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

(72) Inventors:
- **ABUKAWA Genki**
  Tokyo 100-8071 (JP)
- **SHUTO Hiroshi**
  Tokyo 100-8071 (JP)

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

(54) HIGH-STRENGTH STEEL SHEET

(57) A high strength steel sheet according to the present invention contains a predetermined chemical composition, a metallographic structure includes, by an area ratio, ferrite: 20% to 70%, residual austenite: 5% to 40%, fresh martensite: 0% to 30%, tempered martensite and bainite: 20% to 75% in total, and pearlite and cementite: 0% to 10% in total, in a range of a 1/8 thickness to a 3/8 thickness from a surface, a number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to the number of all residual austenite is 50% or more, at a sheet thickness 1/4 position of a cross section parallel to a rolling direction and perpendicular to the surface, a standard deviation of area ratios of ferrite measured at 10 points every 50 mm along a width direction is less than 10%, and a tensile strength is 780 MPa or more.

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Description

[Technical Field of the Invention]

[0001] The present invention relates to a high strength steel sheet having excellent tensile strength, elongation, stretch flangeability, and bendability, and being excellent in terms of material quality stability.

[0002] Priority is claimed on Japanese Patent Application No. 2019-128612, filed in Japan on July 10, 2019, the content of which is incorporated herein by reference.

[Related Art]

[0003] In recent years, from the viewpoint of regulations for greenhouse gas emission in association with global warming countermeasures, there has been a demand for additional improvement in the fuel efficiency of vehicles. In addition, in order to reduce the weights of vehicle bodies and ensure collision safety, the application of high strength steel sheets to a component for a vehicle is becoming increasingly widespread.

[0004] For steel sheets that are used in a component for a vehicle, not only strength but also a variety of workability that is required at the time of forming components such as press formability and weldability are required. Specifically, from the viewpoint of press formability, it is not unusual that excellent elongation (total elongation in a tensile test; EL) and excellent stretch flangeability (hole expansion rate; λ) are required for steel sheets.

[0005] Incidentally, for high strength steel sheets, a technique for obtaining a stable material quality in coils is also important. This is because, thus far, low strength steel sheets have had a relatively simple structure configuration in which a ferrite structure is the main component and the strength is secured with a small amount of a solid solution strengthening element as necessary, whereas high strength steel have had a complex structure in which a low temperature transformation structure such as bainite or martensite or a precipitate such as TiC is used to secure the strength. These phenomena of transformation and precipitation are significantly affected by the temperature history, and, in some cases, temperature variations inevitably occur in manufacturing steps. For example, in a manufacturing step of a hot-rolled steel sheet, there is a possibility that the temperature history may vary in the width direction and the longitudinal direction due to unevenness in a method for applying cooling water in the width direction, unevenness in the cooling rate depending on positions in a wound coil, or the like. Therefore, in the manufacture of high strength steel sheets, there is a need for a technique for stabilizing material qualities such as the use of a manufacturing method in which the temperature history is reduced as much as possible or a material design that decreases the influence of the temperature history as much as possible.

[0006] As a technique for improving the ductility of high strength steel sheets, there is TRIP steel in which the transformation induced plasticity (TRIP) effect is used by leaving austenite in the steel structure (for example, refer to Patent Document 1). TRIP steel has higher ductility than DP steel.

[0007] In addition, Non-Patent Document 1 discloses that the use of a double annealing method, in which a steel sheet is annealed twice, improves the elongation and hole expansibility of steel sheets.

[0008] Incidentally, regarding material quality stability, for example, Patent Document 2 reports a technique in which, in a hot-rolled steel sheet having a tensile strength of 780 MPa or more, the amount of Ti and V added is controlled to be within a certain range, whereby fine carbides are uniformly precipitated during hot rolling and coiling and, consequently, the material quality of the hot-rolled steel sheet is stabilized.

[Prior Art Document]

[Patent Document]

[0009]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2006-274418
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2013-100574

[Non-Patent Document]

[0010] [Non-Patent Document 1] K. Sugimoto et al.: ISIJ International, Effects of Second Phase Morphology on Retained Austenite Morphology and Tensile Properties in a TRIP-aided Dual-phase Steel Sheet (1993), 775

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0011] The present inventors carried out searches to obtain a steel sheet satisfying both elongation and hole expansibility. In the method described in Non-Patent Document 1, since annealing is carried out twice, there is a problem in that the fuel cost or the like increases compared with a manufacturing method in which annealing is carried out once. Therefore, in order to build the same planar structure (that is, a structure in which the aspect ratio of austenite is large) without carrying out annealing twice, the present inventors made an attempt of a manufacturing method in which a TRIP steel sheet is built by annealing a hot-rolled steel sheet. Specifically, the present inventors studied a manufacturing method in which a hot-rolled steel sheet is coiled at low temperatures of 450°C or lower and then annealed. Coiling at low temperatures is capable of turning the structure of the hot-rolled steel sheet into a structure in which a low temperature transformation structure is the main component. The present inventors considered that a planar structure can be obtained by single annealing by annealing a hot-rolled steel sheet having a structure in which a low temperature transformation structure is the main component.

[0012] However, in steel sheets obtained by this method, the material quality becomes instable. Specifically, the variation in the amount of ferrite measured along the width direction increased, and consequently, the variation in mechanical properties increased.

[0013] An object of the present invention is to provide a high strength hot-rolled steel sheet having excellent tensile strength, elongation, stretch flangeability, and bendability and being excellent in terms of material quality stability. The material quality stability means that the variation in tensile strength and total elongation is small in each portion in a steel sheet.

[Means for Solving the Problem]

[0014]

(1) A high strength steel sheet according to one aspect of the present invention contains, as a chemical composition, by mass%, C: 0.030% to 0.280%, Si: 0.50% to 2.50%, Mn: 1.00% to 4.00%, sol. Al: 0.001% to 2.000%, P: 0.100% or less, S: 0.0200% or less, N: 0.01000% or less, O: 0.0100% or less, B: 0% to 0.010%, Ti: 0% to 0.20%, Nb: 0% to 0.20%, V: 0% to 1.000%, Cr: 0% to 1.000%, Mo: 0% to 1.000%, Cu: 0% to 1.000%, Co: 0% to 1.000%, W: 0% to 1.000%, Ni: 0% to 1.000%, Ca: 0% to 0.0100%, Mg: 0% to 0.0100%, REM: 0% to 0.0100%, Zr: 0% to 0.0100%, and a remainder including Fe and impurities, a metallographic structure includes, by an area ratio, ferrite: 20% to 70%, residual austenite: 5% to 40%, fresh martensite: 0% to 30%, tempered martensite and bainite: 20% to 75% in total, and pearlite and cementite: 0% to 10% in total, in a range of a 1/8 thickness to a 3/8 thickness from a surface, a number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to the number of all residual austenite is 50% or more, at a sheet thickness 1/4 position of a cross section parallel to a rolling direction and perpendicular to the surface, a standard deviation of area ratios of ferrite measured at 10 points every 50 mm along a width direction is less than 10%, and a tensile strength is 780 MPa or more.

(2) In the high strength steel sheet according to (1), at 10 positions at intervals of 50 mm in the width direction, a standard deviation of surface roughness Ra may be 0.5 μm or less.

(3) The high strength steel sheet according to (1) or (2) may contain, as the chemical composition, by mass%, at least one from the group consisting of B: 0.001% to 0.010%, Ti: 0.01 to 0.20%, Nb: 0.01% to 0.20%, V: 0.005% to 1.000%, Cr: 0.005% to 1.000%, Mo: 0.005% to 1.000%, Cu: 0.005% to 1.000%, Co: 0.005% to 1.000%, W: 0.005% to 1.000%, Ni: 0.005% to 1.000%, Ca: 0.0003% to 0.0100%, Mg: 0.0003% to 0.0100%, REM: 0.0003% to 0.0100%, and Zr: 0.0003% to 0.0100%.

[Effects of the Invention]

[0015] According to the above-described aspect, it is possible to obtain a high strength steel sheet having excellent tensile strength, elongation, stretch flangeability, and bendability and being excellent in terms of material quality stability.

[Brief Description of the Drawings]

[0016]

FIG. 1 is a conceptual diagram showing an observed section for evaluating a metallographic structure.
FIG. 2 is a conceptual diagram showing an observed section for evaluating residual austenite.

FIG. 3 is a conceptual diagram showing an observed section for evaluating the standard deviation of the area ratios of ferrite.

[Embodiments of the Invention]

[0017] The present inventors repeated intensive studies regarding causes for impairing material quality stability in steel sheets that were annealed once. In addition, the present inventors found that a variation in the surface properties of hot-rolled steel sheets before annealing affects the material quality stability of the steel sheets after annealing. A variation in the surface properties (surface roughness) of hot-rolled steel sheets tends to be larger than that of cold-steel sheets. When surface roughness is uneven, in a process of heating for annealing, the unevenness in the surface roughness causes an unevenness in emissivity, and a resulting temperature variation is brought to steel sheets. As a result, a variation in the amount of ferrite in annealed steel sheets increases. It was clarified for the first time by the present inventors' finding that the control of the surface properties of hot-rolled steel sheets contributes to the stabilization of the material quality of hot-rolled annealed sheets.

[0018] In addition, the present inventors also found a hot rolling method effective for suppressing the variation in the surface properties of steel steels (hot-rolled steel sheets) before annealing. The present inventors discovered that a phenomenon in which, during hot rolling, surface layer scale is pressed against a steel sheet with a hot rolling roll significantly characterizes the surface properties of the hot-rolled steel sheet. In addition, it was found that, in order to control the surface properties of hot-rolled steel sheets, the control of scale growth during hot rolling is important, and this can be achieved by spraying a water film onto the surfaces of the steel sheets under specific conditions during rolling.

[0019] Hereinafter, a high strength steel sheet according to one embodiment of the present invention will be described in detail. Here, the present invention is not limited only to a constitution disclosed in the present embodiment and can be modified in a variety of manners within the scope of the gist of the present invention. In addition, numerical limiting ranges described below includes the lower limits and the upper limits in the ranges. Numerical values expressed with 'more than' or 'less than' are not included in the numerical ranges. "%" regarding the amount of each element means "mass%".

[0020] In a high strength steel sheet 1 according to the present embodiment, a rolling direction RD, a thickness direction TD, and a width direction WD shown in FIG. 1 to FIG. 3 are defined as described below. The rolling direction RD means a direction in which the steel sheet is moved by a rolling roll during rolling. The thickness direction TD is a direction perpendicular to a rolled surface 11 of the steel sheet. The width direction WD is a direction perpendicular to the rolling direction RD and the thickness direction TD. The rolling direction RD can be easily specified based on the stretching direction of the crystal grain of the steel sheet. Therefore, the rolling direction RD can be specified even for a steel sheet cut out from a rolled material steel sheet.

[0021] In the high strength steel sheet according to the present embodiment, the amount of ferrite and the like in the metallographic structure are regulated. The metallographic structure is evaluated in a cross section 12 parallel to the rolling direction RD and perpendicular to the rolled surface 11 (refer to FIG. 1). Hereinafter, there will be cases where the cross section 12 parallel to the rolling direction RD and perpendicular to the rolled surface 11 is simply referred to as the cross section parallel to the rolling direction RD. A detailed method for evaluating the metallographic structure will be described below.

[0022] In addition, in the high strength steel sheet according to the present embodiment, the number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to the number of all residual austenite is previously defined. Residual austenite is evaluated in a cross section parallel to the rolling direction RD and the thickness direction TD (refer to FIG. 2). A detailed method for evaluating residual austenite will be described below.

[0023] Furthermore, in the high strength steel sheet according to the present embodiment, the standard deviation of the area ratios of ferrite is regulated. The area ratio of ferrite is measured at a sheet thickness 1/4 position 121 of the cross section 12 parallel to the rolling direction RD and perpendicular to the rolled surface 11 (refer to FIG. 3). Ten cross sections 12 parallel to the rolling direction RD and perpendicular to the rolled surface 11 are produced every 50 mm along the width direction WD, and the standard deviation of the 10 area ratios of ferrite measured on these surfaces is regarded as the standard deviation of the area ratios of ferrite according to the present embodiment.

[0024] The sheet thickness 1/4 position is a position at a depth of 1/4 of the thickness of the steel sheet 1 from the rolled surface 11 of the steel sheet 1. In FIG. 1 and FIG. 2, only the position at a depth of 1/4 of the thickness of the steel sheet 1 from the upper rolled surface 11 of the steel sheet 1 is shown as the sheet thickness 1/4 position. However, it is needless to say that the position at a depth of 1/4 of the thickness of the steel sheet 1 from the lower rolled surface 11 of the steel sheet 1 can also be treated as the sheet thickness 1/4 position. In addition, FIG. 3 shows only some of the 10 measurement surfaces. Furthermore, FIG. 3 merely conceptually shows the measurement points of the area ratios of ferrite, and there is no need to form the number density of measurement surfaces as shown in FIG. 3 as long as a predetermined requirement is satisfied. A detailed method for evaluating the standard deviation of the area ratios of ferrite will be described below.

[High strength steel sheet]

[0025] The high strength steel sheet according to the present embodiment contains, as a chemical composition, by mass%,

C: 0.030% to 0.280%,
Si: 0.50% to 2.50%,
Mn: 1.00% to 4.00%,
sol. Al: 0.001 % to 2.000%,
P: 0.100% or less,
S: 0.0200% or less,
N: 0.01000% or less,
O: 0.0100% or less,
B: 0% to 0.010%,
Ti: 0% to 0.20%,
Nb: 0% to 0.20%,
V: 0% to 1.000%,
Cr: 0% to 1.000%,
Mo: 0% to 1.000%,
Cu: 0% to 1.000%,
Co: 0% to 1.000%,
W: 0% to 1.000%,
Ni: 0% to 1.000%,
Ca: 0% to 0.0100%,
Mg: 0% to 0.0100%,
REM: 0% to 0.0100%,
Zr: 0% to 0.0100% or less, and
remainder: Fe and impurities

a metallographic structure includes, by an area ratio,

ferrite: 20% to 70%,
residual austenite: 5% to 40%,
fresh martensite: 0% to 30%,
tempered martensite and bainite: 20% to 75% in total, and
pearlite and cementite: 0% to 10% in total,

in a range of a 1/8 thickness to a 3/8 thickness from a surface, a number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to all residual austenite is 50% or more,

at a sheet thickness 1/4 position of a cross section parallel to a rolling direction and perpendicular to the surface, a standard deviation of area ratios of ferrite measured at 10 points every 50 mm in a width direction is less than 10%, and a tensile strength is 780 MPa or more.

1. Chemical composition

[0026] Hereinafter, the composition of the high strength steel sheet according to the present embodiment will be described in detail. The high strength steel sheet according to the present embodiment contains, as a chemical composition, basic elements and an optional element as necessary, and the remainder includes Fe and impurities.

(C: 0.030% or more and 0.280% or less)

[0027] C is an important element for ensuring the strength of the steel sheet. When the C content is less than 0.030%, it is not possible to ensure a tensile strength of 780 MPa or more. Therefore, the C content is set to 0.030% or more, preferably 0.050% or more, 0.100% or more, 0.120% or more, or 0.140% or more.

[0028] On the other hand, when the C content becomes more than 0.280%, since the weldability becomes poor, the upper limit is set to 0.280%. The C content is preferably 0.260% or less or 0.250% or less and more preferably 0.200% or less, 0.180% or less, or 0.160% or less.

(Si: 0.50% or more and 2.50% or less)

[0029] Si is an important element for suppressing the precipitation of an iron-based carbide and stabilizing residual γ. When the Si content is less than 0.50%, since it is difficult to obtain 5% or more of residual γ, and the elongation deteriorates, the Si content is set to 0.50% or more. The Si content is preferably 0.80% or more, 1.00% or more, or 1.20% or more.

[0030] On the other hand, when the Si content is more than 2.50%, since the deterioration of the surface properties is caused, the Si content is set to 2.50% or less. The Si content is preferably 2.00% or less, more preferably 1.80% or less, 1.50% or less, or 1.30% or less.

(Mn: 1.00% or more and 4.00% or less)

[0031] Mn is an effective element for increasing the mechanical strength of the steel sheet. When the Mn content is less than 1.00%, it is not possible to ensure a tensile strength of 780 MPa or more. Therefore, the Mn content is set to 1.00% or more. The Mn content is preferably 1.50% or more and more preferably 1.80% or more, 2.00% or more, or 2.20% or more.

[0032] On the other hand, when an excess of Mn is added, the structure becomes uneven due to the segregation of Mn, and the bending workability deteriorates. Therefore, the Mn content is set to 4.00% or less, preferably 3.00% or less, more preferably 2.80% or less, 2.60% or less, or 2.50% or less.

(sol. Al: 0.001% or more and 2.000% or less)

[0033] Al is an element having an action of deoxidizing steel to make the steel sheet sound. When the sol. Al content is less than 0.001%, since sufficient deoxidation is not possible, the sol. Al content is set to 0.001% or more. However, in a case where sufficient deoxidation is required, 0.010% or more of sol. Al is desirably added. The sol. Al content is more desirably 0.020% or more, 0.030% or more, or 0.050% or more.

[0034] On the other hand, when the sol. Al content is more than 2.000%, the degradation of the weldability becomes significant, and the number of oxide-based inclusions increases, which significantly degrades the surface properties. Therefore, the sol. Al content is set to 2.000% or less and is preferably 1.500% or less, more preferably 1.000% or less, or 0.700% or less and most preferably 0.090% or less, 0.080% or less, or 0.070% or less. Sol. Al means acid-soluble Al that does not turn into an oxide such as Al_2O_3 and is soluble in acids.

[0035] The high strength steel sheet according to the present embodiment contains, as the chemical composition, impurities. The "impurities" refer to, for example, elements that are contained by accident from ore or scrap that is a raw material or from the manufacturing environments or the like at the time of industrially manufacturing steel. The impurities mean, for example, elements such as P, S, and N. These impurities are preferably limited as described below in order to make the effect of the present embodiment sufficiently exhibited. In addition, since the amount of the impurities is preferably small, it is not necessary to limit the lower limit, and the lower limit of impurities may be 0%.

(P: 0.100% or less)

[0036] P is ordinarily an impurity that is contained in steel, but has an action of increasing the tensile strength, and thus P may be positively contained. However, when the P content is more than 0.100%, the deterioration of the weldability becomes significant. Therefore, the P content is limited to 0.100% or less. The P content is preferably limited to 0.080% or less, 0.070% or less, or 0.050% or less. In order to more reliably obtain the effect of the above-described action, the P content may be set to 0.001% or more, 0.002% or more, or 0.005% or more.

(S: 0.0200% or less)

[0037] S is an impurity that is contained in steel, and the S content is preferably as low as possible from the viewpoint of the weldability. When the S content is more than 0.0200%, the weldability significantly deteriorates, the amount of MnS precipitated increases, and the low temperature toughness deteriorates. Therefore, the S content is limited to 0.0200% or less. The S content is preferably 0.0100% or less and more preferably limited to 0.0080% or less, 0.0070% or less, or 0.0050% or less. From the viewpoint of the desulfurization cost, the S content may be set to 0.0010% or more, 0.0015% or more, or 0.0020% or more.

(N: 0.01000% or less)

[0038] N is an impurity that is contained in steel, and the N content is preferably as low as possible from the viewpoint

of the weldability. When the N content is more than 0.01000%, the degradation of the weldability becomes significant. Therefore, the N content is limited to 0.01000% or less and may be preferably 0.00900% or less, 0.00700% or less, or 0.00500% or less. The lower limit of the N content is not particularly limited, but the N content may be set to, for example, 0.00005% or more, 0.00010% or more, or 0.00020% or more.

(O: 0.0100% or less)

[0039] O is an impurity that is contained in steel, and the O content is preferably as low as possible from the viewpoint of the weldability. When the O content is more than 0.0100%, the degradation of the weldability becomes significant. Therefore, the O content is limited to 0.0100% or less and is preferably 0.0090% or less, 0.0070% or less, or 0.0050% or less. The lower limit of the O content is not particularly limited, but the O content may be set to, for example, 0.0005% or more, 0.0008% or more, or 0.0010% or more.

[0040] The high strength steel sheet according to the present embodiment may contain an optional element in addition to the basic elements and the impurities described above. For example, instead of some of Fe that is the remainder described above, B, Ti, Nb, V, Cr, Mo, Cu, Co, W, Ni, Ca, Mg, REM, and Zr may be contained as the optional elements. These optional elements may be contained according to the purpose. Therefore, it is not necessary to limit the lower limits of these optional elements, and the lower limits may be 0%. In addition, even when these optional elements are contained as impurities, the above-described effects are not impaired.

(B: 0% or more and 0.010% or less)

(Ti: 0% or more and 0.20% or less)

(Nb: 0% or more and 0.20% or less)

(V: 0% or more and 1.000% or less)

(Cr: 0% or more and 1.000% or less)

(Mo: 0% or more and 1.000% or less)

(Cu: 0% or more and 1.000% or less)

(Co: 0% or more and 1.000% or less)

(W: 0% or more and 1.000% or less)

(Ni: 0% or more and 1.000% or less)

[0041] B, Ti, Nb, V, Cr, Mo, Cu, Co, W, and Ni are all effective elements for stably ensuring the strength. Therefore, these elements may be contained. However, even when more than 0.010% of B, more than 0.20% of each of Ti and Nb, and more than 1.000% of each of V, Cr, Mo, Cu, Co, W, and Ni are contained, the effect of the above-described action is likely to be saturated, and there are cases where containing such elements becomes economically disadvantageous.

[0042] Therefore, the B content is set to 0.010% or less, the amount of each of Ti and Nb is set to 0.20% or less, and the amount of each of V, Cr, Mo, Cu, Co, W, and Ni is set to 1.0% or less or 1.000% or less. The B content may be set to 0.008% or less, 0.007% or less, or 0.005% or less. The upper limit of the amount of each of Ti and Nb may be set to 0.18%, 0.15%, or 0.10%. The upper limit of the amount of each of V, Cr, Mo, Cu, Co, W, and Ni may be set to 0.500% or less, 0.300% or less, or 0.100% or less.

[0043] In order to more reliably obtain the effect of the above-described action, at least one of

B: 0.001% or more, 0.002% or more, or 0.004% or more,
Ti: 0.01% or more, 0.02% or more, or 0.05% or more,
Nb: 0.01% or more, 0.02% or more, or 0.05% or more,
V: 0.005% or more, 0.008% or more, or 0.010% or more,
Cr: 0.005% or more, 0.008% or more, or 0.010% or more,
Mo: 0.005% or more, 0.008% or more, or 0.010% or more,
Cu: 0.005% or more, 0.008% or more, or 0.010% or more,

Co: 0.005% or more, 0.008% or more, or 0.010% or more,
W: 0.005% or more, 0.008% or more, or 0.010% or more, and
Ni: 0.005% or more, 0.008% or more, or 0.010% or more

is preferably contained.

(Ca: 0% or more and 0.0100% or less)

(Mg: 0% or more and 0.0100% or less)

(REM: 0% or more and 0.0100% or less)

(Zr: 0% or more and 0.0100% or less)

[0044] Ca, Mg, REM, and Zr are all elements that contribute to the control of an inclusion, particularly, the fine dispersion of an inclusion and have an action of enhancing toughness. Therefore, one or more of these elements may be contained. However, when the content is more than 0.0100% for any of the elements, there are cases where the deterioration of surface properties becomes apparent. Therefore, the amount of each of Ca, Mg, REM, and Zr is preferably set to 0.01% or less or 0.0100% or less. The upper limit of the amount of each of Ca, Mg, REM, and Zr may be set to 0.0080%, 0.0050%, or 0.0030%. In order to more reliably obtain the effect of the above-described action, the amount of at least one of these elements is preferably set to 0.0003% or more, 0.0005% or more, or 0.0010% or more.

[0045] Here, REM refers to a total of 17 elements of Sc, Y and lanthanoids and is at least one of them. The REM content means the total amount of at least one of these elements. Industrially, lanthanoids are added in a mischmetal form.

[0046] The high strength steel sheet according to the present embodiment preferably contains, as the chemical composition, by mass%, at least one of Ca: 0.0003% or more and 0.0100% or less, Mg: 0.0003% or more and 0.0100% or less, REM: 0.0003% or more and 0.0100% or less, and Zr: 0.0003% or more and 0.0100% or less.

[0047] The above-described steel composition may be measured by an ordinary analysis method of steel. For example, the steel composition may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). C and S may be measured using an infrared absorption method after combustion, N may be measured using an inert gas melting-thermal conductivity method, and O may be measured using an inert gas fusion-nondispersive infrared absorption method.

2. Metallographic structure

[0048] In the high strength steel sheet according to the present embodiment, the metallographic structure includes, by the area ratio, ferrite: 20% to 70%, residual austenite: 5% to 40%, fresh martensite: 0% to 30%, tempered martensite and bainite: 20% to 75% in total, and pearlite and cementite: 0% to 10% in total.

(Ferrite: 20% to 70%)

[0049] Ferrite is a structure that is relatively soft and contributes to forming. Having ferrite improves elongation, hole expansibility, and bendability. In order to obtain this effect, 20% or more of ferrite needs to be included. Therefore, the area ratio of ferrite in the metallographic structure is set to 20% or more. The area ratio of ferrite may be set to 25% or more, 30% or more, or 35% or more.

[0050] When more than 70% of ferrite is included, it becomes difficult to increase the tensile strength to 780 MPa or more. Therefore, the area ratio of ferrite in the metallographic structure is set to 70% or less. The area ratio of ferrite may be set to 65% or less, 60% or less, or 50% or less.

(Residual austenite: 5% to 40%)

[0051] Residual austenite is a structure that contributes to elongation. In order to obtain this effect, 5% or more of residual austenite needs to be included. Therefore, the area ratio of residual austenite in the metallographic structure is set to 5% or more and is preferably 8% or more, 10% or more, or 15% or more.

[0052] In a manufacturing method according to the present embodiment, it is substantially impossible to leave 40% or more of residual austenite. Therefore, the upper limit of the area ratio of residual austenite in the metallographic structure is 40%. The area ratio of residual austenite may be set to 35% or less, 30% or less, or 25% or less.

(Fresh martensite: 0% to 30%)

[0053] Fresh martensite is a structure that impairs formability instead of contributing to strength. Therefore, fresh martensite may not be included, and the lower limit thereof is set to 0%.

[0054] In order to obtain the effect of improving the strength by fresh martensite, it is preferable to have 2% or more, 5% or more, or 8% or more of fresh martensite.

[0055] On the other hand, when more than 30% of fresh martensite is included, since the elongation or the hole expansibility are degraded, the area ratio of fresh martensite in the metallographic structure is set to 30% or less. The area ratio of fresh martensite is preferably 20% or less and more preferably 15% or less or 10% or less.

(Tempered martensite and bainite: 20% to 75% in total)

[0056] Tempered martensite and bainite are structures that contribute to strength. In order to obtain a tensile strength of 780 MPa or more, a total of 20% or more of tempered martensite and bainite need to be included. Therefore, in the metallographic structure of the high strength steel sheet according to the present embodiment, the total area ratio of tempered martensite and bainite is set to 20% or more and is preferably 30% or more, 40% or more, or 50% or more.

[0057] It is not necessary to regulate the upper limit of the total of tempered martensite and bainite. As described above, the metallographic structure of the steel sheet according to the present embodiment includes 20% or more of ferrite and 5% or more of residual austenite, and all of the remainder may be tempered martensite and bainite. In other words, the total area ratio of tempered martensite and bainite can be set to a maximum of 75%. The total area ratio of tempered martensite and bainite may be 70% or less, 60% or less, or 55% or less.

(Pearlite and cementite: 0% to 10% in total)

[0058] Pearlite and cementite are structures that impair formability. In a case where the total area ratio of pearlite and cementite is more than 10%, the deterioration of the formability becomes significant, which is not preferable. Therefore, the total area ratio of pearlite and cementite is set to 10% or less in total. The total area ratio of pearlite and cementite may be set to 8% or less, 5% or less, or 3% or less. Since pearlite and cementite are not required to solve the problem of the present invention, the lower limit of the total area ratio thereof is 0%. However, the total area ratio of pearlite and cementite may be 0.5% or more, 1% or more, or 2% or more.

Method for measuring metallographic structure

[0059] The identification of the above-described bainite, tempered martensite, ferrite, pearlite, residual austenite, and martensite that configure the metallographic structure of the high strength steel sheet according to the present embodiment, the confirmation of the presence positions thereof, and the measurement of the area fractions thereof are carried out by the following methods.

[0060] First, a cross section parallel to the rolling direction (that is, a cross section parallel to the rolling direction and perpendicular to the surface) is corroded using a Nital reagent and a reagent disclosed in Japanese Unexamined Patent Application, First Publication No. S59-219473. Regarding the corrosion of the cross section, specifically, a solution prepared by dissolving 1 to 5 g of picric acid in 100 ml of ethanol is used as a solution A, a solution prepared by dissolving 1 to 25 g of sodium thiosulfate and 1 to 5 g of citric acid in 100 ml of water is used as a solution B, the solution A and the solution B are mixed at a proportion of 1:1 to prepare a liquid mixture, and nitric acid is further added and mixed at a proportion of 1.5% to 4% with respect to the total amount of this liquid mixture, thereby preparing a pretreatment liquid. In addition, the above-described pretreatment liquid is added to and mixed with a 2% Nital liquid at a proportion of 10% with respect to the total amount of the 2% Nital liquid, thereby preparing a post-treatment liquid. The cross section parallel to the rolling direction (that is, the cross section parallel to the rolling direction and perpendicular to the surface) is immersed in the pretreatment solution for 3 to 15 seconds, washed with an alcohol, dried, then, immersed in the post-treatment solution for 3 to 20 seconds, then, washed with water, and dried, thereby corroding the cross section.

[0061] Next, as shown in FIG. 1, at a position at a depth of 1/4 of the sheet thickness from the surface (rolled surface 11) of the steel sheet 1 and at the center in the width direction WD, at least three 40 μm $\times$ 30 μm regions are observed at a magnification of 1000 to 100,000 times using a scanning electron microscope, thereby identifying the metallographic structure, confirming the presence positions, and measuring the area fractions. In any case where the measurement object is a steel sheet that does not undergo any special machining after manufactured (in other words, a steel sheet that is not cut from a coil) or a steel sheet that is cut from a coil, the width direction central position is a position that is substantially equidistant from both ends of the steel sheet 1 in the width direction WD.

[0062] In addition, it is difficult to distinguish lower bainite and tempered martensite by the above-described measuring method. Therefore, in the present embodiment, there is no need to distinguish both. That is, the total area fraction of

"bainite and tempered martensite" is obtained by measuring the area fractions of "upper bainite" and "lower bainite or tempered martensite". Upper bainite is an aggregate of laths and a structure containing a carbide between the laths. Lower bainite is a structure containing iron-based carbides having major axes of 5 nm or more and extending in the same direction. Tempered martensite is an aggregate of lath-shaped crystal grains and a structure containing iron-based carbides having major axes of 5 nm or more and extending in different directions.

[0063] Ferrite is a region in which the brightness is low and no sub-microstructure is observable. A region in which the brightness is high and a sub-microstructure is not exposed by etching is determined as fresh martensite or residual austenite. Therefore, the area fraction of fresh martensite can be obtained as a difference between the area fraction of a non-corroded region that is observed with FE-SEM and the area fraction of residual austenite measured with X-rays described below.

[0064] Pearlite means a region in which planar cementite and planar ferrite are alternately arranged. In the observation with an FE-SEM, it is possible to clearly distinguish pearlite and the above-described structures (ferrite, bainitic ferrite, bainite, and tempered martensite).

[0065] As a method for measuring the area fraction of residual austenite, there are methods in which X-ray diffraction, electron back scattering diffraction pattern (EBSP) analysis, or magnetic measurement is used, and there are cases where measurement values vary with measurement methods. In the present embodiment, the area fraction of residual austenite is measured by X-ray diffraction. In the measurement of the area fraction of residual austenite by X-ray diffraction in the present embodiment, first, in a cross section parallel to the rolling direction (that is, a cross section parallel to the rolling direction and at a right angle with respect to the surface) at the 1/4 depth position of the sheet thickness of the steel sheet, the integrated intensities of a total of six peaks of $\alpha(110)$, $\alpha(200)$, $\alpha(211)$, $\gamma(111)$, $\gamma(200)$, and $\gamma(220)$ are obtained using Co-Kα rays, and then the area fraction of residual austenite is obtained by calculation using the strength averaging method.

(In range of 1/8 thickness to 3/8 thickness, number proportion of residual austenite having aspect ratio of 2.0 or more in all residual austenite being 50% or more)

[0066] Building the microstructural morphology of residual austenite in a planar shape contributes to improvement in elongation, hole expansibility, and bendability and is one of the important structure building points in the present invention. Forming residual austenite into a planar shape has an effect of suppressing the distribution of strain into austenite during forming and appropriately stabilizing residual austenite against plastic deformation, thereby improving elongation and hole expansibility. In the morphology of residual austenite having this effect, the aspect ratio is 2.0 or more.

[0067] In order to obtain this effect, in a range of a 1/8 thickness to a 3/8 thickness, the number proportion of residual austenite having an aspect ratio of 2.0 or more needs to be 50% or more with respect to all residual austenite. Therefore, the number proportion is set to 50% or more and preferably set to 70% or more. When the number proportion is less than 50%, it becomes difficult to satisfy all of excellent elongation, excellent hole expansibility, and excellent bendability, which is not preferable.

[0068] The aspect ratios and major axes of residual austenite grains that are included in the steel structure inside the steel sheet are evaluated by observing the crystal grains using an FE-SEM and carrying out high-resolution crystal orientation analysis by the electron back scattering diffraction method (EBSD method).

[0069] First, as shown in FIG. 2, a cross section parallel to the rolling direction and the thickness direction of the steel sheet is regarded as an observed section 13 and collected as a sample, and the observed section is finished to a mirror surface by polishing. Next, in one or a plurality of observed visual fields in a range 131 from a 1/8 thickness to a 3/8 thickness that is centered at the position of a 1/4 thickness from the surface (rolled surface) 11 in the observed section 13, the crystal structure is analyzed by the EBSD method for an area of a total of 2.0×10^{-9} m^2 or more (possibly in any of a plurality of visual fields or the same visual field). Next, in order to avoid a measurement error, only austenite having a major axis length of 0.1 μm or more is extracted from the crystal orientation of the residual austenite grains measured by the above-described method, and a crystal orientation map is drawn. A boundary from which a crystal orientation difference of 10° or more is generated is regarded as a crystal grain boundary between the residual austenite grains. The aspect ratio is defined as a value obtained by dividing the major axis length of a residual austenite grain by the minor axis length. The major axis is defined as the major axis length of a residual austenite grain. In the measurement, "OIM Analysis 6.0" manufactured by TSL Solutions is used for the analysis of data obtained by the EBSD method. In addition, the distance between evaluation points (step) is set to 0.01 to 0.20 μm. From the observation results, a region that is determined as FCC iron is defined as residual austenite. From this result, the number proportion of residual austenite having an aspect ratio of 2.0 or more in all residual austenite in the range of a 1/8 thickness to a 3/8 thickness is obtained.

(At sheet thickness 1/4 position of cross section parallel to rolling direction and perpendicular to surface, standard deviation of area ratios of ferrite being less than 10% when measured at 10 points every 50 mm in width direction)

[0070] In the present invention, ferrite is important in order to secure elongation and hole expansibility. Incidentally, strength, elongation, or hole expansibility changes depending on the microstructural fraction of ferrite. Therefore, it is important for the microstructure fraction of ferrite to be uniformly distributed in the hot rolling width direction in terms of obtaining material quality stability.

[0071] When the area ratio of ferrite at the sheet thickness 1/4 position 121 of a cross section parallel to the rolling direction (that is, the cross section 12 parallel to the rolling direction and perpendicular to the surface) is measured at 10 points every 50 mm along the width direction (that is, a direction at a right angle with respect to the rolling direction RD) WD as shown in FIG. 3, if the standard deviation of the area ratios of ferrite is 10% or more, a variation in mechanical properties is caused, and material quality stability cannot be obtained. Therefore, the above-described standard deviation of the area ratio of ferrite is set to less than 10% and is preferably 8% or less, less than 5%, or 4% or less. When the size of the steel sheet, which is a future measurement object, along the width direction is sufficiently large, the measurement points for the standard deviation of the area ratios of ferrite may be disposed on one straight line along the width direction. On the other hand, when the size of the steel sheet, which is a future measurement object, along the width direction is less than 450 mm, the measurement points for the standard deviation of the area ratios of ferrite may be disposed on two or more straight lines along the width direction. At the time of measuring the standard deviation in the width direction of characteristics other than ferrite (for example, surface roughness and the like), the measurement points can be disposed as described above.

3. Standard deviation of surface roughness Ra

(Standard deviation of surface roughness Ra measured at 10 points every 50 mm along width direction being preferably 0.5 μm or less)

[0072] The steel sheet according to the present embodiment is not particularly limited as long as the chemical composition, the metallographic structure, and the tensile strength described below are within predetermined ranges. When the surface roughness Ra of the rolled surface 11 is measured at 10 points every 50 mm along the width direction (that is, a direction at a right angle with respect to the rolling direction), the standard deviation of the surface roughness Ra may be set to 0.5 μm or less. When a variation in the surface roughness Ra is suppressed, it is possible to suppress a variation in bending workability and to further enhance material quality stability. Therefore, the standard deviation is preferably set to 0.5 μm or less. Here, the surface roughness of the steel sheet can be changed at will by additional processing. For example, after a high strength steel sheet having excellent material quality stability is manufactured by a preferable manufacturing method described below, processing for changing the surface roughness such as hairline processing may be carried out on this high strength steel sheet. From this viewpoint as well, setting the standard deviation of the surface roughness Ra within the above-described range is not essential.

[0073] For the surface roughness Ra, a roughness curve that is 5 mm long in the width direction is acquired at each measurement position using a contact type roughness meter (SURFTEST SJ-500 manufactured by Mitutoyo Corporation), and the arithmetic average roughness Ra is obtained by the method described in JIS B0601: 2001. The standard deviation of the surface roughness Ra is obtained using the value of the arithmetic average roughness Ra at each measurement position obtained as described above.

[0074] In addition, in a case where a surface treatment membrane such as a plating or a coating is disposed on the surface of the steel sheet, the "surface roughness Ra of the steel sheet" means the surface roughness that is measured after removing the surface treatment membrane from the steel sheet. That is, the surface roughness Ra of the steel sheet is the surface roughness of the base metal. The method for removing the surface treatment membrane can be appropriately selected according to the type of the surface treatment membrane to an extent that the surface roughness of the base metal is not affected. For example, in a case where the surface treatment membrane is a zinc plating, it is necessary to dissolve the galvanized layer using dilute hydrochloric acid to which an inhibitor is added. This makes it possible to exfoliate only the galvanized layer from the steel sheet. The inhibitor is an additive that is used to suppress a change in roughness attributed to the prevention of the excessive dissolution of the base metal. For example, a substance obtained by adding a corrosion inhibitor for hydrochloric acid pickling "IBIT No. 700BK" manufactured by Asahi Chemical Co., Ltd. to hydrochloric acid diluted 10 to 100 times such that the concentration reaches 0.6 g/L can be used as exfoliation means for the galvanized layer.

4. Mechanical properties

(Tensile Strength TS: 780 MPa or more)

[0075] The high strength steel sheet according to the present embodiment has, as a sufficient strength that contributes to the weight reduction of vehicles, a tensile strength (TS) of 780 MPa or more. The tensile strength of the steel sheet may be 800 MPa or more, 900 MPa or more, or 1000 MPa or more. Meanwhile, it is assumed that it is difficult to obtain a tensile strength of more than 1470 MPa with the configuration of the present embodiment. Therefore, it is not necessary to particularly specify the upper limit of the tensile strength, but the substantial upper limit of the tensile strength in the present embodiment can be set to 1470 MPa. In addition, the tensile strength of the steel sheet may be set to 1400 MPa or less, 1300 MPa or less, or 1200 MPa or less.

[0076] A tensile test may be carried out in the following order in accordance with JIS Z 2241 (2011). JIS No. 5 test pieces are collected from 10 positions in the high strength steel sheet at intervals of 50 mm in the width direction. Here, the width direction of the steel sheet and the longitudinal direction of the test pieces are made to coincide with each other. In addition, individual test pieces are collected at positions shifted in the rolling direction of the steel sheet such that the collection positions of the individual test pieces do not interfere with each other. Tensile tests are carried out on these test pieces in accordance with the regulations of JIS Z 2241 (2011), tensile strengths TS (MPa) are obtained, and the average value thereof is calculated. This average value is regarded as the tensile strength of the high strength steel sheet.

[0077] In addition, the high strength steel sheet according to the present embodiment may have the following characteristics in terms of elongation and hole expansibility as an index of formability. These mechanical properties are obtained due to a variety of properties of the high strength steel sheet according to the present embodiment described above.

(Total elongation EL)

[0078] The high strength steel sheet according to the present embodiment may have a total elongation of 14% or more in the tensile test as an index of elongation. Meanwhile, it is difficult to obtain a total elongation of more than 35% with the configuration of the present embodiment. Therefore, the substantial upper limit of the total elongation may be set to 35%.

(Hole expansibility)

[0079] The high strength steel sheet according to the present embodiment may have a hole expansion rate of 25% or more as an index of hole expansibility. Meanwhile, it is difficult to obtain a hole expansion rate of more than 80% with the configuration of the present embodiment. Therefore, the substantial upper limit of the hole expansion rate may be set to 80%.

[0080] The hole expansion rate can be evaluated by a hole expansion test in accordance with the test method described in the Japan Iron and Steel Federation Standard JFS T 1001-1996.

(Bendability)

[0081] In the case of using a value R/t obtained by dividing the limit bend radius R (mm) by the sheet thickness t (mm) as an index of bendability, the high strength steel sheet according to the present embodiment may have R/t of 2.0 or less. Meanwhile, it is difficult to set the index R/t of the bendability to 0.1 or less with the configuration of the present embodiment. Therefore, the substantial lower limit of the index R/t of the bendability may be set to 0.1.

[0082] The limit bend radius R is obtained by repeatedly carrying out bending tests to which a variety of bend radii are applied. In the bending test, bending is carried out in accordance with JIS Z 2248 (V block 90° bending test). The bend radius (to be exact, the inner radius of bending) changes at pitches of 0.5 mm. As the bend radius in the bending test decreases, cracks and other defects are more likely to be generated in the steel sheet. The minimum bending at which cracks and other defects are not generated in the steel sheet, which has been obtained in this test, is regarded as the limit bend radius R. In addition, a value obtained by dividing this limit bend radius R by the thickness t of the steel sheet is used as the index R/t for evaluating the bendability.

[0083] In the high strength steel sheet according to the present embodiment, as an index of the material quality being stable, among tensile test results measured at 10 points every 50 mm along the width direction (that is, a direction at a right angle with respect to the rolling direction), the standard deviation of TS may be 50 MPa or less, and the standard deviation of EL may be 1% or less. The method for obtaining the TS standard deviation and the EL standard deviation is the same as the above-described tensile test method for obtaining the average value of the tensile strengths. The TS

standard deviation and the EL standard deviation can be obtained by obtaining the standard deviation of the results of 10 tensile tests by the above-described method.

[0084] In addition, in the high strength steel sheet according to the present embodiment, the standard deviation of R/t (limit bend radius R (mm), sheet thickness t (mm)) measured at 10 points every 50 mm along the width direction may be set to 0.2 or less.

5. Manufacturing method

[0085] Next, an example of a preferred method for manufacturing the high strength steel sheet according to the present embodiment will be described. However, it should be noted that the method for manufacturing the high strength steel sheet according to the present embodiment is not particularly limited. Any steel sheet that satisfies the above-described requirements is regarded as the steel sheet according to the present embodiment regardless of manufacturing methods therefor.

[0086] A manufacturing step preceding hot rolling is not particularly limited. That is, subsequent to melting with a blast furnace, an electric furnace, or the like, a variety of secondary smelting is carried out, and then casting may be carried out by a method such as ordinary continuous casting, casting by an ingot method, or thin slab casting. In the case of the continuous casting, a cast slab may be hot-rolled after being once cooled to a low temperature and then heated again or the cast slab may be hot-rolled as it is after being cast without being cooled to a low temperature. Scrap may be used as a raw material.

[0087] A heating step is carried out on the cast slab. In this heating step, the slab is preferably heated to a temperature of 1100°C or higher and 1300°C or lower. Since there is a possibility that a coarse precipitate precipitated in the slab (an iron-based carbide, a carbonitride of an alloying element, or the like) impairs material quality stability, the slab is preferably heated to 1100°C or higher in order to dissolve the coarse precipitate. On the other hand, from the viewpoint of preventing a scale loss, the slab heating temperature is preferably 1300°C or lower.

[0088] Next, a rough rolling step of rough-rolling the heated slab to produce a rough rolled sheet is carried out.

[0089] In the rough rolling, conditions therefor are not particularly limited as long as the slab is made into a desired dimension and a desired shape. The thickness of the rough rolled sheet affects the amount of the temperature lowered from the tip to the tail of the hot-rolled steel sheet during the beginning of the rolling to the completion of the rolling in a finish rolling step and is thus preferably determined in consideration of such a fact.

[0090] Finish rolling is carried out on the rough rolled sheet. In this finish rolling step, multi-stage finish rolling is carried out. In the present embodiment, finish rolling is carried out within a temperature range of 850°C to 1200°C under conditions that satisfy the following formula (1).

$$K'/Si^{*} \geq 2.5 \quad \cdots \quad (1)$$

[0091] Here, when $Si \geq 0.35$, Si^{*} is set to $140\sqrt{Si}$, and, when $Si < 0.35$, Si^{*} is set to 80. Si represents the Si content (mass%) of the steel sheet.

[0092] In addition, K' in the formula (1) is represented by the following formula (2).

$$K' = D \times (DT - 930) \times 1.5 + \Sigma((FT_n - 930) \times S_n) \quad \cdots \quad (2)$$

[0093] Here, D is the amount sprayed per hour (m^3/min) of hydraulic descaling before the start of the finish rolling, DT is the steel sheet temperature (°C) at the time of the hydraulic descaling before the start of the finish rolling, FT_n is the steel sheet temperature (°C) in the n^{th} stage of the finish rolling, and S_n is the amount sprayed per hour (m^3/min) at the time of spraying water to the steel sheet on spray between the $n\text{-}1^{th}$ stage and the n^{th} stage of the finish rolling.

[0094] Si^{*} is a parameter relating to a steel sheet component that indicates the easiness in the generation of unevenness attributed to scale. When the amount of Si in a steel sheet component is large, scale that is generated on the surface layer during hot rolling changes from wustite (FeO) to fayalite (Fe_2SiO_4), in which the wustite is relatively easily descaled and is unlikely to produce unevenness on the steel sheet and the fayalite grows so as to lay down roots in the steel sheet and is likely to produce unevenness. Therefore, as the amount of Si increases, that is, as the Si^{*} increases, unevenness on the surface layer is more likely to be formed. Here, the addition of Si to facilitate the formation of unevenness on the surface layer becomes significantly effective particularly when 0.35 mass% or more of Si is added. Therefore, when 0.35 mass% or more of Si is added, Si^{*} acts as a function of Si; however, when 0.35 mass% or less of Si is added, Si^{*} acts as a constant.

[0095] K' is a parameter of a manufacturing condition that indicates the difficulty in forming unevenness. The first item of the formula (2) indicates that, when hydraulic descaling is carried out before the start of the finish rolling in order to

suppress the formation of unevenness, as the amount sprayed per hour of the hydraulic descaling increases and as the steel sheet temperature increases, the hydraulic descaling becomes more effective from the viewpoint of descaling. When a plurality of times of descaling is carried out before the start of the finish rolling, the value of descaling that is closest to the finish rolling is used.

[0096] The second item of the formula (2) is an item that indicates the effect of descaling, during finish rolling, scale that has not been completely exfoliated by descaling before finishing or scale that is formed again during the finish rolling and indicates that spraying a large amount of water onto spray to the steel sheet at high temperatures facilitates descaling.

[0097] When the ratio of the parameter K' of the manufacturing condition that indicates the difficulty in forming unevenness to the parameter Si* relating to the steel sheet component that indicates the easiness in forming a scale flaw portion is 2.5 or more or 2.50 or more, it is possible to sufficiently suppress unevenness and to suppress a temperature variation during tempering. Therefore, K'/Si* is set to 2.5 or more, preferably 3.0 or more, and more preferably 3.5 or more.

[0098] In order to set the standard deviation of the surface roughness Ra measured at 10 positions at intervals of 50 mm in the width direction (that is, a direction at a right angle with respect to the rolling direction) to 0.5 μm or less, which is a preferable form of the steel sheet relating to the present invention, K'/Si* is preferably set to 3.0 or more (K'/Si* ≥ 3.0).

[0099] Following the finish rolling, cooling is carried out at an average cooling rate of 50 °C/s or faster, and coiling is carried out at a coiling temperature of 450°C or lower. This is because the morphology of residual γ after annealing is controlled by including bainite and martensite, which are low temperature transformation structures, as the main structures as described above. Here, the average cooling rate is a value obtained by dividing the difference in temperature between the start of the cooling and before the coiling by the time therebetween. When the average cooling rate is slower than 50 °C/s, ferritic transformation occurs, the control of the microstructural morphology in the subsequent annealing step is impaired, and it is not possible to control the number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to the number of all residual austenite to be 50% or more.

[0100] Similarly, when the coiling temperature is higher than 450°C, ferritic transformation occurs, and, similarly, it becomes difficult to set the total of bainite and tempered martensite to 20% or more of all structures. In addition, when the coiling temperature is higher than 450°C, it is not possible to control the number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to all residual austenite to be 50% or more. From this viewpoint, the coiling temperature is set to 450°C or lower, preferably set to 400°C or lower, and more preferably set to 200°C or lower. In addition, setting the coiling temperature to 450°C or lower also has an effect of suppressing the formation of an internal oxide on the surface of the steel sheet after the coiling and an increase in the roughness of the surface layer.

[0101] Pickling is carried out on the high strength steel sheet manufactured in this manner for the purpose of removing an oxide on the surface of the steel sheet. The pickling may be carried out, for example, with hydrochloric acid having a concentration of 3% to 10% at a temperature of 85°C to 98°C for 20 seconds to 100 seconds.

[0102] In addition, soft reduction with a rolling reduction of 20% or smaller may be carried out on the manufactured hot-rolled steel sheet for the purpose of shape correction. However, when the rolling reduction of the soft reduction becomes larger than 20%, recrystallization occurs in an annealing process, and it becomes impossible to obtain the effect of the morphology control that can be obtained from the low temperature transformation structure during annealing, and thus the rolling reduction is set to 20% or smaller even in a case where soft reduction is carried out. The soft reduction may be carried out before the pickling or carried out after the pickling. The soft reduction being carried out after the pickling has an effect of further reducing the roughness of the surface layer. In order to satisfy the standard deviation of the surface roughness Ra of 0.5 μm or less when the surface roughness Ra is measured at 10 positions at intervals of 50 mm in the width direction (that is, a direction at a right angle with respect to the rolling direction), which is a preferable form in the present invention, it is necessary to carry out the soft reduction after the pickling.

[0103] An annealing treatment is carried out on the obtained steel sheet.

[0104] In the annealing step, the heating temperature is set to A_{c1} point to A_{c3} point - 10°C that is calculated by the following formula.

$$A_{c1} = 723 - 10.7 \times Mn - 16.9 \times Ni + 29.1 \times Si + 16.9 \times Cr$$

$$A_{c3} = 879 - 346 \times C + 65 \times Si - 18 \times Mn + 54 \times Al \quad \cdots \quad (9)$$

[0105] During the heating, ferrite-austenite transformation occurs from a carbide formed between the laths of the low temperature transformation structure, and planar austenite is generated. A region that has not undergone austenitic transformation can also be considered as a low temperature transformation structure that has been tempered at high temperatures (tempered martensite or tempered bainite). However, since the dislocation density is significantly reduced by tempering, and the sub-microstructure is also not clear, the region is a region that is evaluated as ferrite in the structural observation after annealing. Therefore, here, the region will be referred to as ferrite. A region that is evaluated as tempered martensite or bainite in the structural observation after annealing mainly refers to a region generated by the

bainitic transformation or martensitic transformation of austenite formed by heating during the retention of the austenite at 150°C to 550°C, which will be described below.

[0106] The reason for the heating temperature being set to A_{c1} point to A_{c3} point - 10°C is that an appropriate ferrite-austenite transformation fraction is set in order to set the area ratio of ferrite to 20% to 70%. The heating time is set to 10 seconds to 1000 seconds. When the retention time is shorter than one second, cementite remains undissolved in steel and there is a concern that the properties of the steel sheet may deteriorate. When the retention time is longer than 1000 seconds, this effect is saturated, the productivity deteriorates, and thus the upper limit of the retention time is set to 1000 seconds.

[0107] After that, the steel sheet is retained at 150°C to 550°C for 10 seconds to 1000 seconds.

[0108] In this temperature range, some of austenite is caused to undergo bainitic transformation or martensitic transformation, and solid solution carbon is emitted to austenite along with the bainitic transformation or solid solution carbon is emitted to austenite along with the tempering of martensite, thereby stabilizing austenite. When the steel sheet is retained at 150°C or lower, the majority of austenite undergoes martensitic transformation, and a sufficient amount of residual austenite cannot be obtained. On the other hand, when the steel sheet is retained at 550°C or higher, pearlitic transformation occurs, and it is not possible to sufficiently stabilize residual austenite. When the retention time is shorter than 10 seconds, carbon does not sufficiently diffuses, and it is not possible to sufficiently stabilize residual austenite. When the retention time is longer than 1000 seconds, the effect of stabilizing residual austenite is saturated, and the productivity deteriorates.

[0109] While the steel sheet is retained in the temperature range, the steel sheet may be heated or cooled in this temperature range. For example, when the steel sheet is once cooled to a temperature range of 250°C or lower to transform some of residual austenite into martensite and then reheated to a temperature range of approximately 400°C, martensite acts as a nucleation site of bainitic transformation, and an effect of accelerating bainitic transformation is obtained.

[0110] In addition, hot-dip galvanizing or hot-dip galvannealing may be carried out in this temperature range. As plating conditions such as the hot-dip galvanizing bath temperature and the hot-dip galvanizing bath composition in the hot-dip galvanizing step, ordinary conditions can be used, and there is no particular limitation. For example, the plating bath temperature may be 420°C to 500°C, the intrusion sheet temperature of the steel sheet may be 420°C to 500°C, and the immersion time may be five seconds or shorter. The plating bath is preferably a plating bath containing 0.08% to 0.2% of Al and may additionally contain Fe, Si, Mg, Mn, Cr, Ti, Pb, or the like, which is an impurity. In addition, the basis weight of hot-dip galvanizing is preferably controlled by a well-known method such as gas wiping. The basis weight may be 5 g/m^2 or more per surface, and is preferably set to 25 to 75 g/m^2 and more preferably set to 20 to 120 g/m^2.

[0111] In a case where an alloying treatment is carried out, the alloying treatment may be carried out according to a normal method, but the alloying treatment temperature is preferably set to 460°C to 550°C. When the alloying treatment is lower than 460°C, since the alloying rate becomes slower, the productivity is impaired, and an unevenness is also caused in the alloying treatment, the alloying treatment temperature is preferably set to 460°C or higher. On the other hand, when the alloying treatment temperature exceeds 550°C, pearlitic transformation occurs, and it is not possible to sufficiently stabilize residual austenite.

[0112] In addition, the alloying treatment is preferably carried out under conditions that the iron concentration in a hot-dip galvanized layer reaches 6.0 mass% or more.

[0113] In a case where hot-dip galvanizing or hot-dip galvannealing is not carried out, an electrogalvanized layer may be formed on the steel sheet manufactured as described above. The electrogalvanized layer can be formed by a well-known conventional method.

[0114] The high strength steel sheet according to the present embodiment can be manufactured by the above-described manufacturing method.

[Examples]

[0115] Hereinafter, the high strength steel sheet according to the present invention will be described more specifically with reference to examples. Here, the following examples are examples of the high strength steel sheet of the present invention, and the high strength steel sheet of the present invention is not limited to the following aspects. Conditions in examples to be described below are exemplary conditions adopted to confirm the feasibility and effects of the present invention, and the present invention is not limited to these exemplary conditions. The present invention is capable of adopting a variety of conditions within the scope of the gist of the present invention as long as the object of the present invention is achieved.

[0116] Steels having chemical compositions shown in Table 1 were cast, after the casting, slabs were heated to a temperature range of 1200°C to 1350°C as they were or after being once cooled to room temperature and then retained, and then the slabs were rough-rolled at temperatures of 1100°C or higher, thereby producing rough-rolled steel sheets. In Table 1, values outside the scope of the invention are underlined.

[Table 1]

Steel material	Chemical composition (Unit: mass%, remainder is Fe and impurities)									A_{c1} (°C)	A_{c3} (°C)	Category
	C	Si	Mn	sol.Al	P	S	N	O	Others			
A	0.220	1.02	2.59	0.100	0.009	0.0010	0.00400	0.0010		725	828	Invention steel
B	0.220	1.49	2.60	0.080	0.009	0.0020	0.01000	0.0010		739	857	Invention steel
C	0.200	1.51	2.21	0.090	0.074	0.0030	0.00300	0.0010	B:0.002	743	873	Invention steel
D	0.220	1.52	2.00	0.050	0.029	0.0010	0.01000	0.0010	Cr:0.5	754	868	Invention steel
E	0.220	1.50	2.22	0.050	0.022	0.0020	0.00800	0.0010	Cu:0.2	743	863	Invention steel
F	0.260	1.01	2.60	0.060	0.046	0.0050	0.00800	0.0010	Ca:0.005	725	811	Invention steel
G	0.240	0.69	2.60	0.020	0.026	0.0030	0.00800	0.0010		715	795	Invention steel
H	0.220	0.59	2.59	0.700	0.007	0.0020	0.01000	0.0010		712	832	Invention steel
I	0.220	0.40	2.49	0.100	0.014	0.0030	0.00500	0.0010		708	789	Comparative steel
J	0.140	1.80	3.00	0.100	0.009	0.0010	0.00400	0.0010		725	828	Invention steel
K	0.220	0.99	2.58	0.100	0.009	0.0010	0.00400	0.0010	Ti:0.02 Nb:0.02 V:0.02	724	826	Invention steel
L	0.210	1.00	2.60	0.100	0.009	0.0010	0.00400	0.0010	Mo:0.1 Co:0.1 W:0.1 Ni:0.05 Mg:0.005 REM0.002 Zr:0.002	724	830	Invention steel

[0117] On the rough rolled sheets, multi-stage finish rolling including a total of seven stages was carried out under conditions shown in Table 2.

[0118] After that, cooling and coiling after finish rolling were carried out under individual conditions shown in Table 3.

[0119] After that, pickling was carried out for all conditions; however, for some of the conditions, soft reduction was carried out in a step before or after the pickling. After that, the steel sheets were heated up to heating temperatures shown in Table 3 with heating rates of 30 °C/s to 150 °C/s. After the heating, the steel sheets were retained at the heating temperatures for times shown in Table 3. After that, under a condition A, a steel sheet was cooled to 250°C at 50 to 100 °C/s, reheated to 400°C, and then retained for 300 seconds. Under a condition B, a steel sheet was cooled to 360°C at 50 to 100 °C/s and retained for 50 seconds. Under a condition C, which is a comparative example, a steel sheet was cooled to 100°C at 100 °C/s and retained for 300 seconds.

[0120] After that, for some of the conditions, hot-dip galvannealing or hot-dip galvanizing was carried out. In the plating step, the steel sheets were in a temperature range of 400°C to 520°C.

[Table 2]

Remarks	No.	Steel type	Thickness (mm)	Amount of Si (%)	Steel sheet temperature (°C) in n^{th} stage of finish rolling							Amount sprayed during hydraulic descaling (m^3/min)							
					FT_1	FT_2	FT_3	FT_4	FT_5	FT_6	FT_7	Before finish rolling	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Example	1	A	1.2	1.02	1005	996	986	977	968	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Example	2	A	1.0	1.02	1066	1047	1028	1009	989	970	951	1	0.4	0	1.2	0	0	0	2.4
Example	3	A	1.6	1.02	1065	1046	1027	1008	988	969	950	1	0.4	0	1.2	0	0	0	2.4
Example	4	A	2.0	1.02	1067	1048	1029	1009	990	971	952	1	0.4	0	1.2	0	0	0	2.4
Example	5	A	2.4	1.02	1064	1045	1026	1006	987	968	949	1	0.4	0	1.2	0	0	0	2.4
Example	6	A	1.2	1.02	1067	1048	1028	1009	990	971	952	1	0.4	0	0	1	0	0	2.4
Example	7	A	2.8	1.02	1068	1048	1029	1010	991	972	953	1	0.4	0	1.2	0	0	0	2.4
Example	8	A	3.5	1.02	1064	1045	1026	1007	988	969	949	1	0.4	0	1.2	0	0	0	2.4
Comparative example	9	A	1.2	1.02	1009	1000	991	981	972	963	954	0	0.4	1	2.4	0	0	0.5	2.4
Comparative example	10	A	1.2	1.02	997	988	978	970	963	953	950	1	0.4	1	0	0	1	1.5	2.4
Comparative example	11	A	2.0	1.02	1008	998	989	980	971	962	953	1	0.4	1	2.4	1	0	1.5	2.4
Comparative example	12	A	2.0	1.02	1007	998	988	979	970	961	952	1	0.4	1	2.4	1	0	1.5	2.4
Comparative example	13	A	2.0	1.02	1009	1000	991	981	972	963	954	1	0.4	1	2.4	1	0	1.5	2.4
Comparative example	14	A	2.0	1.02	1005	996	987	978	968	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Example	15	A	2.0	1.02	1005	996	987	978	969	960	950	1	0.4	1	2.4	1	0	1.5	2.4
Comparative example	16	A	2.0	1.02	1007	998	988	979	970	961	952	1	0.4	1	2.4	1	0	1.5	2.4
Example	17	B	2.0	1.49	1006	997	987	978	969	960	951	1	0.4	1	2.4	1	0	1.5	2.4
Example	18	B	2.4	1.49	1066	1047	1028	1009	989	970	951	1	0.4	1	1.2	0	0	0	2.4
Example	19	C	2.0	1.51	1009	1000	991	982	973	964	954	1	0.4	1	2.4	1	0	1.5	2.4
Example	20	C	2.4	1.51	1065	1046	1027	1008	989	969	950	2	0.4	0	1.2	0	1	0	2.4
Example	21	D	2.0	1.52	1005	996	987	978	969	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Example	22	D	2.4	1.52	1067	1048	1028	1009	990	971	952	1	0.4	1	1.2	0	1	0	2.4
Example	23	E	2.0	1.50	1005	996	987	977	968	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Example	24	E	2.4	1.50	1065	1046	1026	1007	988	969	950	1	0.4	1	1.2	0	1	0	2.4
Example	25	F	2.0	1.01	1008	998	989	980	971	962	953	1	0.4	1	2.4	1	0	1.5	2.4
Example	26	F	2.4	1.01	1063	1044	1025	1006	986	967	948	1	0.4	0	1.2	0	1	0	2.4
Example	27	G	2.0	0.69	1005	995	986	977	968	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Example	28	G	2.4	0.69	1065	1046	1027	1007	988	969	950	1	0.4	0	1.2	0	1	0	2.4
Example	29	H	2.0	0.59	1005	996	986	977	968	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Example	30	H	2.4	0.59	1066	1047	1028	1009	990	971	951	1	0.4	0	1.2	0	1	0	2.4
Comparative example	31	I	2.0	0.40	1005	996	987	978	969	959	950	1	0.4	1	2.4	1	0	1.5	2.4
Comparative example	32	I	2.4	0.40	1067	1048	1029	1010	990	971	952	1	0.4	0	1.2	0	1	0	2.4
Example	33	J	1.6	1.80	1064	1046	1028	1009	987	968	950	1	0.4	1	1.2	1	0.5	0.5	2.4
Example	34	K	1.6	0.99	1063	1045	1026	1008	987	967	950	1	0.4	0	1.2	0	0	0.5	2.4
Example	35	L	1.6	1.00	1066	1043	1027	1009	987	967	950	1	0.4	0	1.2	0	0	0.5	2.4

[Table 3]

Remarks	No.	Average cooling rate after finish rolling (°C/s)	Coiling temperature (°C)	Soft reduction ratio (%)	Timing of soft reduction	Heating temperature (°C)	Heating time (sec)	Retention pattern	Type of plating
Examples	1	100	≤100	5	After pickling	752	100	A	Hot-dip galvannealing
Examples	2	100	≤100	5	After pickling	751	100	A	No plating
Examples	3	60	≤100	5	After pickling	748	100	A	Hot-dip galvannealing
Examples	4	100	430	5	After pickling	752	100	A	Hot-dip galvannealing
Examples	5	100	≤100	0	-	751	100	A	Hot-dip galvanizing
Examples	6	100	≤100	10	After pickling	750	100	A	Hot-dip galvannealing
Examples	7	100	≤100	5	Before pickling	749	100	A	Hot-dip galvannealing
Examples	8	100	≤100	10	Before pickling	752	100	A	No plating
Comparative examples	9	100	≤100	5	After pickling	750	100	A	Hot-dip galvannealing
Comparative examples	10	100	≤100	5	After pickling	750	100	A	Hot-dip galvannealing
Comparative examples	11	30	≤100	5	After pickling	749	100	A	Hot-dip galvannealing
Comparative examples	12	100	500	5	After pickling	750	100	A	Hot-dip galvannealing
Comparative examples	13	100	≤100	5	After pickling	700	100	A	Hot-dip galvannealing
Comparative examples	14	100	≤100	30	After pickling	748	100	A	Hot-dip galvannealing
Examples	15	100	≤100	5	After pickling	750	100	B	Hot-dip galvannealing
Comparative examples	16	100	≤100	5	After pickling	752	100	C	Hot-dip galvannealing
Examples	17	100	≤100	5	After pickling	772	100	A	Hot-dip galvannealing
Examples	18	100	≤100	0	-	772	100	A	No plating
Examples	19	100	≤100	5	After pickling	790	100	A	Hot-dip galvannealing
Examples	20	100	≤100	0	-	791	100	A	Hot-dip galvannealing
Examples	21	100	≤100	5	After pickling	771	100	A	Hot-dip galvannealing
Examples	22	100	≤100	0	-	768	100	A	Hot-dip galvannealing
Examples	23	100	≤100	5	After pickling	769	100	A	Hot-dip galvannealing
Examples	24	100	≤100	0	-	771	100	A	Hot-dip galvannealing
Examples	25	100	≤100	5	After pickling	768	100	A	Hot-dip galvannealing
Examples	26	100	≤100	0	-	768	100	A	Hot-dip galvannealing
Examples	27	100	≤100	5	After pickling	771	100	A	Hot-dip galvannealing
Examples	28	100	≤100	0	-	771	100	A	Hot-dip galvannealing
Examples	29	100	≤100	5	After pickling	770	100	A	Hot-dip galvannealing
Examples	30	100	≤100	0	-	768	100	A	Hot-dip galvannealing
Comparative examples	31	100	≤100	5	After pickling	768	100	A	Hot-dip galvannealing
Comparative examples	32	100	≤100	0	-	770	100	A	Hot-dip galvannealing
Examples	33	100	300	5	After pickling	749	100	A	Hot-dip galvannealing
Examples	34	100	300	5	After pickling	750	100	A	Hot-dip galvannealing
Examples	35	100	300	5	After pickling	750	100	A	Hot-dip galvannealing

[0121] The metallographic structures of the obtained high strength steel sheets were observed by the following method.

[0122] First, a cross section parallel to the rolling direction and perpendicular to the surface was corroded using a Nital reagent and a reagent disclosed in Japanese Unexamined Patent Application, First Publication No. S59-219473. Regarding the corrosion of the cross section, specifically, a solution prepared by dissolving 1 to 5 g of picric acid in 100 ml of ethanol was used as a solution A, a solution prepared by dissolving 1 to 25 g of sodium thiosulfate and 1 to 5 g of citric acid in 100 ml of water was used as a solution B, the solution A and the solution B were mixed at a proportion of 1:1 to prepare a liquid mixture, and nitric acid was further added and mixed at a proportion of 1.5% to 4% with respect to the total amount of this liquid mixture, thereby preparing a pretreatment liquid. In addition, the above-described pretreatment liquid was added to and mixed with a 2% Nital liquid at a proportion of 10% with respect to the total amount of the 2% Nital liquid, thereby preparing a post-treatment liquid. The cross section parallel to the rolling direction and perpendicular to the surface was immersed in the pretreatment solution for 3 to 15 seconds, washed with an alcohol, dried, then, immersed in the post-treatment solution for 3 to 20 seconds, then, washed with water, and dried, thereby corroding the cross section.

[0123] Next, at a position at a depth of 1/4 of the sheet thickness from the surface of the steel sheet and at the center in the width direction, at least three 40 μm $\times$ 30 μm regions were observed at a magnification of 1000 to 100,000 times using a scanning electron microscope, thereby identifying the metallographic structure, confirming the presence positions, and measuring the area fractions.

[0124] The total area fraction of "bainite and tempered martensite" was obtained by measuring the area fractions of "upper bainite" and "lower bainite or tempered martensite".

[0125] A region in which the brightness was low and no sub-microstructure was observed was determined as ferrite. A region in which the brightness was high and a sub-microstructure was not exposed by etching was determined as fresh martensite or residual austenite. The area fraction of fresh martensite was obtained as the difference between the area fraction of a non-corroded region that is observed with FE-SEM and the area fraction of residual austenite measured with X-rays.

[0126] In the observation with an FE-SEM, since pearlite could be clearly distinguished from pearlite, ferrite, bainitic ferrite, bainite, and tempered martensite, the area ratios were obtained by this method.

[0127] The area fraction of residual austenite was measured by X-ray diffraction. First, in a cross section parallel to the rolling direction and perpendicular to the surface at the 1/4 depth position of the sheet thickness of the steel sheet, the integrated intensities of a total of six peaks of α(110), α(200), α(211), γ(111), γ(200), and y(220) were obtained using Co-Kα rays, and the area fraction of residual austenite was obtained by calculation using the strength averaging method.

[0128] The aspect ratios and major axes of residual austenite grains that were included in the steel structure in the steel sheet were evaluated by observing the crystal grains using an FE-SEM and carrying out high-resolution crystal orientation analysis by the electron back scattering diffraction method (EBSD method).

[0129] First, a cross section parallel to the rolling direction and the thickness direction of the steel sheet was regarded as an observed section and collected as a sample, and the observed section was finished to a mirror surface by polishing. Next, in one or a plurality of observed visual fields in a range from a 1/8 thickness to a 3/8 thickness that was centered at the position of a 1/4 thickness from the surface in the observed section, the crystal structure was analyzed by the EBSD method for an area of a total of 2.0×10^{-9} m^2 or more (possibly in any of a plurality of visual fields or the same visual field). Next, in order to avoid a measurement error, only austenite having a major axis length of 0.1 μm or more was extracted from the crystal orientation of the residual austenite grains measured by the above-described method, and a crystal orientation map was drawn. A boundary from which a crystal orientation difference of 10° or more was generated was regarded as a crystal grain boundary between the residual austenite grains. The aspect ratio was defined as a value obtained by dividing the major axis length of a residual austenite grain by the minor axis length. The major axis was defined as the major axis length of a residual austenite grain. In the measurement, "OIM Analysis 6.0" manufactured by TSL Solutions was used for the analysis of data obtained by the EBSD method. In addition, the distance between evaluation points (step) was set to 0.01 to 0.20 μm. From the observation results, a region that was determined as FCC iron was defined as residual austenite. From this result, the number proportion of residual austenite having an aspect ratio of 2.0 or more in all residual austenite in the range of a 1/8 thickness to a 3/8 thickness was obtained.

[0130] The area ratio of ferrite at a sheet thickness 1/4 position of the cross section parallel to the rolling direction and perpendicular to the surface was obtained by the above-described method. The area ratios of ferrite were obtained by the same method at 10 points at intervals of 50 mm in the width direction, and the standard deviation of the area ratios was calculated.

[0131] The standard deviation of the surface roughness Ra that was measured at 10 positions at intervals of 50 mm in the width direction was obtained in the following order. A roughness curve that was 5 mm long in the width direction was acquired at each measurement position using a contact type roughness meter (SURFTEST SJ-500 manufactured by Mitutoyo Corporation), and the arithmetic average roughness Ra was obtained by the method described in JIS B0601: 2001. The standard deviation of the surface roughness Ra was obtained using the value of the arithmetic average roughness Ra at each measurement position obtained as described above.

[0132] Regarding the tensile strength, a tensile test was carried out in accordance with the regulations of JIS Z 2241

(2011) using a JIS No. 5 test piece collected from the high strength steel sheet in a manner that the width direction was along the longitudinal direction, and the tensile strength TS (MPa) and the butt elongation (total elongation) EL (%) were obtained. The samples were collected from 10 positions in the steel sheet at intervals of 50 mm in the width direction. The average value of the tensile strengths of the 10 test pieces was regarded as the tensile strength TS of the steel sheet, and, in a case where TS $\geq$ 780 MPa was satisfied, the steel sheet was determined as a high strength hot-rolled steel sheet and evaluated as pass.

[0133] In addition, the standard deviations of TS's and EL's at 10 positions at intervals of 50 mm in the width direction were obtained. A steel sheet having a standard deviation of TS of 50 MPa or less and a standard deviation of EL of 1% or less was determined as a steel sheet having excellent material quality stability.

[0134] The hole expansion rate was evaluated by a hole expansion test in accordance with the test method described in the Japan Iron and Steel Federation Standard JFS T 1001-1996.

[0135] A bending test was carried out in accordance with JIS Z 2248 (V block 90° bending test), and the bend R (mm) was tested at pitches of 0.5 mm.

[0136] In addition, R/t's were measured at 10 positions at intervals of 50 mm in the width direction, and the standard deviation thereof was obtained.

[Table 4]

Remarks	No.	Si*	K'	K'/Si*	Area ratio of ferrite (%)	Area ratio of residual austenite (%)	Area ratio of fresh martensite (%)	Area ratio of tempered martensite and bainite (%)	Area ratio of pearlite and cementite (%)	Proportion of residual austenite having aspect ratio of 2.0 or more (%)	Standard deviation of area ratios of ferrite (%)	Standard deviation of surface roughness Ra (μm)
Examples	1	141	500	3.5	50	13.2	1.8	32.6	2.4	79.6	2.4	0.3
Examples	2	141	426	3.0	50	13.8	1.8	34.3	0.0	76.3	2.2	0.3
Examples	3	141	421	3.0	53	14.3	4.3	27.2	1.6	70.7	3.7	0.3
Examples	4	141	431	3.1	49	10.5	3.7	36.1	1.0	63.8	2.4	0.3
Examples	5	141	415	2.9	54	15.7	2.0	27.0	1.7	73.8	5.6	0.8
Examples	6	141	391	2.8	53	15.0	1.6	29.9	0.5	70.6	2.1	0.1
Examples	7	141	435	3.1	53	15.4	3.7	26.6	0.9	72.4	5.6	0.8
Examples	8	141	417	2.9	49	16.9	3.7	27.8	2.8	68.3	5.4	0.7
Comparative examples	9	141	334	2.4	53	16.7	3.9	24.0	2.6	81.0	13.9	1.1
Comparative examples	10	141	309	2.2	49	13.4	2.0	35.2	0.7	82.9	12.8	10.0
Comparative examples	11	141	529	3.7	49	13.5	1.7	35.3	0.0	33.0	3.7	0.3
Comparative examples	12	141	519	3.7	51	13.4	1.5	32.0	1.6	33.2	3.9	0.2
Comparative examples	13	141	542	3.8	92	0	2.5	4.3	1.6	-	2.1	0.3
Comparative examples	14	141	502	3.6	52	12.7	3.1	29.9	1.9	16.9	4.0	0.2
Examples	15	141	505	3.6	51	13.4	9.4	23.7	2.7	73.7	2.1	0.3
Comparative examples	16	141	520	3.7	50	4.2	20.2	22.9	2.4	67.7	3.6	0.3
Examples	17	171	509	3.0	38	17.1	4.1	39.1	1.4	82.9	2.8	0.2
Examples	18	171	543	3.2	44	17.2	2.5	34.4	2.0	81.0	7.1	0.7
Examples	19	172	547	3.2	28	9.5	9.4	50.4	2.5	66.9	2.9	0.3
Examples	20	172	683	4.0	32	11.8	10.1	44.3	2.2	73.3	2.8	0.8
Examples	21	173	503	2.9	50	16.6	3.3	27.5	2.4	81.8	3.7	0.3
Examples	22	173	608	3.5	52	16.8	4.0	25.2	1.5	79.1	6.1	0.7
Examples	23	171	501	2.9	48	13.1	4.3	32.7	2.0	76.1	2.8	0.2
Examples	24	171	593	3.5	54	14.4	4.3	25.8	1.7	76.5	7.0	0.8
Examples	25	141	528	3.8	52	15.8	3.1	27.3	1.4	78.3	3.2	0.3
Examples	26	141	467	3.3	47	15.5	3.7	33.1	0.3	83.5	7.0	0.7
Examples	27	116	497	4.3	31	8.6	9.7	48.8	1.9	68.0	2.5	0.3
Examples	28	116	478	4.1	26	9.3	11.1	50.6	2.5	72.5	7.3	0.7
Examples	29	108	499	4.6	34	6.6	10.8	46.3	2.8	73.6	2.4	0.2
Examples	30	108	488	4.5	34	8.5	12.0	44.9	1.0	67.3	7.2	0.7
Comparative examples	31	89	504	5.7	28	2.3	11.5	56.4	2.3	66.4	2.2	0.3
Comparative examples	32	89	492	5.6	32	2.7	13.3	50.8	1.0	69.0	7.1	0.7
Examples	33	188	565	3.0	47	14.3	3.0	34.7	1.0	70.2	3.5	0.3
Examples	34	139	435	3.1	45	10.1	2.1	41.8	1.0	69.5	3.7	0.3
Examples	35	140	441	3.2	47	10.2	2.3	39.5	1.0	71.0	3.6	0.3

[Table 5]

Remarks	No.	Average tensile strength TS (MPa)	Standard deviation of TS (MPa)	Average total elongation EL (%)	Standard deviation of EL (%)	Hole expansibility λ (%)	Average limit bend radius R/t	standard deviation of R/t
Example	1	1015	5	24.5	0.2	40	0.5	0.1
Example	2	1020	6	23.6	0.3	40	0.5	0.1
Example	3	1024	5	23.1	0.2	35	0.5	0.1
Example	4	1020	6	24.4	0.2	30	0.5	0.1
Example	5	1026	30	24.7	0.9	41	0.5	0.3
Example	6	1015	4	25.0	0.3	39	0.5	0.3
Example	7	1023	20	23.7	0.6	39	0.5	0.3
Example	8	1022	25	24.7	0.7	40	0.5	0.3
Comparative example	9	1016	65	23.4	1.3	41	0.5	0.4
Comparative example	10	1023	55	24.0	1.3	39	0.5	0.4
Comparative example	11	1023	3	15.2	0.3	20	1.2	0.1
Comparative example	12	1017	5	15.7	0.3	20	1.2	0.1
Comparative example	13	747	3	20.4	0.2	41	0.5	0.1
Comparative example	14	986	4	16.9	0.3	20	1.2	0.1
Example	15	1035	5	21.8	0.3	31	1.0	0.1
Comparative example	16	1074	15	13.4	0.3	16	1.5	0.2
Example	17	1026	5	25.3	0.4	37	0.8	0.1
Example	18	1034	16	24.1	0.6	36	0.8	0.3
Example	19	1196	6	16.1	0.3	40	0.8	0.1
Example	20	1198	18	16.4	0.4	40	0.8	0.3
Example	21	1019	5	24.6	0.3	40	0.5	0.1
Example	22	1025	16	25.4	0.5	36	0.8	0.3
Example	23	1016	5	24.9	0.3	40	0.5	0.1
Example	24	1031	16	24.7	0.6	37	0.8	0.3
Example	25	1101	7	18.0	0.2	31	0.7	0.1
Example	26	1101	21	18.4	0.5	30	1.1	0.3
Example	27	1001	3	21.9	0.3	41	0.5	0.1
Example	28	996	15	22.6	0.6	41	0.5	0.3
Example	29	1006	3	22.0	0.5	40	0.5	0.1
Example	30	1004	15	22.0	0.7	40	0.5	0.3
Comparative example	31	997	4	12.7	0.3	22	0.5	0.1
Comparative example	32	1002	15	12.8	0.6	22	0.5	0.3
Example	33	983	6	25.3	0.3	35	0.5	0.1
Example	34	1036	5	21.3	0.3	33	0.5	0.1
Example	35	1043	6	22.1	0.2	32	0.5	0.1

[0137] In Table 4 and Table 5, values outside the scope of the invention are underlined. As shown in the tables, in the examples in which the conditions of the present invention were satisfied, the tensile strength, the elongation, the hole expansibility (stretch flangeability), the bendability, variation in the tensile strength, and variation in the elongation were all excellent. On the other hand, in the comparative examples in which at least one of the conditions of the present

invention was not satisfied, at least one property of the tensile strength, the elongation, the hole expansibility (stretch flangeability), the bendability, variation in the tensile strength, and variation in the elongation was not sufficient.

[0138] Specifically, in Comparative Example 9 and Comparative Example 10, the standard deviation of the ferrite area ratio became large, and the TS standard deviation and the EL standard deviation were failed. This is assumed to be because hot rolling was carried out under conditions that K'/Si* was insufficient.

[0139] In Comparative Example 11, the proportion of residual austenite having an aspect ratio of 2.0 or more was insufficient, and the hole expansibility was impaired. This is assumed to be because the average cooling rate after the finish rolling was insufficient.

[0140] In Comparative Example 12, the proportion of residual austenite having an aspect ratio of 2.0 or more was insufficient, and the hole expansibility was impaired. This is assumed to be because the coiling temperature after the finish rolling was too high.

[0141] In Comparative Example 13, the ferrite area ratio became excessive, the area ratio of the other structures was insufficient, and the tensile strength was insufficient. This is assumed to be because the heating temperature in the annealing step was lower than the A_{c1} point of the steel material A.

[0142] In Comparative Example 14, the proportion of residual austenite having an aspect ratio of 2.0 or more was insufficient, and the hole expansibility was impaired. This is assumed to be because the rolling reduction of the soft reduction that was carried out on the steel sheet before the annealing of the steel sheet was excessive.

[0143] In Comparative Example 16, the amount of residual austenite was insufficient, and the total elongation and the hole expansibility were impaired. This is assumed to be because the retention pattern in the annealing step was inappropriate, that is, the retention temperature was too low.

[0144] In Comparative Example 31 and Comparative Example 32, the amount of Si was insufficient. Therefore, in Comparative Example 31 and Comparative Example 32, the amount of residual austenite was insufficient, and the total elongation and the hole expansibility were impaired.

[Brief Description of the Reference Symbols]

[0145]

1 high strength steel sheet (steel sheet)
11 Surface (rolled surface)
12 cross section parallel to rolling direction and perpendicular to surface
121 sheet thickness 1/4 position of cross section parallel to rolling direction and perpendicular to surface
13 Measurement surface of residual austenite
131 Range of 1/8 thickness to 3/8 thickness from surface (rolled surface) on measurement surface of residual austenite.
RD Rolling direction
TD Thickness direction
WD Width direction

Claims

1. A high strength steel sheet comprising, as a chemical composition, by mass%:

C: 0.030% to 0.280%;
Si: 0.50% to 2.50%;
Mn: 1.00% to 4.00%;
sol. Al: 0.001% to 2.000%;
P: 0.100% or less;
S: 0.0200% or less;
N: 0.01000% or less;
O: 0.0100% or less;
B: 0% to 0.010%;
Ti: 0% to 0.20%;
Nb: 0% to 0.20%;
V: 0% to 1.000%;
Cr: 0% to 1.000%;
Mo: 0% to 1.000%;

Cu: 0% to 1.000%;
Co: 0% to 1.000%;
W: 0% to 1.000%;
Ni: 0% to 1.000%;
Ca: 0% to 0.0100%;
Mg: 0% to 0.0100%;
REM: 0% to 0.0100%;
Zr: 0% to 0.0100%; and
a remainder including Fe and impurities,
wherein a metallographic structure includes, by an area ratio,

ferrite: 20% to 70%,
residual austenite: 5% to 40%,
fresh martensite: 0% to 30%,
tempered martensite and bainite: 20% to 75% in total, and
pearlite and cementite: 0% to 10% in total,

in a range of a 1/8 thickness to a 3/8 thickness from a surface, a number proportion of residual austenite having an aspect ratio of 2.0 or more with respect to the number of all residual austenite is 50% or more,
at a sheet thickness 1/4 position of a cross section parallel to a rolling direction and perpendicular to the surface, a standard deviation of area ratios of ferrite measured at 10 points every 50 mm along a width direction is less than 10%, and
a tensile strength is 780 MPa or more.

2. The high strength steel sheet according to claim 1,
wherein, at 10 positions at intervals of 50 mm in the width direction, a standard deviation of surface roughness Ra is 0.5 μm or less.

3. The high strength steel sheet according to claim 1 or 2, comprising, as the chemical composition, by mass%, at least one from the group consisting of:

B: 0.001% to 0.010%;
Ti: 0.01% to 0.20%;
Nb: 0.01% to 0.20%;
V: 0.005% to 1.000%;
Cr: 0.005% to 1.000%;
Mo: 0.005% to 1.000%;
Cu: 0.005% to 1.000%;
Co: 0.005% to 1.000%;
W: 0.005% to 1.000%;
Ni: 0.005% to 1.000%;
Ca: 0.0003% to 0.0100%;
Mg: 0.0003% to 0.0100%;
REM: 0.0003% to 0.0100%; and
Zr: 0.0003% to 0.0100%.

FIG. 1

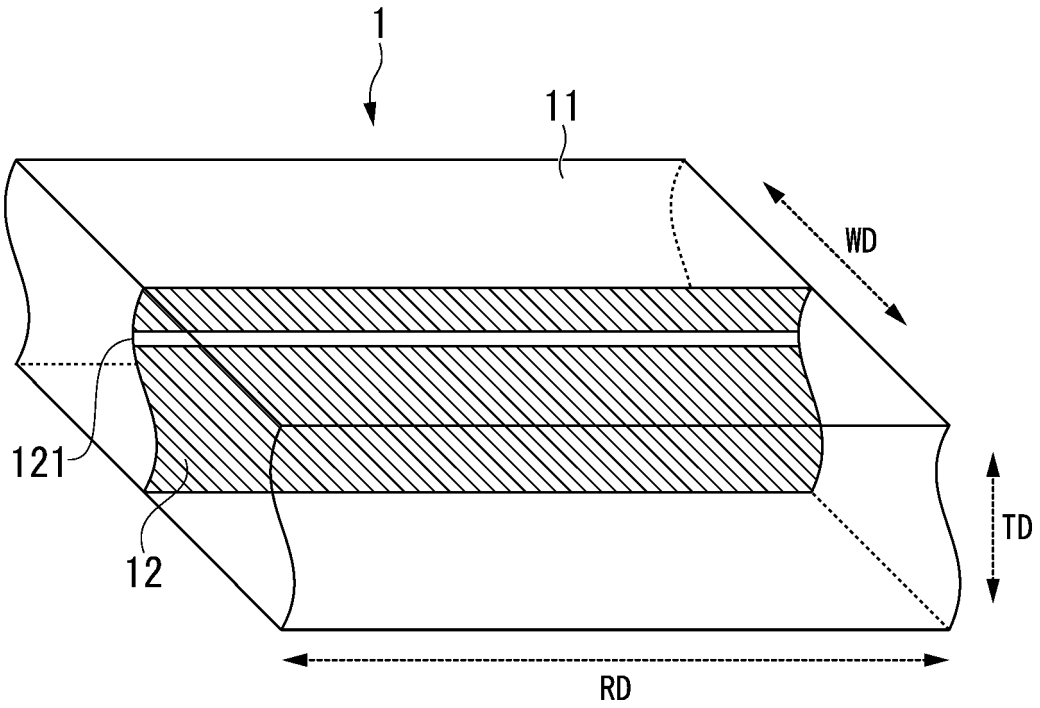


FIG. 2

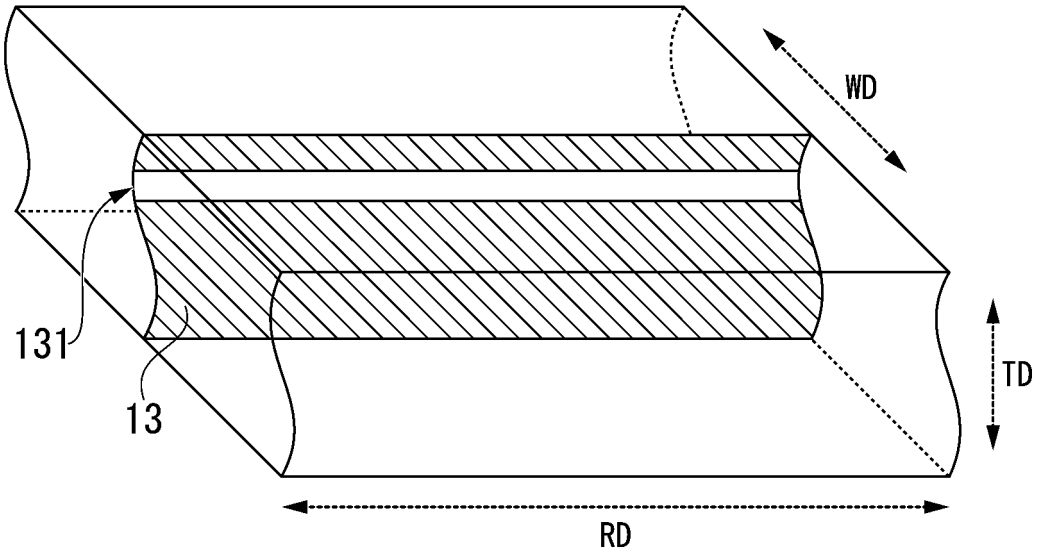
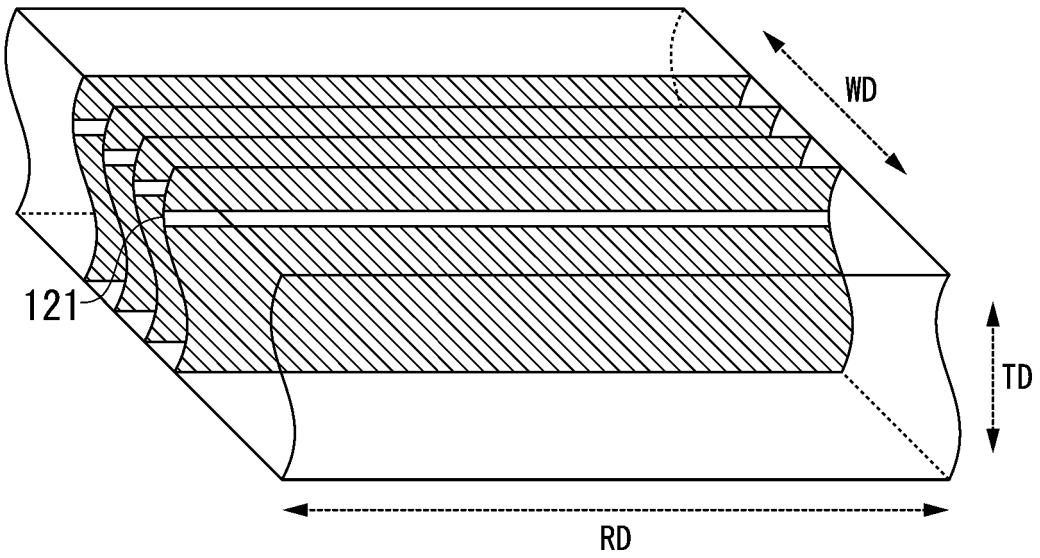


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/026704

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D9/46(2006.01)i, C22C38/58(2006.01)i
FI: C22C38/00301W, C22C38/58, C21D9/46T

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)
Int.Cl. C22C38/00-38/60, C21D9/46, B21B45/08

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	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	JP 6414371 B1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 31.10.2018 (2018-10-31)	1-3
A	JP 2011-140672 A (JFE STEEL CORPORATION) 21.07.2011 (2011-07-21)	1-3
A	WO 2014/208089 A1 (JFE STEEL CORPORATION) 31.12.2014 (2014-12-31)	1-3
A	JP 2012-87339 A (JFE STEEL CORPORATION) 10.05.2012 (2012-05-10)	1-3

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14.09.2020	24.09.2020

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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REFERENCES CITED IN THE DESCRIPTION

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