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

(11) EP 4 474 512 A1

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

(43) Date of publication:
11.12.2024 Bulletin 2024/50

(21) Application number: **23774242.4**

(22) Date of filing: **30.01.2023**

(51) International Patent Classification (IPC):
***C22C 38/00** (2006.01)* ***C21D 9/46** (2006.01)*
***C22C 38/06** (2006.01)* ***C22C 38/60** (2006.01)*

(52) Cooperative Patent Classification (CPC):
C21D 9/46; C22C 38/00; C22C 38/06; C22C 38/60

(86) International application number:
PCT/JP2023/002917

(87) International publication number:
WO 2023/181643 (28.09.2023 Gazette 2023/39)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **25.03.2022 JP 2022049759**

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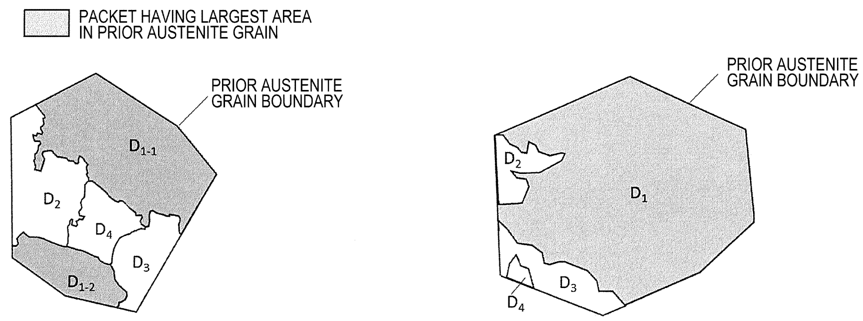
(54) HIGH-STRENGTH STEEL SHEET AND MANUFACTURING METHOD THEREFOR

(57) Objects are to provide a high strength steel sheet having 980 MPa or higher TS and 10% or more El and being excellent in toughness, flatness in the width direction, and working embrittlement resistance; and to provide a method for manufacturing the same.

The high strength steel sheet has a specific chemical composition and is such that in a region at 1/4 sheet thickness, the area fraction of martensite is 60% or more, the volume fraction of retained austenite is 30 or more and 15% or less, the area fraction of the total of ferrite and bainitic ferrite is more than 10%, and the average of the proportions of packets having the largest area in prior austenite grains is 70% by area or less of the prior austenite grain.

FIG. 1



$$\text{(PROPORTION OF PACKET HAVING LARGEST AREA IN PRIOR AUSTENITE GRAIN)} = \frac{(D_{1\text{-}1}+D_{1\text{-}2})}{(D_{1\text{-}1}+D_{1\text{-}2}+D_2+D_3+D_4)}\times 100$$

$$\text{(PROPORTION OF PACKET HAVING LARGEST AREA IN PRIOR AUSTENITE GRAIN)} = \frac{D_1}{(D_1+D_2+D_3+D_4)}\times 100$$

PACKET HAVING LARGEST AREA IN PRIOR AUSTENITE GRAIN

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Description

Technical Field

[0001] The present invention relates to a high strength steel sheet excellent in tensile strength, El, toughness, flatness in the width direction, and working embrittlement resistance, and to a method for manufacturing the same. The high strength steel sheet of the present invention may be suitably used as structural members, such as automobile parts.

Background Art

[0002] Steel sheets for automobiles are being increased in strength in order to reduce CO_2 emissions by weight reduction of vehicles and to enhance crashworthiness by weight reduction of automobile bodies at the same time, with introduction of new laws and regulations one after another. To increase the strength of automobile bodies, high strength steel sheets having a tensile strength (TS) of 980 MPa or higher grade are increasingly applied to principal structural parts of automobiles.

[0003] High strength steel sheets used in automobiles require excellent press formability. For example, high strength steel sheets with high El are suitably applied to automobile frame parts, such as bumpers. From the point of view of crash safety, excellent toughness and working embrittlement resistance are required.

[0004] Furthermore, high strength steel sheets used in automobiles require high flatness. Patent Literature 1 describes that warpage of a steel sheet causes operational troubles in forming lines and adversely affects the dimensional accuracy of products. The present inventors carried out extensive studies and have found that the dimensional accuracy of products is affected not only by the warpage of steel sheets but also by the flatness in the width direction that is evaluated as steepness. For example, the steepness in the width direction is suitably 0.02 or less in order to achieve excellent dimensional accuracy.

[0005] To meet the above demands, for example, Patent Literature 2 provides a high strength steel sheet having a tensile strength of 1100 MPa or more and being excellent in YR, surface quality, and weldability, and a method for manufacturing the same. However, the technique described in Patent Literature 2 does not take into consideration El, toughness, flatness in the width direction, and working embrittlement resistance.

[0006] Patent Literature 3 provides a hot-dip galvanized steel sheet with excellent press formability and low-temperature toughness that has a tensile strength of 980 MPa or more, and a method for manufacturing the same. While the steel sheet of Patent Literature 3 is improved in embrittlement at low temperatures, the technique does not take into consideration the working embrittlement of the steel sheet or the flatness in the width direction.

Citation List

Patent Literature

[0007]

PTL 1: Japanese Patent No. 4947176
PTL 2: Japanese Patent No. 6525114
PTL 3: Japanese Patent No. 6777272

Non Patent Literature

[0008] NPL 1: Journal of Smart Processing, 2013, Vol. 2, No. 3, pp. 110-118

Summary of Invention

Technical Problem

[0009] The present invention has been developed in view of the circumstances discussed above. Objects of the present invention are therefore to provide a high strength steel sheet having 980 MPa or higher TS and 10% or more El and being excellent in toughness, flatness in the width direction, and working embrittlement resistance; and to provide a method for manufacturing the same.

Solution to Problem

[0010] The present inventors carried out extensive studies directed to solving the problems described above and have consequently found the following facts.

(1) 980 MPa or higher TS can be realized by limiting the area fraction of martensite to 60% or more.
(2) 10% or more El can be achieved by limiting the volume fraction of retained austenite to 3% or more and the area fraction of the total of ferrite and bainitic ferrite to more than 10%.
(3) Excellent toughness can be realized by limiting the volume fraction of retained austenite to 3% or more.
(4) Excellent working embrittlement resistance can be achieved by limiting the proportion of a packet having the largest area in a prior austenite grain to 70% by area or less on average.
(5) Excellent working embrittlement resistance can be realized by limiting the volume fraction of retained austenite to 15% or less and by limiting the proportion of a packet having the largest area in a prior austenite grain to 70% by area or less on average.

[0011] The present invention has been made based on the above findings. Specifically, a summary of configurations of the present invention is as follows.

[1] A high strength steel sheet having a chemical composition including, in mass%, C: 0.030% or more and 0.500% or less, Si: 0.50% or more and 2.50% or less, Mn: 1.00% or more and 5.00% or less, P: 0.100% or less, S: 0.0200% or less, Al: 1.000% or less, N: 0.0100% or less, and O: 0.0100% or less, a balance being Fe and incidental impurities, the high strength steel sheet being such that in a region at 1/4 sheet thickness, an area fraction of martensite is 60% or more, a volume fraction of retained austenite is 3% or more and 15% or less, an area fraction of a total of ferrite and bainitic ferrite is more than 10%, and an average of proportions of packets having the largest area in prior austenite grains is 70% by area or less of the prior austenite grain.
[2] The high strength steel sheet according to [1], wherein the chemical composition further includes at least one element selected from, in mass%, Ti: 0.200% or less, Nb: 0.200% or less, V: 0.200% or less, Ta: 0.10% or less, W: 0.10% or less, B: 0.0100% or less, Cr: 1.00% or less, Mo: 1.00% or less, Co: 0.010% or less, Ni: 1.00% or less, Cu: 1.00% or less, Sn: 0.200% or less, Sb: 0.200% or less, Ca: 0.0100% or less, Mg: 0.0100% or less, REM: 0.0100% or less, Zr: 0.100% or less, Te: 0.100% or less, Hf: 0.10% or less, and Bi: 0.200% or less.
[3] The high strength steel sheet according to [1] or [2], which has a coated layer on a surface of the steel sheet.
[4] A method for manufacturing the high strength steel sheet according to [1] or [2], the method including providing a cold rolled steel sheet produced by subjecting a steel having the chemical composition to hot rolling, pickling, and cold rolling; annealing the steel sheet by heating at an annealing temperature Ta of 700°C or above and 900°C or below for a holding time at the annealing temperature Ta of 10 seconds or more and 1000 seconds or less; bending and unbending the steel sheet 1 to 15 times in total with a roll having a radius of 800 mm or less during the annealing; cooling the steel sheet at an average cooling rate of 20°C/s or more in a temperature range from 700°C to 600°C and at an average cooling rate of less than 20°C/s in a temperature range from 499°C to Ms; bending and unbending the steel sheet in the temperature range from 499°C to Ms, 1 to 15 times in total with a roll having a radius of 800 mm or less; cooling the steel sheet at an average cooling rate of 150°C/s or less in a temperature range from Ms to a cooling stop temperature Tb; applying a tension to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb while controlling the tension to 5 MPa or more and 100 MPa or less, the cooling stop temperature Tb being 100°C or above and (Ms - 80°C) or below where Ms is a martensite start temperature (°C) defined by formula (1); and tempering the steel sheet at a tempering temperature of Tb or above and 450°C or below for a holding time at the tempering temperature of 10 seconds or more and 1000 seconds or less,

$$Ms = 519 - 474 \times [\% C] - 30.4 \times \times [\% Mn] - 12.1 \times [\% Cr] - 7.5 \times [\% Mo] - 17.7 \times [\% Ni] - Ta/80 \quad (1)$$

wherein [% C], [% Mn], [% Cr], [% Mo], and [% Ni] indicate the contents (mass%) of C, Mn, Cr, Mo, and Ni, respectively, and are zero when the element is absent.
[5] The method for manufacturing the high strength steel sheet according to [4], further including performing a coating treatment.

Advantageous Effects of Invention

[0012] According to the present invention, a high strength steel sheet can be obtained that has 980 MPa or higher TS and 10% or more El and excels in toughness, flatness in the width direction, and working embrittlement resistance. Furthermore, for example, the high strength steel sheet of the present invention may be applied to automobile structural members to reduce the weight of automobile bodies and thereby to enhance fuel efficiency. Thus, the present invention is highly valuable in industry.

Brief Description of Drawings

[0013]

[Fig. 1] Fig. 1 is a set of views illustrating a structure of a packet having the largest area in a prior austenite grain according to the present invention, and how the proportion of the packet is calculated.
[Fig. 2] Fig. 2 is a set of views illustrating the concept of the steepness λ in the width direction of a steel sheet according to the present invention, and how the steepness is calculated.

Description of Embodiments

[0014] Embodiments of the present invention will be described below.
[0015] First, appropriate ranges of the chemical composition of the high strength steel sheet and the reasons why the chemical composition is thus limited will be described. In the following description, "%" indicating the contents of constituent elements of steel means "mass%" unless otherwise specified.

[C: 0.030% or more and 0.500% or less]

[0016] Carbon is one of the important basic components of steel. Particularly in the present invention, carbon is an important element that affects the amount of martensite. When the C content is less than 0.030%, the amount of martensite is so small that realizing 980 MPa or higher TS is difficult. When, on the other hand, the C content is more than 0.500%, martensite becomes brittle to cause deterioration in toughness and working embrittlement resistance. Thus, the C content is limited to 0.030% or more and 0.500% or less. The lower limit of the C content is preferably 0.050% or more. The upper limit of the C content is preferably 0.400% or less. The lower limit of the C content is more preferably 0.100% or more. The upper limit of the C content is more preferably 0.350% or less.

[Si: 0.50% or more and 2.50% or less]

[0017] Silicon is one of the important basic components of steel and is an important element that affects TS and the amount of retained austenite. When the Si content is less than 0.50%, the strength of martensite decreases to make it difficult to achieve 980 MPa or higher TS. When, on the other hand, the Si content is more than 2.50%, the amount of retained austenite is increased excessively, and toughness and working embrittlement resistance are lowered. Thus, the Si content is limited to 0.50% or more and 2.50% or less. The lower limit of the Si content is preferably 0.55% or more. The upper limit of the Si content is preferably 2.00% or less. The lower limit of the Si content is more preferably 0.60% or more. The upper limit of the Si content is more preferably 1.80% or less.

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

[0018] Manganese is one of the important basic components of steel and is an important element that affects the amount of martensite. When the Mn content is less than 1.00%, the amount of martensite is so small that realizing 980 MPa or higher TS is difficult. When, on the other hand, the Mn content is more than 5.00%, martensite becomes brittle to cause deterioration in toughness and working embrittlement resistance. Thus, the Mn content is limited to 1.00% or more and 5.00% or less. The lower limit of the Mn content is preferably 1.50% or more. The upper limit of the Mn content is preferably 4.50% or less. The lower limit of the Mn content is more preferably 2.00% or more. The upper limit of the Mn content is more preferably 4.00% or less.

[P: 0.100% or less]

[0019] Phosphorus is segregated at prior austenite grain boundaries and makes the grain boundaries brittle, thereby lowering the ultimate deformability of steel sheets and causing deterioration in toughness and working embrittlement resistance. Thus, the P content needs to be 0.100% or less. The lower limit of the P content is not particularly specified. In view of the fact that phosphorus is a solid solution strengthening element and can increase the strength of steel sheets, the lower limit is preferably 0.001% or more. For the reasons above, the P content is limited to 0.100% or less. The lower limit of the P content is preferably 0.001% or more. The upper limit of the P content is preferably 0.070% or less.

[S: 0.0200% or less]

[0020] Sulfur forms sulfides and lowers the ultimate deformability of steel sheets to cause deterioration in toughness and working embrittlement resistance. Thus, the S content needs to be 0.0200% or less. The lower limit of the S content is not particularly specified but is preferably 0.0001% or more due to production technique limitations. For the reasons above, the S content is limited to 0.0200% or less. The lower limit of the S content is preferably 0.0001% or more. The upper limit of the S content is preferably 0.0050% or less.

[Al: 1.000% or less]

[0021] Aluminum forms the oxide and lowers the ultimate deformability of steel sheets to cause deterioration in toughness and working embrittlement resistance. Thus, the Al content needs to be 1.000% or less. The lower limit of the Al content is not particularly specified. In view of the fact that aluminum suppresses the occurrence of carbides during continuous annealing and promotes the formation of retained austenite, the Al content is preferably 0.001% or more. For the reasons above, the Al content is limited to 1.000% or less. The lower limit of the Al content is preferably 0.001% or more. The upper limit of the Al content is preferably 0.500% or less.

[N: 0.0100% or less]

[0022] Nitrogen forms nitrides and lowers the ultimate deformability of steel sheets to cause deterioration in toughness and working embrittlement resistance. Thus, the N content needs to be 0.0100% or less. The lower limit of the N content is not particularly specified but the N content is preferably 0.0001% or more due to production technique limitations. For the reasons above, the N content is limited to 0.0100% or less. The lower limit of the N content is preferably 0.0001% or more. The upper limit of the N content is preferably 0.0050% or less.

[O: 0.0100% or less]

[0023] Oxygen forms oxides and lowers the ultimate deformability of steel sheets to cause deterioration in toughness and working embrittlement resistance. Thus, the O content needs to be 0.0100% or less. The lower limit of the O content is not particularly specified but the O content is preferably 0.0001% or more due to production technique limitations. For the reasons above, the O content is limited to 0.0100% or less. The lower limit of the O content is preferably 0.0001% or more. The upper limit of the O content is preferably 0.0050% or less.

[0024] The chemical composition of the high strength steel sheet according to an embodiment of the present invention includes the components described above, and the balance is Fe and incidental impurities. Here, the incidental impurities include Zn, Pb, As, Ge, Sr, and Cs. A total of 0.100% or less of these impurities is acceptable.

[0025] In addition to the components in the proportions described above, the high strength steel sheet of the present invention may further include at least one element selected from, in mass%, Ti: 0.200% or less, Nb: 0.200% or less, V: 0.200% or less, Ta: 0.10% or less, W: 0.10% or less, B: 0.0100% or less, Cr: 1.00% or less, Mo: 1.00% or less, Ni: 1.00% or less, Co: 0.010% or less, Cu: 1.00% or less, Sn: 0.200% or less, Sb: 0.200% or less, Ca: 0.0100% or less, Mg: 0.0100% or less, REM: 0.0100% or less, Zr: 0.100% or less, Te: 0.100% or less, Hf: 0.10% or less, and Bi: 0.200% or less. These elements may be contained singly or in combination.

[0026] When the contents of Ti, Nb, and V are each 0.200% or less, coarse precipitates and inclusions will not occur in large amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the contents of Ti, Nb, and V are each preferably 0.200% or less. The lower limits of the contents of Ti, Nb, and V are not particularly specified. These elements form fine carbides, nitrides, or carbonitrides during hot rolling or continuous annealing to increase the strength of steel sheets. In view of this fact, the contents of Ti, Nb, and V are each more preferably 0.001% or more. When titanium, niobium, and vanadium are added, the contents thereof are each limited to 0.200% or less for the reasons above. The lower limits of the contents of Ti, Nb, and V, when added, are each more preferably 0.001% or more. The upper limits of the contents of Ti, Nb, and V, when added, are each more preferably 0.100% or less.

[0027] When the contents of Ta and W are each 0.10% or less, coarse precipitates and inclusions will not occur in large amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the contents of Ta and W are each preferably 0.10% or less. The lower limits of the contents of Ta and W are not particularly specified. These elements form fine carbides, nitrides, or carbonitrides during hot rolling or continuous annealing to increase the strength of steel sheets. In view of this fact, the contents of Ta and W are each more preferably 0.01% or more. When tantalum and tungsten are added, the contents thereof are each limited to 0.10% or less for the reasons above. The lower limits of the contents of Ta and W, when added, are each more preferably 0.01% or more. The upper limits of the contents of Ta and W, when added, are each more preferably 0.08% or less.

[0028] When the B content is 0.0100% or less, inner cracks that lower the ultimate deformability of steel sheets will not form during casting or hot rolling and thus there will be no deterioration in toughness or working embrittlement resistance. Thus, the B content is preferably 0.0100% or less. The lower limit of the B content is not particularly specified. The B content is more preferably 0.0003% or more in view of the fact that this element is segregated at austenite grain boundaries during annealing and enhances hardenability. When boron is added, the content thereof is limited to 0.0100% or less for the reasons above. The lower limit of the content of B, when added, is more preferably 0.0003% or more. The upper limit of the content of B, when added, is more preferably 0.0080% or less.

[0029] When the contents of Cr, Mo, and Ni are each 1.00% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the contents of Cr, Mo, and Ni are each preferably 1.00% or less. The lower limits of the contents of Cr, Mo, and Ni are not particularly specified. In view of the fact that these elements enhance hardenability, the contents of Cr, Mo, and Ni are each more preferably 0.01% or more. When chromium, molybdenum, and nickel are added, the contents thereof are each limited to 1.00% or less for the reasons above. The lower limits of the contents of Cr, Mo, and Ni, when added, are each more preferably 0.01% or more. The upper limits of the contents of Cr, Mo, and Ni, when added, are each more preferably 0.80% or less.

[0030] When the Co content is 0.010% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the Co content is preferably 0.010% or less. The lower limit of the Co content is not particularly specified. In view of the fact that this element enhances hardenability, the Co content is more preferably 0.001% or more. When cobalt is added, the content thereof is limited to 0.010% or less for the reasons above. The lower limit of the content of Co, when added, is more preferably 0.001% or more. The upper limit of the content of Co, when added, is more preferably 0.008% or less.

[0031] When the Cu content is 1.00% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the Cu content is preferably 1.00% or less. The lower limit of the Cu content is not particularly specified. In view of the fact that this element enhances hardenability, the Cu content is preferably 0.01% or more. When copper is added, the content thereof is limited to 1.00% or less for the reasons above. The lower limit of the content of Cu, when added, is more preferably 0.01% or more. The upper limit of the content of Cu, when added, is more preferably 0.80% or less.

[0032] When the Sn content is 0.200% or less, inner cracks that lower the ultimate deformability of steel sheets will not form during casting or hot rolling and thus there will be no deterioration in toughness or working embrittlement resistance. Thus, the Sn content is preferably 0.200% or less. The lower limit of the Sn content is not particularly specified. The Sn content is more preferably 0.001% or more in view of the fact that tin enhances hardenability (in general, is an element that enhances corrosion resistance). When tin is added, the content thereof is limited to 0.200% or less for the reasons above. The lower limit of the content of Sn, when added, is more preferably 0.001% or more. The upper limit of the content of Sn, when added, is more preferably 0.100% or less.

[0033] When the Sb content is 0.200% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the Sb content is preferably 0.200% or less. The lower limit of the Sb content is not particularly specified. In view of the fact that this element enables control of the thickness of surface layer softening and the strength, the Sb content is more preferably 0.001% or more. When antimony is added, the content thereof is limited to 0.200% or less for the reasons above. The lower limit of the content of Sb, when added, is more preferably 0.001% or more. The upper limit of the content of Sb, when added, is more preferably 0.100% or less.

[0034] When the contents of Ca, Mg, and REM are each 0.0100% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the contents of Ca, Mg, and REM are each preferably 0.0100% or less. The lower limits of the contents of Ca, Mg, and REM are not particularly specified. In view of the fact that these elements change the shapes of nitrides and sulfides into spheroidal and enhance the ultimate deformability of steel sheets, the contents of Ca, Mg, and REM are each more preferably 0.0005% or more. When calcium, magnesium, and rare earth metal(s) are added, the contents thereof are each limited to 0.0100% or less for the reasons above. The lower limits of the contents of Ca, Mg, and REM, when added, are each more preferably 0.0005% or more. The upper limits of the contents of Ca, Mg, and REM, when added, are each more preferably 0.0050% or less.

[0035] When the contents of Zr and Te are each 0.100% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the contents of Zr and Te are each preferably 0.100% or less. The lower limits of the contents of Zr and Te are not particularly specified. In view of the fact that these elements change the shapes of nitrides and sulfides into spheroidal and enhance the ultimate deformability of steel sheets, the contents of Zr and Te are each more preferably 0.001% or more. When zirconium and tellurium are added, the contents thereof are each limited to 0.100% or less for the reasons above. The lower limits of the contents of Zr and Te, when added, are each more preferably 0.001% or more. The upper limits of the contents of Zr and Te, when added, are each more preferably 0.080% or less.

[0036] When the Hf content is 0.10% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the Hf content is preferably 0.10% or less. The lower limit of the Hf content is not particularly specified. In view of the fact that this element changes the shapes of nitrides and sulfides into spheroidal and enhances the ultimate deformability of steel sheets, the Hf content is more preferably 0.01% or more. When hafnium is added, the content thereof is limited to 0.10% or less for the reasons above. The lower limit of the content of Hf, when added, is more preferably 0.01% or more. The upper limit of the content of Hf, when added, is more preferably 0.08% or less.

[0037] When the Bi content is 0.200% or less, coarse precipitates and inclusions will not occur in increased amounts and thus will not cause lowering of the ultimate deformability of steel sheets; hence there will be no deterioration in toughness or working embrittlement resistance. Thus, the Bi content is preferably 0.200% or less. The lower limit of the Bi content is not particularly specified. In view of the fact that this element reduces the occurrence of segregation, the Bi content is more preferably 0.001% or more. When bismuth is added, the content thereof is limited to 0.200% or less for the reasons above. The lower limit of the content of Bi, when added, is more preferably 0.001% or more. The upper limit of the content of Bi, when added, is more preferably 0.100% or less.

[0038] When the content of any of Ti, Nb, V, Ta, W, B, Cr, Mo, Ni, Co, Cu, Sn, Sb, Ca, Mg, REM, Zr, Te, Hf, and Bi is below the preferred lower limit, the element does not impair the advantageous effects of the present invention and is regarded as an incidental impurity.

[0039] Next, the steel microstructure of the high strength steel sheet of the present invention will be described.

[Area fraction of martensite: 60% or more]

[0040] This configuration is a very important requirement that constitutes the present invention. 980 MPa or higher TS can be achieved when the area fraction of martensite is 60% or more. Thus, the area fraction of martensite is limited to 60% or more. The area fraction is preferably 62% or more, and more preferably 64% or more.

[Volume fraction of retained austenite: 3% or more and 15% or less]

[0041] This configuration is a very important requirement that constitutes the present invention. When the volume fraction of retained austenite is less than 3%, it is difficult to realize 10% or more El and it is also difficult to attain excellent toughness because the toughness enhancement effect by retained austenite cannot be obtained. When the amount of retained austenite is more than 15%, retained austenite is excessively transformed into hard martensite at the time of working and the steel sheet is lowered in ultimate deformability and will not attain excellent working embrittlement resistance. Thus, the retained austenite is limited to 3% or more and 15% or less. The lower limit of the amount of retained austenite is preferably 5% or more. The upper limit of the amount of retained austenite is preferably 140 or less. The lower limit of the amount of retained austenite is more preferably 7% or more. The upper limit of the amount of retained austenite is more preferably 13% or less.

[0042] Here, retained austenite is measured as follows. The steel sheet is polished to expose a face 0.1 mm below 1/4 sheet thickness and is thereafter further chemically polished to expose a face 0.1 mm below the face exposed above. The face is analyzed with an X-ray diffractometer using CoKα radiation to determine the integral intensity ratios of the diffraction peaks of {200}, {220}, and {311} planes of fcc iron and {200}, {211}, and {220} planes of bcc iron. Nine integral intensity ratios thus obtained are averaged to determine retained austenite.

[Area fraction of the total of ferrite and bainitic ferrite: more than 10%]

[0043] This configuration is a very important requirement that constitutes the present invention. When the total amount of ferrite and bainitic ferrite is 10% or less, it is difficult to achieve 10% or more El. Thus, the total amount of ferrite and bainitic ferrite is limited to more than 10%. The total amount is preferably 120 or more, and more preferably 13% or more. The upper limit of the total amount of ferrite and bainitic ferrite is not particularly limited.

[0044] Here, the total amount of ferrite and bainitic ferrite is measured as follows. A longitudinal cross section of the steel sheet is polished and is etched with 3 vol% Nital. A portion at 1/4 sheet thickness (a location corresponding to 1/4 of the sheet thickness in the depth direction from the steel sheet surface) is observed using SEM in 10 fields of view at a magnification of $\times$2000. In the microstructure images, ferrite and bainitic ferrite are recessed structures having a flat interior and containing no inner carbides. The values thus obtained are averaged to determine the total amount of ferrite and bainitic ferrite.

[0045] The amount of martensite is measured as follows. The amount of martensite can be determined by measuring the amounts of retained austenite, ferrite, and bainitic ferrite based on the methods described above, and subtracting the total thereof from 100%. Thus, the amount of martensite in the present invention includes both quenched martensite and tempered martensite. Because the volume fraction of retained austenite is almost equal to the area fraction, the amount is subtracted as such from 100% together with the amounts of ferrite and bainitic ferrite expressed in area fraction.

[Average of the proportions of packets having the largest area in prior austenite grains: 70% by area or less]

[0046] This configuration is a very important requirement that constitutes the present invention. The proportion of a packet having the largest area in a prior austenite grain affects the flatness in the width direction and the working embrittlement resistance. As illustrated in Fig. 1, a prior austenite grain contains up to four kinds of packets distinguished by crystal habit plane formed by transformation. The packet having the largest area in a prior austenite grain is the packet that occupies the largest area among such packets.

[0047] The proportion of one packet in a prior austenite grain is determined by dividing the area of the packet of interest by the area of the whole prior austenite grain.

[0048] As a result of extensive studies, the present inventors have found that strain among the packets is reduced and the flatness in the width direction is improved by lowering the proportion of a packet having the largest area in a prior austenite grain. The present inventors have also found that lowering the proportion of a packet having the largest area in a prior austenite grain leads to a fine microstructure and suppresses crack propagation, thereby enhancing the working embrittlement resistance of the steel sheet. Thus, the average of the proportions of packets having the largest area in prior austenite grains is limited to 70% or less. The average proportion is preferably 60% or less. The lower limit of the average proportion of packets having the largest area in prior austenite grains is not particularly limited. The grains contain up to four kinds of packets. When four packets are evenly distributed, the proportion of a packet having the largest area in the prior austenite grain is 25%. Thus, the lower limit of the average proportion of packets having the largest area in prior austenite grains is preferably 25% or more. However, the lower limit of the average proportion is not necessarily limited thereto.

[0049] Here, the average proportion of packets having the largest area in prior austenite grains is measured as follows. First, a test specimen for microstructure observation is sampled from the cold rolled steel sheet. Next, the sampled test specimen is polished by vibration polishing with colloidal silica to expose a cross section in the rolling direction (a longitudinal cross section) for use as observation surface. The observation surface is specular. Next, electron backscatter diffraction (EBSD) measurement is performed with respect to a portion at 1/4 sheet thickness (a location corresponding to 1/4 of the sheet thickness in the depth direction from the steel sheet surface) to obtain local crystal orientation data. Here, the SEM magnification is ×1000, the step size is 0.2 um, the measured region is 80 um square, and the WD is 15 mm. The local orientation data obtained is analyzed with OIM Analysis 7 (OIM), and a map (a CP map) that shows close-packed plane groups (CP groups) with different colors is created using the method described in Non Patent Literature 1. In the present invention, a packet is defined as a region or regions belonging to the same CP group. From the CP map obtained, the area of the packet having the largest area is determined and is divided by the area of the whole prior austenite grain to give the proportion of the packet having the largest area in the prior austenite grain. This analysis is performed with respect to 10 or more adjacent prior austenite grains, and the results are averaged to give the average proportion of packets having the largest area in prior austenite grains.

[0050] Next, a manufacturing method of the present invention will be described.

[0051] In the present invention, a steel material (a steel slab) may be obtained by any known steelmaking method without limitation, such as a converter or an electric arc furnace. To prevent macro-segregation, the steel slab (the slab) is preferably produced by a continuous casting method.

[0052] In the present invention, the slab heating temperature, the slab soaking holding time, and the coiling temperature in hot rolling are not particularly limited. For example, the steel slab may be hot rolled in such a manner that the slab is heated and is then rolled, that the slab is subjected to hot direct rolling after continuous casting without being heated, or that the slab is subjected to a short heat treatment after continuous casting and is then rolled. The slab heating temperature, the slab soaking holding time, the finish rolling temperature, and the coiling temperature in hot rolling are not particularly limited. The lower limit of the slab heating temperature is preferably 1100°C or above. The upper limit of the slab heating temperature is preferably 1300°C or below. The lower limit of the slab soaking holding time is preferably 30 minutes or more. The upper limit of the slab soaking holding time is preferably 250 minutes or less. The lower limit of the finish rolling temperature is preferably Ar_3 transformation temperature or above. Furthermore, the lower limit of the coiling temperature is preferably 350°C or above. The upper limit of the coiling temperature is preferably 650°C or below.

[0053] The hot rolled steel sheet thus produced is pickled. Pickling can remove oxides on the steel sheet surface and is thus important to ensure good chemical convertibility and a high quality of coating in the final high strength steel sheet. Pickling may be performed at a time or several. The hot rolled sheet that has been pickled may be cold rolled directly or may be subjected to heat treatment before cold rolling.

[0054] The rolling reduction in cold rolling and the sheet thickness after rolling are not particularly limited. The lower limit of the rolling reduction is preferably 30% or more. The upper limit of the rolling reduction is preferably 80% or less. The advantageous effects of the present invention may be obtained without any limitations on the number of rolling passes and the rolling reduction in each pass.

[0055] The cold rolled steel sheet obtained as described above is annealed. Annealing conditions are as follows.

[Annealing temperature Ta: 700°C or above and 900°C or below]

[0056] When the annealing temperature Ta is below 700°C, the amount of martensite is so small that realizing 980 MPa or higher TS is difficult. When, on the other hand, the annealing temperature is above 900°C, the total amount of ferrite and bainitic ferrite decreases to make it difficult to achieve 10% or more El. Thus, the annealing temperature is limited to 700°C or above and 900°C or below. The lower limit of the annealing temperature is preferably 750°C or above. The upper limit of the annealing temperature is preferably 870°C or below.

[Holding time during annealing at the annealing temperature Ta: 10 seconds or more and 1000 seconds or less]

[0057] When the holding time at the annealing temperature Ta is less than 10 seconds, the amount of martensite is so small that realizing 980 MPa or higher TS is difficult. When, on the other hand, the holding time at the annealing temperature Ta is more than 1000 seconds, the total amount of ferrite and bainitic ferrite decreases to make it difficult to achieve 10% or more El. Thus, the holding time at the annealing temperature Ta is limited to 10 seconds or more and 1000 seconds or less. The lower limit of the holding time at the annealing temperature Ta is preferably 50 seconds or more. The upper limit of the holding time at the annealing temperature Ta is preferably 500 seconds or less.

[During the annealing, the steel sheet is bent and unbent 1 to 15 times in total with a roll having a radius of 800 mm or less.]

[0058] As a result of extensive studies, the present inventors have found that bending and unbending of the steel sheet during annealing affects the proportion of a packet having the largest area in a prior austenite grain. When the steel sheet being annealed is not subjected to bending and unbending with a roll having a radius of 800 mm or less, the amount of nucleation sites for martensite transformation is reduced. Consequently, the average proportion of packets having the largest area in prior austenite grains exceeds 70%, and the flatness in the width direction and also the working embrittlement resistance are deteriorated. When, on the other hand, the steel sheet being annealed is subjected to bending and unbending 16 times or more with a roll having a radius of 800 mm or less, the steel sheet is deteriorated in ultimate deformability and also in working embrittlement resistance. Thus, in the annealing, the total count of bending and unbending with a roll having a radius of 800 mm or less is limited to 1 or more and 15 or less. The radius of the roll is preferably 600 mm or less. The lower limit of the total count of bending and unbending is preferably 3 or more. The upper limit of the total count of bending and unbending is preferably 10 or less. The lower limit of the radius of the roll is not necessarily limited but is preferably 50 mm or more.

[0059] Incidentally, "bending and unbending" is a treatment that bends the steel sheet with a roll in one direction according to a known technique and unbends the steel sheet in the opposite direction to cancel the bend. Bending and unbending are not counted in pairs. That is, each bending is counted one and each unbending is counted one.

[Average cooling rate in the temperature range from 700°C to 600°C: 20°C/s or more]

[0060] As a result of extensive studies, the present inventors have found that the average cooling rate in the temperature range from 700°C to 600°C affects the proportion of a packet having the largest area in a prior austenite grain. When the average cooling rate in the temperature range from 700°C to 600°C is less than 20°C/s, the effects imparted by bending and unbending of the steel sheet during annealing are lowered and the amount of nucleation sites for martensite transformation is reduced. Consequently, the average proportion of packets having the largest area in prior austenite grains exceeds 70%, and the flatness in the width direction and also the working embrittlement resistance are deteriorated. Thus, the average cooling rate from 750°C to 600°C is limited to 20°C/s or more and is preferably 30°C/s or more. The upper limit is not necessarily limited but is preferably 100°C/s or less.

[Average cooling rate in the temperature range from 499°C to Ms: less than 20°C/s]

[0061] The average cooling rate in the temperature range from 499°C to Ms affects the total area fraction of ferrite and bainitic ferrite. When the average cooling rate in the temperature range from 499°C to Ms is 20°C/s or more, the total amount of ferrite and bainitic ferrite decreases to make it difficult to achieve 10% or more El. Thus, the average cooling rate in the temperature range from 499°C to Ms is limited to less than 20°C/s. The average cooling rate is preferably 18°C/s or less. The lower limit is not necessarily limited but is preferably 5°C/s or more.

[0062] The martensite start temperature Ms (°C) is defined by the following formula (1):

$$Ms = 519 - 474 \times [\% C] - 30.4 \times [\% Mn] - 12.1 \times [\% Cr] - 7.5 \times [\% Mo] - 17.7 \times [\% Ni] - Ta/80 \quad (1)$$

wherein [% C], [% Mn], [% Cr], [% Mo], and [% Ni] indicate the contents (mass%) of C, Mn, Cr, Mo, and Ni, respectively, and are zero when the element is absent.

[0063] [The steel sheet in the temperature range from 499°C to Ms is bent and unbent 1 to 15 times in total with a roll having a radius of 800 mm or less.]

[0064] As a result of extensive studies, the present inventors have found that bending and unbending of the steel sheet in the temperature range from 499°C to Ms affects the proportion of a packet having the largest area in a prior austenite grain. When the steel sheet in the temperature range from 499°C to Ms is not subjected to bending and unbending with a roll having a radius of 800 mm or less, the amount of martensite nucleation sites is reduced. Consequently, the average proportion of packets having the largest area in prior austenite grains exceeds 70%, and the flatness in the width direction and also the working embrittlement resistance are deteriorated. When, on the other hand, the steel sheet in the temperature range from 499°C to Ms is subjected to bending and unbending 16 times or more with a roll having a radius of 800 mm or less, the steel sheet is deteriorated in ultimate deformability and also in working embrittlement resistance. Thus, the total count of bending and unbending in the temperature range from 499°C to Ms with a roll having a radius of 800 mm or less is limited to 1 or more and 15 or less. The radius of the roll is preferably 600 mm or less. The lower limit of the total count of bending and unbending is preferably 3 or more. The lower limit of the total count of bending and unbending is preferably 10 or less. The lower limit of the radius of the roll is not necessarily limited but is preferably 50 mm or more.

[Average cooling rate in the temperature range from Ms to cooling stop temperature Tb: 150°C/s or less]

[0065] As a result of extensive studies, the present inventors have found that the average cooling rate in the temperature range from Ms to the cooling stop temperature Tb affects the proportion of a packet having the largest area in a prior austenite grain. When the average cooling rate in the temperature range from Ms to the cooling stop temperature Tb is more than 150°C/s, the martensite transformation rate is so fast that a packet grows fast easily. Consequently, the average proportion of packets having the largest area in prior austenite grains exceeds 70%, and the flatness in the width direction and also the working embrittlement resistance are deteriorated. Thus, the average cooling rate in the temperature range from Ms to the cooling stop temperature Tb is limited to 150°C/s or less. The average cooling rate is preferably 120°C/s or less. The lower limit is not necessarily limited but is preferably 5°C/s or more.

[Tension applied to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb: 5 MPa or more and 100 MPa or less]

[0066] As a result of extensive studies, the present inventors have found that the application of tension to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb affects the proportion of a packet having the largest area in a prior austenite grain. When the tension applied to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb is less than 5 MPa, the amount of martensite nucleation sites is reduced. Consequently, the average proportion of packets having the largest area in prior austenite grains exceeds 70%, and the flatness in the width direction and also the working embrittlement resistance are deteriorated. When, on the other hand, more than 100 MPa tension is applied to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb, the total amount of ferrite and bainitic ferrite is excessively increased and thus the amount of martensite decreases to make it difficult to realize 980 MPa or higher TS. Thus, the tension applied to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb is limited to 5 MPa or more and 100 MPa or less. The lower limit of the tension applied to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb is preferably 6 MPa or more. The upper limit of the tension applied to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb is preferably 50 MPa or less. The tension is applied in a usual manner. As an example, the tension may be applied by controlling the roll speeds of the rolls in the furnace.

[0067] While the bending and unbending process increases the number of nucleation sites that are martensite start sites, the tension application process produces different effects by promoting martensite transformation itself.

[Cooling stop temperature Tb: 100°C or above and (Ms - 80°C) or below]

[0068] When the cooling stop temperature Tb is below 100°C, the amount of retained austenite decreases and bendability is lowered. When, on the other hand, the cooling stop temperature Tb is above (Ms - 80°C), the amount of retained austenite is excessively increased and the prior austenite grain size is excessively enlarged to cause deterioration in working embrittlement resistance. Thus, the cooling stop temperature Tb is limited to 100°C or above and (Ms - 80°C) or below. The lower limit of the cooling stop temperature Tb is preferably 120°C or above. The upper limit of the cooling stop temperature Tb is preferably (Ms - 100°C) or below.

[Tempering temperature: Tb or above and 450°C or below]

[0069] After the cooling is stopped at the cooling stop temperature Tb, the steel sheet is held at the temperature or is reheated and held at a temperature of 450°C or below to stabilize retained austenite. When the tempering temperature is below Tb, retained austenite cannot be obtained as desired; consequently El is lowered and excellent toughness is hardly obtained. When the tempering temperature is above 450°C, martensite is excessively tempered to make it difficult to achieve 980 MPa or higher TS. Thus, the tempering temperature is limited to Tb or above and 450°C or below. The lower limit of the tempering temperature is preferably (Tb + 10°C) or above. The upper limit of the tempering temperature is preferably 420°C or below.

[Holding time at the tempering temperature: 10 seconds or more and 1000 seconds or less]

[0070] When the holding time at the tempering temperature is less than 10 seconds, austenite stabilization is insufficient and retained austenite cannot be obtained as desired; consequently El is lowered and excellent toughness is hardly obtained. When the holding time at the tempering temperature is more than 1000 seconds, martensite is excessively tempered to make it difficult to achieve 980 MPa or higher TS. Thus, the holding time at the tempering temperature is limited to 10 seconds or more and 1000 seconds or less. The lower limit of the holding time at the tempering temperature is preferably 50 seconds or more. The upper limit of the holding time at the tempering temperature is preferably 800 seconds or less.

[0071] Post-temper cooling is not particularly limited and the steel sheet may be cooled to a desired temperature in an appropriate manner. Incidentally, the desired temperature is preferably about room temperature.

[0072] Furthermore, the high strength steel sheet described above may be worked under conditions where the amount of equivalent plastic strain is 0.10% or more and 5.00% or less. The working may be followed by reheating at 100°C or above and 400°C or below.

[0073] When the high strength steel sheet is a product that is traded, the steel sheet is usually traded after being cooled to room temperature.

[0074] The high strength steel sheet may be subjected to coating treatment during annealing or after annealing.

[0075] For example, the coating treatment during annealing may be hot-dip galvanizing treatment performed when the annealed steel sheet is being cooled or has been cooled from 700°C to 600°C at an average cooling rate of 20°C/s or more. The hot-dip galvanizing treatment may be followed by alloying. For example, the coating treatment after annealing may be Zn-Ni electrical alloy coating treatment or pure Zn electroplated coating treatment performed after tempering. A coated layer may be formed by electroplated coating, or hot-dip zinc-aluminum-magnesium alloy coating may be applied. While the coating treatment has been described above focusing on zinc coating, the types of coating metals, such as Zn coating and Al coating, are not particularly limited. Other conditions in the manufacturing method are not particularly limited. From the point of view of productivity, the series of treatments including annealing, hot-dip galvanizing, and alloying treatment of the coated zinc layer is preferably performed on hot-dip galvanizing line CGL (continuous galvanizing line). To control the coating weight of the coated layer, the hot-dip galvanizing treatment may be followed by wiping. Conditions for operations, such as coating, other than those conditions described above may be determined in accordance with the usual hot-dip galvanizing technique.

[0076] After the coating treatment after annealing, the steel sheet may be worked again under conditions where the amount of equivalent plastic strain is 0.10% or more and 5.00 or less. The working may be followed by reheating at 100°C or above and 400°C or below.

EXAMPLES

[0077] Steels having a chemical composition described in Table 1 and 2, with the balance being Fe and incidental impurities, were smelted in a converter and were continuously cast into slabs. Next, the slabs obtained were heated, hot rolled, pickled, cold rolled, and subjected to annealing treatment described in Table 3 and 4. High strength cold rolled steel sheets having a sheet thickness of 0.6 to 2.2 mm were thus obtained. During annealing, the steel sheet was subjected to bending and unbending with a roll having a radius of 300 mm. In the temperature range from 499°C to Ms, the steel sheet was subjected to bending and unbending with a roll having a radius of 300 mm. Incidentally, some of the steel sheets were subjected to coating treatment during or after annealing.

[0078] The high strength cold rolled steel sheets obtained as described above were used as test steels. Tensile characteristics, flatness in the width direction, toughness, and working embrittlement resistance were evaluated in accordance with the following test methods.

[Table 1]

Steels	Chemical composition (mass%)													
	C	Si	Mn	P	S	N	O	Al	Ti	B	Nb	Cu	Others	
A	0.172	1.37	2.54	0.013	0.0014	0.005	0.005	0.039						INV. EX.
B	0.157	1.07	2.86	0.005	0.0011	0.003	0.005	0.028						INV. EX.
C	0.175	1.33	2.42	0.014	0.0007	0.004	0.002	0.031						INV. EX.
D	0.172	1.14	2.80	0.009	0.0013	0.004	0.005	0.060						INV. EX.
E	0.161	1.10	2.85	0.006	0.0012	0.006	0.007	0.049						INV. EX.
F	0.037	1.01	2.66	0.010	0.0009	0.003	0.004	0.042						INV. EX.
G	0.028	1.10	2.55	0.007	0.0006	0.006	0.007	0.023						COMP. EX.
H	0.461	1.33	2.43	0.012	0.0009	0.002	0.004	0.032						INV. EX.
I	0.505	1.38	2.83	0.011	0.0007	0.004	0.002	0.015						COMP. EX.
J	0.182	0.58	2.81	0.015	0.0006	0.005	0.002	0.037						INV. EX.
K	0.179	0.42	2.45	0.011	0.0014	0.003	0.005	0.044						COMP. EX.
L	0.180	2.34	2.64	0.008	0.0014	0.003	0.003	0.059						INV. EX.
M	0.172	2.54	2.74	0.009	0.0008	0.005	0.005	0.024						COMP. EX.
N	0.165	1.15	1.05	0.013	0.0007	0.003	0.002	0.046						INV. EX.
O	0.170	1.29	0.95	0.011	0.0013	0.005	0.006	0.025						COMP. EX.
P	0.163	1.27	4.96	0.006	0.0008	0.003	0.005	0.018						INV. EX.
Q	0.177	1.09	5.16	0.008	0.0013	0.005	0.005	0.013						COMP. EX.
R	0.171	1.14	2.73	0.097	0.0008	0.001	0.005	0.038						INV. EX.
S	0.180	1.38	2.50	0.109	0.0012	0.004	0.004	0.048						COMP. EX.
T	0.184	1.39	2.82	0.012	0.0195	0.006	0.004	0.033						INV. EX.
U	0.160	1.24	2.58	0.011	0.0204	0.004	0.004	0.042						COMP. EX.
V	0.157	1.38	2.80	0.009	0.0012	0.004	0.005	0.924						INV. EX.
W	0.166	1.36	2.47	0.011	0.0014	0.002	0.004	1.049						COMP. EX.
X	0.187	1.25	2.61	0.010	0.0006	0.0090	0.005	0.013						INV. EX.
Y	0.186	1.05	2.65	0.010	0.0014	0.0110	0.005	0.059						COMP. EX.

(continued)

Steels	Chemical composition (mass%)													
	C	Si	Mn	P	S	N	O	Al	Ti	B	Nb	Cu	Others	
Z	0.167	1.34	2.87	0.008	0.0011	0.006	0.0090	0.026						INV. EX.
AA	0.180	1.33	2.65	0.015	0.0009	0.007	<u>0.0110</u>	0.026						COMP. EX.
AB	0.176	1.24	2.77	0.007	0.0012	0.004	0.007	0.047						INV. EX.
AC	0.188	1.22	2.68	0.006	0.0011	0.005	0.007	0.042	0.003					INV. EX.
AD	0.152	1.14	2.71	0.010	0.0014	0.002	0.003	0.054	0.196					INV. EX.
AE	0.156	1.18	2.46	0.011	0.0006	0.007	0.004	0.035	<u>0.204</u>					COMP. EX.
AF	0.183	1.14	2.47	0.007	0.0015	0.005	0.004	0.048		0.0003				INV. EX.
AG	0.154	1.18	2.77	0.009	0.0011	0.006	0.004	0.027		0.0075				INV. EX.
AH	0.183	1.34	2.86	0.009	0.0007	0.003	0.004	0.029		<u>0.0106</u>				COMP. EX.
AI	0.178	1.27	2.89	0.009	0.0010	0.002	0.006	0.020			0.001			INV. EX.
AJ	0.164	1.16	2.51	0.011	0.0005	0.002	0.002	0.035			0.183			INV. EX.
AK	0.167	1.08	2.55	0.014	0.0006	0.004	0.004	0.055			<u>0.204</u>			COMP. EX.
AL	0.154	1.04	2.67	0.005	0.0015	0.002	0.003	0.035				0.02		INV. EX.
AM	0.176	1.20	2.47	0.005	0.0011	0.004	0.005	0.053				0.95		INV. EX.
Underlines indicate being outside the range of the present invention.														

[Table 2]

Steels	Chemical composition (mass%)													
	C	Si	Mn	P	S	N	O	Al	Ti	B	Nb	Cu	Others	
AN	0.178	1.22	2.78	0.009	0.0011	0.004	0.007	0.035				1.05		COMP. EX.
AO	0.177	1.03	2.46	0.014	0.0012	0.006	0.002	0.035					V:0.126	INV. EX.
AP	0.166	1.06	2.50	0.006	0.0014	0.002	0.003	0.045					Ta:0.01	INV. EX.
AQ	0.161	1.14	2.62	0.005	0.0012	0.001	0.006	0.037					W:0.04	INV. EX.
AR	0.163	1.15	2.88	0.009	0.0013	0.006	0.007	0.025					Cr:0.71	INV. EX.
AS	0.155	1.08	2.87	0.012	0.0007	0.003	0.002	0.023					Mo:0.07	INV. EX.
AT	0.173	1.24	2.53	0.013	0.0013	0.003	0.002	0.036					Co:0.008	INV. EX.
AU	0.178	1.15	2.86	0.007	0.0011	0.004	0.005	0.056					Ni:0.18	INV. EX.
AV	0.167	1.01	2.47	0.005	0.0014	0.004	0.001	0.051					Sn:0.131	INV. EX.
AW	0.173	1.06	2.42	0.006	0.0011	0.003	0.004	0.037					Sb:0.026	INV. EX.
AX	0.189	1.01	2.73	0.012	0.0008	0.005	0.007	0.054					Ca:0.0073	INV. EX.
AY	0.184	1.15	2.82	0.007	0.0006	0.003	0.006	0.022					Mg:0.0014	INV. EX.
AZ	0.184	1.04	2.52	0.012	0.0014	0.002	0.006	0.011					Zr:0.072	INV. EX.
BA	0.158	1.39	2.55	0.014	0.0013	0.006	0.007	0.027					Te:0.024	INV. EX.
BB	0.190	1.36	2.89	0.013	0.0011	0.006	0.005	0.053					Hf:0.10	INV. EX.
BC	0.164	1.12	2.74	0.008	0.0011	0.003	0.003	0.039					REM:0.0097	INV. EX.
BD	0.183	1.06	2.80	0.011	0.0012	0.002	0.005	0.011					Bi:0.153	INV. EX.
BE	0.158	1.33	2.65	0.007	0.0015	0.006	0.004	0.033					Zn:0.074	INV. EX.
BF	0.176	1.26	2.49	0.010	0.0007	0.004	0.006	0.014					Pb:0.076	INV. EX.
BG	0.159	1.08	2.68	0.012	0.0008	0.001	0.004	0.052					As:0.096	INV. EX.
BH	0.178	1.15	2.53	0.011	0.0008	0.004	0.002	0.019					Ge:0.022	INV. EX.
BI	0.178	1.38	2.75	0.006	0.0012	0.001	0.001	0.043					Sr:0.012	INV. EX.
BJ	0.167	1.02	2.41	0.014	0.0015	0.006	0.001	0.036					Cs:0.047	INV. EX.
BK	0.156	1.18	2.55	0.014	0.0010	0.003	0.006	0.049						INV. EX.
BL	0.150	1.02	2.88	0.014	0.0007	0.006	0.005	0.040						INV. EX.
BM	0.187	1.21	2.67	0.015	0.0013	0.006	0.006	0.014						INV. EX.
BN	0.161	1.32	2.57	0.014	0.0009	0.006	0.006	0.047						INV. EX.
BO	0.175	1.02	2.73	0.011	0.0008	0.001	0.005	0.047						INV. EX.
Underlines indicate being outside the range of the present invention.														

[Table 3]

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending during annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type"	
1	A	837	142	10	80	13	3	350	270	232	16	13	333	223	CR	INV. EX.
2	B	840	129	10	68	13	3	347	267	202	14	8	258	131	CR	INV. EX.
3	B	740	81	10	63	15	3	348	268	231	16	10	327	119	CR	INV. EX.
4	B	697	74	10	60	11	3	349	269	222	19	9	290	144	CR	COMP. EX.
5	B	890	180	10	51	15	3	347	267	202	19	16	330	104	CR	INV. EX.
6	B	901	132	10	74	12	3	346	266	226	19	9	348	228	CR	COMP. EX.
7	B	828	23	10	59	12	3	347	267	198	14	10	282	119	CR	INV. EX.
8	B	842	6	10	55	10	3	347	267	206	18	13	261	224	CR	COMP. EX.
9	B	808	809	10	53	11	3	348	268	200	14	8	284	188	CR	INV. EX.
10	B	845	1020	10	63	13	3	347	267	206	17	18	268	297	CR	COMP. EX.
11	B	829	131	1	65	13	3	347	267	205	13	13	308	179	CR	INV. EX.
12	B	827	186	0	60	13	3	347	267	218	13	15	264	129	CR	COMP. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending during annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type"	
13	B	847	110	15	59	10	3	347	267	200	11	17	326	235	CR	INV. EX.
14	B	842	50	15	64	12	3	347	267	205	16	12	294	184	CR	INV. EX.
15	B	830	131	3	22	11	3	347	267	202	14	9	310	278	CR	INV. EX.
16	B	839	176	3	12	12	3	347	267	233	18	11	274	253	CR	COMP. EX.
17	B	849	99	3	73	11	3	347	267	216	11	15	257	132	CR	INV. EX.
18	B	808	89	3	67	12	3	348	268	205	17	8	326	262	CR	INV. EX.
19	B	803	100	3	73	19	3	348	268	215	17	13	326	156	CR	INV. EX.
20	B	812	74	3	67	28	3	347	267	230	17	12	302	295	CR	COMP. EX.
21	B	802	133	3	75	14	3	348	268	198	103	18	279	219	CR	INV. EX.
22	B	842	161	3	58	12	3	347	267	219	14	13	219	246	CR	INV. EX.
23	B	811	82	3	73	12	1	348	268	234	16	12	251	278	CR	INV. EX.
24	B	824	105	3	77	12	0	347	267	198	14	10	275	282	CR	COMP. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending during annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type"	
25	B	841	73	3	63	12	15	347	267	201	17	15	338	238	CR	INV. EX.
26	B	827	165	3	54	15	15	347	267	211	13	17	313	101	CR	INV. EX.
27	B	803	173	3	51	15	3	348	268	104	14	10	312	265	CR	INV. EX.
28	B	842	98	3	79	15	3	347	267	95	17	13	313	280	CR	COMP. EX.
29	B	818	187	3	75	14	3	347	267	267	16	15	284	189	CR	INV. EX.
30	B	828	71	3	61	12	3	347	267	272	11	10	309	259	CR	COMP. EX.
31	B	833	193	3	75	11	3	347	267	222	13	12	285	278	CR	INV. EX.
32	B	825	129	3	55	14	3	347	267	232	13	15	296	262	CR	INV. EX.
33	B	819	65	3	67	14	3	347	267	220	149	17	311	106	CR	INV. EX.
34	B	817	125	10	64	12	3	347	267	216	155	17	344	274	CR	COMP. EX.
35	B	841	123	10	58	12	3	347	267	222	15	5	293	258	CR	INV. EX.
36	B	803	63	10	69	12	3	348	268	201	14	4	338	114	CR	COMP. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending during annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type"	
37	B	823	66	10	69	14	3	347	267	216	18	99	276	184	CR	INV. EX.
38	B	847	166	10	60	13	3	347	267	219	16	104	347	137	CR	COMP. EX.
39	B	806	72	10	64	15	3	348	268	223	14	14	223	242	CR	INV. EX.
40	B	825	120	10	66	13	3	347	267	206	13	15	206	106	CR	INV. EX.
41	B	844	170	10	74	12	3	347	267	226	19	13	420	151	CR	INV. EX.
42	B	810	124	10	75	13	3	348	268	211	18	17	448	273	CR	INV. EX.
43	B	846	111	10	68	11	10	347	267	235	19	8	282	23	CR	INV. EX.
44	B	821	167	3	73	13	10	347	267	237	17	11	303	3	CR	COMP. EX.
45	B	830	71	3	71	13	10	347	267	203	14	15	347	964	CR	INV. EX.
46	B	831	196	3	77	14	10	347	267	224	16	8	327	824	CR	INV. EX.
47	B	827	80	3	69	14	10	347	267	210	15	8	320	266	CR	INV. EX.
48	B	830	158	3	62	14	10	347	267	200	95	12	285	101	CR	INV. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending during annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type"	
49	C	841	123	3	58	11	10	352	272	202	105	11	288	214	CR	INV. EX.
50	D	826	188	3	59	11	10	342	262	201	16	12	321	103	CR	INV. EX.
51	E	809	134	3	56	12	3	346	266	210	11	12	287	281	CR	INV. EX.
52	F	802	157	3	77	12	3	411	331	269	10	9	345	270	CR	INV. EX.
53	G	849	143	3	55	13	3	418	338	279	14	14	349	122	CR	COMP. EX.

Underlines indicate being outside the range of the present invention.
(*)CR: cold rolled steel sheet (no coating), GI: hot-dip galvanized steel sheet (no alloying of zinc coating), GA: galvannealed steel sheet, EG: electrogalvanized steel sheet

[Table 4]

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending durin annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type*	
54	H	816	172	3	56	13	3	216	136	110	12	14	318	158	CR	INV. EX.
55	I	839	183	3	79	13	3	183	103	101	20	17	299	117	CR	COMP. EX.
56	J	840	157	3	58	13	3	337	257	198	19	10	276	115	CR	INV. EX.
57	K	821	141	3	59	11	3	349	269	230	17	13	281	282	CR	COMP. EX.
58	L	825	147	3	78	15	3	343	263	197	16	16	347	188	CR	INV. EX.
59	M	824	157	10	67	12	3	344	264	226	13	17	275	286	GA	COMP. EX.
60	N	846	112	10	75	12	3	398	318	265	13	15	334	181	GA	INV. EX.
61	O	832	167	10	68	14	3	399	319	259	11	16	321	163	GA	COMP. EX.
62	P	824	61	10	66	11	3	281	201	150	11	12	278	234	GA	INV. EX.
63	Q	807	158	10	61	13	3	268	188	123	17	11	259	102	GA	COMP. EX.
64	R	805	110	10	71	13	3	345	265	195	12	9	346	271	CR	INV. EX.
65	S	808	123	3	63	11	3	348	268	207	18	8	270	104	CR	COMP. EX.

(continued)

No-s.	Steel-s	Anneal-ing temp. Ta (°C)	Anneal-ing time (s)	Count of bending and unbend-ing durin anneal-ing (times)	Average cooling rate in tempera-ture range of 700-600°C (°C/s)	Average cooling rate in tempera-ture range of 499°C-Ms (°C/s)	Count of bending and unbending in tempera-ture range of 499°C-Ms (times)	Ms (°-C)	(M-s-8-0) (°C)	Cool-ing stop temp. Tb (°C)	Average cooling rate in tempera-ture range of Ms-Tb (°C/s)	Tension in tempera-ture range of Ms-Tb (MPa)	Temper-ing temp. (°C)	Temper-ing time (s)	Typ-e*	
66	T	830	100	3	58	14	3	336	256	199	16	14	260	218	GA	INV. EX.
67	U	826	194	3	59	11	3	354	274	231	14	14	314	197	GA	COMP. EX.
68	V	805	174	3	70	11	3	349	269	200	15	11	319	199	GI	INV. EX.
69	W	815	161	3	52	15	3	355	275	227	19	11	347	259	GA	COMP. EX.
70	X	824	121	3	61	13	10	341	261	195	12	14	331	109	GA	INV. EX.
71	Y	844	54	3	68	11	10	340	260	229	11	14	311	161	GA	COMP. EX.
72	Z	818	76	3	50	14	10	342	262	205	13	14	299	208	GA	INV. EX.
73	AA	806	181	3	50	11	10	343	263	231	18	10	284	162	GI	COMP. EX.
74	AB	812	140	3	80	12	10	341	261	225	19	15	335	114	GA	INV. EX.
75	AC	811	86	3	62	14	10	338	258	199	12	12	292	190	GA	INV. EX.
76	AD	842	97	3	57	14	10	354	274	226	19	18	270	129	GA	INV. EX.
77	AE	804	64	3	76	11	10	360	280	247	17	9	285	234	GA	COMP. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending durin annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type*	
78	AF	801	168	3	72	14	3	347	267	230	15	15	313	235	GA	INV. EX.
79	AG	822	76	3	78	13	3	352	272	214	11	8	332	192	GI	INV. EX.
80	AH	837	109	10	70	12	3	335	255	187	18	16	290	135	GA	COMP. EX.
81	AI	840	100	10	56	12	3	336	256	212	19	16	275	273	GA	INV. EX.
82	AJ	832	76	10	64	14	3	355	275	222	16	9	305	180	GA	INV. EX.
83	AK	810	186	10	63	13	3	352	272	208	14	9	263	114	GA	COMP. EX.
84	AL	807	95	10	65	13	3	355	275	220	11	11	269	174	CR	INV. EX.
85	AM	848	136	10	68	13	3	350	270	202	11	17	276	151	CR	INV. EX.
86	AN	834	181	10	70	14	3	340	260	207	19	10	285	211	GA	COMP. EX.
87	AO	749	90	10	55	11	3	351	271	215	13	12	318	104	GA	INV. EX.
88	AP	876	150	10	74	10	3	353	273	218	15	17	321	181	GA	INV. EX.
89	AQ	832	27	10	64	11	3	353	273	212	18	18	298	191	GA	INV. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending durin annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type*	
90	AR	828	846	10	73	12	3	335	255	204	15	12	282	290	GA	INV. EX.
91	AS	828	141	1	56	11	3	347	267	219	18	15	262	224	GA	INV. EX.
92	AT	849	157	15	77	15	3	349	269	203	12	15	348	183	GA	INV. EX.
93	AU	803	90	3	25	13	3	334	254	209	13	15	292	107	CR	INV. EX.
94	AV	849	197	3	65	15	3	354	274	242	11	11	338	232	CR	INV. EX.
95	AW	846	152	10	55	18	3	353	273	206	18	8	252	208	CR	INV. EX.
96	AX	826	62	10	60	11	3	336	256	207	19	17	207	160	CR	INV. EX.
97	AY	838	99	10	50	14	1	336	256	199	14	16	283	278	CR	INV. EX.
98	AZ	840	97	10	60	14	15	345	265	218	16	10	328	293	CR	INV. EX.
99	BA	824	60	3	72	14	3	356	276	110	14	15	326	300	CR	INV. EX.
100	BB	848	162	3	55	15	3	330	250	248	11	8	344	277	CR	INV. EX.
101	BC	820	165	10	64	12	3	348	268	210	13	11	257	201	CR	INV. EX.

(continued)

No-s.	Steel-s	Anneal-ing temp. Ta (°C)	Anneal-ing time (s)	Count of bending and unbend-ing durin anneal-ing (times)	Average cooling rate in tempera-ture range of 700-600°C (°C/s)	Average cooling rate in tempera-ture range of 499°C-Ms (°C/s)	Count of bending and unbending in tempera-ture range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cool-ing stop temp. Tb (°C)	Average cooling rate in tempera-ture range of Ms-Tb (°C/s)	Tension in tempera-ture range of Ms-Tb (MPa)	Temper-ing temp. (°C)	Temper-ing time (s)	Typ-e*	
102	BD	829	131	10	66	13	3	337	257	208	137	15	297	252	CR	INV. EX.
103	BE	807	70	3	72	13	3	353	273	209	10	6	308	231	CR	INV. EX.
104	BF	840	65	3	76	11	3	349	269	214	16	100	298	229	CR	INV. EX.
105	BG	805	139	10	71	12	3	352	272	237	13	15	237	170	CR	INV. EX.
106	BH	846	142	10	63	12	3	347	267	201	17	15	405	113	CR	INV. EX.
107	BI	837	63	10	76	13	3	341	261	213	12	15	300	15	CR	INV. EX.
108	BJ	822	109	10	53	13	3	356	276	232	18	14	270	847	CR	INV. EX.
109	BK	822	59	10	53	11	12	357	277	225	17	15	308	215	EG	INV. EX.
110	BL	838	70	5	50	13	12	350	270	221	15	10	257	294	GI	INV. EX.
111	BM	830	57	5	58	11	3	339	259	221	13	16	273	287	EG	INV. EX.
112	BN	802	57	12	62	13	3	355	275	236	92	11	323	109	GI	INV. EX.

(continued)

Nos.	Steels	Annealing temp. Ta (°C)	Annealing time (s)	Count of bending and unbending durin annealing (times)	Average cooling rate in temperature range of 700-600°C (°C/s)	Average cooling rate in temperature range of 499°C-Ms (°C/s)	Count of bending and unbending in temperature range of 499°C-Ms (times)	Ms (°C)	(Ms-80) (°C)	Cooling stop temp. Tb (°C)	Average cooling rate in temperature range of Ms-Tb (°C/s)	Tension in temperature range of Ms-Tb (MPa)	Tempering temp. (°C)	Tempering time (s)	Type*	
113	BO	847	198	12	54	12	3	342	262	225	105	9	317	219	GA	INV. EX.

Underlines indicate being outside the range of the present invention.
(*)CR: cold rolled steel sheet (no coating), GI: hot-dip galvanized steel sheet (no alloying of zinc coating), GA: galvannealed steel sheet, EG: electrogalvanized steel sheet

(Microstructure observation)

[0079] The amount of martensite, the amount of retained austenite, and the total amount of ferrite and bainitic ferrite were determined by the methods described hereinabove.

(Proportion of packets having the largest area in prior austenite grains)

[0080] The average proportion of packets having the largest area in prior austenite grains was determined by the method described hereinabove.

(Tensile test)

[0081] A JIS No. 5 test specimen (gauge length: 50 mm, parallel section width: 25 mm) was sampled so that the longitudinal direction of the test specimen would be perpendicular to the rolling direction. A tensile test was performed in accordance with JIS Z 2241 under conditions where the crosshead speed was 1.67×10^{-1} mm/sec. TS and El were thus measured. In the present invention, 980 MPa or higher TS was determined to be acceptable, and 10% or more El was determined to be acceptable.

(Toughness)

[0082] Toughness was evaluated by Charpy test. A Charpy test specimen was a 2 mm deep V-notched test piece that was a stack of steel sheets fastened together with bolts to eliminate any gaps between the steel sheets. The number of steel sheets that were stacked was controlled so that the thickness of the stack as the test piece would be closer to 10 mm. When, for example, the sheet thickness was 1.2 mm, eight sheets were stacked to give a 9.6 mm thick test piece. The Charpy test specimen was evaluated as "excellent in toughness" when the stack had a strength of 40 J/cm^2 or more. Conditions other than those described above conformed to JIS Z 2242: 2018.

(Flatness in the width direction)

[0083] The cold rolled steel sheets obtained as described above were analyzed to measure the flatness in the width direction. The measurement is illustrated in Fig. 2. Specifically, a sheet with a length of 500 mm in the rolling direction (coil width × 500 mm L × sheet thickness) was cut out from the coil and was placed on a surface plate in such a manner that the warp at the ends would face upward. The height on the steel sheet was measured with a contact displacement meter by continuously moving the stylus over the width. Based on the results, the steepness as an index of the flatness of the steel sheet shape was measured as illustrated in Fig. 2. The flatness was rated as "×" when the steepness was more than 0.02, as "o" when the steepness was more than 0.01 and 0.02 or less, and as "◎" when the steepness was 0.01 or less. The steel sheet was evaluated as "excellent in the flatness in the width direction" when the steepness was 0.02 or less.

(Working embrittlement resistance)

[0084] The working embrittlement resistance was evaluated by Charpy test. A Charpy test specimen was a 2 mm deep V-notched test piece that was a stack of steel sheets fastened together with bolts to eliminate any gaps between the steel sheets. The number of steel sheets that were stacked was controlled so that the thickness of the stack as the test piece would be closer to 10 mm. When, for example, the sheet thickness was 1.2 mm, eight sheets were stacked to give a 9.6 mm thick test piece. The sheets for stacking into the Charpy test specimen were sampled so that the width direction would be the longitudinal direction. As an index of the working embrittlement resistance, the ratio $vE_{0\%}/vE_{10\%}$ of the absorbed impact energy at room temperature of the as-produced (unworked) steel sheet to that of the steel sheet after 10% rolling was measured. The working embrittlement resistance was rated as "×" when $vE_{0\%}/vE_{10\%}$ was less than 0.6, as "o" when $vE_{0\%}/vE_{10\%}$ was 0.6 or more and less than 0.7, and as "◎" when $vE_{0\%}/vE_{10\%}$ was 0.7 or more. The Charpy test specimen was evaluated as "excellent in working embrittlement resistance" when $vE_{0\%}/vE_{10\%}$ was 0.6 or more. Conditions other than those described above conformed to JIS Z 2242: 2018.

[0085] The results are described in Tables 5 to 7. As shown in Tables 5 to 7, INVENTIVE EXAMPLES achieved 980 MPa or higher TS, 10% or more El, and excellent toughness, flatness in the width direction, and working embrittlement resistance. In contrast, COMPARATIVE EXAMPLES were unsatisfactory in one or more of TS, El, toughness, flatness in the width direction, and working embrittlement resistance.

[Table 5]

Nos.	Steels	Martensite (area%)	Retained austenite (vol%)	Total of ferrite and bainitic ferrite (area%)	Average proportion of packets having the largest area in prior austenite grains (area%)	TS (MPa)	El (%)	Absorbed energy (J/cm^2)	Flatness in width direction	Working embrittlement resistance	
1	A	70	11	19	47	1283	19	51	◎	◎	INV. EX.
2	B	71	11	18	50	1277	20	50	◎	◎	INV. EX.
3	B	61	8	31	49	1010	33	53	◎	◎	INV. EX.
4	B	53	8	39	46	928	32	55	◎	◎	COMP. EX.
5	B	79	10	11	48	1394	11	45	◎	◎	INV. EX.
6	B	84	9	7	59	1632	8	50	◎	◎	COMP. EX.
7	B	60	8	32	60	1009	35	50	◎	◎	INV. EX.
8	B	49	11	40	48	897	33	51	◎	◎	COMP. EX.
9	B	77	10	13	47	1238	11	49	◎	◎	INV. EX.
10	B	82	10	8	52	1113	8	49	◎	◎	COMP. EX.
11	B	75	8	17	69	1158	20	49	○	○	INV. EX.
12	B	77	9	14	80	1232	16	51	×	×	COMP. EX.
13	B	71	11	18	48	1197	21	41	◎	○	INV. EX.
14	B	71	10	19	58	1118	18	41	◎	○	INV. EX.
15	B	70	11	19	68	1357	14	50	○	○	INV. EX.
16	B	73	9	18	88	1274	17	54	×	×	COMP. EX.
17	B	71	11	18	53	1271	16	48	◎	◎	INV. EX.
18	B	74	10	16	58	1314	19	45	◎	◎	INV. EX.
19	B	79	10	11	50	1355	11	46	◎	◎	INV. EX.
20	B	82	9	9	47	1467	9	47	◎	◎	COMP. EX.
21	B	68	12	20	56	1267	19	49	◎	◎	INV. EX.
22	B	75	10	15	58	1198	15	53	◎	◎	INV. EX.
23	B	73	11	16	66	1157	21	48	○	○	INV. EX.
24	B	73	9	18	92_	1357	15	46	×	×	COMP. EX.

(continued)

Nos.	Steels	Martensite (area%)	Retained austenite (vol%)	Total of ferrite and bainitic ferrite (area%)	Average proportion of packets having the largest area in prior austenite grains (area%)	TS (MPa)	El (%)	Absorbed energy (J/cm^2)	Flatness in width direction	Working embrittlement resistance	
25	B	70	11	19	50	1235	20	41	◎	○	INV. EX.
26	B	69	11	20	60	1109	18	42	◎	○	INV. EX.
27	B	78	4	18	52	1236	10	42	◎	◎	INV. EX.
28	B	80	2	18	59	1591	8	33	◎	◎	COMP. EX.
29	B	71	13	16	54	1035	24	63	◎	○	INV. EX.
30	B	66	16	18	49	1033	28	62	◎	×	COMP. EX.
31	B	72	10	18	45	1278	17	51	◎	◎	INV. EX.
32	B	72	10	18	47	1267	15	47	◎	◎	INV. EX.
33	B	71	10	19	67	1308	18	54	○	○	INV. EX.
34	B	73	12	15	81	1232	19	46	×	×	COMP. EX.
35	B	70	12	18	68	1227	17	45	○	○	INV. EX.
36	B	71	10	19	89	1272	18	45	×	×	COMP. EX.

Underlines indicate being outside the range of the present invention.

[Table 6]

Nos.	Steels	Martensite (area%)	Retained austenite (vol%)	Total of ferrite and bainitic ferrite (area%)	Average proportion of packets having the largest area in prior austenite grains (area%)	TS (MPa)	El (%)	Absorbed energy (J/cm^2)	Flatness in width direction	Working embrittlement resistance	
37	B	64	9	27	55	999	25	42	◎	◎	INV. EX.
38	B	54	10	36	59	884	30	40	◎	◎	COMP. EX.
39	B	70	10	20	57	1237	18	54	◎	◎	INV. EX.
40	B	71	10	19	55	1234	15	46	◎	◎	INV. EX.
41	B	72	9	19	48	1012	25	52	◎	◎	INV. EX.
42	B	75	10	15	51	985	23	46	◎	◎	INV. EX.
43	B	83	3	14	58	1307	10	40	◎	◎	INV. EX.
44	B	80	2	18	54	1433	9	30	◎	◎	COMP. EX.
45	B	71	12	17	46	1006	23	50	◎	◎	INV. EX.
46	B	73	10	17	56	1017	27	52	◎	◎	INV. EX.
47	B	74	11	15	59	1039	20	55	◎	◎	INV. EX.
48	B	73	10	17	47	1317	19	55	◎	◎	INV. EX.
49	C	73	9	18	49	1114	18	52	◎	◎	INV. EX.
50	D	76	8	16	53	1284	17	52	◎	◎	INV. EX.
51	E	77	9	14	46	1332	17	47	◎	◎	INV. EX.
52	F	60	8	32	52	989	30	45	◎	◎	INV. EX.
53	G	48	12	40	54	920	35	55	◎	◎	COMP. EX.
54	H	72	10	18	54	1604	11	42	◎	○	INV. EX.
55	I	77	9	14	48	1766	11	26	◎	x	COMP. EX.
56	J	69	11	20	55	1014	25	45	◎	◎	INV. EX.
57	K	72	11	17	58	898	25	54	◎	◎	COMP. EX.
58	L	69	13	18	51	1342	17	58	◎	○	INV. EX.
59	M	70	16	14	56	1095	27	60	◎	x	COMP. EX.
60	N	61	9	30	59	1017	31	48	◎	◎	INV. EX.

(continued)

Nos.	Steels	Martensite (area%)	Retained austenite (vol%)	Total of ferrite and bainitic ferrite (area%)	Average proportion of packets having the largest area in prior austenite grains (area%)	TS (MPa)	El (%)	Absorbed energy (J/cm^2)	Flatness in width direction	Working embrittlement resistance	
61	O	52	12	36	56	899	30	48	◎	◎	COMP. EX.
62	P	74	11	15	48	1216	21	41	◎	○	INV. EX.
63	Q	73	12	15	54	1535	15	33	◎	x	COMP. EX.
64	R	74	10	16	48	1189	19	41	◎	○	INV. EX.
65	S	73	11	16	54	1175	17	28	◎	x	COMP. EX.
66	T	73	10	17	48	1372	17	42	◎	o	INV. EX.
67	U	72	10	18	60	1117	18	28	◎	x	COMP. EX.
68	V	70	12	18	51	1299	17	41	◎	○	INV. EX.
69	W	71	11	18	48	1144	17	30	◎	x	COMP. EX.
70	X	74	8	18	54	1362	15	40	◎	○	INV. EX.
71	Y	76	9	15	52	1349	15	31	◎	x	COMP. EX.

Underlines indicate being outside the range of the present invention.

[Table 7]

Nos.	Steels	Martensite (area%)	Retained austenite (vol%)	Total of ferrite and bainitic ferrite (area%)	Average proportion of packets having the largest area in prior austenite grains (area%)	TS (MPa)	El (%)	Absorbed energy (J/cm^2)	Flatness in width direction	Working embrittlement resistance	
72	Z	75	10	15	47	1277	19	42	◎	○	INV. EX.
73	AA	73	9	18	48	1387	15	<u>26</u>	◎	<u>x</u>	COMP. EX.
74	AB	72	10	18	57	1415	19	46	◎	◎	INV. EX.
75	AC	75	10	15	57	994	23	52	◎	◎	INV. EX.
76	AD	73	10	17	52	1169	20	42	◎	○	INV. EX.
77	AE	77	9	14	54	1676	12	<u>27</u>	◎	<u>x</u>	COMP. EX.
78	AF	77	9	14	59	1010	25	47	◎	◎	INV. EX.
79	AG	73	9	18	57	1151	22	43	◎	○	INV. EX.
80	AH	72	11	17	51	1630	15	<u>29</u>	◎	<u>x</u>	COMP. EX.
81	AI	75	9	16	56	1014	18	46	◎	◎	INV. EX.
82	AJ	74	11	15	46	1271	17	42	◎	○	INV. EX.
83	AK	74	11	15	46	1554	13	<u>26</u>	◎	<u>x</u>	COMP. EX.
84	AL	71	9	20	48	1006	23	49	◎	◎	INV. EX.
85	AM	71	10	19	57	1350	19	42	◎	○	INV. EX.
86	AN	72	9	19	47	1515	14	<u>28</u>	◎	<u>x</u>	COMP. EX.
87	AO	60	8	32	48	1015	30	47	◎	◎	INV. EX.
88	AP	76	11	13	46	1393	11	51	◎	◎	INV. EX.
89	AQ	61	9	30	46	1005	33	49	◎	◎	INV. EX.
90	AR	76	12	12	56	1417	12	55	◎	◎	INV. EX.
91	AS	75	8	17	59	1104	24	47	○	○	INV. EX.
92	AT	78	8	14	49	1225	20	41	◎	◎	INV. EX.
93	AU	69	12	19	69	1304	18	55	○	○	INV. EX.
94	AV	70	11	19	50	1349	17	49	◎	◎	INV. EX.
95	AW	61	9	30	59	993	34	51	◎	◎	INV. EX.

(continued)

Nos.	Steels	Martensite (area%)	Retained austenite (vol%)	Total of ferrite and bainitic ferrite (area%)	Average proportion of packets having the largest area in prior austenite grains (area%)	TS (MPa)	El (%)	Absorbed energy (J/cm^2)	Flatness in width direction	Working embrittlement resistance	
96	AX	74	8	18	48	1195	19	50	◎	◎	INV. EX.
97	AY	78	8	14	64	1121	21	47	○	○	INV. EX.
98	AZ	72	12	16	52	1129	20	50	◎	◎	INV. EX.
99	BA	77	3	20	51	1354	10	45	◎	◎	INV. EX.
100	BB	68	13	19	54	1198	20	54	◎	○	INV. EX.
101	BC	76	9	15	50	1367	18	52	◎	◎	INV. EX.
102	BD	73	11	16	62	1183	18	53	○	○	INV. EX.
103	BE	75	8	17	67	1116	19	53	○	○	INV. EX.
104	BF	70	11	19	59	1357	17	42	◎	◎	INV. EX.
105	BG	75	9	16	46	1187	15	45	◎	◎	INV. EX.
106	BH	72	9	19	56	1017	27	52	◎	◎	INV. EX.
107	BI	81	4	15	50	1468	10	42	◎	◎	INV. EX.
108	BJ	75	9	16	58	1007	23	53	◎	◎	INV. EX.
109	BK	73	11	16	51	1063	25	54	◎	◎	INV. EX.
110	BL	71	11	18	53	1090	21	53	◎	◎	INV. EX.
111	BM	70	10	20	58	1320	18	49	◎	◎	INV. EX.
112	BN	69	12	19	52	1122	21	49	◎	◎	INV. EX.
113	BO	70	10	20	46	1319	16	48	◎	◎	INV. EX.

Underlines indicate being outside the range of the present invention.

Claims

1. A high strength steel sheet having a chemical composition comprising, in mass%,

C: 0.030% or more and 0.500% or less,
Si: 0.50% or more and 2.50% or less,
Mn: 1.00% or more and 5.00% or less,
P: 0.100% or less,
S: 0.0200% or less,
Al: 1.000% or less,
N: 0.0100% or less, and
O: 0.0100% or less,
a balance being Fe and incidental impurities,
the high strength steel sheet being such that in a region at 1/4 sheet thickness,
an area fraction of martensite is 60% or more,
a volume fraction of retained austenite is 30 or more and 15% or less,
an area fraction of a total of ferrite and bainitic ferrite is more than 10%, and
an average of proportions of packets having the largest area in prior austenite grains is 70% by area or less of the prior austenite grain.

2. The high strength steel sheet according to claim 1, wherein the chemical composition further comprises at least one element selected from, in mass%,

Ti: 0.200% or less, Nb: 0.200% or less,
V: 0.200% or less, Ta: 0.10% or less,
W: 0.10% or less, B: 0.0100% or less,
Cr: 1.00% or less, Mo: 1.00% or less,
Co: 0.010% or less, Ni: 1.00% or less,
Cu: 1.00% or less, Sn: 0.200% or less,
Sb: 0.200% or less, Ca: 0.0100% or less,
Mg: 0.0100% or less, REM: 0.0100% or less,
Zr: 0.100% or less, Te: 0.100% or less,
Hf: 0.10% or less, and Bi: 0.200% or less.

3. The high strength steel sheet according to claim 1 or 2, which has a coated layer on a surface of the steel sheet.

4. A method for manufacturing the high strength steel sheet according to claim 1 or 2, the method comprising:

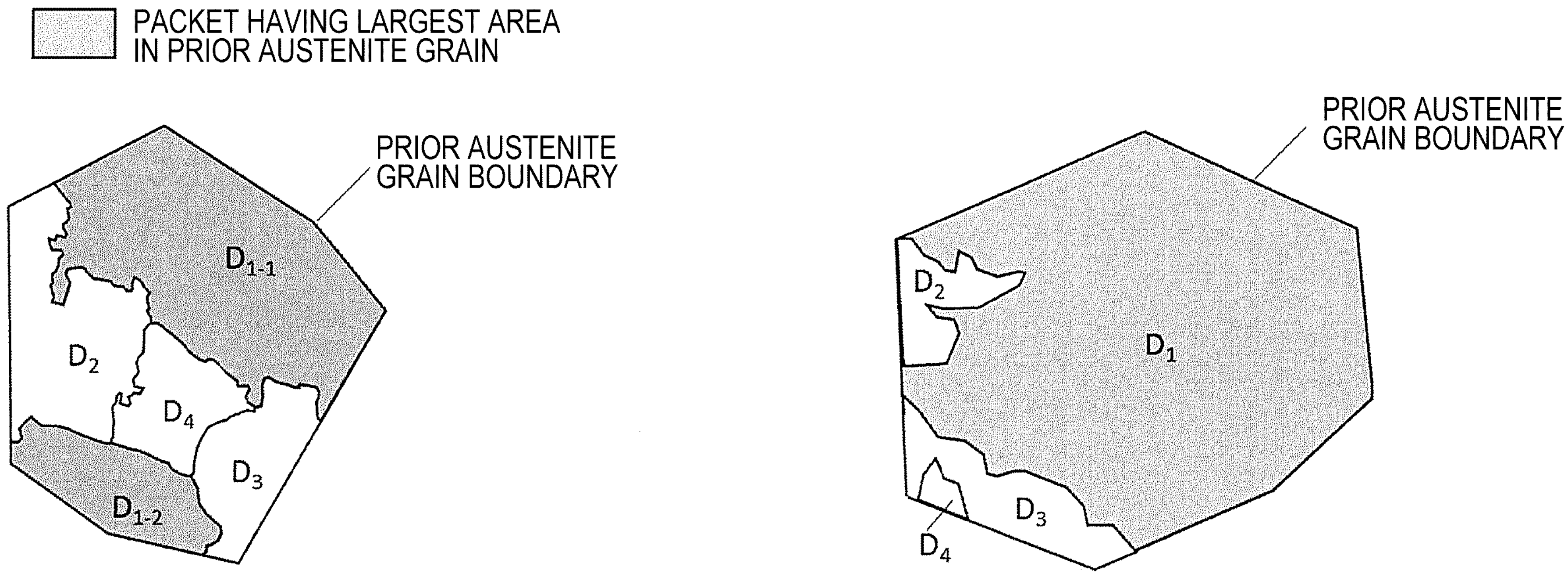
providing a cold rolled steel sheet produced by subjecting a steel having the chemical composition to hot rolling, pickling, and cold rolling;
annealing the steel sheet by heating at an annealing temperature Ta of 700°C or above and 900°C or below for a holding time at the annealing temperature Ta of 10 seconds or more and 1000 seconds or less;
bending and unbending the steel sheet 1 to 15 times in total with a roll having a radius of 800 mm or less during the annealing;
cooling the steel sheet at an average cooling rate of 20°C/s or more in a temperature range from 700°C to 600°C and at an average cooling rate of less than 20°C/s in a temperature range from 499°C to Ms;
bending and unbending the steel sheet in the temperature range from 499°C to Ms, 1 to 15 times in total with a roll having a radius of 800 mm or less;
cooling the steel sheet at an average cooling rate of 150°C/s or less in a temperature range from Ms to a cooling stop temperature Tb;
applying a tension to the steel sheet in the temperature range from Ms to the cooling stop temperature Tb while controlling a tension to 5 MPa or more and 100 MPa or less,
the cooling stop temperature Tb being 100°C or above and (Ms - 80°C) or below where Ms is a martensite start temperature (°C) defined by formula (1); and
tempering the steel sheet at a tempering temperature of Tb or above and 450°C or below for a holding time at the tempering temperature of 10 seconds or more and 1000 seconds or less,

$$Ms = 519 - 474 \times [\%\ C] - 30.4 \times [\%\ Mn] - 12.1 \times [\%\ Cr] - 7.5 \times [\%\ Mo] - 17.7 \times [\%\ Ni] - Ta/80 \quad (1)$$

where [% C], [% Mn], [% Cr], [% Mo], and [% Ni] indicate contents (mass%) of C, Mn, Cr, Mo, and Ni, respectively, and are zero when the element is absent.

5. The method for manufacturing the high strength steel sheet according to claim 4, further comprising performing a coating treatment.

FIG. 1

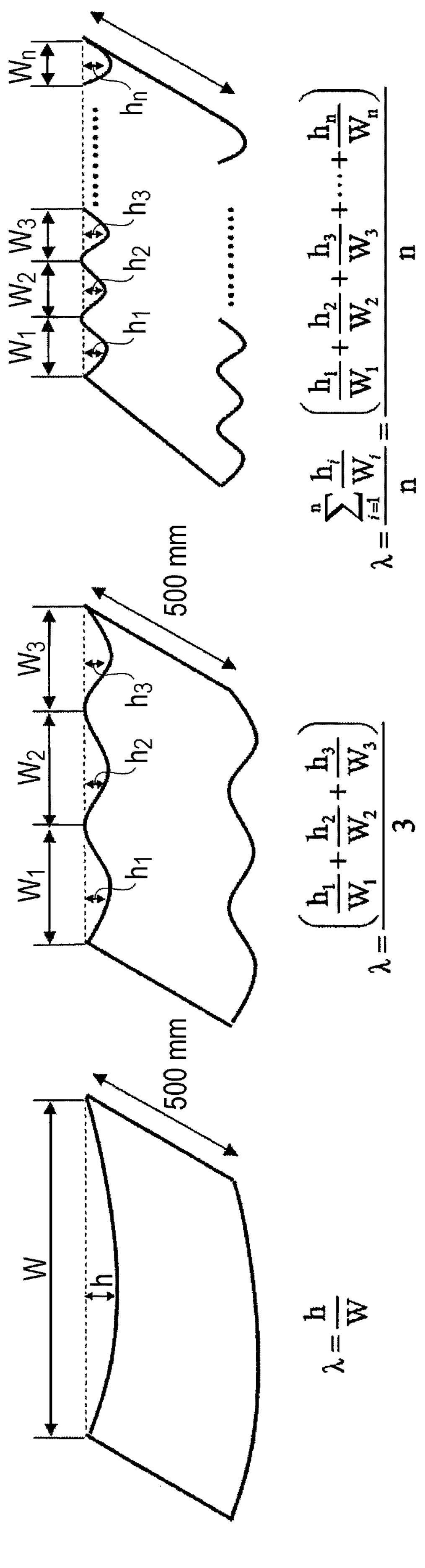


$$\text{(PROPORTION OF PACKET HAVING LARGEST AREA IN PRIOR AUSTENITE GRAIN)} = \frac{(D_{1\text{-}1} + D_{1\text{-}2})}{(D_{1\text{-}1} + D_{1\text{-}2} + D_2 + D_3 + D_4)} \times 100$$

$$\text{(PROPORTION OF PACKET HAVING LARGEST AREA IN PRIOR AUSTENITE GRAIN)} = \frac{D_1}{(D_1 + D_2 + D_3 + D_4)} \times 100$$

PACKET HAVING LARGEST AREA IN PRIOR AUSTENITE GRAIN

FIG. 2


W
h
500 mm
$\lambda = \frac{h}{W}$
W1
W2
W3
h1
h2
h3
500 mm
$\lambda = \frac{\left(\frac{h_1}{W_1} + \frac{h_2}{W_2} + \frac{h_3}{W_3}\right)}{3}$
W1
W2
W3
Wn
h1
h2
h3
hn
$\lambda = \frac{\sum_{i=1}^{n} \frac{h_i}{W_i}}{n} = \frac{\left(\frac{h_1}{W_1} + \frac{h_2}{W_2} + \frac{h_3}{W_3} + \cdots + \frac{h_n}{W_n}\right)}{n}$

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/002917

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301U; C21D9/46 F; C21D9/46 J; C22C38/00 301T; C22C38/06; 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; C21D9/46

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2018/216522 A1 (KABUSHIKI KAISHA KOBE SEIKO SHO) 29 November 2018 (2018-11-29) claims	1-5
A	JP 2020-20033 A (NIPPON STEEL CORP.) 06 February 2020 (2020-02-06) claims	1-5
A	WO 2020/158066 A1 (JFE STEEL CORP.) 06 August 2020 (2020-08-06) claims	1-5
A	WO 2018/124157 A1 (JFE STEEL CORP.) 05 July 2018 (2018-07-05) claims	1-5
P, A	WO 2022/209519 A1 (JFE STEEL CORP.) 06 October 2022 (2022-10-06) claims, paragraphs [0054]-[0058], [0068]-[0074]	1-5

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

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 April 2023	**18 April 2023**

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

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/002917

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2018/216522 A1	29 November 2018	EP 3633058 A1 claims US 2020/0071787 A1 CN 110651062 A JP 2018-197380 A	
JP 2020-20033 A	06 February 2020	(Family: none)	
WO 2020/158066 A1	06 August 2020	EP 3889282 A1 claims US 2022/0081734 A1 CN 113366133 A	
WO 2018/124157 A1	05 July 2018	EP 3564400 A1 claims US 2020/0190617 A1 CN 110121568 A	
WO 2022/209519 A1	06 October 2022	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 4947176 B **[0007]**
- JP 6525114 B **[0007]**
- JP 6777272 B **[0007]**

Non-patent literature cited in the description

- *Journal of Smart Processing*, 2013, vol. 2 (3), 110-118 **[0008]**