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(54) **COLD-ROLLED STEEL SHEET AND COLD-ROLLED STEEL SHEET MANUFACTURING METHOD**

(57) To provide a cold-rolled steel sheet with excellent blanking workability. A cold-rolled steel sheet having a prescribed chemical composition and a steel microstructure in which the average grain size of the ferrite is 10 μm or less, the average grain size of cementite in the

ferrite grain boundaries is 5 μm or less, the average grain size of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in the ferrite grain, is 0.5 μm or less, and the average spacing of the NaCl-type carbides is 710 nm or less.

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Description

TECHNICAL FIELD

5 **[0001]** The present disclosure relates to cold-rolled steel sheets, especially to cold-rolled steel sheets with excellent press-blanking workability. The present disclosure further relates to a method of producing the cold-rolled steel sheets.

BACKGROUND

10 **[0002]** Press blanking is a widely used method for processing cold-rolled steel sheets into part shapes. For example, in the manufacture of textile machinery parts such as knitting needles used in knitting machines, cold-rolled steel sheets are worked into part shapes by press blanking, then subjected to working such as cutting, drawing, and polishing, and heat treatment such as quenching and tempering before the final textile machinery parts are produced.

15 **[0003]** However, in press blanking, there is a problem where burrs occur on edge surfaces when punching material. In addition to reducing dimensional accuracy, the occurrence of burrs can cause problems when parts with burrs are used in textile machinery such as knitting machines. Therefore, grinding or polishing is used to remove burrs after press blanking, but removing burrs sufficiently is difficult depending on the dimensions and the complexity of shape of a part.

[0004] Therefore, there is a need for cold-rolled steel sheets with excellent blanking workability, i.e., with as little burr generation as possible in press blanking.

20 **[0005]** To address the above issues, various technologies have been proposed to improve the blanking workability of cold-rolled steel sheets.

[0006] For example, JP 2019-039056 A (PTL 1) proposes a medium- to high-carbon cold-rolled steel sheet in which a controlled microstructure suppresses the generation of waviness and rollover on the punched end surface due to blanking.

25 **[0007]** JP H05-171288 A (PTL 2) proposes a method for producing high-carbon steel sheets that are soft and have excellent formability by optimizing the chemical composition and production conditions.

[0008] WO 2019/163828 A (PTL 3) proposes a high-carbon cold-rolled steel sheet with improved fine blanking workability by optimizing the grain size of cementite and ferrite, etc.

30 CITATION LIST

Patent Literature

[0009]

35 PTL 1: JP 2019-039056 A
 PTL 2: JP H05-171288 A
 PTL 3: WO 2019/163828 A

40 SUMMARY

(Technical Problem)

45 **[0010]** According to the technology of PTL 1, increasing the pearlitic microstructure ratio and decreasing spheroidal carbide ratio in the metallic structure improves the punched end surface characteristics due to the alignment of crack directions. However, the ferrite in pearlite is coarse and has a variety of deformation directions, resulting in burrs increasing in height in shear directions. Therefore, the blanking workability was still insufficient.

[0011] The technology proposed in PTL 2 reduces variations in material properties within a coil to suppress the reduction in workability caused by the variations and does not improve the intrinsic blanking workability of the steel sheet.

50 **[0012]** On the other hand, the technology proposed in PTL 3 shows a certain improvement in blanking workability, but further improvement in the blanking workability is required.

[0013] In view of the circumstances, the present disclosure has been developed to provide a cold-rolled steel sheet with excellent blanking workability.

55 (Solution to Problem)

[0014] The present inventors have studied methods of further improving the blanking workability of cold-rolled steel sheets and have found the following.

(1) When material is punched during blanking, voids generate from the ferrite grain boundaries, and the ferrite grains undergo a large amount of plastic deformation as the voids grow and connect, resulting in burrs on the punched edge surface increasing in height.

(2) Therefore, when the plastic deformation of ferrite grains is suppressed, burrs can be made smaller. In detail, when ferrite grains undergo large plastic deformation, many voids generate and consolidate at ferrite grain boundaries, resulting in burrs increasing in height, but when the plastic deformation of the ferrite grains is small, burrs become smaller.

(3) The reduction in plastic deformation of ferrite grains also has a further effect of reducing residual stress. In other words, when the plastic deformation of ferrite grains is small, both shape defects due to burring and dimensional variation due to residual stresses are reduced, and as a result residual stresses decrease.

(4) To reduce the amount of plastic deformation of ferrite grains, hardening the ferrite grains themselves is necessary. Hardening of ferrite grains is possible by making the ferrite grains finer and by dispersing fine carbides within the ferrite grains.

(5) To make ferrite grains fine and disperse fine carbides within the ferrite grains, it is necessary for cementite existing at the ferrite grain boundaries (hereinafter sometimes referred to as "grain boundary cementite") to be fine. In addition, by suppressing the formation of coarse grain boundary cementite, the formation of coarse voids at the grain boundary can be suppressed, and as a result can make burrs generate smaller.

[0015] The present disclosure was completed based on these discoveries, and the primary features thereof are as described below.

1. A cold-rolled steel sheet comprising:
a chemical composition containing (consisting of), in mass%,

C: 0.60 % to 1.25 %,
Si: 0.1 % to 0.55 %,
Mn: 0.5 % to 2.0 %,
P: 0.0005 % to 0.05 %,
S: 0.0001 % to 0.01 %,
Al: 0.001 % to 0.10 %,
N: 0.001 % to 0.009 %,
Cr: 0.05 % to 0.65 %, and
at least one selected from the group consisting of Ti: 0.001 % to 0.30 %, Nb: 0.01 % to 0.1 %, and V: 0.005 % to 0.5 %,
with the balance being Fe and inevitable impurities; and
a steel microstructure in which
an average grain size of ferrite is 10 μm or less,
an average grain size of cementite in ferrite grain boundaries is 5 μm or less,
an average grain size of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in ferrite grains, is 0.5 μm or less, and
an average spacing of the NaCl-type carbides is 710 nm or less.

2. The cold-rolled steel sheet according to aspect 1, wherein the chemical composition further contains, in mass%, at least one selected from the group consisting of

Sb: 0.1 % or less,
Hf: 0.5 % or less,
REM: 0.1 % or less,
Cu: 0.5 % or less,
Ni: 3.0 % or less,
Sn: 0.5 % or less,
Mo: 1 % or less, and
Zr: 0.5% or less.

3. A method of producing a cold-rolled steel sheet, comprising:

heating a steel slab having the chemical composition according to aspect 1 or 2;
subjecting the heated steel slab to hot rolling under a set of conditions including a hot rolling start temperature

of an Ac3 point or more and a finisher delivery temperature of 800 °C or more, to make a hot-rolled steel sheet; subjecting the hot-rolled steel sheet to cooling under a set of conditions in which a time from hot-rolling finish to cooling start is 5.0 seconds or less, an average cooling rate is 25 °C/s or more, and a cooling stop temperature is 620 °C to 740 °C;

winding the cooled hot-rolled steel sheet;

subjecting the hot-rolled steel sheet after the winding to first annealing under a set of conditions including an annealing temperature of 730 °C or less and an annealing time of 5 hours or more;

subjecting the hot-rolled steel sheet after the first annealing to bending and reverse bending;

subjecting the hot-rolled steel sheet after the bending and reverse bending to second annealing at an annealing temperature of 600 °C or more, and

subjecting the hot-rolled steel sheet, after the second annealing, to two or more repetitions of cold rolling at a rolling ratio of 15 % or more and third annealing at an annealing temperature of 600 °C or more.

(Advantageous Effect)

[0016] The present disclosure can provide a cold-rolled steel sheet with excellent blanking workability. The cold-rolled steel sheet according to the present disclosure is extremely suitable for use as a material for press blanking, especially for textile machinery parts such as knitting needles, because burr generation is suppressed when press blanking is performed, and residual stress is smaller.

DETAILED DESCRIPTION

[0017] The cold-rolled steel sheet and method according to the present disclosure is described in detail below. Note that the present disclosure is not limited to the embodiments herein.

[Chemical composition]

[0018] The cold-rolled steel sheet of the present disclosure has the chemical composition described above. The reason for this limitation is described below. As used herein, "%" as a unit of content refers to "mass percent" unless otherwise specified.

C: 0.60 % to 1.25 %

[0019] C is an element that has an effect of increasing hardness through quenching and plays an important role in blanking workability. C forms cementite with Fe, and as a result a boundary occurs between the generated cementite and ferrite. This boundary then becomes the initiation point for a void during blanking. When shearing occurs with a void as an initiation point, plastic deformation of ferrite is suppressed and the burr height lowers. When the C content is less than 0.60 %, carbon is consumed in cementite formation and carbides are not formed in grains, resulting in plastic deformation of ferrite grains growing. As a result, burrs increase in height and residual stress increases, and shape and dimensional accuracy decrease. The C content is therefore 0.60 % or more, preferably 0.65 % or more, and more preferably 0.70 % or more. On the other hand, when the C content exceeds 1.25 %, the cold-rolled steel sheet becomes too hard and embrittlement fractures are likely to occur, resulting in cracking occurring on the shear end face during blanking. The C content is therefore 1.25 % or less, preferably 1.20 % or less, and more preferably 1.15 % or less.

Si: 0.1 % to 0.55 %

[0020] Si is an element that has an effect of increasing the strength of a ferrite microstructure through solid solution strengthening, and the addition of Si can improve blanking workability. To obtain the above effects, a Si content is 0.1 % or more, preferably 0.12 % or more, and more preferably 0.14 % or more. On the other hand, excessive Si content promotes ferrite formation and grain growth, and ferrite strength decreases. The promoted ferrite formation also promotes the precipitation of coarse cementite to the grain boundary, and the frequency of void generation decreases. As a result, plastic deformation increases and blanking workability decreases. The Si content is therefore 0.55 % or less, preferably 0.52 % or less, and more preferably 0.50 % or less.

Mn: 0.5 % to 2.0 %

[0021] Mn is an element that mixes with cementite and inhibits cementite growth. The refinement of cementite formed at ferrite grain boundaries can suppress the plastic deformation of ferrite and improve blanking workability. To obtain

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the above effects, a Mn content is 0.5 % or more, preferably 0.52 % or more, and more preferably 0.54 % or more. On the other hand, when the Mn content exceeds 2.0 %, the segregation of Mn sulfides generates an extensive band-like structure in the rolling direction, resulting in an abnormal microstructure formation. As a result, abnormal grain growth of ferrite grains is promoted, and cementite precipitation becomes inhomogeneous, and blanking workability decreases. Therefore, the Mn content is 2.0 % or less, preferably 1.95 % or less, more preferably 1.90 % or less, and even more preferably 1.85 % or less.

P: 0.0005 % to 0.05 %

[0022] P is an element that strengthens ferrite. Therefore, the addition of a trace amount of P can suppress the plastic deformation of ferrite and improve the blanking workability. A P content is therefore 0.0005 % or more, and preferably 0.0010 % or more. On the other hand, when the P content exceeds 0.05 %, the grain boundary segregation of P suppresses cementite formation at the grain boundary, increases the plastic deformation of ferrite, resulting in blanking workability decreasing. The P content is therefore 0.05 % or less, and preferably 0.04 % or less.

S: 0.0001 % to 0.01 %

[0023] S forms sulfides with Mn contained in the steel. The formation of MnS at ferrite grain boundaries improves blanking workability, like cementite, by serving as a starting point for voids at the boundary between ferrite and precipitates. A S content is therefore 0.0001 % or more, and preferably 0.0005 % or more. On the other hand, when the S content exceeds 0.01 %, large amounts of expanded band-like MnS occur, which promotes abnormal grain growth, leading to local deformation and deteriorating blanking workability. The S content is therefore 0.01 % or less, and preferably 0.008 % or less.

Al: 0.001 % to 0.10 %

[0024] Al is dispersed in the steel as oxide and forms a solid solution to strengthen ferrite, thereby suppressing plastic deformation of ferrite and improving blanking workability. An Al content is therefore 0.001 % or more, and preferably 0.002 % or more. On the other hand, when the Al content exceeds 0.10 %, ferrite grain growth is promoted and plastic deformation increases, resulting in blanking workability decreasing. The Al content is therefore 0.10 % or less, preferably 0.08 % or less, and more preferably 0.06 % or less.

N: 0.001 % to 0.009 %

[0025] N combines with Al in steel to form AlN. When a N content is less than 0.001 %, ferrite crystal grains coarsen and blanking workability decreases. Therefore, the N content is 0.001 % or more. On the other hand, when the N content exceeds 0.009 %, AlN precipitates at ferrite grain boundaries of the hot-rolled steel sheet, which is an intermediate product, and the ferrite grains expand and coarsen, resulting in blanking workability decreasing. The N content is therefore 0.009 % or less, and preferably 0.006 % or less.

Cr: 0.05 % to 0.65 %

[0026] Cr is an element that increases the hardenability of steel and improves its strength and affects blanking workability. When the Cr content is less than 0.05 %, cementite coarsens, void density decreases, and blanking workability decreases. Therefore, the Cr content is 0.05 % or more, preferably 0.08 % or more, more preferably 0.10 % or more, and even more preferably 0.15 % or more. On the other hand, excessive Cr content leads to the formation of coarse Cr carbides and Cr nitrides, which precede the voids that occur at the interface between cementite and ferrite. In addition, the formation of coarse Cr carbides suppresses carbide formation within the grains and reduces the strength of the ferrite. This localizes deformation and blanking workability decreases. Therefore, the Cr content is 0.65 % or less, and preferably 0.60 % or less.

[0027] The above chemical composition contains at least one selected from the group consisting of Ti: 0.001 % to 0.30 %, Nb: 0.01 % to 0.1 %, and V: 0.005 % to 0.5%.

Ti: 0.001 % to 0.30 %

[0028] Ti forms fine TiC within the ferrite grains, which strengthens the ferrite grains and suppresses the amount of plastic deformation. Therefore, the addition of Ti can improve the blanking workability. However, when the Ti content is less than 0.001 %, Ti is consumed by the precipitation of TiN before TiC, resulting in a blanking workability improvement

effect being unobtainable. Therefore, when adding Ti, a Ti content is 0.001 % or more and preferably 0.005 % or more. On the other hand, when the Ti content exceeds 0.30 %, coarse TiC is formed, and void formation and growth occur locally around the coarse TiC. As a result, plastic deformation is localized and blanking workability decreases. The Ti content is therefore 0.30 % or less, preferably 0.28 % or less, and more preferably 0.26 % or less.

Nb: 0.01 % to 0.1 %

[0029] Nb forms fine NbC in the ferrite grains, which strengthens the ferrite grains and suppresses plastic deformation. Therefore, the addition of Nb can improve the blanking workability. However, when the Nb content is less than 0.01 %, the amount of precipitation of NbC is small, resulting in the blanking workability improvement effect being unobtainable. Therefore, when adding Nb, a Nb content is 0.01 % or more and preferably 0.015 % or more. On the other hand, when the Nb content exceeds 0.1 %, coarse Nb(CN) is formed and voids localize around the coarse Nb(CN), and deformations are localized, resulting in blanking workability decreasing. Therefore, the Nb content is 0.1 % or less, and preferably 0.09 % or less.

V: 0.005 % to 0.5 %

[0030] V forms fine VC in the ferrite grains, which strengthens the ferrite grains and suppresses plastic deformation. Therefore, the addition of V can improve the blanking workability. However, when a V content is less than 0.005 %, the amount of VC precipitation is small, resulting in the blanking workability improvement effect being unobtainable. Therefore, when adding V, the V content is 0.005 % or more and preferably 0.010 % or more. On the other hand, when the V content exceeds 0.5 %, coarse V(CN) is formed and voids localize around the coarse V(CN), resulting in uneven deformation and blanking workability decreases. The V content is therefore 0.5 % or less, preferably 0.45 % or less, and more preferably 0.40 % or less.

[0031] The cold-rolled steel sheet according to one of the embodiments of the present disclosure comprises a chemical composition containing the above components, with the balance being Fe and inevitable impurities.

[0032] In other embodiments according to the present disclosure, the above composition may optionally further contain at least one selected from the group consisting of Sb: 0.1 % or less, Hf: 0.5 % or less, REM: 0.1 % or less, Cu: 0.5 % or less, Ni: 3.0 % or less, Sn: 0.5 % or less, Mo: 1 % or less, and Zr: 0.5 % or less.

Sb: 0.1 % or less

[0033] Sb is an effective element for improving corrosion resistance, but when added in excess, a rich Sb layer forms under scale generated during hot rolling, which causes surface scabs (scratches) on the steel sheet after hot rolling. Therefore, the Sb content is 0.1 % or less. Although the lower limit of the Sb content is not particularly limited, in terms of increasing the effect of adding Sb, the Sb content is preferably 0.0003 % or more.

Hf: 0.5 % or less

[0034] Hf is an effective element for improving corrosion resistance, but when added in excess, a rich Hf layer is formed under the scale generated during hot rolling, which causes surface scabs (scratches) on the steel sheet after hot rolling. Therefore, the Hf content is 0.5 % or less. Although the lower limit of the Hf content is not particularly limited, in terms of increasing the effect of adding Hf, the Hf content is preferably 0.001 % or more.

REM: 0.1 % or less

[0035] An REM (rare earth metal) is an element that increases the strength of steel. However, excessive addition of REM may retard carbide refinement, which may promote inhomogeneous deformation during cold working and degrade surface characteristics. Therefore, the REM content is 0.1 % or less. Although the lower limit of the REM content is not particularly limited, in terms of increasing the effect of adding REM, the REM content is preferably 0.005 % or more.

Cu: 0.5 % or less

[0036] Cu is an effective element for improving corrosion resistance, but when added in excess, a rich Cu layer is formed under the scale generated during hot rolling, which causes surface scabs (scratches) on the steel sheet after hot rolling. Therefore, the Cu content is 0.5 % or less. Although the lower limit of the Cu content is not particularly limited, in terms of increasing the effect of adding Cu, the Cu content is preferably 0.01 % or more.

Ni: 3.0 % or less

[0037] Ni is an element that increases the strength of steel. However, excessive addition may retard carbide refinement, which may promote inhomogeneous deformation during cold working and degrade surface characteristics. Therefore, the Ni content is 3.0 % or less. Although the lower limit of the Ni content is not particularly limited, in terms of increasing the effect of adding Ni, the Ni content is preferably 0.01 % or more.

Sn: 0.5 % or less

[0038] Sn is an effective element for improving corrosion resistance, but when added in excess, a rich Sn layer is formed under the scale generated during hot rolling, which causes surface scabs (scratches) on the steel sheet after hot rolling. Therefore, the Sn content is 0.5 % or less. Although the lower limit of the Sn content is not particularly limited, in terms of increasing the effect of adding Sn, the Sn content is preferably 0.0001 % or more.

Mo: 1 % or less

[0039] Mo is an element that increases the strength of steel. However, excessive addition may retard carbide refinement, which may promote inhomogeneous deformation during cold working and degrade surface characteristics. Therefore, the Mo content is 1 % or less. Although the lower limit of the Mo content is not particularly limited, in terms of increasing the effect of adding Mo, the Mo content is preferably 0.001 % or more.

Zr: 0.5 % or less

[0040] Zr is an effective element for improving corrosion resistance, but when added in excess, a rich Zr layer is formed under the scale generated during hot rolling, which causes surface scabs (scratches) on the steel sheet after hot rolling. Therefore, the Zr content is 0.5 % or less. Although the lower limit of the Zr content is not particularly limited, in terms of increasing the effect of adding Zr, the Zr content is preferably 0.01 % or more.

[Microstructure]

[0041] Next, the microstructure of the cold-rolled steel sheet according to the present disclosure will be described.

Average grain size of ferrite: 10 μm or less

[0042] The finer the grain size of ferrite, the more the plastic deformation of ferrite is suppressed. To obtain excellent blanking workability, the average grain size of ferrite is 10 μm or less. On the other hand, the finer the ferrite, the more desirable, and therefore the lower limit of the average grain size is not limited. In terms of industrial production, the average particle size may be 0.5 μm or more. The average particle size of ferrite can be measured by the method described in the EXAMPLES section below.

Average grain size of cementite at ferrite grain boundaries: 5 μm or less

[0043] Cementite is present both within the ferrite grains and at the ferrite grain boundaries, and the cementite at the ferrite grain boundaries is relatively coarser than the cementite within the ferrite grains. The present inventors found that the blanking workability can be improved by controlling the average grain size of the cementite present at ferrite grain boundaries.

[0044] In other words, when blanking cold-rolled steel sheets, shearing proceeds due to the generation of voids between the grain boundaries and cementite. At this time, void formation progresses at the boundaries formed by the coarse cementite, and local deformations increase burr height. Therefore, it is necessary for cementite at ferrite grain boundaries to be fine to improve blanking workability. The average grain size of cementite at ferrite grain boundaries is 5 μm or less. On the other hand, the smaller the average particle diameter is, the better, and therefore the lower limit of the average particle diameter is not particularly limited. However, cementite at the grain boundary tends to grow because annealing is repeatedly performed in the later-described production method. Therefore, realistically, the average particle size is 0.5 μm or more. The average grain size of cementite at ferrite grain boundaries can be measured by the method described in the EXAMPLES section below.

[0045] As mentioned above, in the present disclosure, it is important that the grain boundary cementite be fine, but refinement results in the cementite spheroidizing. The spheroidization ratio of grain boundary cementite is not particularly limited but is preferably 2.5 or less. The spheroidization ratio of the grain boundary cementite is defined by the following

formula.

$$\text{Sphericity} = L_a/L_b$$

where L_a is the average of the major axis length of cementite, and L_b is the average of the minor axis length of cementite. L_a and L_b are determined as the average values of the major axis lengths and minor axis lengths, respectively, of all grain boundary cementite in an image obtained by photographing a cross-section of a cold-rolled steel sheet cut in the sheet thickness direction using a scanning electron microscope (SEM) at a magnification of 1000x for 3 observation fields. In this case, the major axis lengths and minor axis lengths are the values when cementite is assumed to be an ellipsoid or sphere.

Average grain size of NaCl-type carbides in ferrite grains: 0.5 μm or less

[0046] The cold-rolled steel sheet according to the present disclosure further contains at least one of Ti, Nb, and V. These elements form NaCl-type carbides and then precipitate in the ferrite grain and at ferrite grain boundaries. The NaCl-type carbides are finely dispersed within the ferrite grains to harden the ferrite and may reduce the amount of plastic deformation of the ferrite grains. As a result, the burr height during press blanking can be reduced.

[0047] Therefore, in the present disclosure, the average grain size of NaCl-type carbides containing at least one of Nb, Ti, and V in the ferrite grains is 0.5 μm or less. On the other hand, the smaller the average grain size, the more effective the average grain size is in strengthening ferrite, and therefore the lower limit of the average grain size is not particularly limited. However, precipitates tend to grow because annealing is repeatedly performed in the later-described production method. Therefore, realistically, the average particle size is 0.01 μm or more. The average particle size can be measured by the method described in the EXAMPLES section below. In the following description, NaCl-type carbides containing at least one of Nb, Ti, and V in ferrite grains may be simply referred to as "NaCl-type carbides".

Average spacing of NaCl-type carbides: 710 nm or less

[0048] The strengthening of ferrite by the above NaCl-type carbides is due to the finely dispersed NaCl-type carbides acting as an obstacle to dislocations, and such strengthening is referred to as strengthening by precipitation. In strengthening by precipitation, the smaller the distance between precipitates, the greater the strengthening. When the average spacing of the NaCl-type carbides is larger than 710 nm, the reduction of plastic deformation of ferrite grains by strengthening by precipitation is insufficient, and as a result press blanking workability decreases. Therefore, in the present disclosure, the average spacing of said NaCl-type carbides in the ferrite grains is 710 nm or less, preferably 250 nm or less. On the other hand, the lower limit of the average spacing is not particularly limited but is 30 nm or more in a realistic production environment. The average spacing of NaCl-type carbides in the ferrite grains can be measured by the method described in the EXAMPLES section below.

[0049] The number density of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in the ferrite grain, is not particularly limited but is preferably less than 100 grains/ μm^2 .

[0050] The number density of grain boundary cementite with a grain size of 0.5 μm or more is not particularly limited but is preferably not less than 5 grains/100 μm^2 . On the other hand, the upper limit of the number density of grain boundary cementite with a grain size of 0.5 μm or more is also not particularly limited but is preferably not more than 50 grains/100 μm^2 .

[0051] In the present disclosure, the blanking workability is improved by reducing the amount of plastic deformation of ferrite as described above. Therefore, the cold-rolled steel sheet according to the present disclosure has a ferrite-containing microstructure. Although the ferrite area ratio is not particularly limited, the cold-rolled steel sheet preferably has a ferrite-dominated microstructure. "Ferrite-dominated" is defined as having a ferrite area ratio of 50 % or more. The ferrite area ratio is preferably 68 % or more.

[0052] The microstructure can also contain any microstructure other than ferrite. However, in terms of reducing coarse cementite, the cementite area ratio is preferably less than 30 %.

[0053] A cold-rolled steel sheet according to one of the embodiments of the present disclosure may, for example, have a microstructure containing, in area ratio, 68 % or more ferrite, less than 30 % cementite, with the balance being precipitates other than cementite. The "precipitates other than cementite" may include, for example, carbides excluding cementite (Fe_3C), nitrides, carbonitrides, sulfides, and carbon sulfides. More specific examples include carbides, nitrides, and carbonitrides of at least one of Ti, V, and Nb, as well as Mn-based sulfides and Ti-based complex carbosulfides.

[Sheet Thickness]

[0054] The sheet thickness of the cold-rolled steel sheet is not particularly limited and may be any thickness. Considering the press blanking and a use as material for textile machinery parts, the sheet thickness is preferably 0.1 mm or more. The sheet thickness is preferably 1.6 mm or less. In particular, considering a use as a material for knitting needles, the sheet thickness is preferably 0.2 mm or more. The sheet thickness is preferably 0.8 mm or less.

Production Method

[0055] The following describes a method of producing a cold-rolled steel sheet according to one of the embodiments of the present disclosure.

[0056] Cold-rolled steel sheets can be produced by subjecting steel slabs having the above chemical composition to the following processes in order.

- (1) Heating
- (2) Hot rolling
- (3) Cooling
- (4) Winding
- (5) First annealing
- (6) Bending and reverse bending
- (7) Second annealing
- (8) Cold rolling
- (9) Third annealing

[0057] Then, processes (8) and (9) are then repeated two or more times. The following describes each process in order.

(1) Heating

[0058] First, a steel slab with the above chemical composition is heated. The method of producing the steel slab is not particularly limited and any method may be used. For example, adjustments to the chemical composition of the steel slab may be performed by blast furnace converter steelmaking process or electric furnace steelmaking process. Casting from molten steel into slabs may be performed by continuous casting or by blooming.

[0059] A heating temperature of the steel slab is not particularly limited but may be adjusted such that a temperature of the steel slab, at the stage when the next hot rolling starts, is in the austenite region as described later.

(2) Hot rolling

[0060] Next, the heated steel slab subjected to hot rolling to obtain a hot-rolled steel sheet. In the hot rolling described above, rough rolling and finish rolling may be performed according to conventional methods.

Hot rolling start temperature: Ac3 point or more

[0061] In hot rolling, when the starting temperature of hot rolling is less than the Ac3 point, expanded ferrite is generated in the hot-rolled steel sheet of the intermediate product and remains until the final product, increasing burr height. Therefore, the hot rolling start temperature is the Ac3 point or more. The Ac3 point (°C) is obtained by the following formula (1).

$$\text{Ac3 (}^{\circ}\text{C)} = 910 - (203 \times \text{C}^{1/2}) + (44.7 \times \text{Si}) - (30 \times \text{Mn}) - (11 \times \text{Cr}) + (400 \times \text{Ti}) + (460 \times \text{Al}) + (700 \times \text{P}) + (104 \times \text{V}) + 38 \dots (1)$$

[0062] Here, the element symbols denote the contents (mass%) of the respective elements, and the content of any element not contained is 0 mass%.

Finisher delivery temperature: 800 °C or more

[0063] Similarly, when the finisher delivery temperature is less than 800 °C, expanded ferrite is generated in the hot-

rolled steel sheet of the intermediate product and remains until the final product, increasing burr height. Therefore, the finisher delivery temperature is 800 °C or more.

(3) Cooling

Time to cooling start: 5.0 seconds or less

[0064] Next, the hot-rolled steel sheet is cooled. When a long time passes from hot-rolling finish to cooling start, carbides containing at least one of Ti, Nb, and V precipitate at the austenite grain boundary, elongated grains generate in the final product, and as a result blanking decreases. Therefore, the time from hot-rolling finish to cooling start (hereinafter simply referred to as "time to cooling start") is 5.0 seconds or less, preferably 4.5 seconds or less, and more preferably 4.0 seconds or less. On the other hand, although, the lower limit of the time to cooling start is not particularly limited, in terms of compatibility with general production lines, the time to start cooling is preferably 0.2 seconds or more and more preferably 0.5 seconds or more.

Average cooling rate: 25 °C/s or more

[0065] When the average cooling rate in the above cooling is less than 25 °C/s, elongated grains generate in the cold-rolled steel sheet, which is the final product, and as a result blanking workability decreases. Therefore, the average cooling rate is 25 °C/s or more. On the other hand, although the upper limit of the average cooling rate is not particularly limited, in terms of compatibility with general production lines, the average cooling rate is preferably 80 °C/s or less, more preferably 60 °C/s or less, and even more preferably 50 °C/s or less.

Cooling stop temperature: 620 °C to 740 °C

[0066] When the cooling is stopped at a temperature higher than 740 °C, carbides precipitate at the austenite grain boundaries, elongated grains generate in the final product, and blanking workability decreases. Therefore, the cooling stop temperature is 740 °C or less. On the other hand, when the cooling is stopped at a temperature lower than 620 °C, ferrite precipitates and the pearlite is unevenly distributed. This uneven distribution leads to uneven cementite dispersion in the final product. Therefore, the cooling stop temperature is 620 °C or more, and preferably 630 °C or more.

(4) Winding

[0067] After the cooling is stopped, the cooled hot-rolled steel sheet is wound into a coil. Although the winding temperature is not particularly limited, the winding temperature is preferably 600 °C or more. The winding temperature is preferably 730 °C or less.

[0068] The hot-rolled steel sheet is also preferably pickled after the winding and prior to the next first annealing.

(5) First annealing

[0069] The hot-rolled steel sheet after winding has a pearlitic microstructure. Therefore, the cementite contained in the pearlite is decomposed by the first annealing of the hot-rolled steel sheet after winding. By decomposing the cementite, the cementite becomes fine in the subsequent second annealing and cold rolling. Therefore, as a result, the ferrite is refined, and the plastic deformation of ferrite grains can be suppressed.

Annealing temperature: 730 °C or less

[0070] When the annealing temperature in the first annealing process is higher than 730 °C, phase transformation preferentially proceeds in one area, resulting in local coarsening of ferrite grains, and as a result an increase in plastic deformation. A locally coarse microstructure also results in inhomogeneous working and poor part shape accuracy. Therefore, the annealing temperature is 730 °C or less. On the other hand, although the lower limit of said annealing temperature is not particularly limited, in terms of cementite reforming a solid solution in pearlite to promote cementite decomposition, the annealing temperature is preferably 450 °C or more, more preferably 500 °C or more, and even more preferably 520 °C or more.

Annealing time: 5 hours or more

[0071] When the annealing time in the first annealing is less than 5 hours, the decomposition of cementite does not

progress. When the decomposition of cementite does not proceed, sheet like cementite will remain, and subsequent working by cold rolling or other means will result in inhomogeneity and poor part shape accuracy. Therefore, the annealing time is 5 hours or more. The upper limit of the annealing time is not particularly limited. However, the microstructural change saturates after cementite decomposition begins, and therefore in terms of manufacturing efficiency, the annealing temperature is preferably 50 hours or less, and more preferably 40 hours or less.

[0072] The hot-rolled steel sheet is also preferably pickled after the first annealing and prior to the next bending and reverse bending.

(6) Bending and reverse bending

[0073] Next, the hot-rolled steel sheet after the first annealing is subjected to bending and reverse bending. This bending and reverse bending is extremely important for achieving a desired microstructure in the finally-obtained cold-rolled steel sheet. In detail, the hot-rolled steel sheet is subjected to bending and reverse bending after the cementite is decomposed by the first annealing. The bending and reverse bending provides processing strain which introduces strain energy. Subsequently, a later-described second annealing promotes cementite refinement. Without bending and reverse bending, the coarsened cementite localizes, and the amount of plastic deformation increases locally, resulting in blanking workability decreasing.

[0074] The introduction of processing strain by bending and reverse bending can be done by any method without any particular limitation. For example, bending and reverse bending may be applied using a leveler used in shape adjustment, a skin pass mill, or a slitter for shearing steel sheets, and bending and reverse bending may be applied during unwinding from a coil and rewinding into a coil.

[0075] In terms of increasing the amount of strain introduced, using small-diameter rolls is preferable for bending and reverse bending. Specifically, using rolls with a diameter of 1100 mm or less is preferable, and using rolls with a diameter of 800 mm or less is more preferable. Using rolls with a diameter of 1100 mm or less for bending and reverse bending can introduce an equivalent strain necessary to promote cementite refinement after annealing. However, when the diameter of the rolls is too small, the rolling load is limited, and making the dimensions of the plate smaller by shearing or slitting beforehand is necessary, which increases production hours. In addition, the diameter of the rolls being too small contributes to meandering and cracking. Therefore, the diameter of the rolls is preferably 300 mm or more, and more preferably 450 mm or more. The rolls may be bridge rolls. When bridge rolls are used, strain is introduced by passing the sheet through the bridge rolls.

(7) Second annealing

[0076] After the bending and reverse bending, the hot-rolled steel sheet is subjected to second annealing. As mentioned above, after the bending and reverse bending to apply processing strain, the second annealing promotes cementite refinement.

Annealing temperature: 600 °C or more

[0077] When the annealing temperature in the second annealing is less than 600 °C, cementite refinement does not progress and the formation of NaCl-type carbides containing at least one of Nb, Ti and V is suppressed. When the formation of NaCl-type carbides is suppressed, the plastic deformation of the ferrite grains cannot be suppressed, resulting in burrs increasing in height. Therefore, the annealing temperature in the second annealing is 600 °C or more. On the other hand, although the upper limit of the annealing temperature is not particularly limited, when the upper limit is too high, the structure becomes coarse and the burrs increase in height, and therefore the annealing temperature is preferably 790 °C or less, and more preferably 770 °C or less.

(8) Cold rolling

(9) Third annealing

[0078] The hot-rolled steel sheet after the second annealing is subjected to two or more repetitions of cold rolling and third annealing. The cold rolling adjusts the sheet thickness of the final cold-rolled steel sheet. After cold rolling, the third annealing removes strain caused by the cold rolling. Performing the cold rolling and third annealing two or more times improves the uniformity of the microstructure and strengthens the ferrite by refining the ferrite microstructure, resulting in improved blanking workability. To achieve the above effects, the rolling ratio in the cold rolling is 15 % or more, and the annealing temperature in the third annealing is 600 °C or more. On the other hand, although, the upper limit of the rolling ratio is not particularly limited, when the rolling ratio is excessively high, the microstructure becomes locally coarse,

and the burrs increase in height. Therefore, the rolling ratio is preferably 52 % or less, and more preferably 50 % or less. The upper limit of the annealing temperature in a third annealing is not particularly limited, but an excessively high annealing temperature coarsens the microstructure and burrs increase in height. Therefore, the annealing temperature is preferably 750 °C or less, and more preferably 720 °C or less.

[0079] After the cold rolling and third annealing are repeated two or more times, a further final cold rolling may be performed. When the final cold rolling is performed, the rolling ratio in the final cold rolling is not particularly limited but is preferably 20 % or more. The upper limit of the rolling reduction in the final cold rolling is also not particularly limited but is preferably 50 % or less.

[0080] Meeting the above conditions enables cold-rolled steel sheets with good blanking workability to be produced. The finally-obtained cold-rolled steel sheets may also be subjected to further optional surface treatment.

EXAMPLES

[0081] In order to determine the effect of this disclosure, cold-rolled steel sheets were produced by the following procedure, and the blanking workability of each of the resulting cold-rolled sheets was evaluated.

[0082] First, steel having the chemical compositions listed in Table 1 was melted in a converter and made into steel slabs by continuous casting. The steel slabs were then subjected to heating, hot rolling, cooling, winding, pickling, first annealing, pickling, bending and reverse bending, second annealing, cold rolling, and third annealing in order to produce cold-rolled steel sheets with a final thickness of about 0.4 mm. Each process was performed under the conditions listed in Tables 2 and 3. Cold rolling and third annealing were repeated the number of times listed in Tables 2 and 3. The bending and reverse bending was performed during coil unwinding using bridge rolls of the diameters listed in Tables 2 and 3. For comparison, in some examples, bending and reverse bending was not performed (Comparative Example No. 16).

(Microstructure)

[0083] Next, the microstructures of resulting cold-rolled steel sheets were evaluated by the following procedure.

Average particle size of ferrite

[0084] First, a test piece for microstructure observation was taken from each of the resulting cold-rolled steel sheets. After polishing a rolling direction cross-section (L-section) of the test piece for microstructure observation, the polished surface was corroded with a 3 vol% nital solution to reveal the microstructure. The surface of the test piece for microstructure observation was then imaged using the scanning electron microscope (SEM) at a magnification of 3,000x to obtain a microstructure image. The ferrite grain sizes were measured from the obtained microstructure image by the cutting method according to Japan Industrial Standard (JIS) G0551:2020. The average ferrite grain size measured in 5 observation fields was calculated and used as the average grain size.

Average grain size and number density of grain boundary cementite

[0085] First, a test piece for microstructure observation was taken from each of the resulting cold-rolled steel sheets. After polishing a rolling direction cross-section (L-section) of the test piece for microstructure observation, the polished surface was corroded with a 3 vol% nital solution to reveal the microstructure. The surface of the test piece for microstructure observation was then imaged using the SEM at a magnification of 3000x to obtain a microstructure image. The grain size of only the grain boundary cementite was measured from the obtained microstructure image, and the measurement was made by the cut-off method. The average grain size of the grain boundary cementite measured in 3 observation fields was calculated and used as the average grain size of the grain boundary cementite. The number density of grain boundary cementite with a grain size of 0.5 μm or more was determined from the microstructure image.

Average particle size of NaCl-type carbides

[0086] The average grain size of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in the ferrite grain, was measured using the following procedure. The surface of the test piece was imaged using a transmission electron microscope (TEM) at a magnification of 80,000x to obtain microstructure images for five observation fields. Using image processing with circular approximation, the individual grain diameters of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in the ferrite grains, in the obtained microstructure image were determined and their average value was calculated. Whether the carbides contained at least one of Nb, Ti, or V was identified using a TEM-EPMA (electron probe micro analyzer).

Average spacing of NaCl-type carbides

[0087] The average spacing of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in the ferrite grain, was determined by measuring the spacing of all NaCl-type carbides that could be seen in an observation field at 80,000x and calculating the average value for five observation fields.

[0088] The measurement results are as listed in Tables 4 and 5. The NaCl-type carbides in Tables 4 and 5 refer to NaCl-type carbides which contain at least one of Nb, Ti, and V and are present in ferrite grains.

(Blanking workability)

[0089] Next, to evaluate the blanking workability of the obtained cold-rolled steel sheets, blanking tests were conducted under a set of conditions including the following conditions, and the burr height was measured.

[0090] First, a test piece 20 mm wide, 150 mm long, and 0.4 mm thick was taken from each cold-rolled steel sheet. A ϕ 10 SKD (die steel) or cemented carbide punch was then used to perform blanking on the test piece. The clearance in the blanking was 100 μ m. The blanking was performed 10 times for each test piece. In this case, the distance from the edge of the test piece to the blanking hole was 5 mm or more for the first blanking. The distance between adjacent blanking holes was 5 mm or more for the second and subsequent blankings.

[0091] The height of burrs occurring in the circumferential direction was then observed using a microscope. The height of the burrs was measured at five locations evenly in the circumferential direction for each hole, and the average of the burr heights at the five locations was calculated. The same measurements were then performed on 10 holes, and the average value of the burr heights calculated for each hole was adopted as the burr height.

[Table 1]

[0092]

Table 1

Steel sample ID	Chemical composition (mass%) *											Ac3	Remarks
	C	Si	Mn	P	S	Al	N	Cr	Ti	Nb	V		
A	1.00	0.24	0.71	0.011	0.003	0.003	0.001	0.41	0.008	0.02	-	742	Conforming steel
B	0.95	0.25	0.62	0.010	0.010	0.002	0.002	0.50	0.020	0.02	0.010	753	Conforming steel
C	0.98	0.25	0.65	0.015	0.003	0.003	0.003	0.38	0.012	-	-	751	Conforming steel
D	0.96	0.30	0.55	0.010	0.010	0.003	0.003	0.40	-	0.01	-	750	Conforming steel
E	1.00	0.28	0.50	0.016	0.006	0.004	0.002	0.44	-	0.06	-	751	Conforming steel
F	1.10	0.19	0.92	0.018	0.003	0.005	0.001	0.09	0.001	0.09	0.010	730	Conforming steel
G	0.88	0.19	0.91	0.013	0.002	0.004	0.001	0.35	-	0.08	-	746	Conforming steel
H	0.79	0.16	0.92	0.033	0.008	0.003	0.002	0.40	-	-	0.280	767	Conforming steel
Q	0.94	0.42	0.70	0.012	0.005	0.003	0.001	0.38	-	0.09	0.020	755	Conforming steel
X	0.88	0.32	1.55	0.014	0.002	0.005	0.003	0.48	0.010	0.08	-	736	Conforming steel
Y	1.02	0.25	0.89	0.026	0.001	0.003	0.001	0.42	0.012	0.04	-	747	Conforming steel
Z	0.98	0.16	0.81	0.016	0.010	0.080	0.002	0.41	0.010	-	-	777	Conforming steel
AA	0.83	0.30	0.60	0.013	0.006	0.008	0.008	0.50	-	-	0.125	766	Conforming steel
AB	0.98	0.31	0.90	0.010	0.010	0.003	0.003	0.50	0.010	0.03	0.080	741	Conforming steel
I	0.55	0.28	0.6	0.010	0.009	0.003	0.003	0.52	0.020	0.04	-	803	Comparative steel
J	1.26	0.28	0.78	0.036	0.005	0.007	0.001	0.55	0.010	0.01	-	736	Comparative steel
K	1.10	0.59	0.39	0.008	0.002	0.006	0.005	0.58	0.002	0.03	0.020	753	Comparative steel
L	0.90	0.28	0.33	0.010	0.010	0.003	0.003	0.52	0.252	0.30	0.011	861	Comparative steel
M	0.94	0.22	2.1	0.001	0.001	0.077	0.004	0.39	0.010	-	0.220	733	Comparative steel
N	0.88	0.42	1.42	0.090	0.008	0.004	0.003	0.60	0.098	0.01	0.011	831	Comparative steel
O	1.22	0.20	0.41	0.022	0.040	0.002	0.005	0.39	0.142	0.02	0.015	789	Comparative steel
P	1.10	0.18	0.65	0.019	0.004	0.120	0.005	0.18	0.143	0.02	0.031	847	Comparative steel

(continued)

Steel sample ID	Chemical composition (mass%) *												Ac3	Remarks
	C	Si	Mn	P	S	Al	N	Cr	Ti	Nb	V	Others	°C	
R	0.98	0.33	0.63	0.031	0.007	0.001	0.020	0.08	0.119	0.03	0.029	-	812	Comparative steel
S	0.99	0.46	0.65	0.016	0.001	0.070	0.005	0.02	0.002	0.02	0.318	-	791	Comparative steel
T	0.85	0.22	1.31	0.015	0.008	0.002	0.001	0.99	0.010	0.08	-	-	736	Comparative steel
U	1.18	0.28	0.58	0.038	0.002	0.002	0.002	0.10	0.320	0.01	0.404	-	877	Comparative steel
V	1.23	0.39	0.58	0.011	0.002	0.082	0.001	0.11	0.000	-	-	-	767	Comparative steel
W	0.86	0.46	1.63	0.014	0.010	0.003	0.003	0.35	-	0.29	-	-	739	Comparative steel
*Balance is Fe and inevitable impurities														

[Table 2]

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[0093]

Table 2

No.	Steels ample ID	Ac3 °C	Hot rolling		Cooling			First annealing		Bending and re- vers e bending	Second annealing	Cold rolling	Third an- nealing	Repetition frequency	Remarks
			Hot rolling Start temp.	Finisher delivery temp.	Time to cooling start	Average cooling rate	Cooling stop temp.	Annealing temp.	Annealing time	Roll diam- eter	Annealing temp.	Rolling ratio	Annealing temp.		
			°C	°C	seconds	°C/s	°C	°C	h	mm	°C	%	°C	No. of times	
1	A	742	1070	910	1.2	28	720	690	10	800	640	30	680	3	Example
2	B	753	1100	900	1.0	25	725	685	18	800	690	40	690	2	Example
3	C	751	1130	880	1.6	32	715	640	10	1000	640	20	680	5	Example
4	D	750	1050	880	0.8	25	700	705	12	800	700	35	650	3	Example
5	E	751	1080	890	1.0	30	680	605	8	800	650	30	680	3	Example
6	F	730	975	822	1.1	25	700	650	12	800	650	25	680	4	Example
7	G	746	1090	834	0.5	42	690	685	10	800	700	35	700	2	Example
8	H	767	1120	899	1.2	29	735	650	10	600	710	40	630	3	Example
9	D	750	1180	880	4.5	30	680	605	8	800	650	30	680	3	Example
10	H	751	<u>744</u>	<u>689</u>	1.1	38	710	700	15	800	640	35	680	4	Comparative example
11	H	767	960	<u>760</u>	0.8	49	735	690	15	600	640	25	680	3	Comparative example
12	C	751	1000	880	<u>5.8</u>	36	730	690	10	800	680	25	680	2	Comparative example
13	D	750	980	845	0.8	<u>18</u>	720	700	10	800	640	25	600	3	Comparative example
14	B	753	1055	889	1.0	31	<u>610</u>	710	10	550	630	35	680	5	Comparative example

(continued)

No.	Steels sample ID	Ac3 °C	Hot rolling		Cooling			First annealing		Bending and re- vers e bending	Second annealing	Cold rolling	Third an- nealing	Repetition frequency		Remarks
			Hot rolling Start temp.	Finisher delivery temp.	Time to cooling start	Average cooling rate	Cooling stop temp.	Annealing temp.	Annealing time							
		°C	°C	°C	seconds	°C/s	°C	°C	h	mm	°C	%	°C	No. of times		
15	B	753	1034	850	1.0	36	<u>760</u>	660	10	550	680	25	660	4	Comparative example	
16	A	742	1034	850	1.1	36	740	690	48	-	700	25	640	3	Comparative example	
17	A	742	1034	850	0.7	36	740	<u>750</u>	8	500	710	25	660	3	Comparative example	
18	C	751	1105	830	0.9	30	680	650	<u>4</u>	800	690	45	740	2	Comparative example	
19	E	751	1000	805	1.0	28	690	680	32	1250	720	45	700	2	Example	
20	G	746	1070	840	1.0	26	690	705	8	500	<u>580</u>	25	720	4	Comparative example	

[Table 3]

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[0094]

Table 3

No.	Steels ample ID	Ac3 °C	Hot rolling		Cooling			First annealing		Bending and re- vers e bending	Second annealing	Cold rolling	Third an- nealing	Repetition frequency	Remarks
			Hot rolling Start temp.	Finisher delivery temp.	Time to cooling start	Average cooling rate	Cooling stop temp.	Annealing temp.	Annealing time						
			°C	°C	seconds	°C/s	°C	°C	h	mm	°C	%	°C	No. of times	
21	F	730	1000	810	0.9	38	710	675	18	600	720	<u>10</u>	680	3	Comparative example
22	F	730	990	805	1.1	27	700	675	20	800	650	50	<u>580</u>	3	Comparative example
23	E	751	980	830	1.2	40	705	580	48	800	750	20	660	<u>1</u>	Comparative example
24	<u>V</u>	767	1050	880	0.8	28	700	710	12	1100	700	35	650	3	Comparative example
25	<u>R</u>	811	1050	880	0.8	25	700	710	12	1000	700	35	650	3	Comparative example
26	<u>I</u>	803	1130	880	1.1	39	700	670	14	1100	690	30	690	3	Comparative example
27	<u>J</u>	736	1090	830	1.2	40	705	650	8	1000	700	30	690	2	Comparative example
28	<u>K</u>	753	1060	860	1.1	25	710	650	10	1000	700	20	690	2	Comparative example
29	<u>L</u>	861	1100	880	0.9	27	690	650	6	650	710	35	700	3	Comparative example
30	<u>M</u>	733	1120	900	1.3	30	700	680	10	650	705	40	700	3	Comparative example

(continued)

No.	Steel sample ID	Ac3 °C	Hot rolling		Cooling			First annealing		Bending and reversing bending	Second annealing	Cold rolling	Third annealing	Repetition frequency		Remarks
			Hot rolling Start temp.	Finisher delivery temp.	Time to cooling start	Average cooling rate	Cooling stop temp.	Annealing temp.	Annealing time							
			°C	°C	seconds	°C/s	°C	°C	h	mm	°C	%	°C	No. of times		
31	N	831	1150	900	1.1	30	660	680	12	650	720	25	700	3	Comparative example	
32	O	789	1080	910	1.2	35	660	690	12	650	770	25	720	3	Comparative example	
33	P	847	1100	905	1.1	45	670	700	6	900	740	30	705	2	Comparative example	
34	U	877	1150	915	1.0	50	650	670	14	900	770	45	720	2	Comparative example	
35	W	828	1080	890	0.5	52	670	650	16	900	770	45	730	2	Comparative example	
36	S	791	1120	880	0.9	27	710	680	18	550	710	35	700	3	Comparative example	
37	T	736	1100	900	0.8	30	715	680	18	550	720	30	690	2	Comparative example	
38	Q	755	1100	900	1.4	25	725	685	18	800	690	40	690	2	Example	
39	X	736	1070	910	1.2	28	720	690	10	800	640	30	680	3	Example	
40	Y	747	1090	834	0.5	42	690	685	10	800	700	35	700	2	Example	
41	Z	777	1120	899	2.0	29	735	650	10	600	710	40	630	3	Example	
42	AA	766	1120	899	2.5	29	735	650	10	600	710	40	630	3	Example	
43	AB	741	1050	880	0.8	25	630	705	12	800	740	35	650	3	Example	

(continued)

No.	Steels sample ID	Ac3 °C	Hot rolling		Cooling			First annealing		Bending and re- vers e bending	Second annealing	Cold rolling	Third an- nealing	Repetition frequency	Remarks
			Hot rolling Start temp.	Finisher delivery temp.	Time to cooling start	Average cooling rate	Cooling stop temp.	Annealing temp.	Annealing time	Roll diam- eter	Annealing temp.	Rolling ratio	Annealing temp.		
		°C	°C	°C	seconds	°C/s	°C	°C	h	mm	°C	%	°C	No. of times	
44	AB	741	1100	880	0.8	25	630	705	12	800	770	35	650	4	Example
45	AB	741	1115	880	0.8	25	640	700	24	1000	740	40	650	5	Example
46	AB	741	1100	900	0.8	25	630	705	12	800	560	40	650	2	Comparative example

[Table 4]

[0095]

Table 4

No.	Steel's ample ID	Microstructure					Blanking workability	Remarks
		Average grain size of ferrite	Average grain size of grain boundary cementite	Average grain size of NaCl- type carbides	Average spacing of NaCl- type carbides	Number density of grain boundary cementite with a grain size of 0.5 μm or more	Burr height	
		μm	μm	μm	nm	Gains/100 μm^2	μm	
1	A	7	3	0.01	120	26	45	Example
2	B	5	3	0.05	100	23	35	Example
3	C	7	3	0.10	190	24	50	Example
4	D	5	3	0.04	30	27	75	Example
5	E	6	1	0.03	180	26	45	Example
6	F	7	3	0.10	90	24	75	Example
7	G	7	2	0.07	185	25	80	Example
8	H	1	3	0.05	80	27	60	Example
9	D	10	5	0.05	110	20	95	Example
10	H	<u>17</u>	<u>12</u>	0.30	230	24	110	Comparative example
11	H	10	<u>8</u>	0.05	285	21	110	Comparative example
12	C	<u>13</u>	5	0.10	225	19	120	Comparative example
13	D	<u>12</u>	<u>7</u>	0.05	250	23	110	Comparative example
14	B	<u>17</u>	<u>6</u>	0.05	330	20	110	Comparative example
15	B	7	<u>8</u>	0.10	180	20	120	Comparative example
16	A	<u>15</u>	<u>10</u>	0.10	310	13	160	Comparative example
17	A	<u>22</u>	<u>10</u>	0.25	405	23	125	Comparative example
18	C	<u>20</u>	<u>8</u>	0.40	250	24	110	Comparative example
19	E	10	5	0.20	220	15	95	Example
20	G	7	4	0.09	320	24	115	Example

[Table 5]

[0096]

Table 5

No.	Steel sample ID	Microstructure					Blanking workability	Remarks
		Average grain size of ferrite	Average grain size of grain boundary cementite	Average grain size of NaCl-type carbides	Average spacing of NaCl-type carbides	Number density of grain boundary cementite with a grain size of 0.5 μm or more	Burr height	
		μM	μm	μm	nm	Grains/ 100 μm^2	μM	
21	F	<u>14</u>	<u>8</u>	0.10	205	24	120	Comparative example
22	F	<u>12</u>	<u>6</u>	<u>0.75</u>	440	21	135	Comparative example
23	E	10	<u>6</u>	0.50	160	24	125	Comparative example
24	<u>V</u>	10	5	<u>0.55</u>	410	24	110	Comparative example
25	<u>R</u>	<u>17</u>	<u>12</u>	<u>0.60</u>	250	27	105	Comparative example
26	<u>I</u>	10	3	-	-	17	110	Comparative example
27	<u>J</u>	8	<u>6</u>	0.50	90	31	150	Comparative example
28	<u>K</u>	<u>45</u>	4	0.50	80	24	180	Comparative example
29	<u>L</u>	<u>42</u>	4	0.06	130	23	135	Comparative example
30	<u>M</u>	10	<u>8</u>	0.05	105	24	115	Comparative example
31	<u>N</u>	<u>11</u>	1	0.04	220	25	120	Comparative example
32	<u>O</u>	<u>40</u>	5	0.05	145	22	160	Comparative example
33	<u>P</u>	<u>45</u>	3	0.08	170	21	185	Comparative example
34	<u>U</u>	7	3	<u>1.20</u>	250	17	115	Comparative example
35	<u>W</u>	8	3	<u>1.00</u>	240	18	125	Comparative example
36	<u>S</u>	10	<u>11</u>	0.10	190	19	110	Comparative example
37	<u>T</u>	10	5	-	-	19	115	Comparative example

(continued)

No.	Steel sample ID	Microstructure					Blanking workability	Remarks
		Average grain size of ferrite	Average grain size of grain boundary cementite	Average grain size of NaCl-type carbides	Average spacing of NaCl-type carbides	Number density of grain boundary cementite with a grain size of 0.5 μm or more	Burr height	
		μM	μm	μm	nm	Grains/100 μm^2	μM	
38	Q	10	5	0.23	210	25	90	Example
39	X	10	4	0.10	180	22	75	Example
40	Y	8	4	0.13	170	30	85	Example
41	Z	9	5	0.13	170	16	90	Example
42	AA	10	4	0.10	180	10	90	Example
43	AB	5	3	0.04	680	24	60	Example
44	AB	5	2	0.04	590	32	70	Sample
45	AB	5	3	0.10	710	30	75	Sample
46	AB	10	5	0.22	<u>780</u>	25	120	Comparative example

Claims

1. A cold-rolled steel sheet comprising:

a chemical composition containing, in mass%,

C: 0.60 % to 1.25 %,

Si: 0.1 % to 0.55 %,

Mn: 0.5 % to 2.0 %,

P: 0.0005 % to 0.05 %,

S: 0.0001 % to 0.01 %,

Al: 0.001 % to 0.10 %,

N: 0.001 % to 0.009 %,

Cr: 0.05 % to 0.65 %, and

at least one selected from the group consisting of Ti: 0.001 % to 0.30 %, Nb: 0.01 % to 0.1 %, and V: 0.005 % to 0.5 %,

with the balance being Fe and inevitable impurities; and

a steel microstructure in which

an average grain size of ferrite is 10 μm or less,

an average grain size of cementite in ferrite grain boundaries is 5 μm or less,

an average grain size of NaCl-type carbides, which contain at least one of Nb, Ti, and V and are present in ferrite grains, is 0.5 μm or less, and

an average spacing of the NaCl-type carbides is 710 nm or less.

2. The cold-rolled steel sheet according to claim 1, wherein the chemical composition further contains, in mass%, at least one selected from the group consisting of

Sb: 0.1 % or less,

Hf: 0.5 % or less,
 REM: 0.1 % or less,
 Cu: 0.5 % or less,
 Ni: 3.0 % or less,
 Sn: 0.5 % or less,
 Mo: 1 % or less, and
 Zr: 0.5% or less.

3. A method of producing a cold-rolled steel sheet, comprising:

heating a steel slab having the chemical composition according to claim 1 or 2;
 subjecting the heated steel slab to hot rolling under a set of conditions including a hot rolling start temperature of an Ac3 point or more and a finisher delivery temperature of 800 °C or more, to make a hot-rolled steel sheet;
 subjecting the hot-rolled steel sheet to cooling under a set of conditions in which a time from hot-rolling finish to cooling start is 5.0 seconds or less, an average cooling rate is 25 °C/s or more, and a cooling stop temperature is 620 °C to 740 °C;
 winding the cooled hot-rolled steel sheet;
 subjecting the hot-rolled steel sheet after the winding to first annealing under a set of conditions including an annealing temperature of 730 °C or less and an annealing time of 5 hours or more;
 subjecting the hot-rolled steel sheet after the first annealing to bending and reverse bending;
 subjecting the hot-rolled steel sheet after the bending and reverse bending to second annealing at an annealing temperature of 600 °C or more, and
 subjecting the hot-rolled steel sheet, after the second annealing, to two or more repetitions of cold rolling at a rolling ratio of 15 % or more and third annealing at an annealing temperature of 600 °C or more.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/015630

A. CLASSIFICATION OF SUBJECT MATTER <i>C21D 9/46</i> (2006.01)i; <i>C22C 38/00</i> (2006.01)i; <i>C22C 38/38</i> (2006.01)i; <i>C22C 38/60</i> (2006.01)i FI: C22C38/00 301S; C21D9/46 G; C22C38/38; C22C38/60 According to International Patent Classification (IPC) or to both national classification and IPC																					
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C21D9/46; C22C38/00; C22C38/38; C22C38/60 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2022 Registered utility model specifications of Japan 1996-2022 Published registered utility model applications of Japan 1994-2022 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																					
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>JP 2008-133514 A (JFE STEEL KK) 12 June 2008 (2008-06-12) entire text</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>JP 2006-97109 A (JFE STEEL KK) 13 April 2006 (2006-04-13) entire text</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>JP 2015-105384 A (NIPPON STEEL & SUMITOMO METAL CORP) 08 June 2015 (2015-06-08) entire text, all drawings</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>JP 2017-193752 A (NIPPON STEEL & SUMITOMO METAL CORP) 26 October 2017 (2017-10-26) entire text, all drawings</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>JP 6690792 B1 (NIPPON STEEL CORP) 28 April 2020 (2020-04-28) entire text, all drawings</td> <td>1-3</td> </tr> <tr> <td>A</td> <td>JP 2017-75349 A (NISSHIN STEEL CO LTD) 20 April 2017 (2017-04-20) entire text, all drawings</td> <td>1-3</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A	JP 2008-133514 A (JFE STEEL KK) 12 June 2008 (2008-06-12) entire text	1-3	A	JP 2006-97109 A (JFE STEEL KK) 13 April 2006 (2006-04-13) entire text	1-3	A	JP 2015-105384 A (NIPPON STEEL & SUMITOMO METAL CORP) 08 June 2015 (2015-06-08) entire text, all drawings	1-3	A	JP 2017-193752 A (NIPPON STEEL & SUMITOMO METAL CORP) 26 October 2017 (2017-10-26) entire text, all drawings	1-3	A	JP 6690792 B1 (NIPPON STEEL CORP) 28 April 2020 (2020-04-28) entire text, all drawings	1-3	A	JP 2017-75349 A (NISSHIN STEEL CO LTD) 20 April 2017 (2017-04-20) entire text, all drawings	1-3
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Information on patent family members

International application No.
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JP 2008-133514 A	12 June 2008	(Family: none)	
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JP 2017-75349 A	20 April 2017	(Family: none)	

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