence	Presence	
33	10	7	865	182	Presence	Presence	
34	43	32	759	79	Presence	Presence	
35	5	5	860	220	Presence	Presence	
36	9	7	861	83	Absence	Absence	
37	9	8	860	120	Absence	Absence	

[Table 2-6]

Test No.	Annealing Step						Remarks
	Average Temperature Rising Rate until Annealing Temperature (°C/sec)	Average Temperature Rising Rate at 550°C or Higher (°C/sec)	Annealing Temperature (°C)	Holding Time (sec)	Presence or Absence of Plating	Presence or Absence of Alloying	
38	8	6	845	98	Absence	Absence	Comparative Example
39	9	7	889	158	Presence	Presence	
40	10	7	885	79	Presence	Presence	
41	11	8	868	77	Absence	Absence	
42	31	29	845	76	Absence	Absence	
43	9	7	840	79	Presence	Presence	
44	8	6	832	97	Presence	Absence	
45	8	8	860	243	Presence	Presence	
46	8	6	820	215	Presence	Presence	
47	11	8	891	254	Presence	Absence	
48	7	6	856	90	Presence	Absence	Comparative Example
49	7	5	798	79	Presence	Absence	
50	11	7	880	76	Absence	Absence	
51	24	13	840	82	Presence	Absence	
52	-						
53	15	9	858	132	Presence	Presence	
54	9	6	800	77	Presence	Presence	
55	<u>1</u>	1	894	81	Presence	Absence	
56	14	10	<u>950</u>	225	Presence	Presence	
57	8	7	880	<u>340</u>	Presence	Presence	
58	8	6	830	155	Presence	Presence	Invention Example

[0154] In these cold-rolled steel sheets, the area ratio of the microstructure structure (ferrite, bainite, martensite, tempered martensite, pearlite, and residual austenite (residual γ)) in a range (thickness 1/4 part) of 1/8 to 3/8 of the thickness, centered at a position that was at a depth of 1/4 of the sheet thickness from the surface; the ratio (N_6/N_T) of the number N_6 of crystal grains of ferrite and bainite having an area of 6 μm^2 or less to the total number NT of crystal grains of ferrite and bainite and the ratio (N_{50}/N_T) of the number N_{50} of crystal grains of ferrite and bainite having an area of greater than 50 μm^2 to the total number NT of crystal grains of ferrite and bainite in the thickness 1/4 part; the difference ΔMn between the maximum value of the Mn concentration in a region up to 0.5 μm from an interface between ferrite and martensite in a direction perpendicular to the interface and toward the inside of the ferrite grains and the average Mn content; and the average aspect ratio of ferrite and bainite having an area of 6 μm^2 or less in the thickness 1/4 part were evaluated. The results were shown in Table 3. These evaluations were performed according to the above-described methods.

[0155] Furthermore, the tensile strengths (TS), uniform elongation (uEl), and $\sigma\Delta$ of the cold-rolled steel sheets were evaluated by the following method. The results are shown in Tables 3-1 to 3-4. In Tables 1-1 to 3-4, the underline indicates that the underlined numerical value is outside the range of the present invention, or preferable properties are not obtained.

[Table 3-1]

Test No.	Component	Structure Proportion (Area Ratio)				
		Ferrite (%)	Ferrite and Bainite (%)	Martensite and Tempered Martensite (%)	Pearlite and Residual γ (%)	Residual γ (%)
1	a	56	56	44	0	0
2	a	43	43	57	0	0
3	a	50	50	50	0	0
4	b	11	14	86	0	0
5	c	83	84	16	0	0
6	c	82	82	18	0	0
7	d	20	21	79	0	0
8	d	15	21	79	0	0
9	e	51	51	49	0	0
10	f	48	48	52	0	0
11	9	44	44	56	0	0
12	h	17	17	83	0	0
13	h	20	20	80	0	0
14	h	10	10	90	0	0
15	i	48	51	49	0	0
16	j	75	79	21	0	0
17	k	54	54	46	0	0
18	1	78	78	22	0	0
19	m	15	19	81	0	0
20	n	79	82	18	0	0
21	o	47	47	53	0	0
22	P	75	77	23	0	0
23	P	80	82	18	0	0
24	P	85	85	15	0	0
25	q	54	54	46	0	0
26	r	75	77	23	0	0
27	s	75	76	24	0	0
28	t	78	81	19	0	0
29	u	77	81	19	0	0
30	v	85	86	14	0	0
31	w	80	80	12	8	8
32	x	77	79	21	0	0
33	y	78	82	18	0	0
34	z	82	82	18	0	0
35	aa	57	57	33	10	10

(continued)

Test No.	Component	Structure Proportion (Area Ratio)				
		Ferrite (%)	Ferrite and Bainite (%)	Martensite and Tempered Martensite (%)	Pearlite and Residual γ (%)	Residual γ (%)
36	ab	46	46	54	0	0
37	ac	55	59	41	0	0

[Table 3-2]

Test No.	Component	Structure Proportion (Area Ratio)				
		Ferrite (%)	Ferrite and Bainite (%)	Martensite and Tempered Martensite (%)	Pearlite and Residual γ (%)	Residual γ (%)
38	ad	75	75	25	0	0
39	ae	11	11	89	0	0
40	af	20	20	80	0	0
41	ag	88	89	11	0	0
42	ah	13	16	84	0	0
43	ai	76	76	24	0	0
44	aj	15	17	83	0	0
45	ak	50	51	49	0	0
46	al	13	13	87	0	0
47	am	11	11	89	0	0
48	b	7	10	90	0	0
49	b	10	10	90	0	0
50	b	9	9	91	0	0
51	b	12	16	84	0	0
52	m	Cold Rolling is not Possible Due to Excessive Cold Rolling Load				0
53	m	6	8	92	0	0
54	k	15	15	85	0	0
55	k	11	11	89	0	0
56	u	12	16	84	0	0
57	u	10	10	90	0	0
58	aa	65	65	26	9	6

[Table 3-3]

Test No.	Characteristics of Structure				Properties			Remarks
	N_6/N_T (%)	N_{50}/N_T (%)	Average Aspect Ratio of Crystal Grains Having Area of 6 μm^2 or Less	ΔMn (mass%)	Tensile Strength (MPa)	Uniform Elongation u-El (%)	$\Delta\sigma$ (MPa)	
1	73	0	1.3	1.07	1028	10.2	27	Invention Example
2	75	0	1.3	0.56	1066	9.3	27	
3	66	0	1.4	0.52	1046	11.0	29	
4	74	0	1.3	1.20	1158	9.1	27	
5	64	2	1.5	0.34	879	12.5	40	
6	63	0	1.3	0.53	883	12.2	29	
7	70	1	1.4	0.59	1224	8.0	32	
8	79	0	1.2	0.47	1237	8.2	25	
9	73	0	1.3	0.34	1029	12.0	27	
10	68	0	1.3	0.44	866	14.2	28	
11	54	3	1.3	1.04	962	11.7	44	
12	80	0	1.8	0.47	1189	8.7	27	
13	59	3	1.5	0.46	1181	10.6	46	
14	76	0	1.4	0.43	1208	10.2	27	
15	62	1	1.3	1.18	974	10.3	34	
16	56	0	1.1	0.46	841	14.8	30	
17	80	0	1.3	0.53	1147	8.3	25	
18	65	0	1.7	0.48	820	15.3	32	
19	51	2	2.1	0.63	1244	7.4	48	
20	58	0	1.3	0.39	802	14.8	31	
21	65	0	1.4	0.44	1066	10.7	30	
22	67	0	1.4	0.40	831	12.3	29	
23	62	0	1.3	0.39	814	12.5	30	
24	56	0	1.3	0.38	793	14.8	31	
25	68	0	1.8	0.51	926	10.4	31	
26	73	0	1.3	0.56	919	11.5	27	
27	61	0	1.2	0.42	815	15.0	30	
28	48	0	1.3	0.74	791	15.3	34	
29	61	0	1.2	0.43	985	13.1	29	
30	54	0	1.3	0.40	819	12.6	32	
31	65	0	1.3	0.82	838	14.0	29	
32	65	0	1.4	0.35	848	13.7	30	
33	57	0	1.3	0.43	845	12.1	31	
34	54	1	1.9	0.55	831	15.3	43	

(continued)

Test No.	Characteristics of Structure				Properties			Remarks
	N_6/N_T (%)	N_{50}/N_T (%)	Average Aspect Ratio of Crystal Grains Having Area of 6 μm^2 or Less	ΔMn (mass%)	Tensile Strength (MPa)	Uniform Elongation u-El (%)	$\Delta\sigma$ (MPa)	
35	61	0	1.3	1.08	1025	11.4	30	
36	60	0	1.2	0.63	1058	9.6	29	
37	72	0	1.3	0.88	1031	9.7	27	

[Table 3-4]

Test No.	Characteristics of Structure				Properties			Remarks
	N_6/N_T (%)	N_{50}/N_T (%)	Average Aspect Ratio of Crystal Grains Having Area of 6 μm^2 or Less	ΔMn (mass%)	Tensile Strength (MPa)	Uniform Elongation u-El (%)	$\Delta\sigma$ (MPa)	
38	41	0	1.3	1.30	771	12.1	35	Comparative Example
39	73	0	1.3	0.61	1328	6.8	77	
40	77	0	1.4	0.42	1165	8.0	69	
41	50	0	1.4	1.69	765	13.1	34	
42	65	1	1.9	0.77	1159	8.7	65	
43	71	0	1.3	1.76	906	11.6	59	
44	76	0	1.2	0.43	1148	9.4	71	
45	69	0	1.3	0.69	1090	10.2	66	
46	53	0	1.0	1.18	1155	8.1	72	
47	67	1	1.4	0.49	1062	9.4	53	
48	37	6	1.5	0.11	1216	8.6	66	Comparative Example
49	78	8	1.2	0.09	1207	8.4	54	
50	39	6	1.5	0.05	1210	8.5	65	
51	35	2	1.5	0.22	1201	8.8	59	
52	Cold Rolling is not Possible Due to Excessive Cold Rolling Load							
53	76	4	1.3	0.18	1420	4.2	67	
54	50	12	1.8	0.42	1236	9.4	93	
55	77	2	1.6	0.03	1219	9.1	58	
56	52	10	1.2	0.08	1199	9.5	76	
57	67	8	1.3	0.16	1205	8.6	60	
58	62	0	1.3	1.20	967	12.8	26	Invention Example

[0156] Of the steel sheet, the tensile strength (TS) (σ1), the uniform elongation (u-El), and $\Delta\sigma$, that is a difference (σ1 - σ2) between the stress σ2 at uniform elongation + 1.0% and the tensile strength σ1, were evaluated as follows: a JIS No. 5 test piece was collected from the steel sheet so that a longitudinal direction thereof was perpendicular to the rolling direction of the steel sheet, and a tensile test was performed thereon according to JIS Z 2241: 2011.

[0157] Steel sheets having a tensile strength (TS) of 780 MPa or greater were determined as acceptable in terms of tensile strength.

[0158] In addition, steel sheets in which the uniform elongation (u-El) was 5.5% or greater were determined to be excellent in formability.

[0159] In addition, steel sheets in which $\Delta\sigma$ was 50 MPa or less were determined to be excellent in fracture resistance.

[0160] As is clear from Tables 1-1 to 3-4, in the invention examples (Test Nos. 1 to 37, and No. 58) in which both the chemical composition and the production conditions were within the ranges of the present invention, the microstructural fraction of the microstructure, characteristics of the structure ((N_6/N_T), (N_{50}/N_T), ΔMn, average aspect ratio of ferrite and bainite having an area of 6 μm^2 or less), and properties were all within the ranges of the present invention, and the strength, formability, and fracture resistance were excellent.

[0161] On the other hand, in the comparative examples (Test Nos. 38 to 57) in which either or both of the chemical composition and the production conditions did not meet the ranges of the present invention, the chemical composition, microstructural fraction, or characteristics of the structure were outside the ranges of the present invention, and thus at least one of the strength, formability, or fracture resistance was inferior.

[0162] Test Nos. 38 to 47 are comparative examples in which the production conditions are within the ranges of the present invention, but the chemical composition is outside the ranges of the present invention, and at least one of the strength, formability, or fracture resistance thereof is inferior.

[0163] Test Nos. 48 to 57 are comparative examples in which the chemical composition is within the ranges of the present invention, but any of the conditions in the producing method is outside the ranges of the present invention.

[0164] In Test No. 48, since the temperature of the final stand in hot rolling was too high, it was not possible to sufficiently secure N_6/N_T and N_{50}/N_T, and the formation of the Mn-deficient layer became insufficient (ΔMn was less than 0.30). As a result, $\Delta\sigma$, that is an index for fracture resistance, did not meet the target.

[0165] In Test No. 49, the ratio of sheet thickness reduction in the final stand in hot rolling, and in Test No. 50, the rates of sheet thickness reduction in the (n-3)- to (n-1)-th stands were too small. In addition, in Test No. 51, the cooling rate after finish rolling was too low. Therefore, it was not possible to uniformly disperse a large amount of cementite in the hot-rolled steel sheet, the refinement of the structure after annealing and the formation of the Mn-deficient layer became insufficient, and N_6/N_T and N_{50}/N_T were outside the ranges of the present invention. As a result, $\Delta\sigma$ did not meet the target.

[0166] In Test No. 52, since the coiling temperature was too low, the strength of the hot-rolled steel sheet significantly increased. This led to an increase in cold rolling load, which made it impossible to perform cold rolling.

[0167] In Test No. 53, since the holding time in the holding step was too short, the concentration of elements such as Mn in carbide became insufficient, and the formation of the Mn-deficient layer after annealing became insufficient. As a result, $\Delta\sigma$ did not meet the target.

[0168] In Test No. 54, since the ratio of sheet thickness reduction in the cold rolling step was too large, strain accumulation in the steel sheet became insufficient, sites for austenite nuclei were generated during annealing became non-uniform, and N_{50}/N_T was outside the range of the present invention. As a result, $\Delta\sigma$ did not meet the target.

[0169] In Test No. 55, since the temperature rising rate in the annealing step was too high, the Mn-deficient layer disappeared during annealing. As a result, ΔMn became less than 0.30, and $\Delta\sigma$ did not meet the target.

[0170] In Test No. 56, since the heating temperature in the annealing step was too high, the Mn-deficient layer disappeared during annealing, and ΔMn became less than 0.30. In addition, N_{50}/N_T was outside the range of the present invention. As a result, $\Delta\sigma$ did not meet the target.

[0171] In Test No. 57, since the holding time during heating in the annealing step was too long, the Mn-deficient layer disappeared during annealing, and ΔMn became less than 0.30. In addition, N_{50}/N_T was outside the range of the present invention. As a result, $\Delta\sigma$ did not meet the target.

[Industrial Applicability]

[0172] According to the present invention, it is possible to provide a steel sheet having excellent fracture resistance and a method for producing the steel sheet. Therefore, the present invention has high industrial applicability.

Claims

1. A steel sheet consisting of, as a chemical composition, by mass%:

C: 0.07% to 0.15%;
Si: 0.01% to 2.00%;
Mn: 1.5% to 3.0%;

P: 0% to 0.020%;
S: 0% to 0.0200%;
At: 0.001% to 1.000%;
N: 0% to 0.0200%;
O: 0% to 0.0200%;
Co: 0% to 0.500%;
Ni: 0% to 1.000%;
Cu: 0% to 0.500%;
Mo: 0% to 1.000%;
Cr: 0% to 2.000%;
Ti: 0% to 0.5000%;
Nb: 0% to 0.50%;
V: 0% to 0.500%;
W: 0% to 0.100%;
Ta: 0% to 0.100%;
B: 0% to 0.0100%;
Mg: 0% to 0.050%;
Ca: 0% to 0.050%;
Zr: 0% to 0.050%;
REM: 0% to 0.100%;
Sn: 0% to 0.050%;
Sb: 0% to 0.050%;
As: 0% to 0.050%; and
a remainder: Fe and impurities,
wherein a tensile strength is 780 MPa or greater,
in a microstructure,

an area ratio of ferrite is 5% or greater,
a total of the area ratio of ferrite and an area ratio of bainite is 10% or greater and 90% or less,
a total of an area ratio of martensite and an area ratio of tempered martensite is 10% or greater and 90% or less, and
a total of an area ratio of pearlite and an area ratio of residual austenite is 0% or greater and 10% or less,

a number proportion of crystal grains of ferrite and bainite having an area of 6 μm^2 or less is 40% or greater to a total number of crystal grains of the ferrite and the bainite, and
a number proportion of crystal grains of ferrite and bainite having an area of 50 μm^2 or greater is 5% or less to the total number of crystal grains of the ferrite and the bainite, and
a maximum Mn content in a region up to 0.5 μm from an interface between the ferrite and the martensite or the tempered martensite, in a direction perpendicular to the interface and toward an inside of the ferrite grains, is 0.30 mass% or more lower than an average Mn content of the steel sheet.

2. The steel sheet according to claim 1,
wherein an average aspect ratio of the crystal grains of the ferrite and the bainite having an area of 6 μm^2 or less is 1.0 or greater and 2.0 or less.

3. The steel sheet according to claim 1 or 2,
wherein a coating layer containing zinc, aluminum, magnesium, or an alloy of these metals is provided on a surface.

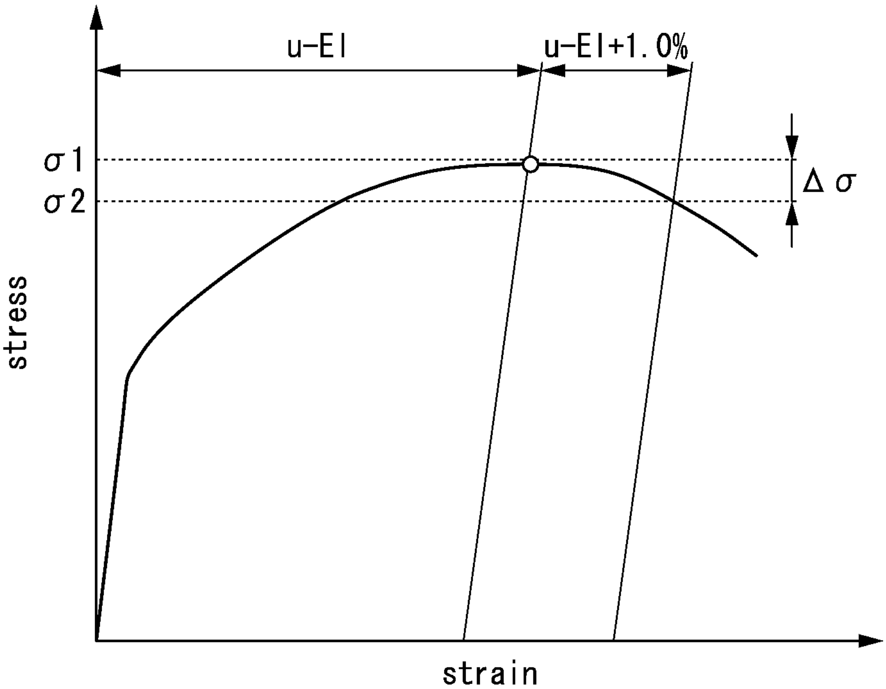
4. A method for producing a steel sheet, the method comprising:

hot-rolling a slab to obtain a hot-rolled steel sheet, the slab including, as a chemical composition, by mass%, C: 0.07% to 0.15%, Si: 0.01% to 2.00%, Mn: 1.5% to 3.0%, P: 0% to 0.020%, S: 0% to 0.0200%, Al: 0.001% to 1.000%, N: 0% to 0.0200%, O: 0% to 0.0200%, Co: 0% to 0.500%, Ni: 0% to 1.000%, Cu: 0% to 0.500%, Mo: 0% to 1.000%, Cr: 0% to 2.000%, Ti: 0% to 0.5000%, Nb: 0% to 0.50%, V: 0% to 0.500%, W: 0% to 0.100%, Ta: 0% to 0.100%, B: 0% to 0.0100%, Mg: 0% to 0.050%, Ca: 0% to 0.050%, Zr: 0% to 0.050%, REM: 0% to 0.100%, Sn: 0% to 0.050%, Sb: 0% to 0.050%, As: 0% to 0.050%, and a remainder: Fe and impurities;
cooling the hot-rolled steel sheet to a coiling temperature of 650°C or lower and 450°C or higher at an average cooling rate of 30 °C/sec or higher, and coiling the hot-rolled steel sheet at the coiling temperature;

holding the hot-rolled steel sheet after the coiling so that a holding time in a temperature range from the coiling temperature to the coiling temperature - 50°C is 2 to 8 hours;
cooling the hot-rolled steel sheet after the holding to a temperature of 300°C or lower at an average cooling rate of 0.1 °C/sec or higher;
cold-rolling the hot-rolled steel sheet after the cooling at a ratio of sheet thickness reduction of 20% to 80% to obtain a cold-rolled steel sheet; and
annealing the cold-rolled steel sheet by heating the cold-rolled steel sheet to an annealing temperature of 740°C to 900°C at an average temperature rising rate of 5 °C/sec or higher and holding the cold-rolled steel sheet at the annealing temperature for 60 to 300 seconds,
wherein in the hot rolling,
finish rolling is performed using a rolling mill having four or more stands, and in a case where an initial stand is defined as a first stand and a final stand is defined as an n-th stand, a ratio of sheet thickness reduction in each of stands ranging from an (n-3)-th stand to the n-th stand is set to 30% or greater, and a rolling temperature in the n-th stand is set to 900°C or lower.

5. The method for producing a steel sheet according to claim 4,
wherein in the annealing, a coating layer containing zinc, aluminum, magnesium, or an alloy of these metals is formed on a surface of the steel sheet.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/029080

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301S; C21D9/46 G; C21D9/46 J; C22C38/00 301T; C22C38/60

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60; C21D8/00-8/04; C21D9/46-9/48

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 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2020/170710 A1 (JFE STEEL CORPORATION) 27 August 2020 (2020-08-27) claims, paragraphs [0093]-[0096], tables 1-3	1-5
A	WO 2018/030503 A1 (JFE STEEL CORPORATION) 15 February 2018 (2018-02-15) claims, paragraph [0046]	1-5
A	WO 2021/145310 A1 (NIPPON STEEL CORPORATION) 22 July 2021 (2021-07-22) claims	1-5

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

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Date of the actual completion of the international search	Date of mailing of the international search report
05 October 2022	**18 October 2022**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/029080

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2020/170710 A1	27 August 2020	(Family: none)	
WO 2018/030503 A1	15 February 2018	EP 3476962 A1 claims, paragraph [0037] US 2019/0161823 A1 CN 109563585 A	
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REFERENCES CITED IN THE DESCRIPTION

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