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(54) HIGH-STRENGTH STEEL SHEET AND METHOD FOR MANUFACTURING SAME

(57) To provide a high-strength steel sheet with high tensile strength, press formability, and bendability, and a method for manufacturing the high-strength steel sheet.

The high-strength steel sheet has a predetermined chemical composition and has a microstructure containing a specific microstructure in a surface layer region extending from a surface of the steel sheet to a position of one-tenth of the thickness of the steel sheet and in an inner region extending from a position of one-tenth to a position of three-tenths of the thickness of the steel sheet. The surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet has an average grain size of 6 pm or less. A difference (HV2 - HV1) between a hardness (HV1) of the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet and a hardness (HV2) of the inner region extending from the position of one-tenth to the position of three-tenths of the thickness of the steel sheet is 5% or more and 15% or less of [0.3 x tensile strength (MPa)], and the steel sheet has a tensile strength of 980 MPa or more, a uniform elongation of 6% or more, and a ratio R/t of a critical bending radius R to a thickness t of 1.5 or less.

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Description

Technical Field

[0001] The present invention relates to a high-strength steel sheet and a method for manufacturing the high-strength steel sheet. In particular, the present invention relates to a high-strength steel sheet that has a tensile strength of 980 MPa or more, a uniform elongation of 6% or more, and high bendability, and that is suitable as a material for a frame, a suspension component, or the like of a truck or a passenger car, and a method for manufacturing the high-strength steel sheet.

Background Art

[0002] Against the background of automobile exhaust emission control aimed at global warming mitigation, there is a need for lighter vehicles. To reduce the vehicle weight, it is effective to reduce the amount of material used for an automotive part by increasing the strength and reducing the thickness of the material used for the automotive part. Thus, high-strength steel sheets have been increasingly used year by year. In particular, high-strength steel sheets with a tensile strength of 980 MPa or more are expected as materials that can dramatically improve the mileage of automobiles through weight reduction.

[0003] However, steel sheets with higher tensile strength have lower ductility and press formability. Automotive parts, particularly chassis parts, such as suspension components, need to have complex shapes to ensure rigidity. Thus, materials for automotive parts require high press formability or ductility.

[0004] Furthermore, steel sheets with increased tensile strength tend to have a crack during bending. A crack in a bent portion may become a fatigue crack initiation point and may result in parts with lower durability than assumed in the design. Thus, materials for automotive parts and the like require high bendability.

[0005] Various techniques for improving the ductility and bendability of steel sheets while increasing the tensile strength of the steel sheets have been proposed.

Citation List

Patent Literature

[0006]

PTL 1: Japanese Unexamined Patent Application Publication No. 2012-012701
PTL 2: International Publication No. WO 2016/010004
PTL 3: Japanese Unexamined Patent Application Publication No. 2013-117068
PTL 4: Japanese Unexamined Patent Application Publication No. 2017-115191
PTL 5: International Publication No. WO 2020/110855
PTL 6: International Publication No. WO 2020/110843

Summary of Invention

Technical Problem

[0007] However, the related art as described in Patent Literature 1 to Patent Literature 6 has problems as described below.

[0008] The techniques described in Patent Literature 1 and Patent Literature 2 cannot achieve a tensile strength of 980 MPa or more. Although it is argued in Patent Literature 1 and Patent Literature 2 that hot-rolled steel sheets have high workability, "elongation" is used as a measure of workability. This "elongation", which is also referred to as the total elongation (El), represents the elongation at the point in time when a test specimen breaks in a tensile test. In practice, however, necking (constriction) occurs before breakage. Necking locally reduces the thickness of the sheet and results in a defective product during press forming. Thus, high total elongation is not sufficient for high press formability. Furthermore, Patent Literature 1 and Patent Literature 2 do not describe bendability.

[0009] Although it is argued that a high-strength steel sheet with high bendability can be manufactured by the techniques described in Patent Literature 3 to Patent Literature 5, attention is given only to a crack formed outside the bend. A crack formed during bending, whether outside or inside the bend, may become a fatigue crack initiation point and decrease the durability of the component. Thus, it cannot be said that the bendability is sufficiently ensured unless cracks inside the bend are reduced.

[0010] Although it is argued that a high-strength steel sheet with high bendability can be manufactured by the technique described in Patent Literature 6, attention is given only to a crack formed inside the bend. A crack formed during bending, whether outside or inside the bend, may become a fatigue crack initiation point and decrease the durability of the component. Thus, the performance of the component cannot be ensured unless cracks are reduced both inside and outside the bend.

[0011] Thus, a technique for manufacturing a high-strength steel sheet with a high level of tensile strength, press formability, and bendability has not yet been established.

[0012] The present invention has been made in view of such situations and aims to provide a high-strength steel sheet with high tensile strength, press formability, and bendability, and a method for manufacturing the high-strength steel sheet.

Solution to Problem

[0013] To solve the above problems, the present inventors made hypothetical stress-strain curves of steel sheets with a tensile strength of 980 MPa or more and with various yield stresses and uniform elongations, and performed a press forming simulation of a suspension component using the stress-strain curves. The characteristics of a steel sheet required for high press formability were examined on the basis of the results of the simulation.

[0014] As a result, it was found that, having a uniform elongation of 6% or more, a steel sheet with a tensile strength of 980 MPa or more can have the minimum thickness reduction during press forming and is less likely to have press forming defects.

[0015] The present inventors have also studied an optimum steel sheet microstructure to achieve a tensile strength of 980 MPa or more and a uniform elongation of 6% or more. As a result, it was found that a microstructure that contains upper bainite as a main phase and contains an appropriate amount of hard second phase containing fresh martensite and/or retained austenite can achieve both a high strength of 980 MPa or more and a uniform elongation of 6% or more.

[0016] The term "upper bainite", as used herein, refers to an aggregate of lath ferrite with an orientation difference of less than 15 degrees and refers to a microstructure with Fe-based carbide and/or retained austenite between lath ferrites (including a microstructure without Fe-based carbide and/or retained austenite between lath ferrites). Unlike lamellar (layered) ferrite or polygonal ferrite in pearlite, lath ferrite has a lath shape and has a relatively high dislocation density inside, so that they can be distinguished with a scanning electron microscope (SEM) or a transmission electron microscope (TEM). In the presence of retained austenite between laths, only a lath ferrite portion is regarded as upper bainite and is distinguished from the retained austenite. The fresh martensite refers to martensite without Fe-based carbide. Fresh martensite and retained austenite have a similar contrast in SEM but can be distinguished by an electron backscatter diffraction patterns (EBSD) method.

[0017] Next, the present inventors examined the bendability of a high-strength steel sheet with a tensile strength of 980 MPa or more and a uniform elongation of 6% or more. More specifically, steel sheets with a tensile strength of 980 MPa or more and a uniform elongation of 6% or more manufactured by different manufacturing methods were subjected to a 90-degree V bending test, and a fracture surface of a flex crack and the microstructure near the crack were observed. On the outside of the bend, a crack fracture surface was a ductile fracture surface, and many voids were observed in the microstructure near the crack, indicating that cracking outside the bend was ductile fracture. On the other hand, on the inside of the bend, a crack fracture surface was a brittle fracture surface, and no voids were observed in the microstructure near the crack. Thus, it was found that cracking inside the bend was brittle fracture due to strong compression. Thus, the improvement of ductility can reduce cracking outside the bend, and the improvement of compression embrittlement resistance characteristics can reduce cracking inside the bend. Thus, it was also found that the microstructure should be controlled in a surface layer region where a flex crack can be formed and in the vicinity thereof.

[0018] The present invention has been made by further examination based on these findings and has the following gist.

[1] A high-strength steel sheet which comprises:

a chemical composition containing, in mass%:

C: 0.05% to 0.20%,
Si: 0.5% to 1.2%,
Mn: 1.5% to 4.0%,
P: 0.10% or less,
S: 0.03% or less,
Al: 0.001% to 2.0%,
N: 0.01% or less,
O: 0.01% or less,
B: 0.0005% to 0.010%, and the remainder being Fe and incidental impurities;

a microstructure in a surface layer region extending from a surface of the steel sheet to a position of one-tenth of a thickness of the steel sheet containing 80% by area or more of upper bainite and 2% by area or more of fresh martensite and/or retained austenite in total,; and
a microstructure in an inner region extending from the position of one-tenth to a position of three-tenths of the thickness of the steel sheet containing 70% by area or more of upper bainite and 3% by area or more of fresh martensite and/or retained austenite in total,
wherein:

the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet has an average grain size of 6 pm or less;
a difference (HV2 - HV1) between a hardness (HV1) of the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet and a hardness (HV2) of the inner region extending from the position of one-tenth to the position of three-tenths of the thickness of the steel sheet is 5% or more and 15% or less of [0.3 x tensile strength (MPa)] ; and
the steel sheet has a tensile strength of 980 MPa or more, a uniform elongation of 6% or more, and a ratio R/t of a critical bending radius R to a thickness t of 1.5 or less.

[2] The high-strength steel sheet according to [1], wherein the chemical composition further contains, in mass%, at least one of

Cr: 1.0% or less and
Mo: 1.0% or less.

[3] The high-strength steel sheet according to [1] or [2], wherein the chemical composition further contains, in mass%, at least one of

Cu: 2.0% or less,
Ni: 2.0% or less,
Ti: 0.3% or less,
Nb: 0.3% or less, and
V: 0.3% or less.

[4] The high-strength steel sheet according to any one of [1] to [3], wherein the chemical composition further contains, in mass%,
Sb: 0.005% to 0.020%.
[5] The high-strength steel sheet according to any one of [1] to [4], wherein the chemical composition further contains, in mass%, at least one of

Ca: 0.01% or less,
Mg: 0.01% or less, and
REM: 0.01% or less.

[6] A method for manufacturing the high-strength steel sheet according to any one of [1] to [5], which comprises:

heating a steel material having the chemical composition to a heating temperature of 1150°C or more;
then rough rolling the steel material, and then hot rolling the steel material into a hot-rolled steel sheet under conditions of a finishing temperature: (RC2 - 50°C) or more and (RC2 + 120°C) or less and a total rolling reduction of 25% or more and 80% or less at a temperature of RC1 or less;
cooling the hot-rolled steel sheet under conditions of a time from completion of the hot rolling to start of cooling: 2.0 seconds or less, an average cooling rate at the position of three-tenths of the thickness of the steel sheet: 15°C/s or more, and a cooling stop temperature: Trs or more and (Trs + 250°C) or less;
coiling the hot-rolled steel sheet after the cooling at a coiling temperature: Trs or more and (Trs + 250°C) or less; and
cooling the hot-rolled steel sheet to 100°C or less at an average cooling rate of 20°C/s or less,
wherein RC1, RC2, and Trs are represented by the following formulae (1), (2), and (3), respectively,

$$RC1\ (^{\circ}C) = 900 + 100 \times C + 100 \times N + 10 \times Mn + 700 \times Ti + 5000 \times B + 10 \times Cr + 50 \times Mo + 2000 \times Nb + 150 \times V \quad (1)$$

$$RC2\ (^{\circ}C) = 750 + 100 \times C + 100 \times N + 10 \times Mn + 350 \times Ti + 5000 \times B + 10 \times Cr + 50 \times Mo + 1000 \times Nb + 150 \times V \quad (2)$$

$$Trs\ (^{\circ}C) = 500 - 450 \times C - 35 \times Mn - 15 \times Cr - 10 \times Ni - 20 \times Mo \quad (3)$$

where each element symbol in the formulae (1), (2), and (3) denotes a corresponding element content (% by mass) and is 0 in the absence of the element.

[7] The method for manufacturing the high-strength steel sheet according to [6], wherein in the cooling after completion of the hot rolling, an average cooling rate of the surface layer and the average cooling rate at the position of three-tenths of the thickness of the steel sheet satisfy the formula (4):

$$\text{Average cooling rate of surface layer} - \text{average cooling rate at position of three-tenths of thickness of steel sheet} \geq 10^{\circ}C/s \quad (4).$$

Advantageous Effects of Invention

[0019] The present invention can provide a high-strength steel sheet with a tensile strength of 980 MPa or more, high press formability, and high bendability. A high-strength steel sheet according to the present invention has high press formability in spite of high tensile strength and can be press-formed without a forming defect, such as necking or cracking. The application of a high-strength steel sheet according to the present invention to a member of a truck or a passenger car can reduce the amount of steel material used while ensuring safety, and reduce the weight of the automobile body, thus contributing to reducing the effects on the environment.

[0020] The phrase "high press formability", as used herein, refers to a uniform elongation of 6% or more. The phrase "high bendability" means that the ratio R/t of the critical bending radius R at which no crack with a depth of 50 pm or more is formed both outside and inside the bend in a 90-degree V bending test to the thickness t of a steel sheet is 1.5 or less.

[0021] The present invention is specifically described below. The following description shows an example of a preferred embodiment of the present invention, and the present invention is not limited to this.

Description of Embodiments

[Chemical Composition]

[0022] First, the reasons for limiting the chemical composition of a high-strength steel sheet according to the present invention are described below. Unless otherwise specified, "%" as a unit of the content refers to "% by mass".

C: 0.05% to 0.20%

[0023] C is an element with the effect of improving the strength of steel. C improves hardenability, thereby promotes the formation of bainite, and contributes to increase the strength. C increases the strength of martensite and also contributes to increase the strength. To achieve a tensile strength of 980 MPa or more, the C content should be 0.05% or more. Thus, the C content is 0.05% or more, preferably 0.06% or more. On the other hand, a C content of more than 0.20% results in martensite with excessively increased strength, a larger difference in strength between upper bainite serving as a main phase and fresh martensite and/or retained austenite, and consequently lower uniform elongation. Thus, the C content is 0.20% or less, preferably 0.18% or less.

Si: 0.5% to 1.2%

[0024] Si has the effect of reducing the formation of Fe-based carbide and reduces the precipitation of cementite during upper bainite transformation. This distributes C to non-transformed austenite, and cooling after coiling in a hot-rolling process transforms the non-transformed austenite into fresh martensite and/or retained austenite, thereby forming the desired fresh martensite and/or retained austenite. These effects require a Si content of 0.5% or more, preferably 0.6% or more. On the other hand, a Si content of more than 1.2% may result in the formation of fresh martensite and/or retained austenite in an amount larger than the desired area ratio, consequently an undesired area ratio of upper bainite, and lower bendability. Thus, the Si content is 1.2% or less, preferably 1.1% or less.

Mn: 1.5% to 4.0%

[0025] Mn stabilizes austenite and contributes to the formation of fresh martensite and/or retained austenite. Such effects require a Mn content of 1.5% or more. Thus, the Mn content is 1.5% or more, preferably 1.7% or more. On the other hand, a Mn content of more than 4.0% results in excessive formation of fresh martensite and/or retained austenite, consequently an undesired area ratio of upper bainite, and lower bendability. Thus, the Mn content is 4.0% or less, preferably 3.8% or less.

P: 0.10% or less

[0026] P is an element that contributes to an increase in the strength of steel through solid solution. However, P is also an element that segregates at an austenite grain boundary during hot rolling and thereby causes slab cracking during the hot rolling. P also segregates at a grain boundary and reduces the uniform elongation. Thus, the P content is preferably minimized and may be 0.10% or less. Thus, the P content is 0.10% or less. Although the lower limit is not particularly limited, the P content is preferably 0.0002% or more because a P content of less than 0.0002% causes a decrease in production efficiency.

S: 0.03% or less

[0027] S binds to Ti or Mn and forms a coarse sulfide, which accelerates the formation of a void and reduces the uniform elongation. Thus, the S content is preferably minimized and may be 0.03% or less. Thus, the S content is 0.03% or less. Although the lower limit is not particularly limited, the S content is preferably 0.0002% or more because a S content of less than 0.0002% causes a decrease in production efficiency.

Al: 0.001% to 2.0%

[0028] Al is an element that acts as a deoxidizing agent and is effective in improving the cleanliness of steel. This effect is insufficient at an Al content of less than 0.001%. Thus, the Al content is 0.001% or more, preferably 0.005% or more, more preferably 0.010% or more. Like Si, Al is effective in reducing the formation of Fe-based carbide and reduces the precipitation of cementite during upper bainite transformation. This contributes to the formation of fresh martensite and/or retained austenite during cooling after coiling. On the other hand, an excessively high Al content results in an increased number of oxide inclusions and lower uniform elongation. Thus, the Al content is 2.0% or less, preferably 1.0% or less, more preferably 0.1% or less.

N: 0.01% or less

[0029] N binds to a nitride-forming element, thereby precipitates as a nitride, and generally contributes to grain refinement. However, N binds to Ti at high temperatures and forms a coarse nitride. Thus, a N content of more than 0.01% results in lower uniform elongation. Thus, the N content is 0.01% or less. Although the lower limit is not particularly limited, the N content is preferably 0.0002% or more because a N content of less than 0.0002% causes a decrease in production efficiency.

O: 0.01% or less

[0030] O generates an oxide and reduces formability. Thus, the O content should be reduced. In particular, this tendency is remarkable at an O content of more than 0.01%. Thus, the O content is 0.01% or less, preferably 0.005%, more preferably 0.003%. Although the lower limit is not particularly specified, the O content is preferably 0.00005% or more because the production efficiency may be significantly lowered at an O content of less than 0.00005%.

B: 0.0005% to 0.010%

[0031] B is an element that segregates in a prior-austenite grain boundary, reduces the formation of ferrite, thereby promotes the formation of upper bainite, and contributes to improving the strength of a steel sheet. These effects require a B content of 0.0005% or more. Thus, the B content is 0.0005% or more, preferably 0.0006%, more preferably 0.0007%. On the other hand, these effects are saturated at a B content of more than 0.010%. Thus, the B content is 0.010% or less, preferably 0.009% or less, more preferably 0.008% or less.

[0032] The remainder is composed of Fe and incidental impurities. Examples of the incidental impurities include Zr, Co, Sn, Zn, and W. When the chemical composition contains at least one of Zr, Co, Sn, Zn, and W as incidental impurities, the total amount of the element(s) is preferably 0.5% or less.

[0033] The chemical composition of a high-strength steel sheet according to the present invention may optionally contain at least one of the following elements.

Cr: 1.0% or less

[0034] Cr is a carbide-forming element and has the effect of reducing driving force for bainite transformation by segregating at an interface between upper bainite and non-transformed austenite during upper bainite transformation after coiling, thereby stopping the upper bainite transformation. Non-transformed austenite remained due to the stopped upper bainite transformation becomes fresh martensite and/or retained austenite by cooling after coiling. Thus, Cr, if added, also contributes to the formation of a desired area ratio of fresh martensite and/or retained austenite. This effect is preferably produced at a Cr content of 0.1% or more. However, a Cr content of more than 1.0% results in excessive formation of fresh martensite and/or retained austenite, consequently an undesired area ratio of upper bainite, and lower bendability. When Cr is added, the Cr content is 1.0% or less, preferably 0.9% or less, more preferably 0.8% or less.

Mo: 1.0% or less

[0035] Mo promotes the formation of bainite through the improvement of hardenability and contributes to improving the strength of a steel sheet. Like Cr, Mo is a carbide-forming element, segregates at an interface between upper bainite and non-transformed austenite during upper bainite transformation after coiling, thereby reduces transformation driving force for bainite, and contributes to the formation of fresh martensite and/or retained austenite after coiling and cooling. However, a Mo content of more than 1.0% results in excessive formation of fresh martensite and/or retained austenite, consequently an undesired area ratio of upper bainite, and lower uniform elongation. This effect is preferably produced at a Mo content of 0.1% or more. Thus, when Mo is added, the Mo content is 1.0% or less, preferably 0.9% or less, more preferably 0.8% or less.

[0036] The chemical composition of a high-strength steel sheet according to the present invention may optionally contain at least one of the following elements.

Cu: 2.0% or less

[0037] Cu is an element that contributes to an increase in the strength of steel through solid solution. Cu promotes the formation of bainite through the improvement of hardenability and contributes to improving the strength. This effect is preferably produced at a Cu content of 0.01% or more. However, a Cu content of more than 2.0% results in a high-strength steel sheet with lower surface quality and bendability. Thus, when Cu is added, the Cu content is 2.0% or less, preferably 1.9% or less, more preferably 1.8% or less.

Ni: 2.0% or less

[0038] Ni is an element that contributes to an increase in the strength of steel through solid solution. Ni promotes the formation of bainite through the improvement of hardenability and contributes to improving the strength. This effect is preferably produced at a Ni content of 0.01% or more. However, a Ni content of more than 2.0% results in an excessive increase of fresh martensite and/or retained austenite, consequently an undesired area ratio of upper bainite, and a high-strength steel sheet with lower ductility. Thus, when Ni is added, the Ni content is 2.0% or less, preferably 1.9% or less, more preferably 1.8% or less.

Ti: 0.3% or less

[0039] Ti is an element with the effect of improving the strength of a steel sheet by precipitation strengthening or solid-solution strengthening. Ti forms a nitride in a hightemperature region of austenite. This reduces the precipitation of BN and results in B in a solid solution state. Thus, Ti, if added, also contributes to ensuring hardenability necessary for the formation of upper bainite and improves the strength. This effect is preferably produced at a Ti content of 0.01% or more. However, a Ti content of more than 0.3% results in a large amount of Ti nitride and lower uniform elongation. Thus, when Ti is added, the Ti content is 0.3% or less, preferably 0.28% or less, more preferably 0.25% or less.

Nb: 0.3% or less

[0040] Nb is an element with the effect of improving the strength of a steel sheet by precipitation strengthening or solid-solution strengthening. Like Ti, Nb increases the recrystallization temperature of austenite during hot rolling, thereby enables rolling in an austenite nonrecrystallization temperature range, and contributes to decreasing the grain size of upper bainite and increasing the area ratio of fresh martensite and/or retained austenite. Like Cr, Nb is a carbide-forming element and is an element that segregates at an interface between upper bainite and non-transformed austenite during upper bainite transformation after coiling and thereby has the effect of reducing transformation driving force for bainite and stopping the upper bainite transformation while leaving the non-transformed austenite. The non-transformed austenite becomes fresh martensite and/or retained austenite by cooling thereafter. Thus, Nb, if added, also contributes to the formation of a desired area ratio of fresh martensite and/or retained austenite. This effect is preferably produced at a Nb content of 0.01% or more. However, a Nb content of more than 0.3% results in an excessive increase of fresh martensite and/or retained austenite, consequently an undesired area ratio of upper bainite, and lower uniform elongation. Thus, when Nb is added, the Nb content is 0.3% or less, preferably 0.28% or less, more preferably 0.25% or less.

V: 0.3% or less

[0041] V is an element with the effect of improving the strength of a steel sheet by precipitation strengthening and solid-solution strengthening. Like Ti, V increases the recrystallization temperature of austenite during hot rolling, thereby enables rolling in an austenite nonrecrystallization temperature range, and contributes to decreasing the grain size of upper bainite. Like Cr, V is a carbide-forming element and is an element that segregates at an interface between upper bainite and non-transformed austenite during upper bainite transformation after coiling and thereby has the effect of reducing transformation driving force for bainite and stopping the upper bainite transformation while leaving the non-transformed austenite. The non-transformed austenite becomes fresh martensite and/or retained austenite by cooling thereafter. Thus, V, if added, also contributes to the formation of a desired area ratio of fresh martensite and/or retained austenite. This effect is preferably produced at a V content of 0.01% or more. However, a V content of more than 0.3% results in an excessive increase of fresh martensite and/or retained austenite, consequently an undesired area ratio of upper bainite, and lower uniform elongation. Thus, when V is added, the V content is 0.3% or less, preferably 0.28% or less, more preferably 0.25% or less.

[0042] The chemical composition of a high-strength steel sheet according to the present invention may further optionally contain the following elements.

Sb: 0.005% to 0.020%

[0043] Sb is an element with the effect of reducing nitriding of the surface of a steel material (slab) when the steel material is heated. The addition of Sb can reduce the precipitation of BN in a surface layer portion of a steel material. As a result, remaining solid solution B contributes to ensuring hardenability necessary for the formation of bainite and thereby improving the strength of a steel sheet. When Sb is added, the Sb content is 0.005% or more, preferably 0.006% or more, more preferably 0.007% or more, to produce the effects. On the other hand, an Sb content of more than 0.020% results in steel with lower toughness and may cause slab cracking and hot-rolling cracking. Thus, when Sb is added, the Sb content is 0.020% or less, preferably 0.019% or less, more preferably 0.018% or less.

[0044] The chemical composition of a high-strength steel sheet according to the present invention may optionally contain at least one of the following elements. The following elements contribute to further improvement of press formability or other characteristics.

Ca: 0.01% or less

[0045] Ca controls the shape of an oxide or sulfide inclusion and contributes to reducing cracking of a sheared end face of a steel sheet and further improving the bendability of a steel sheet. This effect is preferably produced at a Ca content of 0.001% or more. However, a Ca content of more than 0.01% may result in an increase of a Ca-based inclusion and steel with lower cleanliness and rather result in sheared end face cracking or bending cracking. Thus, when Ca is added, the Ca content is 0.01% or less.

Mg: 0.01% or less

[0046] Like Ca, Mg controls the shape of an oxide or sulfide inclusion and contributes to reducing cracking of a sheared end face of a steel sheet and further improving the bendability of a steel sheet. This effect is preferably produced at a Mg content of 0.001% or more. However, a Mg content of more than 0.01% may result in steel with lower cleanliness and rather result in sheared end face cracking or bending cracking. Thus, when Mg is added, the Mg content is 0.01% or less.

REM: 0.01% or less

[0047] Like Ca, a rare-earth metal (REM) controls the shape of an oxide or sulfide inclusion and contributes to reducing cracking of a sheared end face of a steel sheet and further improving the bendability of a steel sheet. This effect is preferably produced at a REM content of 0.001% or more. However, a REM content of more than 0.01% may result in steel with lower cleanliness and rather result in sheared end face cracking or bending cracking. Thus, when REM is added, the REM content is 0.01% or less.

[Microstructure]

[0048] Next, the reasons for limiting the microstructure of a high-strength steel sheet according to the present invention are described below.

[0049] A high-strength steel sheet according to the present invention has a microstructure containing 80% by area or more of upper bainite and 2% by area or more of fresh martensite and/or retained austenite in total in a surface layer region extending from a surface of the steel sheet to a position of one-tenth of the thickness of the steel sheet and 70% by area or more of upper bainite and 3% by area or more of fresh martensite and/or retained austenite in total in an inner region extending from a position of one-tenth to a position of three-tenths of the thickness of the steel sheet. The surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet has an average grain size of 6 pm or less. A difference (HV2 - HV1) between a hardness (HV1) of the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet and a hardness (HV2) of the inner region extending from the position of one-tenth to the position of three-tenths of the thickness of the steel sheet is 5% or more and 15% or less of [0.3 x tensile strength (MPa)].

Upper bainite: 80% or more and fresh martensite and/or retained austenite: 2% by area or more in total in surface layer region extending from surface of steel sheet to position of one-tenth of thickness of steel sheet

[0050] In a high-strength steel sheet according to the present invention, hard fresh martensite and/or retained austenite can be finely dispersed in soft upper bainite to improve ductility and reduce cracking outside the bend. To produce this effect, in a surface layer, the area fraction of upper bainite is 80% or more, and the area ratio of fresh martensite and/or retained austenite is 2% or more. Preferably, the area ratio of upper bainite is 85% or more, and the area ratio of fresh martensite and/or retained austenite is 3% or more. On the other hand, the bendability may be lowered when the total area ratio of fresh martensite and/or retained austenite is 20% or more. The total area ratio of fresh martensite and/or retained austenite is therefore preferably 20% or less, more preferably 18% or less, still more preferably 15% or less.

[0051] In a surface layer region of the steel sheet, due to a high cooling rate, bainite transformation proceeds rapidly, and carbon concentrating for forming fresh martensite and/or retained austenite is lower than that in the inside of the steel sheet. Lower carbon concentrating reduces martensite transformation. This results in a smaller area ratio of fresh martensite and/or retained austenite in the surface layer region than in the inside of the steel sheet.

70% by area or more of upper bainite and 3% by area or more of fresh martensite and/or retained austenite in total in inner region extending from position of one-tenth to position of three-tenths of thickness of steel sheet

[0052] In the present invention, an inner region extending from a position of one-tenth to a position of three-tenths of the thickness of a steel sheet contains upper bainite as a main phase. When the upper bainite has an area ratio of less than 70%, a tensile strength of 980 MPa or more and a uniform elongation of 6% or more cannot be achieved. Thus, the upper bainite has an area ratio of 70% or more, preferably 80% or more. In the present invention, an inner region extending from a position of one-tenth to a position of three-tenths of the thickness of a steel sheet contains fresh martensite and/or retained austenite. Fresh martensite has the effect of promoting work hardening, delaying the onset of plastic instability, and thereby improving the uniform elongation. Retained austenite can improve the uniform elongation by the transformation induced plasticity (TRIP) effect. To produce these effects, the total area ratio of fresh martensite and/or retained austenite is 3% or more, preferably 4% or more. In the present invention, in the microstructure extending from a position of three-tenths of the thickness to the vicinity of the center of the thickness of a steel sheet, the area ratio of upper bainite is preferably 60% or more from the perspective of ductility, although the effect on bendability is small. 40% or less of fresh martensite/tempered martensite/retained austenite and the like may be contained due to Mn segregation at half the thickness of a steel sheet.

Average grain size in surface layer region extending from surface of steel sheet to position of one-tenth of thickness of steel sheet: 6 μm or less

[0053] Cracking inside the bend is brittle fracture due to strong compression. Thus, compression embrittlement resistance characteristics can be improved to reduce cracking inside the bend. Grain refinement can reduce compression embrittlement. To produce this effect, the average grain size in a surface layer region is 6 pm or less, preferably 5 pm or less. Although compression embrittlement resistance is improved as the average grain size decreases, an excessively small average grain size may result in higher strength and lower elongation and cracking in outer bending. Thus, the average grain size in the surface layer region is preferably 2 pm or more.

[0054] Thus, a tensile strength of 980 MPa or more, a uniform elongation of 6% or more, and high bendability can be achieved only by combining the uniform elongation improving effect of fresh martensite and/or retained austenite with the flex cracking suppressive effect by controlling a surface layer microstructure.

Difference (HV2 - HV1) between hardness (HV1) of surface layer region extending from surface of steel sheet to a position of one-tenth of thickness of steel sheet and hardness (HV2) of inner region extending from a position of one-tenth to a position of three-tenths of thickness of steel sheet is 5% or more and 15% or less of [0.3 x tensile strength (MPa)]

[0055] In a high-strength steel sheet according to the present invention, a soft surface layer reduces cracking outside the bend, and a hard inner portion adjacent to the surface layer reduces the growth of a flex crack in the thickness direction of the steel sheet. To produce the effects of reducing the occurrence and growth of a flex crack, the difference (HV2 - HV1) between the hardness (HV1) of the surface layer region and the hardness (HV2) of the inner region is 5% or more, preferably 6% or more, more preferably 7% or more, with respect to 0.3 x tensile strength (MPa). On the other hand, a large difference between the hardness of the surface layer region and the hardness of the inner region results in strain mismatch between the surface layer and the inner portion in a tensile test, thus failing to achieve target tensile properties. Thus, the difference between the hardness of the surface layer region and the hardness of the inner region is 15% or less, preferably 14% or less, more preferably 13% or less, with respect to 0.3 x tensile strength (MPa). The above effects can be produced by controlling the cooling rate on the surface of the steel sheet and in the inside of the steel sheet.

[0056] The microstructure may further contain a microstructure other than upper bainite, fresh martensite, and retained austenite (hereinafter referred to as "another microstructure"). From the perspective of enhancing the effect of microstructure control, another microstructure preferably has a total area ratio of 3% or less. In other words, the upper bainite, fresh martensite, and retained austenite in the microstructure preferably have a total area ratio of 97% or more. Examples of the other microstructure include cementite, polygonal ferrite, pearlite, tempered martensite, and lower bainite.

[Mechanical Properties]

[0057] A high-strength steel sheet according to the present invention has a tensile strength of 980 MPa or more, a uniform elongation of 6% or more, and an R/t (the ratio of the critical bending radius R at which no crack with a depth of 50 pm or more is formed both outside and inside the bend to the thickness t of the steel sheet) of 1.5 or less. Thus, a high-strength steel sheet according to the present invention has high press formability in spite of its high tensile strength, can be press-formed without a forming defect, such as necking or cracking, and can ensure the durability of a component without forming a large crack outside and inside a bent portion. Thus, a high-strength steel sheet according to the present invention applied to a member of a truck or a passenger car can ensure safety.

[0058] The microstructure, hardness, and mechanical properties in the present invention can be determined by measurement methods described below in Examples.

[Manufacturing Method]

[0059] Next, a method for manufacturing a high-strength steel sheet according to an embodiment of the present invention is described. Unless otherwise specified, the temperature in the following description represents the surface temperature of an object (a steel material or a steel sheet).

[0060] A high-strength steel sheet according to the present invention can be manufactured by sequentially subjecting a steel material to the following treatments (1) to (5). Each of the steps is described below.

(1) Heating
(2) Hot rolling
(3) Cooling (first cooling)
(4) Coiling
(5) Cooling (second cooling)

[0061] The steel material may be any material with the chemical composition described above. The chemical composition of the final high-strength steel sheet is the same as the chemical composition of the steel material used. The steel material can be a steel slab, for example. The steel material may be manufactured by any method. For example, a molten steel with the chemical composition described above can be obtained by steelmaking by a known method using a converter or the like, and a steel material can be manufactured by a casting method, such as continuous casting. It is also possible to use a method other than the continuous casting method, such as an ingot casting and blooming method. Scrap may also be used as a raw material. The steel material manufactured by the continuous casting method or the like may be directly subjected to the next heating step or may be cooled and subjected as a hot piece or a cold piece to the heating step.

(1) Heating

[0062] First, the steel material is heated to a heating temperature of 1150°C or more. In general, carbonitrideforming elements, such as Ti, are mostly present as coarse carbonitrides in steel materials. The presence of the coarse and nonuniform precipitates causes degradation of various characteristics generally required for high-strength steel sheets for truck and passenger car components (for example, sheared edge cracking resistance, bendability, burring formability, and the like). Thus, the steel material should be heated before hot rolling to dissolve coarse precipitates. More specifically, the heating temperature of the steel material should be 1150°C or more to sufficiently dissolve coarse precipitates. On the other hand, an excessively high heating temperature of the steel material results in the occurrence of a slab defect and a decrease in yield due to scaling off. Thus, from the perspective of improving the yield, the heating temperature of the steel material is preferably 1350°C or less. The lower limit of the heating temperature of the steel material is more preferably 1180°C or more, still more preferably 1200°C or more or less. The upper limit of the heating temperature of the steel material is more preferably 1300°C or less, still more preferably 1280°C or less.

[0063] In the heating, from the perspective of uniformizing the temperature of the steel material, the temperature of the steel material is preferably increased to the heating temperature and is then maintained at the heating temperature. The holding time at the heating temperature is preferably, but not limited to, 1800 seconds or more from the perspective of improving the temperature uniformity of the steel material. On the other hand, a holding time of more than 10,000 seconds results in an increased amount of scales. This often causes scale biting or the like in the subsequent hot rolling and decreases the yield due to defective surface flaws. Thus, the holding time is preferably 10,000 seconds or less, more preferably 8000 seconds or less.

(2) Hot Rolling

[0064] The heated steel material is then hot-rolled to form a hot-rolled steel sheet. The hot rolling may include rough rolling and finish rolling. The rough rolling may be performed under any conditions. After the rough rolling, descaling is preferably performed to remove surface scales before the finish rolling. In the finish rolling, descaling may be performed between stands.

[0065] Next, in the present invention, in the finish rolling, when the temperature RC1 and the temperature RC2 are defined by the following formulae (1) and (2), the total rolling reduction at a temperature of RC1 or less is 25% or more and 80% or less, and the finishing temperature is (RC2 - 50°C) or more and (RC2 + 120°C) or less.

[0066] RC1 denotes the austenite 50% recrystallization temperature estimated from the chemical composition, and RC2 denotes the austenite recrystallization lower limit temperature estimated from the chemical composition. When the total rolling reduction at RC1 or less is less than 25%, the average grain size increases, and high bendability cannot be achieved. On the other hand, when the total rolling reduction at a temperature of RC1 or less is more than 80%, austenite has a high dislocation density, a bainite microstructure transformed from the austenite with a high dislocation density has low ductility, and the uniform elongation of 6% or more cannot be achieved. Thus, the total rolling reduction at a temperature of RC1 or less is 25% or more and 80% or less.

[0067] The hot rolling is performed under the condition of finishing temperature: (RC2 - 50°C) or more and (RC2 + 120°C) or less. At a finishing temperature below (RC2 - 50°C), bainite transformation occurs from austenite with a high dislocation density. Upper bainite transformed from austenite with a high dislocation density has a high dislocation density and low ductility, resulting in a decrease in the uniform elongation. The uniform elongation also decreases when the finish rolling temperature is low and the rolling is performed at a two-phase temperature of ferrite + austenite. Thus, the finishing temperature is (RC2 - 50°C) or more. On the other hand, at a finishing temperature above (RC2 + 120°C), austenite grains coarsen, and the average grain size of upper bainite increases, resulting in a decrease in the strength. Furthermore, fresh martensite and/or retained austenite also coarsens, and the uniform elongation decreases. Thus, the finishing temperature is (RC2 + 120°C) or less. RC1 and RC2 are defined by the following formulae (1) and (2):

$$\mathrm{RC1}\ (^\circ\mathrm{C}) = 900 + 100 \times \mathrm{C} + 100 \times \mathrm{N} + 10 \times \mathrm{Mn} + 700 \times \mathrm{Ti} + 5000 \times \mathrm{B} + 10 \times \mathrm{Cr} + 50 \times \mathrm{Mo} + 2000 \times \mathrm{Nb} + 150 \times \mathrm{V} \quad (1)$$

$$\mathrm{RC2}\ (^\circ\mathrm{C}) = 750 + 100 \times \mathrm{C} + 100 \times \mathrm{N} + 10 \times \mathrm{Mn} + 350 \times \mathrm{Ti} + 5000 \times \mathrm{B} + 10 \times \mathrm{Cr} + 50 \times \mathrm{Mo} + 1000 \times \mathrm{Nb} + 150 \times \mathrm{V} \quad (2)$$

wherein each element symbol in the formulae (1) and (2) denotes a corresponding element content (% by mass) and is 0 in the absence of the element.

(3) Cooling (First Cooling)

[0068] Next, the hot-rolled steel sheet thus manufactured is cooled (first cooling). The time from completion of the hot rolling (completion of the finish rolling) to the start of the cooling (cooling start time) is 2.0 seconds or less. A cooling start time of more than 2.0 seconds results in the growth of austenite grains, thus failing to achieve a tensile strength of 980 MPa or more. The cooling start time is preferably 1.5 seconds or less.

[0069] The average cooling rate at a position of three-tenths of the thickness of the steel sheet is 15°C/s or more. In the present invention, the surface layer is cooled more rapidly than the inside to form a microstructure that differs between the surface layer and the inside. The rapid cooling of the surface layer advances the bainite transformation start in the surface layer and forms a smaller amount of martensite and retained austenite due to carbon concentrating in the surface layer than in the inside. When the average cooling rate of the cooling is less than 15°C/s, the surface layer is not sufficiently rapidly cooled, and the surface layer microstructure containing 80% by area or more of upper bainite and 2% by area or more of fresh martensite and/or retained austenite in total cannot be formed. Thus, the average cooling rate is 15°C/s or more, preferably 20°C/s or more, more preferably 50°C/s or more. On the other hand, although the average cooling rate may have any upper limit, an excessively high average cooling rate makes it difficult to control the cooling stop temperature. Thus, the average cooling rate is preferably 200°C/s or less. The average cooling rate is specified on the basis of the average cooling rate at the surface of the steel sheet.

[0070] In the present invention, when the average cooling rate of the surface layer - the average cooling rate at a position of three-tenths of the thickness of the steel sheet is 10°C/s or more, the formation of martensite or retained austenite due to carbon concentrating in the surface layer is less than that at the position of three-tenths of the thickness of the steel sheet. Consequently, a soft surface layer microstructure can be formed. On the other hand, in the inside of the steel sheet, the cooling rate is lower than that in the surface layer, and the progress of the bainite transformation is slower than that in the surface layer, so that the formation of martensite or retained austenite due to carbon concentrating is more than in the inside, and an internal microstructure with high hardness can be formed. Thus, a difference in hardness between the surface layer and the inside can be realized. When the average cooling rate of the surface layer at a position of three-tenths of the thickness - the average cooling rate at a position of three-tenths of the thickness of the steel sheet is less than 10°C/s, the above effects are not recognized. Thus, the average cooling rate of the surface layer - the average cooling rate at the position of three-tenths of the thickness of the steel sheet is 10°C/s or more. The average cooling rate is determined by (temperature at the start of cooling - temperature at the end of cooling)/cooling time. The temperature of the surface layer is actually measured with a thermometer. The temperature at the position of three-tenths of the thickness of the steel sheet is determined by calculating the temperature distribution in a cross section of the steel sheet by heat transfer analysis and correcting the result by the actual temperature of the surface of the steel sheet.

[0071] In the cooling, forced cooling may be performed at the average cooling rate. The cooling method is preferably, but not limited to, water cooling, for example.

[0072] The cooling stop temperature is Trs or more and (Trs + 250°C) or less. At a cooling stop temperature below Trs, the microstructure becomes tempered martensite or lower bainite. Both tempered martensite and lower bainite have a high-strength microstructure but have significantly low uniform elongation. Thus, the cooling stop temperature is Trs or more. On the other hand, at a cooling stop temperature above (Trs + 250°C), ferrite is formed, and the tensile strength of 980 MPa cannot be achieved. Thus, the cooling stop temperature is (Trs + 250°C) or less.

[0073] Trs is defined by the formula (3):

$$\mathrm{Trs}\ (^\circ\mathrm{C}) = 500 - 450 \times \mathrm{C} - 35 \times \mathrm{Mn} - 15 \times \mathrm{Cr} - 10 \times \mathrm{Ni} - 20 \times \mathrm{Mo} \quad (3)$$

wherein each element symbol in the formula (3) denotes a corresponding element content (% by mass) and is 0 in the absence of the element.

(4) Coiling

[0074] Next, the hot-rolled steel sheet after the cooling is coiled under the condition of a coiling temperature: Trs or more and (Trs + 250°C) or less. When the coiling temperature is below Trs, martensite transformation or lower bainite transformation proceeds after the coiling, and the desired fresh martensite and/or retained austenite cannot be formed. Thus, the coiling temperature is Trs or more. On the other hand, at a coiling temperature above (Trs + 250°C), ferrite is formed, and the tensile strength of 980 MPa cannot be achieved. Thus, the coiling temperature is (Trs + 250°C) or less.

(5) Cooling (Second Cooling)

[0075] After the coiling, cooling to 100°C or less is further performed at an average cooling rate of 20°C/s or less (second cooling). The average cooling rate has an influence on the formation of fresh martensite and/or retained austenite. At an average cooling rate of more than 20°C/s, most of the non-transformed austenite undergoes martensite transformation, the desired retained austenite cannot be formed, and the uniform elongation decreases. Thus, the average cooling rate is 20°C/s or less, preferably 2°C/s or less, more preferably 0.02°C/s or less. On the other hand, the lower limit of the average cooling rate is preferably, but not limited to, 0.0001°C/s or more.

[0076] The cooling can be performed to any temperature of 100°C or less, preferably in the range of approximately 10°C to 30°C (for example, room temperature). The cooling may be performed in any form, for example, in the state of a coil.

[0077] A high-strength steel sheet according to the present invention can be manufactured in accordance with the procedure described above. The coiling and the subsequent cooling may be followed by routine procedures. For example, temper rolling may be performed, or pickling may be performed to remove scales formed on the surface.

EXAMPLES

[0078] A molten steel with the composition shown in Table 1 was obtained by steelmaking in a converter, and a steel slab as a steel material was manufactured by a continuous casting method. The steel material was heated to the heating temperature shown in Table 2, and the steel material after the heating was then subjected to hot rolling including rough rolling and finish rolling to manufacture a hot-rolled steel sheet. The finishing temperature in the hot rolling was shown in Table 2.

[0079] Next, the hot-rolled steel sheet was cooled under the conditions of the average cooling rate and the cooling stop temperature shown in Table 2 (first cooling). The hot-rolled steel sheet after the cooling was coiled at the coiling temperature shown in Table 2, and the coiled steel sheet was cooled at the average cooling rate shown in Table 2 (second cooling) to manufacture a high-strength steel sheet. The cooling was followed by skin pass rolling and pickling as post-treatment. The pickling was performed at a temperature of 85°C using aqueous hydrochloric acid with a concentration of 10% by mass.

[0080] A test specimen was taken from the high-strength steel sheet, and the microstructure, surface roughness, and mechanical properties were evaluated in accordance with the following procedures.

(Microstructure)

[0081] A test specimen for microstructure observation was taken from the high-strength steel sheet such that a thickness cross section parallel to the rolling direction was an observation surface. The surface of the test specimen was polished and was corroded with a corrosive liquid (3% by volume nital solution) to expose the microstructure.

[0082] A surface layer region extending from the surface of the test specimen to a position of one-tenth of the thickness of the steel sheet and an inner region extending from the position of one-tenth to a position of three-tenths of the thickness of the steel sheet were then photographed with a scanning electron microscope (SEM) at a magnification of 5000 times in 10 visual fields to acquire a SEM image of the microstructure. The SEM image was analyzed by image processing to quantify the area ratios of upper bainite (UB), polygonal ferrite (F), and tempered martensite (TM). Fresh martensite (M) and retained austenite (γ) were difficult to distinguish with the SEM and were therefore identified by an electron backscatter diffraction patterns (EBSD) method, and the area ratio and the average grain size of each were determined. Table 3 shows the area ratio of each microstructure and the average grain size of the surface layer microstructure thus measured. Table 3 also shows the total area ratio (M + γ) of fresh martensite and retained austenite.

(Measurement of Hardness)

[0083] A sample for hardness measurement was taken from the high-strength steel sheet such that a thickness cross section parallel to the rolling direction was a hardness measurement cross section. The hardness was measured in a surface layer region extending from the surface of the steel sheet to a position of one-tenth of the thickness of the steel sheet and in an inner region extending from the position of one-tenth to a position of three-tenths of the thickness of the steel sheet. The hardness of the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet was measured at an indentation distance of 250 pm at a position away from the surface by 50 pm. The hardness of the inner region extending from the position of one-tenth to the position of three-tenths of the thickness of the steel sheet was measured at an indentation distance of 250 pm at a position of one-fifth of the thickness of the steel sheet. The hardness measurement conditions included a load of 100 g, a holding time of 10 seconds, and averaging at five points of measurement.

(Tensile Test)

[0084] A JIS No. 5 test specimen (gauge length (GL): 50 mm) was taken from the high-strength steel sheet such that the tensile direction was perpendicular to the rolling direction. The test specimen was subjected to a tensile test in accordance with JIS Z 2241 to determine the yield strength (yield point, YP), tensile strength (TS), yield ratio (YR), total elongation (El), and uniform elongation (u-El). The tensile test of each high-strength steel sheet was performed twice, and the average of the measured values is shown in Table 3 as the mechanical characteristics of the high-strength steel sheet. In the present invention, a TS of 980 MPa or more was rated as high strength. A uniform elongation of 6% or more was rated as high press formability.

(90-Degree V Bending Test)

[0085] A bending test was performed in accordance with JIS Z 2248 (2014) (a V block 90-degree V bending test) on a test specimen with a rectangular shape of 100 mm x 35 mm, which was taken from the hot-rolled steel sheet at a 1/2 position in the width direction such that the longitudinal direction of the test specimen was perpendicular to the rolling direction. The bending punch radius R ranged in 0.5 mm increments from 0.5 mm to 2.0 times or more of the thickness of the steel sheet t. To determine the presence and depth of a flex crack, the test specimen after the bending test was cut at three positions of a quarter, half, and three quarters of the width of the test specimen in a plane parallel to the longitudinal direction of the test specimen and perpendicular to the surface of the test specimen. The cross-sections were mirror-polished, and a crack outside and inside the bend of the test specimen was observed with an optical microscope to measure the maximum crack depth outside and inside the bend in the three cross-sections, thereby determining the critical bending radius (minimum bending radius) at which the crack depth outside and inside the bend was less than 50 μm. R/t of 1.5 or less was judged to be acceptable. A crack of 50 pm or more outside or inside the bend at a critical bending radius of 2.0 times or more of the thickness t is considered to indicate low bendability, and the critical bending radius R is not determined.

[Table 1]

Type of steel	Chemical composition (% by mass) *										RC1 (°C)	RC2 (°C)	Trs (°C)	RC2-50 (°C)	RC2+120 (°C)	Trs+250 (°C)	Notes
	C	Si	Mn	P	S	Al	N	O	B	Others							
A	0.114	1.20	2.90	0.015	0.0010	0.042	0.0050	0.0013	0.0020	-	951	801	347	751	921	597	Conforming steel
B	0.183	0.90	3.31	0.010	0.0008	0.040	0.0041	0.0025	0.0015	-	959	809	302	759	929	552	Conforming steel
C	0.142	0.75	3.11	0.011	0.0007	0.061	0.0056	0.0009	0.0015	-	953	803	327	753	923	577	Conforming steel
D	0.161	1.15	3.21	0.010	0.0009	0.050	0.0045	0.0020	0.0013	Sb : 0.007	955	805	315	755	925	565	Conforming steel
E	0.172	1.03	2.41	0.015	0.0013	0.038	0.0035	0.0011	0.0015	Cr: 0.20, Ca: 0.0035	951	801	335	751	921	585	Conforming steel
F	0.122	0.73	3.48	0.015	0.0010	0.045	0.0045	0.0020	0.0018	-	956	806	323	756	926	573	Conforming steel
G	0.134	1.08	2.77	0.005	0.0006	0.040	0.0035	0.0016	0.0025	Cr: 0.30	957	807	338	757	927	588	Conforming steel
H	0.144	0.89	2.47	0.009	0.0017	1.910	0.0055	0.0012	0.0006	Cr: 0.60, Sb : 0.019	949	799	340	749	919	590	Conforming steel
I	0.139	0.96	2.96	0.011	0.0009	0.050	0.0040	0.0009	0.0017	Mo : 0.23	964	814	329	764	934	579	Conforming steel
J	0.142	0.88	2.55	0.021	0.0006	0.037	0.0029	0.0007	0.0020	Mo: 0.41	970	820	339	770	940	589	Conforming steel
K	0.118	0.72	2.43	0.012	0.0013	0.048	0.0036	0.0011	0.0032	Mo : 0.34	969	819	355	769	939	605	Conforming steel
L	0.163	1.06	3.56	0.008	0.0006	0.040	0.0028	0.0023	0.0095	Cu : 1.02	1000	850	302	800	970	552	Conforming steel
M	0.145	0.99	2.96	0.014	0.0023	0.047	0.0038	0.0010	0.0010	Ni : 0.48, Mg : 0.0022	949	799	326	749	919	576	Conforming steel

(continued)

Type of steel	Chemical composition (% by mass) *										RC1 (°C)	RC2 (°C)	Trs (°C)	RC2-50 (°C)	RC2+120 (°C)	Trs+250 (°C)	Notes
	C	Si	Mn	P	S	Al	N	O	B	Others							
N	0.122	1.15	2.88	0.013	0.0009	0.043	0.0040	0.0010	0.0015	Ti: 0.021, REM: 0.0016	964	806	344	756	926	594	Conforming steel
O	0.108	1.11	2.77	0.019	0.0018	0.041	0.0098	0.0013	0.0007	Ti : 0.082, Nb : 0.037	1074	859	354	809	979	604	Conforming steel
P	0.125	0.99	2.82	0.034	0.0008	0.041	0.0041	0.0012	0.0009	Ti : 0.125, V: 0.013	1035	841	345	791	961	595	Conforming steel
Q	0.070	0.69	1.80	0.0018	0.0025	0.043	0.0052	0.0031	0.0016	Cr: 0.45, Ti : 0.12	1022	830	399	780	950	649	Conforming steel
a	0.043	1.05	2.50	0.029	0.0012	0.031	0.0044	0.0021	0.0017	-	938	788	393	738	908	643	Comparative steel
b	0.212	0.99	3.08	0.012	0.0039	0.028	0.0035	0.0024	0.0016	-	960	810	297	760	930	547	Comparative steel
c	0.145	0.35	3.42	0.025	0.0031	0.045	0.0055	0.0011	0.0019	-	959	809	315	759	929	565	Comparative steel
d	0.134	1.35	2.80	0.015	0.0005	0.058	0.0034	0.0015	0.0012	-	948	798	342	748	918	592	Comparative example
e	0.138	0.87	2.81	0.013	0.0012	0.052	0.0037	0.0012	0.0003	-	944	794	340	744	914	590	Comparative steel
f	0.142	0.96	1.24	0.020	0.0015	0.065	0.0042	0.0025	0.0019	Cr: 0.80	945	795	381	745	915	631	Comparative steel
9	0.133	0.71	4.15	0.010	0.0015	0.047	0.0062	0.0011	0.0014	-	962	812	295	762	932	545	Comparative steel
h	0.118	1.17	3.05	0.009	0.0009	0.051	0.0036	0.0017	0.0020	Cr : 1.10	964	814	324	764	934	574	Comparative steel

(continued)

Type of steel	Chemical composition (% by mass) *										RC1 (°C)	RC2 (°C)	Trs (°C)	RC2-50 (°C)	RC2+120 (°C)	Trs+250 (°C)	Notes
	C	Si	Mn	P	S	Al	N	O	B	Others							
k	0.140	0.92	2.95	0.014	0.0014	0.042	0.0041	0.0021	0.0008	Ti : 0.350	1193	920	334	870	1040	584	Comparative steel

The underlines are outside the scope of the present invention.
* The remainder is composed of Fe and incidental impurities.

[Table 2]

No.	Type of steel	Manufacturing conditions										Notes
		Heating	Hot rolling		First cooling				Coiling	Second cooling		
		Heating temperature (°C)	Total rolling reduction at of RC1 or less (%)	Finishing temperature (°C)	Time from completion of hot rolling to start of cooling (s)	Average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Average cooling rate of surface layer - average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Average cooling rate (°C/s)	Cooping stop temperature (°C)	
1	A	1250	35	840	1.0	60	15	435	445	5	50	Example
2	A	1210	45	920	1.4	45	17	470	460	8	55	Example
3	A	1200	30	870	0.5	80	18	360	375	4	35	Example
4	A	1240	35	880	0.8	55	16	570	550	6	80	Example
5	B	1230	45	875	1.0	75	22	455	470	11	45	Example
6	C	1220	35	855	1.6	37	16	530	520	17	75	Example
7	D	1220	60	865	1.0	92	21	425	445	5	40	Example
8	E	1270	30	845	0.6	75	15	500	490	7	80	Example
9	F	1200	45	875	0.8	62	18	360	390	3	40	Example
10	G	1250	50	820	1.0	55	19	410	420	3	50	Example
11	G	1230	35	910	1.4	38	18	405	430	7	70	Example
12	G	1260	45	880	0.5	32	22	355	345	4	85	Example
13	G	1240	30	885	0.8	95	21	580	570	8	75	Example
14	H	1230	60	865	1.0	47	17	420	440	6	70	Example
15	I	1250	40	850	1.6	38	16	475	490	4	55	Example
16	J	1240	30	880	1.0	46	15	520	510	9	70	Example

(continued)

No.	Type of steel	Manufacturing conditions										Notes
		Heating	Hot rolling		First cooling				Coiling	Second cooling		
		Heating temperature (°C)	Total rolling reduction at of RC1 or less (%)	Finishing temperature (°C)	Time from completion of hot rolling to start of cooling (s)	Average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Average cooling rate of surface layer - average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Average cooling rate (°C/s)	Cooping stop temperature (°C)	
17	K	1235	35	860	0.6	58	15	405	430	5	50	Example
18	L	1210	50	920	0.8	92	20	385	410	6	55	Example
19	M	1235	45	870	1.4	62	15	500	495	7	80	Example
20	N	1220	50	860	0.5	38	16	410	430	7	55	Example
21	O	1300	60	940	0.8	77	18	525	510	4	35	Example
22	P	1270	75	890	1.0	64	20	540	530	9	75	Example
23	Q	1240	40	900	1.6	70	16	460	440	6	70	Example
24	a	1250	35	900	1.0	88	14	400	420	10	35	Comparative example
25	b	1220	40	900	0.6	29	15	450	470	8	45	Comparative example
26	c	1210	55	890	0.8	16	17	400	435	6	50	Comparative example
27	d	1225	45	910	0.9	60	19	460	445	7	65	Comparative example
28	e	1215	40	905	1.0	46	15	390	425	4	25	Comparative example

(continued)

No.	Type of steel	Manufacturing conditions										Notes
		Heating	Hot rolling		First cooling				Coiling	Second cooling		
		Heating temperature (°C)	Total rolling reduction at of RC1 or less (%)	Finishing temperature (°C)	Time from completion of hot rolling to start of cooling (s)	Average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Average cooling rate of surface layer - average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Average cooling rate (°C/s)	Cooping stop temperature (°C)	
29	f	1230	35	895	1.4	32	16	520	510	5	50	Comparative example
30	g	1260	45	905	0.5	67	15	500	480	3	85	Comparative example
31	h	1220	35	920	0.8	78	16	400	430	3	80	Comparative example
32	t	1290	75	930	1.0	57	21	520	510	7	50	Comparative example
33	A	1245	15	900	1.6	60	15	480	465	8	60	Comparative example
34	A	1240	90	870	1.0	55	16	470	435	5	45	Comparative example
35	A	1250	45	735	1.4	50	17	430	450	5	35	Comparative example
36	A	1230	30	1020	0.5	70	15	525	510	3	45	Comparative example
37	A	1270	50	915	0.8	4	8	420	440	3	85	Comparative example

(continued)

No.	Type of steel	Manufacturing conditions										Notes
		Heating	Hot rolling		First cooling				Coiling	Second cooling		
		Heating temperature (°C)	Total rolling reduction at of RC1 or less (%)	Finishing temperature (°C)	Time from completion of hot rolling to start of cooling (s)	Average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Average cooling rate of surface layer - average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Average cooling rate (°C/s)	Cooping stop temperature (°C)	
38	A	1260	40	900	1.0	45	15	310	330	4	55	Comparative example
39	A	1240	30	920	1.6	50	9	650	630	3	75	Comparative example
40	A	1240	40	895	1.0	37	16	450	470	25	35	Comparative example
41	B	1220	40	750	0.6	49	15	430	440	6	55	Comparative example
42	C	1190	35	1040	0.8	56	15	390	410	3	50	Comparative example
43	D	1215	30	920	1.0	3	20	430	460	2	35	Comparative example
44	E	1230	40	880	1.4	34	15	280	300	6	55	Comparative example
45	G	1250	60	915	0.5	28	17	670	630	3	65	Comparative example

(continued)

No.	Type of steel	Manufacturing conditions										Notes
		Heating	Hot rolling		First cooling				Coiling	Second cooling		
		Heating temperature (°C)	Total rolling reduction at of RC1 or less (%)	Finishing temperature (°C)	Time from completion of hot rolling to start of cooling (s)	Average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Average cooling rate of surface layer - average cooling rate at position of three-tenths of thickness of steel sheet (°C/s)	Cooling stop temperature (°C)	Coiling temperature (°C)	Average cooling rate (°C/s)	Cooping stop temperature (°C)	
46	H	1230	50	905	0.8	67	20	525	510	35	30	Comparative example

The underlines are outside the scope of the present invention.

[Table 3]

No.	Type of steel	Microstructure													Hardness (HV)			Hardness difference with respect to [0.3 x tensile strength (MPa)] (%)	Mechanical properties						Notes
		Area ratio(%)												Average grain size of surface layer*) (μm)											
		Surface layer region*)						inner region**)																	
		UB	M	γ	M+γ	F	TM	UB	M	γ	M+γ	F	TM		Surface layer region*) HV1	Inner region**) HV2	Hardness difference, HV2-HV1		YP (MPa)	TS (MPa)	YR (%)	El (%)	u-El (%)	Critical bending radius R/thickness t	
1	A	90	8	2	10	0	0	88	9	3	12	0	0	4.9	416	453	37	10.0	1000	1232	81	15.9	7.1	1.0	Example
2	A	88	11	1	12	0	0	86	12	2	14	0	0	4.8	403	436	32	9.0	976	1195	82	17.8	9.2	0.8	Example
3	A	93	5	2	7	0	0	91	6	3	9	0	0	4.6	429	475	46	12.0	1025	1273	80	14.6	8.4	0.9	Example
4	A	83	13	4	17	0	0	81	14	5	19	0	0	5.0	412	463	51	14.0	951	1221	78	16.7	7.3	1.1	Example
5	B	82	13	5	18	0	0	80	14	6	20	0	0	4.8	447	490	44	11.0	1068	1325	81	12.7	6.7	0.8	Example
6	C	89	6	5	11	0	0	87	7	6	13	0	0	4.2	414	447	33	9.0	1028	1228	84	13.8	7.2	0.9	Example
7	D	85	12	3	15	0	0	83	13	4	17	0	0	3.5	428	459	30	8.0	1080	1270	85	16.9	9.1	1.0	Example
8	E	90	6	4	10	0	0	88	7	5	12	0	0	4.9	422	460	38	10.0	1102	1252	88	16.2	8.8	0.9	Example
9	F	82	16	2	18	0	0	80	17	3	20	0	0	4.7	438	481	43	11.0	1116	1298	86	13.9	6.1	0.9	Example
10	G	85	12	3	15	0	0	83	13	4	17	0	0	4.5	423	469	45	12.0	1004	1255	80	14.8	7.2	1.0	Example
11	G	85	13	2	15	0	0	83	14	3	17	0	0	4.3	426	464	38	10.0	1023	1263	81	14.7	7.3	1.1	Example
12	G	92	5	3	8	0	0	90	6	4	10	0	0	4.6	455	491	36	9.0	1121	1350	83	13.8	6.5	0.8	Example
13	G	82	14	4	18	0	0	80	15	5	20	0	0	4.0	410	454	44	12.0	1057	1215	87	17.2	7.8	1.2	Example
14	H	82	15	3	18	0	0	81	16	3	19	0	0	3.8	404	454	50	14.0	993	1196	83	17.2	8.8	1.1	Example
15	I	86	11	3	14	0	0	84	12	4	16	0	0	5.0	418	459	41	11.0	954	1239	77	15.8	8.2	0.9	Example
16	J	85	12	3	15	0	0	83	13	4	17	0	0	4.8	418	451	33	9.0	980	1238	79	15.9	8.7	0.8	Example
17	K	82	13	5	18	0	0	81	14	5	19	0	0	4.5	420	450	30	8.0	1010	1246	81	16.2	9.0	0.7	Example
18	L	80	16	4	20	0	0	78	17	5	22	0	0	4.1	433	472	39	10.0	1118	1285	87	13.9	7.1	0.9	Example
19	M	86	13	1	14	0	0	84	14	2	16	0	0	4.6	406	446	40	11.0	950	1203	79	15.9	8.1	0.6	Example
20	N	88	9	3	12	0	0	86	10	4	14	0	0	4.8	408	452	44	12.0	1004	1210	83	14.9	8.1	0.6	Example
21	O	86	10	4	14	0	0	84	11	5	16	0	0	3.8	407	443	36	10.0	1036	1205	86	15.7	9.3	0.7	Example
22	P	90	8	2	10	0	0	88	9	3	12	0	0	3.4	431	466	35	9.0	1125	1278	88	13.5	7.5	1.3	Example
23	Q	98	2	0	2	0	0	94	2	1	3	0	0	4.0	355	393	38	12.0	980	1050	93	18.1	8.9	0.8	Example
24	a	94	5	1	6	0	0	92	6	2	8	0	0	4.9	328	369	41	14.0	870	970	90	18.3	9.6	0.7	Comparative example
25	b	91	6	3	9	0	0	89	7	4	11	0	0	4.9	468	514	46	11.0	1265	1390	91	13.2	3.8	2.1	Comparative example
26	c	99	1	0	1	0	0	98	2	0	2	0	0	4.5	428	463	34	9.0	1080	1270	85	13.1	4.9	1.8	Comparative example
27	d	65	32	3	35	0	0	63	33	4	37	0	0	4.3	420	455	35	9.5	870	1234	71	14.1	6.0	2.0	Comparative example
28	e	69	27	4	31	0	0	68	26	6	32	0	0	5.0	425	455	30	8.0	1096	1260	87	15.2	4.8	1.9	Comparative example
29	f	100	0	0	0	0	0	99	1	0	1	0	0	4.7	395	430	35	10.0	1020	1170	87	16.4	5.4	1.6	Comparative example
30	g	69	26	5	31	0	0	69	26	5	31	0	0	4.9	452	496	44	11.0	871	1340	65	11.8	4.2	2.0	Comparative example
31	h	69	24	7	31	0	0	69	24	7	31	0	0	4.4	475	526	51	12.0	931	1410	66	10.8	3.2	2.0	Comparative example
32	k	69	29	2	31	0	0	67	30	3	33	0	0	2.9	468	510	42	10.0	1100	1390	79	11.7	5.2	2.0	Comparative example
33	A	91	8	1	9	0	0	89	9	2	11	0	0	7.6	398	433	35	10.0	1002	1178	85	13.8	6.4	1.7	Comparative example
34	A	94	5	1	6	0	0	92	6	2	8	0	0	1.7	425	459	34	9.0	1167	1260	93	12.2	5.5	1.6	Comparative example
35	A	90	7	3	10	0	0	88	8	4	12	0	0	2.4	465	514	50	12.0	1158	1379	84	12.9	5.1	2.0	Comparative example
36	A	89	9	2	11	0	0	87	10	3	13	0	0	6.8	388	437	48	16.7	905	965	94	13.8	7.2	1.7	Comparative example
37	A	79	7	4	11	10	0	77	10	3	13	10	0	4.0	328	340	12	4.1	860	970	89	13.8	7.2	1.3	Comparative example
38	A	7	1	0	1	0	92	6	2	0	2	0	92	3.2	478	521	43	10.0	1136	1420	80	9.8	3.2	2.0	Comparative example
39	A	0	0	0	0	100	0	0	0	0	0	100	0	5.4	318	329	11	3.9	840	940	89	14.8	7.2	1.3	Comparative example
40	A	67	31	2	33	0	0	65	32	3	35	0	0	4.6	388	423	35	10.0	897	1150	78	13.7	6.3	1.6	Comparative example
41	B	92	6	2	8	0	0	90	7	3	10	0	0	2.5	452	496	44	11.0	1126	1340	84	12.6	5.4	1.7	Comparative example
42	C	90	7	3	10	0	0	88	8	4	12	0	0	8.2	397	439	42	12.0	905	1175	77	15.9	7.1	1.6	Comparative example
43	D	0	0	0	0	100	0	0	0	0	0	100	0	5.0	325	354	29	10.0	797	960	83	17.8	9.2	1.3	Comparative example
44	E	2	1	1	2	0	96	2	2	0	2	0	96	3.2	492	531	39	9.0	1358	1460	93	8.8	3.2	2.0	Comparative example
45	G	0	0	0	0	100	0	0	0	0	0	100	0	5.7	328	357	29	10.0	930	970	96	14.7	8.3	0.9	Comparative example
46	H	2	95	3	98	0	0	0	96	4	100	0	0	3.8	508	551	43	9.5	1163	1510	77	7.9	3.1	2.0	Comparative example

The underlines are outside the scope of the present invention., UB: upper bainite M: fresh martensite γ: retained austenite F: polygonal ferrite martensite

*) A surface layer region extending from the surface to a position of one-tenth of the thickness of the steel sheet.

**) An inner region extending from one-tenth of the thickness of the steel sheet to a position of three-tenths of the thickness.

[0086] The results in Table 3 show that all the examples have a tensile strength of 980 MPa or more, high press formability, and high bendability.

Claims

1. A high-strength steel sheet comprising:

   a chemical composition containing, in mass%:

      C: 0.05% to 0.20%,
      Si: 0.5% to 1.2%,
      Mn: 1.5% to 4.0%,
      P: 0.10% or less,
      S: 0.03% or less,
      Al: 0.001% to 2.0%,
      N: 0.01% or less,
      O: 0.01% or less,
      B: 0.0005% to 0.010%, and the remainder being Fe and incidental impurities;

   a microstructure in a surface layer region extending from a surface of the steel sheet to a position of one-tenth of a thickness of the steel sheet containing 80% by area or more of upper bainite and 2% by area or more of fresh martensite and/or retained austenite in total; and
   a microstructure in an inner region extending from the position of one-tenth to a position of three-tenths of the thickness of the steel sheet containing 70% by area or more of upper bainite and 3% by area or more of fresh martensite and/or retained austenite in total,
   wherein:

      the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet has an average grain size of 6 pm or less;
      a difference (HV2 - HV1) between a hardness (HV1) of the surface layer region extending from the surface of the steel sheet to the position of one-tenth of the thickness of the steel sheet and a hardness (HV2) of the inner region extending from the position of one-tenth to the position of three-tenths of the thickness of the steel sheet is 5% or more and 15% or less of [0.3 x tensile strength (MPa)]; and
      the steel sheet has a tensile strength of 980 MPa or more, a uniform elongation of 6% or more, and a ratio R/t of a critical bending radius R to a thickness t of 1.5 or less.

2. The high-strength steel sheet according to Claim 1, wherein the chemical composition further contains, in mass%, at least one of

   Cr: 1.0% or less and
   Mo: 1.0% or less.

3. The high-strength steel sheet according to Claim 1 or 2, wherein the chemical composition further contains, in mass%, at least one of

   Cu: 2.0% or less,
   Ni: 2.0% or less,
   Ti: 0.3% or less,
   Nb: 0.3% or less, and
   V: 0.3% or less.

4. The high-strength steel sheet according to any one of Claims 1 to 3, wherein the chemical composition further contains, in mass%,
   Sb: 0.005% to 0.020%.

5. The high-strength steel sheet according to any one of Claims 1 to 4, wherein the chemical composition further contains, in mass%, at least one of

Ca: 0.01% or less,
Mg: 0.01% or less, and
REM: 0.01% or less.

6. A method for manufacturing the high-strength steel sheet according to any one of Claims 1 to 5, comprising:

heating a steel material having the chemical composition to a heating temperature of 1150°C or more;
then rough rolling the steel material, and then hot rolling the steel material into a hot-rolled steel sheet under conditions of a finishing temperature: (RC2 - 50°C) or more and (RC2 + 120°C) or less and a total rolling reduction of 25% or more and 80% or less at a temperature of RC1 or less;
cooling the hot-rolled steel sheet under conditions of a time from completion of the hot rolling to start of cooling: 2.0 seconds or less, an average cooling rate at the position of three-tenths of the thickness of the steel sheet: 15°C/s or more, and a cooling stop temperature: Trs or more and (Trs + 250°C) or less;
coiling the hot-rolled steel sheet after the cooling at a coiling temperature: Trs or more and (Trs + 250°C) or less; and
cooling the hot-rolled steel sheet to 100°C or less at an average cooling rate of 20°C/s or less,
wherein RC1, RC2, and Trs are represented by the following formulae (1), (2), and (3), respectively,

$$\mathrm{RC1}\ (^\circ\mathrm{C}) = 900 + 100 \times \mathrm{C} + 100 \times \mathrm{N} + 10 \times \mathrm{Mn} + 700 \times \mathrm{Ti} + 5000 \times \mathrm{B} + 10 \times \mathrm{Cr} + 50 \times \mathrm{Mo} + 2000 \times \mathrm{Nb} + 150 \times \mathrm{V} \quad (1)$$

$$\mathrm{RC2}\ (^\circ\mathrm{C}) = 750 + 100 \times \mathrm{C} + 100 \times \mathrm{N} + 10 \times \mathrm{Mn} + 350 \times \mathrm{Ti} + 5000 \times \mathrm{B} + 10 \times \mathrm{Cr} + 50 \times \mathrm{Mo} + 1000 \times \mathrm{Nb} + 150 \times \mathrm{V} \quad (2)$$

$$\mathrm{Trs}\ (^\circ\mathrm{C}) = 500 - 450 \times \mathrm{C} - 35 \times \mathrm{Mn} - 15 \times \mathrm{Cr} - 10 \times \mathrm{Ni} - 20 \times \mathrm{Mo} \quad (3)$$

where each element symbol in the formulae (1), (2), and (3) denotes a corresponding element content (% by mass) and is 0 in the absence of the element.

7. The method for manufacturing the high-strength steel sheet according to Claim 6, wherein in the cooling after the hot rolling, an average cooling rate of the surface layer and the average cooling rate at the position of three-tenths of the thickness of the steel sheet satisfy the formula (4):

Average cooling rate of surface layer - average cooling rate at position of three-tenths of thickness of steel sheet ≥ 10°C/s (4).

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/011493

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/06***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301W; C21D9/46 T; C21D8/02 A; C22C38/06; C22C38/60

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21D8/02; C21D9/46; C22C38/00; C22C38/06; C22C38/60

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2018/150955 A1 (JFE STEEL CORP) 23 August 2018 (2018-08-23)	1-7
A	JP 2016-050335 A (NIPPON STEEL & SUMITOMO METAL CORP) 11 April 2016 (2016-04-11)	1-7
A	JP 2015-190015 A (JFE STEEL CORP) 02 November 2015 (2015-11-02)	1-7
A	JP 2007-100190 A (KOBE STEEL LTD) 19 April 2007 (2007-04-19)	1-7

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

* Special categories of cited documents:
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Date of the actual completion of the international search **31 May 2022**	Date of mailing of the international search report **07 June 2022**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/011493

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