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

(72) Inventors:
• **KOBAYASHI, Shunsuke**
Tokyo 100-8071 (JP)
• **OSANAI, Takumi**
Tokyo 100-8071 (JP)
• **SAKURADA, Eisaku**
Tokyo 100-8071 (JP)

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

(54) **STEEL PLATE**

(57) Provided is a steel sheet having a predetermined chemical composition, and a microstructure comprising, by area%, martensite: 90.0% or more and retained austenite: 3.0% or less, wherein a mean particle size of prior austenite grains is 30.0 μm or less, and when

defining a region surrounded by grain boundaries with an orientation difference of 15° or more in the martensite as a "crystal grain", a ratio of crystal grains with an orientation difference in the grains of 4° or more is, by area%, 45.0 to 70.0%.

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Description

FIELD

5 **[0001]** The present invention relates to a steel sheet.

BACKGROUND

10 **[0002]** In recent years, to deal with environmental issues, lightening the weight of auto parts has been desired for the purpose of reduction of emission of CO₂ gas and improvement of fuel efficiency. On the other hand, there have been increasing social calls for improvement of collision safety. To achieve both lighter weight and improved collision safety, increasing the strength of steel materials is an effective means. However, usually, if increasing the strength of steel materials, the workability falls, and therefore steel materials simultaneously improved in strength and workability have been considered necessary.

15 **[0003]** In relation to improvement of strength and workability, for example, PTL 1 describes a hot rolled steel sheet having a chemical composition containing, by mass%, C: 0.020 to 0.070%, Si: 0.10 to 1.70%, Mn: 0.60 to 2.50%, Al: 0.01 to 1.00%, Ti: 0.015 to 0.170%, Nb: 0.005 to 0.050%, etc., limiting P: 0.05% or less, S: 0.010% or less, and N: 0.0060% or less, and having a balance of Fe and impurities, having a structure containing an area ratio of 5 to 60% of ferrite and 30 to 95% of bainite, in which structure, a boundary with an orientation difference of 15° or more being deemed a grain boundary, when
20 defining a region surrounded by the grain boundaries and with a circle equivalent diameter of 0.3 μm or more as a "crystal grain", having a ratio of crystal grains with an orientation difference in the grains of 5 to 14° of an area% of 20 to 100%. Further, PTL 1 teaches that by making the ratio of crystal grains with an orientation difference in the grains of 5 to 14° an area ratio of 20% or more, it is possible to maintain the desired steel sheet strength while improving the stretch flangeability (hole expandability).

25 **[0004]** PTL 2 describes a high strength steel material with prior γ grains of a spherical shape containing, by mass ratio, C: 0.06 to 0.19%, Si: 0.15 to 0.60%, Mn: 0.60 to 1.80%, Cr: 0.05 to 1.20%, and Mo: 0.05 to 1.00% and containing one or more of Nb: 0.005 to 0.10%, V: 0.005 to 0.10%, and Ti: 0.005 to 0.10%, which steel material containing carbonitrides of Nb, Ti, or V with a particle size of 100 nm or less in a volume ratio of 0.01 to 0.8%, having prior γ grains of a particle size no. 7 or more, and having a martensite structure or a mixed structure of martensite and bainite in the prior γ grains. Further, PTL 2 teaches
30 that according to the above configuration, it becomes possible to provide high strength steel material excellent in toughness, arrestability, and weldability and having a large uniform elongation property of more than 10% and a good mass producibility.

[0005] PTL 3 describes a high carbon steel sheet member containing C: 0.80 mass% to 1.10 mass%, Si: 0.05 mass% to 0.40 mass%, Mn: 0.05 mass% to 0.50 mass%, Cr: 0.01 mass% to 0.35 mass%, P: 0.03 mass% or less, and S: 0.03 mass%
35 or less and having a balance of Fe and unavoidable impurities, in which high carbon steel sheet member, a circle equivalent diameter of martensite blocks defined by an orientation difference of 15° or more being 3.2 μm or less, carbides of a circle equivalent diameter of 0.2 μm or more being present in 0.6 to 5.0 area%, an average particle size of the carbides being 0.3 μm or more and 2.0 μm or less, a carbon occupancy on the prior austenite grain boundaries being 0.35% or less, and an average value of KAM measured by EBSD being 0.690 to 0.710. Further, PTL 3 teaches that according to this
40 configuration, it is possible to obtain a high carbon steel sheet member with high levels of both hardness and hardness-toughness balance.

[CITATION LIST]

45 [PATENT LITERATURE]

[0006]

[PTL 1] WO2016/136672

50 [PTL 2] Japanese Unexamined Patent Publication No. 2002-088440

[PTL 3] Japanese Unexamined Patent Publication No. 2018-048375

SUMMARY

55 [TECHNICAL PROBLEM]

[0007] As explained above, it is known that along with higher strength, the workability of a steel material falls and the hole expandability and other properties fall such as described in PTL 1. If the hole expandability falls, for example, sometimes it

is not possible to work the steel into a desired shape in transmission parts of automobiles, etc. For this reason, in the development of a high strength hot rolled steel sheet and other high strength steel sheet, it is important to secure the properties corresponding to the application to a certain extent or more while trying to raise the strength. Further, a steel sheet for automobile use is usually worked into the shape of the desired part by press-forming. Usually, press-forming is performed divided into several steps, and therefore there are a relatively large number of locations for example receiving primary deformation and accumulating strain inside the steel sheet and, in that state, again receiving separate deformation (stretch flange deformation, etc.) However, if strain is introduced into a steel sheet, work hardening occurs and the strength becomes higher, and therefore the workability in the later steps generally falls. For this reason, a steel sheet is being asked to exhibit high formability by for example having excellent work hardening ability (performance of continuing to become harder) even in a state where a certain degree of strain is introduced.

[0008] The present invention was made in consideration of this actual situation and has as its object to provide, by a novel constitution, a steel sheet which, despite being high strength, is improved in hole expandability and work hardening ability.

[SOLUTION TO PROBLEM]

[0009] The inventors engaged in studies focusing on the microstructure of a steel sheet, in particular a hot rolled steel sheet, to achieve the above object. As a result, the inventors discovered that by making the microstructure of a hot rolled steel sheet having a predetermined chemical composition a structure mainly comprised of martensite, it is possible to achieve higher strength and improved hole expandability and that by limiting the mean particle size of prior austenite grains in the microstructure to within a predetermined range while suitably controlling the ratio of crystal grains having a predetermined grain orientation difference in the martensite structure, it is possible to remarkably improve the work hardening ability, and thereby completed the present invention.

[0010] The present invention able to achieve the above object is as follows:

(1) A steel sheet

having a chemical composition comprising, by mass%,

C: 0.040 to 0.200%,

Si: 0.30 to 2.00%,

Mn: 1.00 to 4.00%,

sol. Al: 0.001 to 0.500%,

P: 0.100% or less,

S: 0.0300% or less,

N: 0.0070% or less,

O: 0.0100% or less,

Nb: 0.001 to 1.000%,

Ti: 0 to 0.200%,

V: 0 to 0.300%,

Cu: 0 to 0.40%,

Cr: 0 to 0.90%,

Mo: 0 to 0.12%,

Ni: 0 to 0.30%,

B: 0 to 0.0030%,

Ca: 0 to 0.0010%,

Mg: 0 to 0.0010%,

Bi: 0 to 0.010%,

Zr: 0 to 0.050%,

Co: 0 to 0.010%,

Zn: 0 to 0.010%,

W: 0 to 0.100%,

Sn: 0 to 0.040%,

As: 0 to 0.100%,

REM: 0 to 0.0100%, and

balance: Fe and impurities, and

a microstructure comprising, by area%,

martensite: 90.0% or more, and

retained austenite: 3.0% or less, wherein

a mean particle size of prior austenite grains is 30.0 μm or less, and when defining a region surrounded by grain boundaries with an orientation difference of 15° or more in the martensite as a "crystal grain", a ratio of crystal grains with an orientation difference in the grains of 4° or more is, by area%, 45.0 to 70.0%.

(2) The steel sheet according to the above (1), wherein the chemical composition comprises, by mass%, at least one of

Ti: 0.001 to 0.200%,
V: 0.001 to 0.300%,
Cu: 0.001 to 0.40%,
Cr: 0.001 to 0.90%,
Mo: 0.001 to 0.12%,
Ni: 0.001 to 0.30%,
B: 0.0001 to 0.0030%,
Ca: 0.0001 to 0.0010%,
Mg: 0.0001 to 0.0010%,
Bi: 0.001 to 0.010%,
Zr: 0.001 to 0.050%,
Co: 0.001 to 0.010%,
Zn: 0.001 to 0.010%,
W: 0.001 to 0.100%,
Sn: 0.001 to 0.040%,
As: 0.001 to 0.100%, and
REM: 0.0001 to 0.0100%.

(3) The steel sheet according to the above (1) or (2), wherein the microstructure further comprises, by area%, at least one of

ferrite: 10.0% or less,
bainite: 10.0% or less, and
pearlite: 10.0% or less.

(4) The steel sheet according to any one of the above (1) to (3), wherein a ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains is, by area%, 90.0% or more.

(5) The steel sheet according to any one of the above (1) to (4), wherein a sheet thickness is 1.0 to 7.0 mm.

(6) A part including the steel sheet according to any one of the above (1) to (5).

[ADVANTAGEOUS EFFECTS OF INVENTION]

[0011] According to the present invention, it is possible to provide a steel sheet, in particular a hot rolled steel sheet, which, despite being high strength, is improved in hole expandability and work hardening ability.

DESCRIPTION OF EMBODIMENTS

<Steel Sheet>

[0012] The steel sheet according to an embodiment of the present invention, in particular the hot rolled steel sheet, has a chemical composition comprising, by mass%,

C: 0.040 to 0.200%,
Si: 0.30 to 2.00%,
Mn: 1.00 to 4.00%,
sol. Al: 0.001 to 0.500%,
P: 0.100% or less,
S: 0.0300% or less,
N: 0.0070% or less,
O: 0.0100% or less,
Nb: 0.001 to 1.000%,

Ti: 0 to 0.200%,
 V: 0 to 0.300%,
 Cu: 0 to 0.40%,
 Cr: 0 to 0.90%,
 Mo: 0 to 0.12%,
 Ni: 0 to 0.30%,
 B: 0 to 0.0030%,
 Ca: 0 to 0.0010%,
 Mg: 0 to 0.0010%,
 Bi: 0 to 0.010%,
 Zr: 0 to 0.050%,
 Co: 0 to 0.010%,
 Zn: 0 to 0.010%,
 W: 0 to 0.100%,
 Sn: 0 to 0.040%,
 As: 0 to 0.100%,
 REM: 0 to 0.0100%, and
 balance: Fe and impurities, and
 a microstructure comprising, by area%,
 martensite: 90.0% or more, and
 retained austenite: 3.0% or less, wherein
 a mean particle size of prior austenite grains is 30.0 μm or less, and
 when defining a region surrounded by grain boundaries with an orientation difference of 15° or more in the martensite
 as a "crystal grain", a ratio of crystal grains with an orientation difference in the grains of 4° or more is, by area%, 45.0 to
 70.0%.

[0013] As explained previously, it is known that along with an increase in the strength of a steel material, the hole expandability and other properties fall. For example, to produce a part having a complicated shape such as a lower arm, trailing arm, etc., among the transmission parts of an automobile, a steel sheet securing a high strength, in particular high strength of a tensile strength of 980 MPa or more enabling reduction of weight, while having excellent hole expandability is being sought. From the viewpoint of raising the strength, the microstructure of the steel sheet is preferably made a structure mainly comprised of martensite. However, martensitic steel has a layered structure including packets, blocks, laths, and other substructures in the prior austenite grains. While excellent in strength, in general, there is a problem of a low workability. For this reason, in forming operations performed divided into several steps such as press-forming, due to the work hardening caused by strain introduced in the initial period of deformation, in the latter period of deformation, the workability generally falls. Therefore, a steel sheet able to realize both high strength and workability by exhibiting a high work hardening ability even in the latter period of deformation of press-forming is being sought.

[0014] Therefore, the inventors engaged in studies focusing in particular on the microstructure of the hot rolled steel sheet in addition to prescribing a suitable chemical composition of the steel sheet, in particular the hot rolled steel sheet. First, the inventors discovered that by making the microstructure of hot rolled steel sheet having a predetermined chemical composition a structure mainly comprised of martensite, more specifically, a structure containing, by area%, martensite: 90.0% or more and retained austenite: 3.0% or less, it is possible to achieve high strength, for example, high strength of a tensile strength of 980 MPa or more, while remarkably improving the hole expandability of the hot rolled steel sheet. While not intending to be bound by any specific theory, it is believed that by making the microstructure a more uniform structure comprising martensite in an area% of 90.0% or more, it is possible to reduce the hardness difference in the microstructure compared with the case where other structures softer than martensite, for example, ferrite, etc., are contained in relatively large amounts and that due to such reduction of the hardness difference, the hole expandability can be improved. Further, retained austenite can become starting points for fracture during deformation in press-forming, etc., and therefore by limiting the retained austenite to an area% of 3.0% or less in addition to controlling the martensite to an area% of 90.0% or more, the hole expandability can be improved more remarkably.

[0015] Next, since it is believed prior austenite grain boundaries act as resistance against motion of dislocations and would be effective for improving work hardening ability, the inventors studied improvement of the work hardening ability from the viewpoint of making the particle size of the prior austenite grains in a microstructure mainly comprised of martensite a suitable one. More specifically, by making the prior austenite grains finer, it is possible to increase the density of prior austenite grain boundaries. For this reason, it is possible to increase the obstacles to dislocation by making the prior austenite grains finer and therefore it becomes possible to raise the work hardening ability. However, if just making the prior austenite grains finer, for example, sometimes a sufficient work hardening ability cannot be exhibited in a latter period of deformation of a forming operation such as press-forming performed divided into several steps. Therefore, the inventors

took note of control of the form of the martensite structure in addition to control of the particle size in prior austenite grains and studied the same. As a result, the inventors discovered that by making the prior austenite grains finer within a predetermined range, more specifically controlling the mean particle size of prior austenite grains to 30.0 μm or less, the work hardening ability of the hot rolled steel sheet as a whole is improved while by suitably controlling the ratio of specific

crystal grains in the martensite structure, more specifically, when defining a region surrounded by grain boundaries with an orientation difference of 15° or more in the martensite as a "crystal grain", by controlling a ratio of crystal grains with an orientation difference in the grains of 4° or more to a range of, by area%, 45.0 to 70.0%, it is possible to achieve a high work hardening rate even in a state where a certain extent of strain is introduced such as at the latter period of press-forming.

[0016] While not intending to be bound by any specific theory, by controlling the ratio of crystal grains with an orientation difference in the grains of 4° or more in the martensite to a range of, by area%, 45.0 to 70.0%, it is possible to form a martensite structure with dislocations unevenly dispersed. It is believed that such a martensite structure contributes to a high work hardening rate in the latter period of deformation in press-forming, etc. More specifically, the orientation difference in the crystal grains expresses the state of dispersion of dislocations. The more unevenly the dislocations are dispersed, generally the greater the orientation difference in the grains becomes. Therefore, by including crystal grains raised in orientation difference in the grains in the martensite in a suitable ratio and establishing the presence of a certain amount of a structure with dislocations unevenly dispersed, uneven deformation occurs during press-forming and other working. As a result, even in the latter period of deformation, a sufficient work hardening ability can be maintained and therefore it is believed a high work hardening rate can be achieved. In particular, crystal grains with an orientation difference in the grains of 4° or more are crystal grains sufficient for causing uneven deformation. By controlling such crystal grains to within a range of, by area%, 45.0 to 70.0%, it becomes possible to achieve the desired work hardening rate. Therefore, even at a location receiving primary deformation in for example press-forming, etc., and accumulating strain inside the steel sheet and, in that state, again receiving separate deformation (stretch flange deformation, etc.), according to the steel sheet according to an embodiment of the present invention, it becomes possible to stably form the structure for maintaining a high work hardening ability. The fact that in a microstructure mainly comprised of martensite, by controlling the ratio of the crystal grains with a raised orientation difference in the grains to within a predetermined range and forming a structure with dislocations unevenly dispersed, it is possible to improve the work hardening ability of the steel sheet has not been conventionally known and was first made clear this time by the inventors. As a result, according to the steel sheet according to an embodiment of the present invention, for example, despite being a high strength of a tensile strength of 980 MPa or more, the hole expandability and work hardening ability can be remarkably improved. Therefore, the steel sheet according to an embodiment of the present invention can reliably achieve the contradictory properties of high strength and excellent workability, and therefore is particularly useful in use in the automotive field where realization of both of these properties is sought.

[0017] Below, the steel sheet according to an embodiment of the present invention will be explained in more detail. In the following explanation, the "%" of the units of contents of the elements, unless otherwise indicated, means "mass%". Further, in this Description, the "to" showing a numerical range, unless otherwise indicated, is used in the sense of the numerical values described before and after the same being included as the lower limit value and the upper limit value.

[C: 0.040 to 0.200%]

[0018] C is an element effective for raising the strength of steel sheet. Further, C forms carbides and/or carbonitrides with Nb in the steel and contributes to refinement of the structure by the pinning effect of the precipitates formed. To sufficiently obtain these effects, the C content is 0.040% or more. The C content may also be 0.060% or more, 0.080% or more, 0.100% or more, or 0.120% or more. On the other hand, if excessively containing C, sometimes the workability falls. Therefore, the C content is 0.200% or less. The C content may also be 0.180% or less, 0.160% or less, 0.150% or less, or 0.140% or less.

[Si: 0.30 to 2.00%]

[0019] Si is an element effective for raising the strength as a solution strengthening element. To sufficiently obtain such an effect, the Si content is 0.30% or more. The Si content may also be 0.40% or more, 0.50% or more, 0.60% or more, 0.70% or more, 0.85% or more, 1.00% or more, or 1.20% or more. On the other hand, if excessively containing Si, the chemical convertability and workability fall and during hot rolling, slab cracking sometimes occurs. Therefore, the Si content is 2.00% or less. The Si content may also be 1.80% or less, 1.60% or less, 1.50% or less, or 1.40% or less.

[Mn: 1.00 to 4.00%]

[0020] Mn is an element effective for raising the hardenability and the strength as a solution strengthening element. To sufficiently obtain these effects, the Mn content is 1.00% or more. The Mn content may also be 1.20% or more, 1.50% or

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more, 1.80% or more, 2.00% or more, or 2.20% or more. On the other hand, if excessively containing Mn, the workability sometimes falls. Therefore, the Mn content is 4.00% or less. The Mn content may also be 3.80% or less, 3.50% or less, 3.20% or less, 3.00% or less, or 2.80% or less.

5 [sol. Al: 0.001 to 0.500%]

[0021] sol. Al is an element acting as a deoxidizer of molten steel. Further, sol. Al is an element suppressing the precipitation of the cementite so harmful to hole expandability. To obtain these effects, the sol. Al content is 0.001% or more. The sol. Al content may also be 0.010% or more, 0.020% or more, 0.030% or more, 0.050% or more, or 0.100% or more. On the other hand, even if excessively containing sol. Al, the effect becomes saturated and a rise in production costs is liable to be invited. Therefore, the sol. Al content is 0.500% or less. The sol. Al content may also be 0.400% or less, 0.300% or less, or 0.200% or less. "sol. Al" means acid soluble Al and indicates solid solution Al present in the steel in a solid solution state.

15 [P: 0.100% or Less]

[0022] If P is excessively contained, sometimes grain boundary segregation, etc., causes the workability to fall. Therefore, the P content is 0.100% or less. The P content may also be 0.050% or less, 0.030% or less, 0.020% or less, or 0.015% or less. The lower limit of the P content is not particularly prescribed and may also be 0%, but excessive reduction would invite a rise in costs. Therefore, the P content may also be 0.0001% or more, 0.001% or more, or 0.005% or more.

[S: 0.0300% or Less]

25 [0023] If S is excessively contained, sometimes MnS and other sulfides are formed in large amounts and the workability is made to fall. Therefore, the S content is 0.0300% or less. The S content may also be 0.0200% or less, 0.0100% or less, or 0.0050% or less. The lower limit of the S content is not particularly prescribed and may also be 0%, but excessive reduction would invite a rise in costs. Therefore, the S content may also be 0.0001% or more, 0.0010% or more, or 0.0030% or more.

30 [N: 0.0070% or Less]

[0024] If N is excessively contained, sometimes coarse nitrides are formed and the workability is made to fall. Therefore, the N content is 0.0070% or less. The N content may also be 0.0050% or less, 0.0040% or less, or 0.0030% or less. The lower limit of the N content is not particularly prescribed and may also be 0%, but excessive reduction would invite a rise in costs. Therefore, the N content may also be 0.0001% or more or 0.0005% or more.

[O: 0.0100% or Less]

40 [0025] O is an element entering in the production process. If excessively containing O, coarse inclusions are formed and the workability of the steel sheet is liable to fall. Therefore, the O content is 0.0100% or less. The O content may also be 0.0080% or less, 0.0060% or less, or 0.0040% or less. The lower limit of the O content is not particularly prescribed and may also be 0%, but reduction to less than 0.0001% would require time for refining and invite a drop in productivity. Therefore, the O content may also be 0.0001% or more or 0.0005% or more.

45 [Nb: 0.001 to 1.000%]

[0026] Nb is an element forming carbides, nitrides, and/or carbonitrides in the steel and contributes to refinement of the structure of the retained austenite grains and in turn higher strength of the steel sheet by the pinning effect. To sufficiently obtain these effects, the Nb content is 0.001% or more. The Nb content may also be 0.005% or more, 0.010% or more, 0.050% or more, 0.100% or more, 0.200% or more, or 0.300% or more. On the other hand, if excessively containing Nb, coarse carbides, etc., are formed in the steel and the workability of the steel sheet sometimes falls. Therefore, the Nb content is 1.000% or less. The Nb content may also be 0.800% or less, 0.600% or less, or 0.500% or less.

[0027] The basic chemical composition of the steel sheet according to an embodiment of the present invention is as explained above. Furthermore, the steel sheet may, according to need, further contain at least one of the following elements in place of part of the balance of Fe.

[Cr: 0 to 0.90%]

[0028] Cr is an element raising the hardenability of steel and contributing to improvement of the strength and/or corrosion resistance. The Cr content may also be 0%, but to obtain these effects, the Cr content is preferably 0.001% or more and may also be 0.01% or more, 0.05% or more, or 0.10% or more. On the other hand, even if excessively containing Cr, the effect becomes saturated and a rise in production costs is liable to be invited. Therefore, the Cr content is preferably 0.90% or less and may also be 0.70% or less, 0.50% or less, 0.40% or less, or 0.30% or less.

[Ti: 0 to 0.200%, V: 0 to 0.300%, Cu: 0 to 0.40%, Mo: 0 to 0.12%, Ni: 0 to 0.30%, B: 0 to 0.0030%, Ca: 0 to 0.0010%, Mg: 0 to 0.0010%, Bi: 0 to 0.010%, Zr: 0 to 0.050%, Co: 0 to 0.010%, Zn: 0 to 0.010%, W: 0 to 0.100%, Sn: 0 to 0.040%, As: 0 to 0.100%, and REM: 0 to 0.0100%]

[0029] Ti, V, Cu, Mo, Ni, B, Ca, Mg, Bi, Zr, Co, Zn, W, Sn, As, and REM may be contained in the steel sheet as optional elements or sometimes are present in the steel sheet as tramp elements. The contents of these elements may also be Ti: 0 to 0.200%, or 0.100%, V: 0 to 0.300%, or 0.200%, Cu: 0 to 0.40%, or 0.20%, Mo: 0 to 0.12% or 0.08%, Ni: 0 to 0.30%, or 0.15%, B: 0 to 0.0030%, or 0.0015%, Ca: 0 to 0.0010%, or 0.0008%, Mg: 0 to 0.0010%, or 0.0008%, Bi: 0 to 0.010%, Zr: 0 to 0.050%, or 0.030%, Co: 0 to 0.010%, Zn: 0 to 0.010%, W: 0 to 0.100%, or 0.050%, Sn: 0 to 0.040%, or 0.020%, As: 0 to 0.100%, or 0.050%, and REM: 0 to 0.0100%, or 0.0050%. Regarding the lower limit values of these elements, for example, the Ti, V, Cu, Mo, Ni, Bi, Zr, Co, Zn, W, Sn, and As contents may also be 0.001% or more, 0.005% or more, or 0.008% or more. Similarly, the B, Ca, Mg and REM content may also be 0.0001% or more, 0.0002% or more, or 0.0005% or more.

[0030] In the steel sheet according to an embodiment of the present invention, the balance besides the above-mentioned elements is comprised of Fe and impurities. The "impurities" are constituents, etc., entering from ore, scrap, and other such starting materials due to various factors in the production process when, for example, industrially producing the steel sheet. They are allowed to be included in a range not affecting the effect of the present invention.

[0031] The chemical composition of the steel sheet according to an embodiment of the present invention may be measured by a general analysis method. For example, the chemical composition of the steel sheet may be measured by inductively coupled plasma-atomic emission spectrometry (ICP-AES). C and S can be measured using the combustion-infrared absorption method, N using the inert gas melting-thermal conductivity method, and O using the inert gas melting-nondispersive type infrared absorption method.

[Microstructure]

[Martensite: 90.0% or More and Retained Austenite: 3.0% or Less]

[0032] The microstructure of the steel sheet according to an embodiment of the present invention includes, by area%, martensite: 90.0% or more and retained austenite: 3.0% or less. By configuring the microstructure of the steel sheet to include these structures, it is possible to achieve high strength, for example, high strength of a tensile strength of 980 MPa or more, while remarkably improving the hole expandability of the obtained steel sheet. More specifically, by controlling the hard martensite to a range of, by area%, 90.0% or more to obtain a more uniform structure, not only is higher strength contributed to, but also the hardness difference in the microstructure can be reduced. Due to such reduction of the hardness difference, the hole expandability can be improved. If the area ratio of the martensite is less than 90.0%, the desired strength and hole expandability cannot be achieved. From the viewpoint of further higher strength and improved hole expandability, the higher the area ratio of martensite, the more preferable. For example, it may be 92.0% or more, 94.0% or more, 96.0% or more, or 98.0% or more. The upper limit of the area ratio of martensite is not particularly prescribed and may also be 100.0%. For example, it may be 99.0% or less. On the other hand, retained austenite can form starting points for fracture during deformation in press-forming, etc., and therefore by controlling the martensite to an area% of 90.0% or more plus controlling the retained austenite to an area% of 3.0% or less, it becomes possible to more remarkably improve the hole expandability. If the area ratio of the retained austenite is more than 3.0%, the grains form starting points for fracture during deformation and the hole expandability falls. From the viewpoint of further improving the hole expandability, the lower the area ratio of the retained austenite, the more preferable. For example, it may be 2.5% or less, 2.0% or less, 1.5% or less, or 1.0% or less. The lower limit of the area ratio of the retained austenite is not particularly limited and may be 0%. For example, it may be 0.5% or more.

[Balance Structures]

[0033] The balance structures besides the martensite and retained austenite may be an area% of 0%, but if there are balance structures present, the balance structures may include at least one of ferrite: 10.0% or less, bainite: 10.0% or less, and pearlite: 10.0% or less. If the area ratio of the at least one of ferrite, bainite, and pearlite is a total of more than 10.0%, the

area ratio of martensite becomes less than 90.0%, and therefore as a result the desired strength and hole expandability can no longer be achieved. The lower limits of ferrite, bainite, and pearlite may respectively be 0%. For example, they are respectively 0.1% or more, 0.5% or more, 1.0% or more, 2.0% or more, or 3.0% or more. Similarly, the upper limits of ferrite, bainite, and pearlite may be respectively 8.0% or less, 6.0% or less, 5.0% or less, or 4.0% or less.

[Identification of Microstructure and Calculation of Area Ratios]

[0034] The microstructure in steel sheet is identified and the area ratios are calculated by examination under an optical microscope and X-ray diffraction after corrosion using a Nital reagent or LePera solution. The structure is examined under an optical microscope at a sheet thickness cross-section in a direction vertical to the sheet surface. Note that the sheet thickness cross-section is preferably parallel to the rolling direction. Specifically, first, a sample is taken from the steel sheet and examined surface of the sample is etched by Nital. Next, an optical microscope is used to photograph a $300\text{ }\mu\text{m} \times 300\text{ }\mu\text{m}$ field at the 1/4 depth position of sheet thickness. The obtained structural photograph is analyzed to calculate the total area of the martensite and bainite and the individual area ratios of ferrite and pearlite. Next, the sample with the examined surface corroded by the LePera solution is used and an optical microscope is similarly used to photograph a $300\text{ }\mu\text{m} \times 300\text{ }\mu\text{m}$ field at the 1/4 depth position of sheet thickness. The obtained structural photograph is analyzed to calculate the total area ratio of martensite and retained austenite. Next, a sample ground at its surface down to 1/4 depth of sheet thickness from the logarithmic direction of the rolled surface is used to calculate the volume ratio of the retained austenite by X-ray diffraction measurement. The volume ratio of retained austenite is equal to the area ratio, and therefore this is deemed the area ratio of the retained austenite. The obtained area ratio of retained austenite is subtracted from the total area ratio of martensite and retained austenite similarly calculated previously to calculate the area ratio of martensite. Finally, the obtained area ratio of martensite is subtracted from the total area ratio of martensite and bainite similarly calculated in advance to thereby calculate the area ratio of the bainite.

[Mean Particle Size of Prior Austenite Grains: 30.0 μm or Less]

[0035] In the steel sheet according to an embodiment of the present invention, the mean particle size of the prior austenite grains is 30.0 μm or less. As explained previously, prior austenite grain boundaries act as resistance to motion of dislocations and are believed effective for improvement of the work hardening ability. In relation to this, by refining the prior austenite grains, it is possible to increase the density of the prior austenite grain boundaries. For this reason, by refining the prior austenite grains to 30.0 μm or less, it is possible to increase the obstacles to dislocation and therefore possible to raise the work hardening ability of the obtained steel sheet. From the viewpoint of further raising the work hardening ability of the steel sheet, the smaller the mean particle size of the prior austenite grains, the more preferable. For example, it may be 28.0 μm or less, 25.0 μm or less, 22.0 μm or less, 20.0 μm or less, 18.0 μm or less, or 15.0 μm or less. The lower limit is not particularly prescribed, but the mean particle size of the prior austenite grains may be, for example, 3.0 μm or more, 5.0 μm or more, 8.0 μm or more, 10.0 μm or more, or 12.0 μm or more.

[Ratio of Prior Austenite Grains With Aspect Ratio of 2.0 or Less in All Prior Austenite Grains: By Area% 90.0% or More]

[0036] In the microstructure of a steel sheet according to an embodiment of the present invention, while not particularly limited to this, the ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains may be an area% of for example 90.0% or more, 92.0% or more, 94.0% or more, or 96.0% or more. By making the ratio of the prior austenite grains having a relatively small aspect ratio greater, it is possible to reduce the anisotropy of the microstructure. The upper limit is not particularly prescribed, but for example the ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains may be 100.0% and may also be 99.0% or less or 98.0% or less. The present invention, as mentioned above, has as its object the provision of steel sheet which, while high strength, is improved in hole expandability and work hardening ability. It achieves the above object by making the microstructure of steel sheet having a predetermined chemical composition a structure mainly comprised of martensite and limiting the mean particle size of prior austenite grains in the microstructure to within a predetermined range while suitably controlling the ratio of crystal grains having a predetermined grain orientation difference in the martensite structure. Therefore, it is clear that the ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains is not a technical feature essential in achieving the object of the present invention.

[Methods of Determination of Mean Particle Size of Prior Austenite Grains and Ratio of Prior Austenite Grains With Aspect Ratio of 2.0 or Less in All Prior Austenite Grains]

[0037] The mean particle size of prior austenite grains and the ratio of prior austenite grains with an aspect ratio of 2.0 or

less in all prior austenite grains are determined in the following way. First, a sample is cut out from any position 50 mm or more away from the end faces of the steel sheet (if not possible to take a sample from that position, a position avoiding the end parts) so that a vertical sheet thickness cross-section can be examined. The sheet thickness cross-section is preferably parallel to the rolling direction. The size of the sample, while depending on the measurement device, is made a size enabling examination of about 10 mm in the direction vertical to the sheet thickness direction. The cross-section of the sample is polished using #600 to #1500 silicon carbide paper, then is finished to a mirror surface using particle size 1 to 6 μm diamond powder made to disperse in alcohol or other diluent or pure water. Next, electrolytic polishing is used to finish the examined surface. At the 1/4 depth position of sheet thickness at any position in the longitudinal direction of the sample cross-section, a length 50 μm and sheet thickness direction 50 μm region is measured by electron backscatter diffraction at 0.1 μm measurement intervals to obtain crystal orientation information. For the measurement, an EBSD analysis apparatus comprised of a thermal field emission type scan electron microscope and EBSD detector may be used. For example, an EBSD analysis apparatus comprised of a JSM-7001F made by JEOL and a DVC5 type detector made by TSL may be used. At that time, the vacuum degree inside the EBSD analysis apparatus may be 9.6×10^{-5} Pa or less, the acceleration voltage may be 15 kV, and the probe current level may be 13. The obtained crystal orientation information is used to calculate the crystal orientation of the prior austenite grains from the crystal orientation relationship of general prior austenite grains and crystal grains having a body centered structure after transformation. For the method of calculating the crystal orientation of prior austenite grains, the following method is used. First, the method described in Acta Materialia, 58(2010), 6393-6403 is used to prepare a crystal orientation map of the prior austenite grains. At one of the prior austenite grains contained in the examined field, the average value of the shortest diameter and the longest diameter is calculated. The average value is made the particle size of the prior austenite grains. The above operation is performed for all of the prior austenite grains except for the prior austenite grains not contained in the photographed field in the entirety of the crystal grains such as at the end parts of the photographed field. The particle size of all of the prior austenite grains in the photographed field is sought. The mean particle size is determined by calculating the mean particle size from the particle sizes of all of the prior austenite grains obtained.

[0038] Next, at one of the prior austenite grains contained in the examined field, the ratio of the diameter in the sheet thickness direction and diameter in the rolling direction (rolling direction diameter/sheet thickness direction diameter) is calculated and that value is used as the aspect ratio of the prior austenite grains. If the rolling direction is unclear, the cross-section is examined at a direction of 0°, 45°, 90°, and 135° with respect to any direction, the cross-section with the highest aspect ratio among them is deemed the cross-section parallel to the rolling direction, and the ratio of the diameter in the sheet thickness direction and diameter in the rolling direction (rolling direction diameter/sheet thickness direction diameter) is calculated. The above operation is performed for all of the prior austenite grains except for the prior austenite grains not contained in the photographed field in the entirety of the crystal grains such as at the end parts of the photographed field. The aspect ratio of all of the prior austenite grains in the photographed field is sought. The total number of the prior austenite grains with an aspect ratio of 2.0 or less divided by the number of all prior austenite grains, the ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains is determined.

[Ratio of Crystal Grains With Orientation Difference in Grains in Martensite of 4° or More: Area% 45.0 to 70.0%]

[0039] In the martensite structure of the steel sheet according to an embodiment of the present invention, if a region surrounded by grain boundaries with an orientation difference of 15° or more is defined as a "crystal grain", the ratio of crystal grains with an orientation difference in the grains of 4° or more is controlled to a range of, by area%, 45.0 to 70.0%. As explained earlier, the more unevenly dislocations are dispersed, generally the greater the orientation difference in the grains becomes. Crystal grains with an orientation difference in the grains of 4° or more are crystal grains having an orientation difference sufficient for forming a structure with dislocations unevenly dispersed and causing spread of uneven deformation. In relation to this, in an embodiment of the present invention, by making such crystal grains form in the martensite a range of, by an area%, 45.0 to 70.0% to establish the presence of a certain amount of a structure with dislocations unevenly dispersed, uneven deformation occurs in the press-forming or other working. As a result, it is possible to maintain a sufficient work hardening ability even at the latter period of deformation and therefore possible to achieve a high work hardening rate. If the ratio of crystal grains with an orientation difference in the grains of 4° or more is an area% of less than 45.0% or more than 70.0%, uneven deformation becomes harder to develop during press-forming or other working and therefore the desired work hardening rate becomes impossible to achieve. The ratio of crystal grains with an orientation difference in the grains in the martensite structure of 4° or more may be for example an area% of 48.0% or more, 50.0% or more, or 55.0% or more. Similarly, the ratio of crystal grains with an orientation difference in the grains in the martensite structure of 4° or more may also be for example an area% of 65.0% or less, 62.0% or less, or 60.0% or less.

[Method of Determination of Ratio of Crystal Grains With Orientation Difference in Grains of 4° or More in Martensite]

[0040] The ratio of crystal grains with an orientation difference in the grains of 4° or more in the martensite is measured by

electron backscatter diffraction (EBSD). More specifically, first, a sample is taken from the steel sheet so that a sheet thickness cross-section in a direction vertical to the sheet surface can be examined. At the 1/4 depth position of sheet thickness from the steel sheet surface, a region of 200 μm in the direction vertical to the sheet thickness direction and 100 μm region in the sheet thickness direction is measured by EBSD at 0.2 μm measurement intervals to obtain crystal orientation information. Here, an EBSD analysis apparatus comprised of a thermal field emission type scan electron microscope (JSM-7001F made by JEOL) and EBSD detector (HIKARI detector made by TSL) is used for analysis at a speed of 50 to 300 points/s. At that time, the vacuum degree inside the EBSD analysis apparatus may be 9.6×10^{-5} Pa or less, the acceleration voltage may be 15 kV, and the probe current level may be 13. Next, the obtained crystal orientation information is used to identify the martensite structure using a "Phase Map" function installed in the "OIM Analysis[®]" software attached to the EBSD analysis apparatus. Next, defining a region surrounded by grain boundaries with an orientation difference of 15° or more in the identified martensite structures as a "crystal grain", the average orientation difference in the grains of the crystal grains is calculated and the ratio of crystal grains with an orientation difference in the grains of 4° or more is found. The crystal grains defined as explained above and the average orientation difference in the grains can similarly be calculated using the "OIM Analysis[®]" software attached to the EBSD analysis apparatus. In the present invention, the "orientation difference in the grains" expresses the dispersion of the orientations in a crystal grain called the "grain orientation spread (GOS)". The value of the orientation difference in the grains, as described in "Analysis of Misorientation in Plastic Deformation of Stainless Steel by EBSD Method and X-Ray Diffraction Method", Hidehiko Kimura et al., Transactions of the Japan Society of Mechanical Engineers (A), vol. 71, no. 712, 2005, p. 1722-1728, is found as the average value of misorientation of all measurement points from the crystal orientation used as a reference in the same crystal grain. In this embodiment of the present invention, the crystal orientation used as the reference is the orientation obtained by averaging all measurement points in the same crystal grain. The value of GOS can be calculated using the "OIM Analysis[®] Version 7.0.1" software attached to the EBSD analysis apparatus.

[Sheet Thickness]

[0041] The steel sheet according to an embodiment of the present invention is not particularly limited, but in general it has a 1.0 to 8.0 mm sheet thickness. For example, the sheet thickness may also be 1.2 mm or more, 1.6 mm or more, or 2.0 mm or more and/or may also be 7.0 mm or less, 6.0 mm or less, 5.5 mm or less, 5.0 mm or less, 4.4 mm or less, 4.2 mm or less, or 4.0 mm or less.

[0042] The steel sheet according to an embodiment of the present invention can reliably realize the contradictory properties of high strength and excellent workability and is useful for use for parts in technical fields in which achievement of both of these properties is sought, etc. In particular, it is useful for use for parts in the automotive field, etc. For this reason, in a preferred embodiment, an auto part including steel sheet according to an embodiment of the present invention, in particular, a transmission of an automobile, is provided. As examples of transmission parts of automobiles, a lower arm, trailing arm, etc., may be mentioned. These auto parts, in particular transmission parts of automobiles, need only contain the steel sheet according to an embodiment of the present invention in at least portions of these parts. For this reason, at least portions of these parts satisfy the above features of the chemical composition and structure. At portions of the steel sheet with relatively low degrees of working in press-forming and other forming, the features of the steel sheet do not particularly change before and after forming. Portions of the steel sheet with relatively low degrees of working are judged by being flat in shape without being bent or otherwise deformed, by being small in rate of change of sheet thickness, and other features.

[Mechanical Properties]

[Tensile Strength: TS]

[0043] According to the steel sheet having the above-mentioned chemical composition and microstructure, in particular hot rolled steel sheet, it is possible to achieve a high tensile strength, specifically a tensile strength of 980 MPa or more. The tensile strength is preferably 1000 MPa or more, 1080 MPa or more, or 1180 MPa or more. According to the steel sheet according to an embodiment of the present invention, despite having such an extremely high tensile strength, it is possible to realize excellent hole expandability and work hardening ability by a specific combination of the chemical composition and microstructure explained above. The upper limit of the tensile strength is not particularly prescribed, but, for example, the tensile strength of the steel sheet is 1780 MPa or less, 1700 MPa or less, or 1600 MPa or less. The tensile strength is measured by taking a JIS No. 5 test piece from an orientation (C direction) where the longitudinal direction of the test piece becomes parallel to the rolling perpendicular direction of the steel sheet and performing a tensile test based on JIS Z 2241: 2011. For example, if it is difficult to obtain a JIS No. 5 test piece due to dimensional restrictions, it is possible to use another test piece described in JIS Z 2241: 2011. However, if the sheet thickness is less than 0.5 mm, 0.5 mm is made the lower limit for performing suitable evaluation. For example, if it is difficult to obtain a JIS No. 5 test piece due to dimensional restrictions

and and it is also difficult to use another test piece described in JIS Z 2241: 2011, it is possible to perform a micro Vickers test based on JIS Z 2244-1: 2020 and use the value obtained by converting that hardness (HV) to tensile strength. The sample used for the micro Vickers test can be prepared by the same method as the sample for evaluation of the mean particle size and aspect ratio of the prior austenite grains. The micro Vickers test may be performed by measuring 30 points at the sheet thickness 1/4 position by a load of 500 gf and using the average value. The conversion can be performed by the following formula:

$$\text{Tensile strength [MPa]} = 3.12 \times \text{Vickers hardness [HV]} + 16$$

[Hole Expansion Rate: λ]

[0044] According to the steel sheet having the above-mentioned chemical composition and microstructure, it is possible to obtain a high hole expandability, specifically a 45% or more hole expansion rate. The hole expansion rate may be preferably 50% or more, more preferably 60% or more or 70% or more. The upper limit of the hole expansion rate is not particularly prescribed, but, for example, the hole expansion rate is 150% or less, 120% or less, or 100% or less. The hole expansion rate is determined in the following way: First, a width 100 mm $\times$ length 100 mm test piece is taken from the steel sheet and a punch hole (initial hole: hole diameter d_0 = 10 mm) is prepared using a punch tool with a punch diameter of 10 mm and die diameter of 10.25 to 11.5 mm (clearance 12.5%). Next, while set so that the burr became the die side, a 60° conical punch is used to expand the initial hole until a crack passing through the sheet thickness is formed. The hole diameter d_1 mm is measured at the time of cracking and the hole expansion rate λ (%) of each test piece is found by the following formula. This hole expansion test is conducted three times and the average value of the same is determined as the hole expansion rate λ .

$$\lambda = 100 \times \{(d_1 - d_0) / d_0\}$$

<Method of Production of Steel Sheet>

[0045] Next, a preferable method of production of steel sheet according to an embodiment of the present invention will be explained. The following explanation is intended to illustrate the characteristic method for producing the steel sheet according to an embodiment of the present invention, particularly steel sheet having particularly preferable properties, and is not intended to limit the steel sheet to one produced by the method of production such as explained below. More specifically, below, production of hot rolled steel sheet will be specifically shown, but the steel sheet according to an embodiment of the present invention encompasses any steel sheet having the above explained chemical composition and microstructure, i.e., not only hot rolled steel sheet, but also cold rolled steel sheet, plated steel sheet, etc. Therefore, the following description just simply explains one example of a preferable method of production when the steel sheet according to an embodiment of the present invention is hot rolled steel sheet.

[0046] The method of production of the steel sheet according to an embodiment of the present invention comprises

heating a slab having the chemical composition explained above in relation to the steel sheet and holding it in a temperature region of 1100°C or more for 6000 seconds or more, hot rolling including finish rolling of the slab, wherein the finish rolling satisfies conditions of following (a) to (c):

- (a) a rolling reduction at a rolling pass at one stage before a last stage is 30 to 50% and a rolling reduction at a rolling pass at the last stage is 20 to 50%,
- (b) a total rolling reduction is 90% or more, and
- (c) a rolling temperature at the rolling pass at one stage before the last stage is 970 to 1100°C and a final rolling temperature is 960 to 1050°C,

starting cooling of the finish rolled steel sheet within 0.5 to 10.0 seconds after completion of the hot rolling, then cooling the steel sheet down to a temperature of 400°C or less within 20.0 seconds from the start of cooling, coiling the cooled steel sheet in a temperature region of 400°C or less, and imparting to the obtained steel sheet a strain becoming an absolute value of 0.16 to 1.40% at a sheet thickness 1/4 position of the steel sheet three times or more while repeatedly switching between positive and negative. In the above-mentioned method of production, the temperatures described for the slab and steel sheet respectively mean the surface temperature of the slab and the surface temperature of the steel sheet. Below, the steps will be explained in detail.

[Heating Step]

[0047] First, a slab having a chemical composition explained above in relation to the steel sheet is heated and is held in a temperature region of 1100°C or more for 6000 seconds or more. For the slab, using a slab obtained by continuous casting is preferable from the viewpoint of productivity, but it is also possible to use a slab obtained by casting and blooming. In accordance with need, these which are hot worked or cold worked may also be used. In the present method of production, "holding in the temperature region of 1100°C or more" includes not only the case of holding the temperature of the slab at a 1100°C or more fixed temperature but encompasses the case of holding the temperature of the slab while fluctuating in the temperature region of 1100°C or more. By holding the slab at the temperature region of 1100°C or more for 6000 seconds or more, it is possible to make the coarse carbides present in the structure completely dissolve and possible to eliminate starting points of cracking. If the holding temperature is less than 1100°C or the holding time is less than 6000 seconds, the coarse carbides become incompletely dissolved. If the coarse carbides are incompletely dissolved, in the cooling step explained later, due to the occurrence of ferrite or bainite transformation starting from such carbides, the area ratio of martensite becomes less than 90.0% and as a result it becomes no longer possible to obtain the desired strength and/or hole expandability. The upper limit of the heating temperature of the slab is preferably 1300°C or less or 1200°C or less. Similarly, the upper limit of the holding time at the temperature region of 1100°C or more is preferably 10000 seconds or less.

[Hot Rolling Step]

[Rough Rolling]

[0048] In the present method of production, for example, the heated slab may be rough rolled before the finish rolling so as to adjust the sheet thickness, etc. The rough rolling need only be able to secure the desired sheet bar dimensions. The conditions are not particularly limited.

[(a) Rolling Reduction in Rolling Passes of One Stage Before Last Stage: 30 to 50% and Rolling Reduction in Last Stage: 20 to 50%]

[0049] The heated slab or the slab additionally rough rolled in accordance with need is next finish rolled. In the present method of production, the finish rolling is performed using a tandem rolling mill comprised of several rolling stands, for example, five or more rolling stands. In the present method of production, in the finish rolling performed on the heated slab, the rolling reduction at each rolling pass at the last two stages has to be suitably controlled. Specifically, the rolling reduction at the rolling pass one stage before the last stage is controlled to 30 to 50% while the rolling reduction at the rolling pass at the last stage is controlled to 20 to 50%. By rolling by such a relatively high rolling reduction at each rolling pass at one stage before the last stage and the last stage, recrystallization is promoted and the microstructure can be made finer and in addition the ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains can be raised. If the rolling reduction at the rolling pass at one stage before the last stage is less than 30% and/or the rolling reduction at the rolling pass at the last stage is less than 20%, recrystallization either is not completed or is not sufficiently promoted and in the microstructure of the finally obtained steel sheet, sometimes the desired mean particle size of the prior austenite grains sometimes cannot be reached and/or the ratio of the prior austenite grains with an aspect ratio of 2.0 or less becomes a relatively small value. If the desired mean particle size of the prior austenite grains cannot be achieved, sufficient work hardening ability no longer can be obtained. On the other hand, if the rolling reduction at each rolling pass of one stage before the last stage and/or the last stage is too high, the rolling load becomes excessive and the burden of the rolling mill and other facilities becomes higher. For this reason, the rolling reduction at each rolling pass of one stage before the last stage and the last stage is 50% or less. Preferably the rolling reduction at each rolling pass of one stage before the last stage and the last stage is 45% or less.

[(b) Overall Rolling Reduction: 90% or More]

[0050] In the present method of production, the total rolling reduction in the final rolling is controlled to 90% or more. The Mn contained in the steel is an element causing a drop in the fracture energy of the grain boundaries, and therefore if there are regions where Mn is locally concentrated, sometimes occurrence of cracking is promoted at the time of plastic deformation in the press-forming, etc. There, from the viewpoint of further improving the hole expandability, suppressing or reducing local concentration of Mn would be effective. By controlling the total rolling reduction in finish rolling to 90% or more, it is possible to make the Mn disperse in the steel and in turn suppress or reduce the variation in Mn concentration in the steel, i.e., suppress or reduce the local concentration of Mn. If the total rolling reduction in the finish rolling is less than 90%, the variation in Mn concentration becomes relatively high and, sometimes, locally Mn concentrates and growth of

regions with reduced fracture energy cannot be sufficiently suppressed. In addition, if the total rolling reduction in finish rolling is less than 90%, the cumulative strain during the rolling becomes insufficient, and therefore sometimes the recrystallization will not be completed or not be sufficiently promoted and the desired mean particle size of prior austenite grains in the microstructure of the finally obtained steel sheet will not be able to be achieved and/or the ratio of the prior austenite grains with an aspect ratio of 2.0 or less will become a relatively small value. The upper limit of the total rolling reduction in the finish rolling is, for example, 99% or less or 98% or less. Here, the total rolling reduction in the finish rolling is calculated by the following formula:

Total rolling reduction (%) = (sheet thickness before finish rolling - sheet thickness after finish rolling) / sheet thickness before finish rolling × 100

[(c) Rolling Temperature at Rolling Pass of One Stage Before Last Stage: 970 to 1100°C, Final Rolling Temperature: 960 to 1050°C]

[0051] In the present method of production, in addition to control of the rolling reduction in each rolling pass of the latter two stages in finish rolling, the rolling temperature at the rolling pass of one stage before the last stage (entry side temperature of rolling pass of one stage before the last stage) and the final rolling temperature (end temperature of finish rolling) are also extremely important in control of the microstructure of the steel sheet. If the rolling temperature at the rolling pass of one stage before the last stage is less than 970°C and/or the final rolling temperature is less than 960°C, sometimes the recrystallization is not completed or is not sufficiently promoted and the desired mean particle size of the prior austenite grains in the microstructure of the finally obtained steel sheet cannot be achieved and/or sometimes the ratio of prior austenite grains with an aspect ratio of 2.0 or less becomes a relatively small value. If not able to achieve the desired mean particle size of the prior austenite grains, a sufficient work hardening ability can no longer be obtained. On the other hand, if the rolling temperature of the one stage before the last stage is more than 1100°C and/or the final rolling temperature is more than 1050°C, the prior austenite grains become coarser and sometimes the desired mean particle size of the prior austenite grains cannot be achieved. In this case as well, only naturally, sufficient work hardening ability can no longer be obtained.

[Cooling Step]

[Time From After Completion of Hot Rolling Step to Start of Cooling: 0.5 to 10.0 Seconds]

[Time From Start of Cooling to Becoming 400°C or Less: 20.0 Seconds or Less]

[0052] The finish rolled steel sheet starts to be cooled in the next cooling step within 0.5 to 10.0 seconds after the completion of the hot rolling step, then is cooled down to a temperature of 400°C or less within 20.0 seconds from the start of cooling. By performing such cooling control, in the microstructure of the finally obtained steel sheet, it is possible to achieve the desired mean particle size of the prior austenite grains and the desired ratio of prior austenite grains with an aspect ratio of 2.0 or less.

[0053] If the time from the completion of the hot rolling step to the start of cooling is less than 0.5 second, sometimes the recrystallization will not be completed or not be sufficiently promoted and the desired mean particle size of prior austenite grains in the microstructure of the finally obtained steel sheet will not be able to be achieved and/or the ratio of the prior austenite grains with an aspect ratio of 2.0 or less will not be able to be obtained. If the time from the completion of the hot rolling step to the start of cooling is more than 10.0 seconds, grain growth will proceed too much and the desired mean particle size of the prior austenite grains will no longer be able to be obtained. As a result, in either case, it will become no longer possible to achieve a sufficient work hardening ability in the steel sheet. On the other hand, if the cooling time from the start of cooling down to 400°C or less is more than 20.0 seconds or the cooling stop temperature is more than 400°C, ferrite, bainite, and/or pearlite will be produced during the cooling and the area ratio of martensite will become less than 90.0%. As a result, the desired strength and/or hole expansion ability will no longer be able to be obtained.

[Coiling Step]

[0054] Next, the cooled steel sheet is coiled up at a temperature region of 400°C or less. If the coiling temperature is more than 400°C, in the same way as the case of the cooling step, ferrite, bainite and/or pearlite is formed, the area ratio of the martensite becomes less than 90.0%, and as a result it becomes no longer possible to obtain the desired strength and/or hole expandability.

[Strain Imparting Step]

[0055] Finally, the obtained steel sheet was given strain becoming an absolute value of 0.16 to 1.40% at a sheet thickness 1/4 position of the steel sheet three times or more while repeatedly switching between positive and negative to thereby produce the steel sheet. By repeatedly imparting such strain to the steel sheet, it is possible to unevenly introduce dislocations inside the crystal grains of the martensite structure and as a result control the ratio of crystal grains with an orientation difference in the grains of 4° or more to a range of, by area%, 45.0 to 70.0%. If the absolute value of the strain imparted is less than 0.16% or the number of times of imparting strain is less than three times, the uneven introduction of dislocations in the crystal grains becomes insufficient, and therefore the ratio of crystal grains with an orientation difference in the grains of 4° or more becomes an area% of less than 45.0% and it becomes no longer possible to achieve the desired work hardening rate. On the other hand, if the absolute value of the strain impart becomes more than 1.40%, the accumulation of dislocations at the crystal grains becomes excessive whereby the ratio of crystal grains with an orientation difference in the grains of 4° or more becomes more than an area% of 70.0% and similarly the desired work hardening rate can no longer be achieved. The upper limit of the number of times of imparting strain is not particularly prescribed, but from the viewpoint of productivity is preferably 10 times or less, 7 times or less, or 5 times or less.

[0056] The martensite structure inherits the dislocations in the austenite grains before transformation, and therefore in general the crystal grains of the martensite structure formed from the nonrecrystallized austenite grains become high in value of orientation difference in the grains while the crystal grains of the martensite structure formed from the recrystallized austenite grains become low in value of orientation difference in the grains. In the present method of production, as explained above, recrystallization is promoted in the hot rolling step to make the structure finer whereby the mean particle size of the prior austenite grains is controlled to 30.0 μm or less. However, in such a case, martensite is formed from the recrystallized austenite grains, and therefore the crystal grains of the martensite structure become low in value of the orientation difference in the grains and the ratio of crystal grains with an orientation difference in the grains of 4° or more can no longer be made an area% of 45.0 to 70.0%. Therefore, in the present method of production, for the prior austenite structure, by suitably controlling the conditions of the hot rolling step to make the prior austenite structure a structure with recrystallization substantially or completely completed, it is possible to refine the structure and improve the work hardening ability of the steel sheet as a whole while by unevenly introducing dislocations in some of the crystal grains of the martensite structure in the strain imparting step to suitably form the orientation difference, it becomes possible to achieve a high work hardening rate even in a state with a certain degree of strain introduced such as in the latter period of deformation of press-forming.

[0057] The strain imparting step can be performed by any suitable method known to persons skilled in the art. While not particularly limited to this, as such a method, for example bending-unbending deformation by a tension leveler, etc., may be mentioned. In this case, by changing the size of the rolls or the relative positional relationship of the rolls with each other in the tension leveler and further the sheet thickness of the steel sheet, etc., it is possible to easily change the absolute value of the strain imparted. Therefore, by suitably controlling these parameters, it is possible to easily impart the desired strain to the sheet thickness 1/4 position of the steel sheet.

[0058] According to the steel sheet produced by above-mentioned method of production, by configuring the microstructure by a more uniform structure containing an area% of martensite: 90.0% or more and retained austenite: 3.0% or less, it is possible to achieve a high strength, for example, a high strength of a tensile strength of 980 MPa or more, while remarkably improving the hole expandability due to the reduction of the hardness difference, etc. Furthermore, by controlling the mean particle size of the prior austenite grains in the microstructure to 30.0 μm or less, it becomes possible to improve the work hardening ability of the steel sheet as a whole while by controlling the ratio of crystal grains with an orientation difference in the grains of 4° or more in the martensite to a range of, by area%, 45.0 to 70.0%, it becomes possible to achieve a high work hardening rate even in a state where a certain extent of strain is introduced such as in the latter period of deformation in press-forming. Therefore, the steel sheet produced according to the above-mentioned method of production can reliably achieve both the contradictory properties of high strength and excellent workability, and therefore is particularly useful in use in the automotive field where realization of both of these properties is sought.

[0059] Below, examples will be used to explain the present invention in more detail, but the present invention is not limited to these examples in any way.

EXAMPLES

[0060] In the following examples, steel sheets according to an embodiment of the present invention, in particular hot rolled steel sheets, were produced under various conditions and investigated for the tensile strength (TS), hole expansion rate (λ), and work hardening rate (WHR) of the obtained steel sheets.

[0061] First, molten steels were cast by the continuous casting method to form slabs having the various chemical compositions shown in Tables 1 and 2. These slabs were heated to 1100 to 1200°C in temperature and held over the time periods shown in Table 3, then were hot rolled. The hot rolling was performed by rough rolling and finish rolling. More

specifically, the rough rolling was performed under the same conditions in all of the examples and comparative examples while the finish rolling was performed under the conditions shown in Table 3 using a tandem rolling mill comprised of five rolling stands. Next, the finish rolled steel sheets were cooled and coiled under the conditions shown in Table 3. Finally, strain was imparted to give an absolute value shown in Table 3 at a sheet thickness 1/4 position of the steel sheet a predetermined number of times while repeatedly switching between positive and negative.

[Table 1]

[0062]

Table 1

Steel no.	Chemical composition (mass%), balance of Fe and impurities									Remarks
	C	Si	Mn	sol. Al	P	S	N	O	Nb	
A	0.069	0.70	2.52	0.026	0.001	0.0007	0.0015	0.0035	0.023	Inv. steel
B	0.042	1.80	3.14	0.466	0.005	0.0047	0.0026	0.0022	0.657	Inv. steel
C	0.188	0.65	2.57	0.163	0.003	0.0019	0.0012	0.0046	0.238	Inv. steel
D	0.120	0.31	2.96	0.364	0.024	0.0030	0.0009	0.0042	0.483	Inv. steel
E	0.094	1.92	3.77	0.216	0.024	0.0055	0.0055	0.0048	0.525	Inv. steel
F	0.097	1.69	1.22	0.137	0.015	0.0039	0.0036	0.0065	0.228	Inv. steel
G	0.114	1.42	3.86	0.412	0.015	0.0026	0.0054	0.0040	0.525	Inv. steel
H	0.050	1.17	2.89	0.003	0.010	0.0041	0.0032	0.0021	0.613	Inv. steel
I	0.177	1.02	2.49	0.485	0.030	0.0018	0.0013	0.0051	0.220	Inv. steel
J	0.123	1.02	2.19	0.015	0.020	0.0027	0.0020	0.0066	0.002	Inv. steel
K	0.092	0.86	1.54	0.340	0.025	0.0014	0.0010	0.0006	0.904	Inv. steel
L	0.130	1.02	1.87	0.061	0.023	0.0026	0.0044	0.0005	0.801	Inv. steel
M	0.120	0.55	3.23	0.015	0.014	0.0051	0.0026	0.0022	0.461	Inv. steel
N	0.076	0.81	1.94	0.261	0.022	0.0056	0.0035	0.0039	0.409	Inv. steel
O	0.118	1.31	2.66	0.167	0.002	0.0028	0.0037	0.0070	0.458	Inv. steel
P	0.074	0.68	1.77	0.226	0.028	0.0025	0.0037	0.0050	0.396	Inv. steel
Q	0.112	1.78	2.78	0.309	0.019	0.0005	0.0052	0.0011	0.475	Inv. steel
R	0.168	1.60	3.05	0.179	0.022	0.0032	0.0029	0.0006	0.565	Inv. steel
S	0.182	0.65	2.23	0.231	0.027	0.0028	0.0007	0.0061	0.071	Inv. steel
T	0.091	0.45	3.65	0.322	0.015	0.0017	0.0017	0.0027	0.764	Inv. steel
U	0.122	1.82	3.29	0.424	0.008	0.0059	0.0063	0.0050	0.162	Inv. steel
V	<u>0.038</u>	0.80	1.81	0.147	0.014	0.0058	0.0062	0.0005	0.144	Comp. steel
W	<u>0.211</u>	0.65	2.96	0.408	0.011	0.0052	0.0027	0.0017	0.579	Comp. steel
X	0.133	<u>0.27</u>	2.62	0.154	0.024	0.0048	0.0056	0.0041	0.508	Comp. steel
Y	0.047	<u>2.13</u>	2.63	0.067	0.007	0.0037	0.0006	0.0015	0.659	Comp. steel
Z	0.126	0.57	<u>0.95</u>	0.083	0.021	0.0043	0.0040	0.0015	0.096	Comp. steel
AA	0.147	1.07	<u>4.10</u>	0.271	0.025	0.0032	0.0009	0.0046	0.768	Comp. steel
AB	0.157	1.70	1.75	<u>0.000</u>	0.016	0.0037	0.0060	0.0070	0.276	Comp. steel
AC	0.129	1.70	1.82	0.281	0.012	0.0014	0.0039	0.0043	<u>0.000</u>	Comp. steel
AD	0.069	0.70	3.82	0.233	0.008	0.0005	0.0057	0.0048	<u>1.021</u>	Comp. steel
Underlines indicate outside scope of present invention.										

[Table 2]

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[0063]

Table 2

Steel no.	Chemical composition (mass%), balance of Fe and impurities																Remarks	
	Ti	V	Cu	Cr	Mo	Ni	B	Ca	Mg	Bi	Zr	Co	Zn	W	Sn	As		REM
A																		Inv. steel
B																		Inv. steel
C																		Inv. steel
D																		Inv. steel
E																		Inv. steel
F																		Inv. steel
G																		Inv. steel
H																		Inv. steel
I																		Inv. steel
J																		Inv. steel
K																		Inv. steel
L								0.0005	0.0007									Inv. steel
M																	0.0082	Inv. steel
N										0.008				0.083				Inv. steel
O											0.042					0.084		Inv. steel
P	0.168	0.215																Inv. steel
Q			0.33									0.006						Inv. steel
R				0.54														Inv. steel
S					0.08										0.037			Inv. steel
T						0.20												Inv. steel
U							0.0019						0.007					Inv. steel
V																		Comp. steel
W																		Comp. steel
X																		Comp. steel

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(continued)

Steel no.	Chemical composition (mass%), balance of Fe and impurities															Remarks		
	Ti	V	Cu	Cr	Mo	Ni	B	Ca	Mg	Bi	Zr	Co	Zn	W	Sn		As	REM
Y																		Comp. steel
Z																		Comp. steel
AA																		Comp. steel
AB																		Comp. steel
AC																		Comp. steel
AD																		Comp. steel

[Table 3]

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[0064]

Table 3

Production no.	Steel no.	Heating step	Hot rolling step					Cooling step		Coiling step	Strain imparting step		Remarks
			Rolling reduction of one stage before last stage	Rolling temp. of one stage before last stage	Rolling reduction of last stage	Total rolling reduction	Final rolling temp.	Time until start of cooling	Time from cooling start to 400°C or less		Absolute value of strain	No. of times of imparting strain	
		s	%	°C	%	%	°C	s	s	°C	%	Times	
1	A	8563	39	1052	41	95	1001	0.6	6.5	28	0.37	3	Inv. ex.
2	A	<u>5922</u>	44	999	48	91	968	2.4	8.9	26	0.79	3	Comp. ex.
3	A	8617	<u>28</u>	1052	39	91	1041	4.5	9.7	11	0.68	3	Comp. ex.
4	A	9693	46	<u>965</u>	44	98	960	3.0	7.2	19	0.99	5	Comp. ex.
5	A	7320	45	<u>1108</u>	48	96	1046	8.5	6.9	40	0.81	3	Comp. ex.
6	A	9613	35	1021	<u>17</u>	95	969	3.4	11.3	36	1.08	3	Comp. ex.
7	A	8630	39	973	43	94	<u>953</u>	5.6	11.3	30	1.09	4	Comp. ex.
8	A	7874	44	1098	42	92	<u>1057</u>	3.0	7.8	20	0.89	3	Comp. ex.
9	A	9552	45	1077	43	97	<u>1048</u>	<u>0.2</u>	9.5	31	0.62	3	Comp. ex.
10	A	7035	48	1072	45	91	1041	<u>11.6</u>	10.8	24	1.07	3	Comp. ex.
11	A	8506	39	1044	29	93	986	3.6	<u>21.8</u>	38	0.97	3	Comp. ex.
12	A	6994	39	980	41	93	964	2.9	11.5	<u>414</u>	0.54	3	Comp. ex.
13	A	7429	41	1034	39	96	975	5.8	9.0	11	<u>0.13</u>	3	Comp. ex.
14	A	7243	40	1021	24	92	972	1.8	8.1	24	<u>1.50</u>	3	Comp. ex.
15	A	7237	43	1034	35	92	1015	9.0	9.6	36	0.41	2	Comp. ex.
16	A	7229	42	1030	34	96	1000	9.1	9.3	34	<u>0.00</u>	<u>0</u>	Comp. ex.
17	b	6027	44	1000	46	95	993	5.9	10.1	34	0.54	3	Inv. ex.
18	C	9048	44	972	47	94	962	5.6	11.5	10	0.77	3	Inv. ex.

(continued)

Production no.	Steel no.	Heating step	Hot rolling step					Cooling step		Coiling step	Strain imparting step		Remarks
			Rolling reduction of one stage before last stage	Rolling temp. of one stage before last stage	Rolling reduction of last stage	Total rolling reduction	Final rolling temp.	Time until start of cooling	Time from cooling start to 400°C or less		Absolute value of strain	No. of times of imparting strain	
		s	%	°C	%	%	°C	s	s	°C	%	Times	
19	D	8932	40	1044	24	91	1000	7.9	9.7	269	0.58	3	Inv. ex.
20	E	9213	32	990	45	97	962	4.6	12.0	20	0.44	3	Inv. ex.
21	F	9515	35	1014	27	98	982	3.8	5.4	30	1.35	8	Inv. ex.
22	G	7031	41	1039	25	91	975	3.9	19.1	13	0.95	3	Inv. ex.
23	H	7074	48	986	41	94	963	3.3	8.9	26	0.46	6	Inv. ex.
24	I	8092	38	1036	34	96	1003	3.3	8.7	37	1.18	5	Inv. ex.
25	J	9290	41	1024	39	95	996	9.8	18.6	25	0.49	3	Inv. ex.
26	K	8048	42	1096	28	93	1048	7.4	7.1	11	0.98	3	Inv. ex.
27	L	7859	47	1067	47	94	1044	1.1	6.4	11	0.52	3	Inv. ex.
28	M	8653	45	1039	30	97	1025	6.4	10.8	30	1.10	3	Inv. ex.
29	N	9209	38	1019	40	91	985	8.3	10.7	20	0.32	3	Inv. ex.
30	O	8622	42	998	30	91	976	7.0	10.1	393	0.52	4	Inv. ex.
31	P	8141	46	1006	39	93	998	6.9	6.8	11	0.19	3	Inv. ex.
32	Q	8571	38	976	41	93	967	0.9	17.5	11	1.04	3	Inv. ex.
33	R	9773	47	996	21	95	973	6.3	9.0	39	1.13	3	Inv. ex.
34	S	6952	44	1028	38	96	973	5.1	10.3	24	0.58	3	Inv. ex.
35	T	7790	41	1068	27	98	1043	1.8	7.1	21	0.18	3	Inv. ex.
36	U	8502	40	981	28	95	979	1.9	9.9	13	0.92	3	Inv. ex.
37	V.	9297	42	1033	34	97	981	8.3	8.5	17	0.79	3	Comp. ex.

(continued)

Production no.	Steel no.	Heating step	Hot rolling step					Cooling step		Coiling step	Strain imparting step		Remarks
			Rolling reduction of one stage before last stage	Rolling temp. of one stage before last stage	Rolling reduction of last stage	Total rolling reduction	Final rolling temp.	Time until start of cooling	Time from cooling start to 400°C or less		Absolute value of strain	No. of times of imparting strain	
		s	%	°C	%	%	°C	s	s	°C	%	Times	
38	W	9293	37	1045	28	95	980	1.0	10.1	37	0.28	3	Comp. ex.
39	X	9263	37	1001	31	91	994	2.0	10.5	33	0.69	3	Comp. ex.
40	Y	7941	37	1012	27	91	990	4.0	6.1	40	0.95	6	Comp. ex.
41	Z	6635	47	1051	33	96	1041	7.0	8.1	28	0.44	3	Comp. ex.
42	AA	8547	43	983	41	97	960	9.0	9.0	31	0.66	3	Comp. ex.
43	AB	9730	42	1074	31	93	1041	8.2	7.5	26	1.17	4	Comp. ex.
44	AC	6678	46	999	43	92	987	4.6	11.1	25	0.47	3	Comp. ex.
45	AD	6346	41	1078	28	92	1045	2.8	5.3	14	1.00	3	Comp. ex.
Underlines indicate production conditions not preferable.													

[0065] The properties of the obtained steel sheets were measured and evaluated by the following methods:

[Tensile Strength (TS)]

5 **[0066]** The tensile strength (TS) was measured by taking a JIS No. 5 test piece from an orientation (C direction) where the longitudinal direction of the test piece became parallel with a rolling perpendicular direction of each steel sheet and performing a tensile test based on JIS Z 2241: 2011.

[Hole Expansion Rate (λ)]

10 **[0067]** The hole expansion rate was determined in the following way: First, a width 100 mm $\times$ length 100 mm test piece was taken from each steel sheet and a punch hole (initial hole: hole diameter $d_0=10$ mm) was prepared using a punch tool with a punch diameter of 10 mm and die diameter of 10.25 to 11.5 mm (clearance 12.5%). Next, while set so that the burr became the die side, a 60° conical punch was used to expand the initial hole until a crack passing through the sheet
15 thickness was formed. The hole diameter d_1 mm was measured at the time of cracking and the hole expansion rate λ (%) of each test piece was found by the following formula. This hole expansion test was conducted three times and the average value of the same was determined as the hole expansion rate λ :

$$\lambda = 100 \times \{(d_1 - d_0) / d_0\}$$

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[Work Hardening Ability]

[0068] The work hardening ability was evaluated by finding the work hardening rate (WHR) of steel sheet from a tensile test. Specifically, a state where the region where the strain (true strain) during tensile deformation when performing a
25 tensile test the same as the case of measurement of TS became 0.04 or more was deemed as simulating the state of the latter period of deformation in press-forming, and the maximum value of the work hardening rate (WHR) in that region was found by the following formula:

$$\text{WHR (MPa)} = d\sigma / d\varepsilon$$

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where, σ is the true stress and ε is the true strain.

[0069] Cases where the tensile strength (TS) of the steel sheet was 980 MPa or more, the hole expansion rate (λ) was 45% or more, and a maximum value of the work hardening rate (WHR) in a region of true strain of 0.04 or more became
35 1000 MPa or more were evaluated as steel sheet improved in hole expandability and work hardening ability regardless of being high strength. The results are shown in Table 4.

[Table 4]

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[0070]

Table 4

Production no.	Steel no	Sheet thickness	Microstructure							Mechanical properties			Remarks	
			Martensite	Retained γ	Ferrite	Bainite	Pearlite	Prior austenite grains		Martensite	TS	λ		Max. work hardening rate at true strain ≥ 0.04
								Mean particle size	Area ratio of prior γ grains of aspect ratio 2.0 or less					
		mm	Area%	Area%	Area%	Area%	Area%	μm	%	%	MPa	%	MPa	
1	A	3.0	96.5	0.0	0.0	3.5	0.0	18.2	100.0	51.9	1176	76	1522	Inv. ex.
2	A	4.3	81.5	2.1	0.0	5.2	11.2	17.9	97.5	63.0	966	40	1118	Comp. ex.
3	A	4.0	92.8	2.2	0.0	5.0	0.0	33.6	88.0	51.5	1132	46	983	Comp. ex.
4	A	4.4	94.1	1.6	0.0	4.3	0.0	41.5	86.5	60.7	1188	48	952	Comp. ex.
5	A	2.7	94.4	1.7	0.0	3.9	0.0	44.1	96.6	60.2	1216	98	984	Comp. ex.
6	A	4.4	96.3	1.2	0.0	2.5	0.0	48.2	80.6	60.5	1153	48	996	Comp. ex.
7	A	3.2	96.4	1.0	0.0	2.6	0.0	60.8	76.3	64.4	1223	47	913	Comp. ex.
8	A	4.2	96.1	0.6	0.0	3.3	0.0	55.2	92.6	59.7	1133	74	882	Comp. ex.
9	A	3.8	96.5	0.8	0.0	2.7	0.0	31.3	88.2	53.9	1143	45	938	Comp. ex.
10	A	4.4	98.3	0.0	0.0	1.7	0.0	35.4	98.5	59.3	1256	100	891	Comp. ex.
11	A	3.1	83.0	0.1	10.8	3.8	2.3	25.4	93.5	53.9	953	38	1208	Comp. ex.
12	A	3.0	88.0	0.4	0.0	11.6	0.0	13.7	93.2	64.2	976	41	1096	Comp. ex.
13	A	3.6	96.0	2.3	0.0	1.7	0.0	22.7	96.3	44.2	1152	71	827	Comp. ex.
14	A	3.7	95.7	1.3	0.0	3.0	0.0	17.0	93.8	72.1	1048	92	776	Comp. ex.
15	A	3.8	95.4	0.1	0.0	4.5	0.0	13.7	91.6	42.7	1248	61	966	Comp. ex.

(continued)

Production no.	Steel no	Sheet thickness	Microstructure								Mechanical properties			Remarks	
			Martensite	Retained γ	Ferrite	Bainite	Pearlite	Prior austenite grains		Martensite	TS	λ	Max. work hardening rate at true strain ≥ 0.04		
								Mean particle size	Area ratio of prior γ grains of aspect ratio 2.0 or less						
															Area%
16	A	3.8	95.5	0.1	0.0	4.4	0.0	0.0	13.3	93.2	26.5	1211	89	853	Comp. ex.
17	B	2.8	95.4	0.4	0.0	4.2	0.0	0.0	19.3	95.0	58.0	1125	95	1519	Inv. ex.
18	C	1.4	93.6	1.8	0.0	4.6	0.0	0.0	25.2	91.8	52.0	1236	91	1081	Inv. ex.
19	D	2.8	94.2	2.8	0.0	3.0	0.0	0.0	19.2	97.5	57.7	1066	77	1502	Inv. ex.
20	E	3.0	94.5	0.8	0.0	4.7	0.0	0.0	13.2	95.7	60.0	1290	64	1675	Inv. ex.
21	F	4.2	94.8	0.2	0.0	5.0	0.0	0.0	20.7	91.9	60.8	1210	89	1126	Inv. ex.
22	G	6.6	90.1	0.2	9.6	0.1	0.0	0.0	16.1	92.8	56.1	982	49	1139	Inv. ex.
23	H	2.8	98.7	0.8	0.0	0.5	0.0	0.0	22.1	94.4	46.8	1169	53	1192	Inv. ex.
24	I	2.1	98.1	1.3	0.0	0.6	0.0	0.0	14.9	98.3	58.0	1073	69	1547	Inv. ex.
25	J	2.8	90.5	0.0	0.0	9.5	0.0	0.0	28.6	93.5	55.6	993	46	1015	Inv. ex.
26	K	3.7	98.0	0.8	0.0	1.2	0.0	0.0	23.6	98.0	51.5	1106	69	1453	Inv. ex.
27	L	4.2	98.0	0.9	0.0	1.1	0.0	0.0	18.8	98.7	64.7	1235	56	1205	Inv. ex.
28	M	3.5	98.6	0.2	0.0	1.2	0.0	0.0	15.8	94.6	59.0	1064	91	1256	Inv. ex.
29	N	2.5	95.9	1.0	0.0	3.1	0.0	0.0	17.9	96.3	53.1	1248	82	1472	Inv. ex.
30	O	3.6	93.9	1.8	0.0	4.3	0.0	0.0	21.4	100.0	59.9	1119	62	1643	Inv. ex.
31	P	3.8	94.6	1.0	0.0	4.4	0.0	0.0	15.6	95.5	61.1	1036	79	1523	Inv. ex.
32	Q	4.4	90.2	0.0	1.2	0.0	8.6	0.0	24.1	99.7	50.5	985	48	1395	Inv. ex.

(continued)

Production no.	Steel no	Sheet thickness	Microstructure							Mechanical properties			Remarks	
			Martensite	Retained γ	Ferrite	Bainite	Pearlite	Prior austenite grains		Martensite	TS	λ		Max. work hardening rate at true strain ≥ 0.04
								Mean particle size	Area ratio of prior γ grains of aspect ratio 2.0 or less					
		mm	Area%	Area%	Area%	Area%	Area%	μm	%	%	MPa	%	MPa	
33	R	7.6	96.8	0.8	0.0	2.4	0.0	19.1	99.1	56.2	1122	55	1305	Inv. ex.
34	S	3.1	97.4	2.3	0.0	0.3	0.0	18.2	95.2	68.8	1108	60	1657	Inv. ex.
35	T	2.5	96.7	1.2	0.0	2.1	0.0	22.1	99.8	65.0	1052	61	1394	Inv. ex.
36	U	4.3	98.1	1.4	0.0	0.5	0.0	25.5	93.8	60.5	1292	86	1248	Inv. ex.
37	V	4.4	99.0	0.4	0.0	0.6	0.0	20.1	92.7	63.0	<u>926</u>	92	1376	Comp. ex.
38	W	4.4	94.9	<u>3.2</u>	0.0	1.9	0.0	13.3	96.8	63.2	1244	<u>33</u>	1175	Comp. ex.
39	X	4.5	97.1	0.0	0.0	2.9	0.0	17.1	92.3	52.4	<u>951</u>	91	1550	Comp. ex.
40	Y	2.5	91.9	<u>4.3</u>	0.0	3.8	0.0	21.3	97.8	50.7	1188	<u>36</u>	1335	Comp. ex.
41	Z	3.3	<u>87.7</u>	0.6	2.2	8.3	1.2	14.3	98.8	61.6	<u>950</u>	67	1227	Comp. ex.
42	AA	2.8	92.7	2.4	0.0	4.9	0.0	14.7	93.2	56.2	1055	<u>31</u>	1372	Comp. ex.
43	AB	3.7	97.9	0.2	0.0	1.9	0.0	18.0	97.8	58.1	1238	<u>38</u>	1157	Comp. ex.
44	AC	3.2	95.6	2.1	0.0	2.3	0.0	<u>41.9</u>	98.5	51.0	1115	76	<u>988</u>	Comp. ex.
45	AD	3.3	94.1	1.9	0.0	4.0	0.0	19.8	99.1	54.4	1148	<u>36</u>	1481	Comp. ex.
Underlines indicate outside scope of present invention or not preferable properties.														

[0071] Referring to Tables 1 to 4, in Comparative Example 2, the holding time in the temperature region of 1100°C or more in the heating step was short, and therefore it is believed the coarse carbides incompletely dissolved and such carbides became starting points for ferrite or bainite transformation, etc., in the subsequent cooling step. As a result, the area ratio of martensite became less than 90.0% and the TS and λ fell. In Comparative Examples 3 and 6, the respective rolling reductions in one stage before the last stage and the last stage in the finish rolling were low, and therefore it is believed recrystallization was not completed or was not sufficiently promoted. As a result, the mean particle size of the prior austenite grains in the finally obtained microstructure became larger and the work hardening ability of the steel sheet fell. In Comparative Examples 4 and 7, the respective rolling temperature and final rolling temperature in one stage before the last stage in the finish rolling were low, and therefore it is believed recrystallization was not completed or was not sufficiently promoted. As a result, the mean particle size of the prior austenite grains in the finally obtained microstructure became larger and the work hardening ability of the steel sheet fell. In Comparative Examples 5 and 8, the respective rolling temperature and final rolling temperature in one stage before the last stage in the finish rolling were high, and therefore it is believed the prior austenite grains became coarser overall. As a result, the mean particle size of the prior austenite grains in the finally obtained microstructure became larger and the work hardening ability of the steel sheet fell. In Comparative Example 9, the time from the completion of the hot rolling step to the start of the cooling step was short, and therefore it is believed the recrystallization was not completed or was not sufficiently promoted. As a result, the mean particle size of the prior austenite grains in the finally obtained microstructure became larger and the work hardening ability of the steel sheet fell. In Comparative Example 10, the time from the completion of the hot rolling step to the start of the cooling step was long, and therefore it is believed the grain growth proceeded too much overall. As a result, it was not possible to obtain the desired mean particle size of the prior austenite grains and the work hardening ability of the steel sheet fell. In Comparative Example 11, the time from the start of cooling to when becoming 400°C or less in the cooling step was long, and therefore the area ratio of martensite became less than 90.0% and the TS and λ fell. In Comparative Example 12, the coiling temperature was high, and therefore similarly the area ratio of martensite became less than 90.0% and the TS and λ fell. In Comparative Example 13, the absolute value of strain imparted in the strain imparting step was small, and therefore it is believed dislocations were not sufficiently introduced in the crystal grains. As a result, in the martensite, the ratio of crystal grains with an orientation difference in the grains of 4° or more became smaller and the work hardening ability of the steel sheet fell. In Comparative Example 14, the absolute value of strain imparted in the strain imparting step was large, and therefore it is believed dislocations were excessively accumulated in the crystal grains. As a result, in the martensite, the ratio of crystal grains with an orientation difference in the grains of 4° or more became larger and the work hardening ability of the steel sheet fell. In Comparative Example 15, the number of times of imparting strain in the strain imparting step was small, and therefore it is believed that dislocations were not sufficiently unevenly introduced inside of the crystal grains. As a result, in the martensite, the ratio of crystal grains with an orientation difference in the grains of 4° or more became smaller and the work hardening ability of the steel sheet fell. In Comparative Example 16, the strain imparting step was omitted, and therefore dislocations in the crystal grains could not be unevenly introduced inside of the crystal grains. As a result, in the martensite, the ratio of crystal grains with an orientation difference in the grains of 4° or more became smaller and the work hardening ability of the steel sheet fell.

[0072] In Comparative Examples 37 and 39, the respective C and Si contents were low, and therefore the TS fell. On the other hand, in Comparative Example 38 and in Comparative Example 40, the respective C and Si contents were high, and therefore the retained austenite was formed in a relatively large amount and the λ fell. In Comparative Example 41, the Mn content was low, and therefore the hardenability fell and as a result the area ratio of martensite became lower and the TS fell. In Comparative Example 42, the Mn content was high, and therefore the λ fell. In Comparative Example 43, the sol. Al content was low, and therefore it is believed precipitation of cementite could not be sufficiently suppressed. As a result, the λ fell. In Comparative Example 44, the Nb content was low, and therefore it is believed refinement of the prior austenite grains due to the pinning effect could not be sufficiently promoted. As a result, the mean particle size of the prior austenite grains in the finally obtained microstructure became larger and the work hardening ability of the steel sheet fell. In Comparative Example 45, the Nb content was high, and therefore it is believed coarse carbides, etc., formed in the steel. As a result, the λ fell.

[0073] In contrast to this, in the steel sheets according to all of the invention examples, by having a predetermined chemical composition and, furthermore, by suitably controlling the conditions in the method of production, it was possible to obtain steel sheet having a microstructure containing an area% of martensite: 90.0% or more and retained austenite: 3.0% or less, having a mean particle size of prior austenite grains of 30.0 μm or less, and having in the martensite a ratio of crystal grains with an orientation difference in the grains of 4° or more of an area% of 45.0 to 70.0%. Further, as a result, regardless of being a high strength of a tensile strength of 980 MPa or more, it was possible to remarkably improve the hole expandability and work hardening ability.

Claims

1. A steel sheet having a chemical composition comprising, by mass%,

5 C: 0.040 to 0.200%,
Si: 0.30 to 2.00%,
Mn: 1.00 to 4.00%,
sol. Al: 0.001 to 0.500%,
P: 0.100% or less,
10 S: 0.0300% or less,
N: 0.0070% or less,
O: 0.0100% or less,
Nb: 0.001 to 1.000%,
Ti: 0 to 0.200%,
15 V: 0 to 0.300%,
Cu: 0 to 0.40%,
Cr: 0 to 0.90%,
Mo: 0 to 0.12%,
Ni: 0 to 0.30%,
20 B: 0 to 0.0030%,
Ca: 0 to 0.0010%,
Mg: 0 to 0.0010%,
Bi: 0 to 0.010%,
Zr: 0 to 0.050%,
25 Co: 0 to 0.010%,
Zn: 0 to 0.010%,
W: 0 to 0.100%,
Sn: 0 to 0.040%,
As: 0 to 0.100%,
30 REM: 0 to 0.0100%, and
balance: Fe and impurities, and
a microstructure comprising, by area%,
martensite: 90.0% or more, and
retained austenite: 3.0% or less, wherein
35 a mean particle size of prior austenite grains is 30.0 μm or less, and
when defining a region surrounded by grain boundaries with an orientation difference of 15° or more in the
martensite as a "crystal grain", a ratio of crystal grains with an orientation difference in the grains of 4° or more is,
by area%, 45.0 to 70.0%.

40 2. The steel sheet according to claim 1, wherein the chemical composition comprises, by mass%, at least one of

Ti: 0.001 to 0.200%,
V: 0.001 to 0.300%,
Cu: 0.001 to 0.40%,
45 Cr: 0.001 to 0.90%,
Mo: 0.001 to 0.12%,
Ni: 0.001 to 0.30%,
B: 0.0001 to 0.0030%,
Ca: 0.0001 to 0.0010%,
50 Mg: 0.0001 to 0.0010%,
Bi: 0.001 to 0.010%,
Zr: 0.001 to 0.050%,
Co: 0.001 to 0.010%,
Zn: 0.001 to 0.010%,
55 W: 0.001 to 0.100%,
Sn: 0.001 to 0.040%,
As: 0.001 to 0.100%, and
REM: 0.0001 to 0.0100%.

3. The steel sheet according to claim 1 or 2, wherein the microstructure further comprises, by area%, at least one of

ferrite: 10.0% or less,
bainite: 10.0% or less, and
pearlite: 10.0% or less.

4. The steel sheet according to any one of claims 1 to 3, wherein a ratio of prior austenite grains with an aspect ratio of 2.0 or less in all prior austenite grains is, by area%, 90.0% or more.

5. The steel sheet according to any one of claims 1 to 4, wherein a sheet thickness is 1.0 to 8.0 mm.

6. A part including the steel sheet according to any one of claims 1 to 5.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/009483

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; *C21D 8/02*(2006.01)i; *C21D 9/46*(2006.01)i; *C22C 38/58*(2006.01)i
FI: C22C38/00 301W; C22C38/58; C22C38/00 301A; C21D9/46 T; C21D8/02 A

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2024
Registered utility model specifications of Japan 1996-2024
Published registered utility model applications of Japan 1994-2024

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 2019/216269 A1 (NIPPON STEEL CORPORATION) 14 November 2019 (2019-11-14) entire text	1-6
A	WO 2018/151273 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 23 August 2018 (2018-08-23) entire text	1-6
A	WO 2023/008003 A1 (JFE STEEL CORPORATION) 02 February 2023 (2023-02-02) entire text	1-6
A	WO 2016/031165 A1 (JFE STEEL CORPORATION) 03 March 2016 (2016-03-03) entire text	1-6
A	WO 2022/180146 A1 (SALZGITTER FLACHSTAHL GMBH) 01 September 2022 (2022-09-01) entire text, all drawings	1-6

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

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"P" document published prior to the international filing date but later than the priority date claimed

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

"&" document member of the same patent family

Date of the actual completion of the international search

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Date of mailing of the international search report

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Name and mailing address of the ISA/JP

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3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915
Japan

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2024/009483

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WO 2022/180146 A1	01 September 2022	EP 4298255 A1 entire text, all drawings DE 102021104584 A1 CN 116888283 A KR 10-2023-0148167 A	

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