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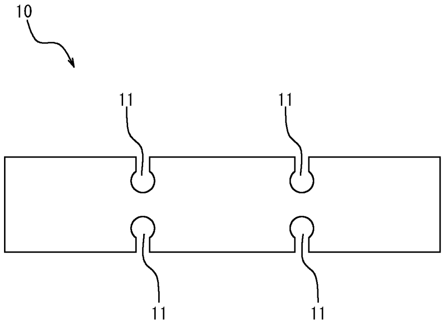
(54) **STEEL PART AND MANUFACTURING METHOD OF STEEL PART**

(57) A steel component having excellent wear resistance is provided. The steel component has a defined chemical composition. The average grain size of prior austenite grains is 25 μm or less. Carbides containing at least one of Nb, Ti, of V are included. Among the carbides, the average particle size of particles having a grain size of 0.1 μm or more is 0.15 μm to 2.5 μm, and the average particle size of particles having a particle size less than 0.1 μm is 0.005 μm to 0.05 μm.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a steel component and in particular to a steel component having excellent wear resistance. Further, the present disclosure relates to a method of producing the steel component.

BACKGROUND

[0002] Carbon steel, a steel containing a high concentration of carbon, has high hardness and is therefore widely used as a material for textile machinery components, bearing components, machine blades, and other steel components that require wear resistance.

[0003] In typical steel component production, a cold-rolled steel sheet as a raw material is worked into a component shape, followed by quenching treatment and tempering treatment. While quenching treatment increases hardness and reduces toughness, subsequent tempering treatment may improve toughness. However, there is a problem that tempering treatment reduces hardness.

[0004] Therefore, various technologies have been proposed to further increase the hardness of steel components and achieve better wear resistance.

[0005] For example, in Patent Literature (PTL) 1, a technology is described for improving formability and wear resistance in a steel sheet having a ferrite-cementite microstructure by increasing the grain size of ferrite, spheroidizing carbides (mainly cementite) of appropriate particle size, and reducing pearlite microstructure.

[0006] Further, in PTL 2, a technology is described for improving wear resistance of a cold-rolled steel sheet by annealing the steel sheet under specific conditions to make the metal microstructure a pearlitic microstructure, which is a layered microstructure of hard cementite and soft ferrite.

[0007] In PTL 3, a technology is described for improving wear resistance of a steel sheet by precipitating coarse Nb, Ti carbides having an equivalent circular diameter of 0.5 μm or more in the ferrite phase matrix microstructure.

[0008] In PTL 4, a technology is described for improving wear resistance of steel by precipitating coarse carbides having a particle size of 2 μm or more in the matrix microstructure.

[0009] In PTL 5, a technology is proposed to improve a spheroidization rate of carbides such as cementite and to improve toughness of a steel sheet containing C: 0.5 mass% to 0.7 mass% by bringing the steel sheet to an annealing finishing state in a stage immediately before final quenching and tempering.

[0010] In PTL 6, a technology is proposed to produce a soft high-carbon steel sheet having excellent blanking properties by increasing the number density of generated voids in the material by bringing the material to an annealing finishing state in a stage immediately before final quenching and tempering.

[0011] In PTL 7, a technology is proposed to improve impact toughness and wear resistance in a high-carbon steel sheet by controlling the formation of cementite, not including niobium, titanium, or vanadium carbides, and by achieving desired values for the spheroidization rate and number density of cementite.

[0012] In PTL 8, a technology is proposed to improve toughness by adjusting the particle size of cementite, not including niobium, titanium, or vanadium carbides, and the grain size of retained austenite and prior austenite, by bringing the material to an annealing finishing state in a stage immediately before final austempering, and further, by obtaining a bainitic microstructure instead of a martensitic tempered microstructure obtainable in a typical heat treatment of quenching and tempering.

CITATION LIST

Patent Literature

[0013]

PTL 1: WO 2016/204288 A
PTL 2: JP 2020-132953 A
PTL 3: JP 2017-190494 A
PTL 4: JP 2010-138453 A
PTL 5: JP 2009-24233 A
PTL 6: JP 2011-12316 A
PTL 7: JP 6880245 B
PTL 8: JP 2018-48374 A

SUMMARY

(Technical Problem)

[0014] According to conventional technologies, such as those proposed in PTL 1 to 8, there is some improvement in the hardness and wear resistance of steel. However, the inventors have found that steel components produced from conventional steel material may not have sufficient wear resistance in actual use.

[0015] In view of the circumstances described above, it would be helpful to provide a steel component having excellent wear resistance.

(Solution to Problem)

[0016] As a result of studies, the inventors arrived at the following discoveries.

(1) When a steel component is actually used, temperature rises due to friction with other parts. For example, when a steel component is used as a textile machinery component, such as a knitting needle, the steel component is constantly exposed to friction with fibers, resulting in a rise in temperature.

(2) Accordingly, to achieve excellent wear resistance in actual use, not only inhibiting static wear caused by abrasion between materials, but also inhibiting softening of the steel sheet due to the rise in temperature during friction is necessary.

(3) To improve the wear resistance of a steel component, carbides containing at least one of Nb, Ti, or V need to be precipitated in the steel. Among the carbides, coarse carbides have an effect of inhibiting static wear. For example, in the case of a textile machinery component, the presence of coarse carbides may reduce the amount of abrasion caused by fibers and foreign matter such as grit attached to fibers.

(4) On the other hand, among the carbides, fine carbides have an effect of inhibiting softening of a steel sheet caused by rising temperature during friction. That is, the presence of fine carbides inhibits a hardness reduction caused by the recovery of dislocation microstructure when temperature rises due to friction. Further, in a steel in which fine carbides are present, prior austenite grains are refined during quenching and tempering, which increases a grain boundary strengthening effect and, as a result, further inhibits hardness reduction caused by dislocation microstructure recovery.

(5) To obtain the effects described above, the average particle sizes of coarse and fine carbides, respectively, need to be controlled within specific ranges.

[0017] The present disclosure is based on the discoveries described above, and primary features of the present disclosure are as described below.

1. A steel component comprising a chemical composition containing (consisting of), in mass%,

C: 0.6 % to 1.25 %,
Si: 0.10 % to 0.55 %,
Mn: 0.20 % to 2.0 %,
P: 0.0005 % to 0.05 %,
S: 0.01 % or less,
Al: 0.001 % to 0.1 %,
N: 0.001 % to 0.009 %,
Cr: 0.05 % to 0.55 %, and
at least one of Ti: 0.05 % to 1.0 %, Nb: 0.1 % to 0.5 %, or V: 0.01 % to 1.0 %,
with the balance being Fe and inevitable impurity,
wherein the average grain size of prior austenite grains is 25 μm or less,
further comprising carbides containing at least one of Nb, Ti, or V, wherein
among the carbides, the average particle size of particles having a particle size of 0.1 μm or more is 0.15 μm to 2.5 μm, and
among the carbides, the average particle size of particles having a particle size less than 0.1 μm is 0.005 μm to 0.05 μm.

2. The steel component 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,
Zr: 0.5 % or less,
B: 0.005 % or less, and
W: 0.01 % or less.

3. The steel component according to aspect 1 or 2, wherein the steel component is any one of a component for textile machinery, a bearing component, or a blade for machinery.
4. A method of producing a steel component, the method comprising:

heating a steel slab comprising the chemical composition according to aspect 1 or 2 under a set of conditions including: a slab heating temperature of 1,100 °C or more and a holding time of 1.0 h or more;
processing the heated steel slab into a hot-rolled steel sheet under a set of conditions including a finishing start temperature of Ac3 or more;
cooling the hot-rolled steel sheet under a set of conditions including: a time from end of hot rolling to start of cooling of 2.0 s or less, an average cooling rate of 25 °C/s or more, and a cooling stop temperature of 640 °C to 720 °C;
coiling the cooled hot-rolled steel sheet;
applying, to the hot-rolled steel sheet after coiling, first annealing under a set of conditions including: an annealing temperature of 650 °C or more and 720 °C or less, and an annealing time of 3 h or more;
applying, to the hot-rolled steel sheet after the first annealing, a cycle applied twice or more of cold rolling at a rolling ratio of 15 % or more and second annealing at an annealing temperature of 600 °C to 800 °C and a heating rate of 50 °C/h or more;
final cold rolling at a rolling ratio of 30 % or more; and
applying, to the cold-rolled steel sheet:

machining into a component shape, and
heat treatment including quenching under a set of conditions including: a quenching temperature of 700 °C or more and 950 °C or less and a holding time of 1.0 min or more to 60 min or less, and tempering under a set of conditions including: a tempering temperature of 100 °C to 400 °C and a holding time of 20 min or more to 3 h or less.

(Advantageous Effect)

[0018] The present disclosure provides a steel component having excellent wear resistance. The steel component according to the present disclosure exhibits excellent wear resistance not only under static conditions, but also under conditions where temperature rises due to friction, and is therefore suitable for use for various applications including components for textile machinery, bearing components, and blades for machinery.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In the accompanying drawings:

FIG. 1 is a schematic diagram illustrating shape of a wear test piece;
FIG. 2 is a schematic diagram of a wear test apparatus; and
FIG. 3 is a schematic diagram illustrating shape of the wear test apparatus used for Examples.

DETAILED DESCRIPTION

[0020] A detailed description is provided below. The present disclosure is not limited to the following embodiments. Further, as described above, the present disclosure focuses on carbides containing at least one of Nb, Ti, or V. Therefore, in the following description, "carbides containing at least one of Nb, Ti, or V" may simply be referred to as "carbides".

[Chemical composition]

[0021] The cold-rolled steel sheet according to the present disclosure has the chemical composition described above. The reasons for the above limitations are described below. Hereinafter, "%" as a unit of content indicates "mass%" unless otherwise specified.

C: 0.6 % to 1.25 %

[0022] C is an element necessary to improve hardness after quenching and tempering. Further, C is an element necessary to form cementite and carbides of elements such as Nb, Ti, V, and the like. To produce the required carbides and to obtain hardness and wear resistance after quenching and tempering, C content needs to be 0.6 % or more. The C content is therefore 0.6 % or more. The C content is preferably 0.7 % or more. On the other hand, when the C content exceeds 1.25 %, hardness increases excessively and embrittlement occurs. When the C content exceeds 1.25 %, surface scale becomes firm during heating, resulting in deterioration of surface characteristics, and the surface becomes prone to cracking during subsequent cold rolling, as well as cracking when quenching, resulting in reduced wear resistance. The C content is therefore 1.25 % or less. The C content is preferably 1.20 % or less.

Si: 0.10 % to 0.55 %

[0023] Si is an element that has an effect of increasing strength through solid solution strengthening, and an increase in strength also improves wear resistance. To achieve this effect, Si content is 0.10 % or more. The Si content is preferably 0.12 % or more. On the other hand, when the Si content is excessive, coarse ferrite is formed on the steel sheet surface during hot working, which inhibits the formation of carbides necessary for improving wear resistance in subsequent working. The Si content is therefore 0.55 % or less. The Si content is preferably 0.50 % or less. The Si content is more preferably 0.45 % or less.

Mn: 0.20 % to 2.0 %

[0024] Mn is an element having an effect of improving hardness by promoting quenching and inhibiting temper softening. In order to inhibit temper softening, inhibiting the formation of C as cementite or delaying dislocation recovery is necessary, and Mn has both of these effects. Further, not only during tempering, Mn also has an effect of inhibiting dislocation recovery caused by friction heat during use of a steel component. To achieve these effects, Mn content is 0.20 % or more. The Mn content is preferably 0.25 % or more. On the other hand, when the Mn content exceeds 2.0 %, a banded microstructure is formed due to Mn segregation. In particular, abnormal grain growth and microstructure nonuniformity are likely to occur at MnS segregations, which inhibit carbide formation and are a cause of cracking and shape defects during component machining. The Mn content is therefore 2.0 % or less. The Mn content is preferably 1.95 % or less.

P: 0.0005 % to 0.05 %

[0025] The addition of a small amount of P increases hardness through solid solution strengthening and thus improves wear resistance. To achieve this effect, P content is 0.0005 % or more. The P content is preferably 0.0008 % or more. On the other hand, when the P content exceeds 0.05 %, the strength of grain boundaries decreases and embrittlement occurs. The P content is therefore 0.05 % or less. The P content is preferably 0.045 % or less.

S: 0.01 % or less

[0026] S consumes Mn by forming sulfides with Mn, and therefore reduces hardenability. As hardenability decreases, strength of steel decreases, resulting in lower wear resistance. S content is therefore 0.01 % or less. From the viewpoint of improving wear resistance, the lower the S content, the better, and therefore a lower limit of S content is not particularly limited and may be 0 %. However, excessive reduction leads to increased production costs, and therefore from the viewpoint of industrial production, the S content is preferably 0.0005 % or more. The S content is more preferably 0.001 % or more.

Al: 0.001 % to 0.1 %

[0027] Al is an element necessary for deoxidation during steelmaking. Al content is therefore 0.001 % or more. On the other hand, an excess of Al results in the formation of coarse nitrides. The nitrides are often formed on the surface of steel, and promote formation of cracks and voids initiating from the nitrides, thus reducing wear resistance. Al content is therefore 0.1 % or less. The Al content is preferably 0.08 % or less. The Al content is more preferably 0.06 % or less.

N: 0.001 % to 0.009 %

[0028] The addition of a small amount of N may form fine nitrides and improve toughness by refining grain size. To achieve these effects, N content is 0.001 % or more. On the other hand, an excess of N combines with Al to form coarse nitrides. The nitrides are often formed on the surface of steel, and promote formation of cracks and voids initiating from the nitrides, thus reducing wear resistance. The N content is therefore 0.009 % or less. The N content is preferably 0.008 % or less.

Cr: 0.05 % to 0.55 %

[0029] Cr is an element that has an effect of increasing hardenability of steel and improving hardness, and therefore the addition of Cr improves wear resistance. To achieve these effects, Cr content is 0.05 % or more. The Cr content is preferably 0.12 % or more. On the other hand, an excess of Cr causes formation of coarse Cr carbides and Cr nitrides, and voids forming around the Cr carbides and Cr nitrides results in reduced performance of steel components. Further, as a result of the formation of Cr carbides, the formation of carbides effective in improving wear resistance is inhibited. The Cr content is therefore 0.55 % or less. The Cr content is preferably 0.95 % or less.

[0030] The chemical composition described above contains at least one element selected from the group consisting of Ti: 0.05 % to 1.0 %, Nb: 0.1 % to 0.5 %, and V: 0.01 % to 1.0 %.

Ti: 0.05 % to 1.0 %

[0031] Ti is an element that has an effect of forming fine carbides and inhibiting both static wear and thermal wear. Further, Ti has an effect of improving wear resistance by refining prior austenite grains during quenching and inhibiting dislocation recovery. When Ti is added, in order to obtain these effects, Ti content is 0.05 % or more. The Ti content is preferably 0.015 % or more. On the other hand, excessive addition of Ti causes carbides to become coarser than necessary, and the carbides become initiation points for voids and cracking, which reduces the workability of steel sheets when worked into component shapes. The Ti content is therefore 1.0 % or less. The Ti content is preferably 0.9 % or less.

Nb: 0.1 % to 0.5 %

[0032] Nb is an element that has an effect of forming fine carbides and inhibiting both static wear and thermal wear. Further, Nb has an effect of improving wear resistance by refining prior austenite grains during quenching and inhibiting dislocation recovery. When Nb is added, in order to obtain these effects, Nb content is 0.1 % or more. On the other hand, excessive addition of Nb causes carbides to become coarser than necessary, and the carbides become initiation points for voids and cracking, which reduces the workability of steel sheets when worked into component shapes. The Nb content is therefore 0.5 % or less. The Nb content is preferably 0.45 % or less.

V: 0.01 % to 1.0 %

[0033] V is an element that has an effect of forming fine carbides and inhibiting both static wear and thermal wear. Further, V has an effect of improving wear resistance by refining prior austenite grains during quenching and inhibiting dislocation recovery. When V is added, to obtain these effects, V content is 0.01 % or more. On the other hand, excessive addition of V causes carbides to become coarser than necessary, and the carbides become initiation points for voids and cracking, which reduces the workability of steel sheets when worked into component shapes. The V content is therefore 1.0 % or less. The V content is preferably 0.95 % or less.

[0034] The cold-rolled steel sheet according to an embodiment of the present disclosure has a chemical composition consisting of the above components, with the balance being Fe and inevitable impurity.

[0035] Further, according to another embodiment of the present disclosure, the chemical composition described above contains 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, Zr: 0.5 % or less, B: 0.005 % or less, and W: 0.01 % or less.

Sb: 0.1 % or less

[0036] Sb is an effective element for improving corrosion resistance, but when added in excess, a rich Sb layer is formed under scale generated during hot rolling, causing surface defects (scratches) on the steel sheet after hot rolling. Sb content is therefore 0.1 % or less. A lower limit of the Sb content is not particularly limited. From the viewpoint of increasing the effect of Sb addition, the Sb content is preferably 0.0003 % or more.

Hf: 0.5 % or less

[0037] Hf is an effective element for improving corrosion resistance, but when added in excess, a rich Hf layer is formed under scale generated during hot rolling, causing surface defects (scratches) on the steel sheet after hot rolling. Hf content is therefore 0.5 % or less. A lower limit of the Hf content is not particularly limited. From the viewpoint of increasing the effect of Hf addition, the Hf content is preferably 0.001 % or more.

REM: 0.1 % or less

[0038] REM (rare earth metals) are elements that improve strength of steel. However, excessive addition of REM may retard refinement of carbides, promote non-uniform deformation during cold working and degrade surface characteristics. REM content is therefore 0.1 % or less. A lower limit of the REM content is not particularly limited. From the viewpoint of increasing the effect of REM addition, the REM content is preferably 0.005 % or more.

Cu: 0.5 % or less

[0039] Cu is an effective element for improving corrosion resistance, but when added in excess, a rich Cu layer is formed under scale generated during hot rolling, causing surface defects (scratches) on the steel sheet after hot rolling. Cu content is therefore 0.5 % or less. A lower limit of the Cu content is not particularly limited. From the viewpoint of increasing the effect of Cu addition, the Cu content is preferably 0.01 % or more.

Ni: 3.0 % or less

[0040] Ni is an element that improves strength of steel. However, excessive addition may promote non-uniform deformation during cold working and degrade surface characteristics. Ni content is therefore 3.0 % or less. A lower limit of the Ni content is not particularly limited. From the viewpoint of increasing the effect of Ni addition, the Ni content is preferably 0.01 % or more.

Sn: 0.5 % or less

[0041] Sn is an effective element for improving corrosion resistance, but when added in excess, a rich Sn layer is formed under scale generated during hot rolling, causing surface defects (scratches) on the steel sheet after hot rolling. Sn content is therefore 0.5 % or less. A lower limit of the Sn content is not particularly limited. From the viewpoint of increasing the effect of Sn addition, the Sn content is preferably 0.0001 % or more.

Mo: 1 % or less

[0042] Mo is an element that improves strength of steel. However, excessive addition of Mo may retard the spheroidization of carbides, promote non-uniform deformation during cold working, and degrade surface characteristics. The Mo content is therefore 1 % or less. A lower limit of the Mo content is not particularly limited. From the viewpoint of increasing the effect of Mo addition, the Mo content is preferably 0.001 % or more.

Zr: 0.5 % or less

[0043] Zr is an effective element for improving corrosion resistance, but when added in excess, a rich Zr layer is formed under scale generated during hot rolling, causing surface defects (scratches) on the steel sheet after hot rolling. Zr content is therefore 0.5 % or less. A lower limit of the Zr content is not particularly limited. From the viewpoint of increasing the effect of Zr addition, the Zr content is preferably 0.01 % or more.

B: 0.005 % or less

[0044] B is an element that has an effect of improving hardenability and may be added. However, when B content exceeds 0.005 %, surface cracking is likely to occur during quenching. The B content is therefore 0.005 % or less. A lower limit of the B content is not particularly limited. From the viewpoint of increasing the effect of B addition, when B is added, the B content is preferably 0.0001 % or more.

W: 0.01 % or less

[0045] W is an element that has an effect of improving hardenability and may be added. However, when W content exceeds 0.01 %, surface cracking is likely to occur during quenching. The W content is therefore 0.01 % or less. A lower limit of the W content is not particularly limited. From the viewpoint of increasing the effect of W addition, when W is added, the W content is preferably 0.001 % or more.

Average grain size of prior austenite grains: 25 μm or less

[0046] A grain boundary strengthening effect is improved by refining prior austenite grains. As a result, dislocation recovery during frictional heat generation is inhibited, and therefore hardness may be maintained even under a hot environment, improving wear resistance. To achieve the effect, the average grain size of prior austenite grains is 25 μm or less.

[Carbides]

[0047] The steel component according to the present disclosure contains carbides including at least one of Nb, Ti, or V. Conventionally, cementite has been used to improve wear resistance, but carbides containing at least one of Nb, Ti, or V are harder than cementite, and therefore precipitation of carbides containing at least one of Nb, Ti, or V is able to improve wear resistance more than conventionally.

[0048] As mentioned previously, among the carbides, coarse carbides have the effect of inhibiting static wear, while fine carbides have the effect of inhibiting wear at elevated temperatures caused by friction. Therefore, by appropriately controlling particle sizes of coarse carbides and fine carbides, respectively, the wear resistance of steel components in actual use may be effectively improved.

[0049] According to the present disclosure, among carbides containing at least one of Nb, Ti, or V, carbides having a particle size of 0.1 μm or more are defined as coarse carbides and carbides having a grain size of less than 0.1 μm are defined as fine carbides.

• Coarse carbides

[0050] The coarse carbides act to inhibit static wear. For example, in the case of a textile machinery component such as a knitting needle, the presence of the coarse carbides may reduce wear caused by abrasion with fibers and foreign matter such as grit attached to the fibers. However, when the average particle size of the coarse carbides is less than 0.15 μm, resistance to static wear is not exhibited. The average particle size of the coarse carbides is therefore 0.15 μm or more. On the other hand, when the carbides become too coarse, the opportunity for the carbides to function as resistance is reduced, and therefore the effect of resistance to wear saturates. The average particle size of the coarse carbides is therefore 2.5 μm or less. The number density of the coarse carbides is not particularly limited. The higher the number density, the better, and 250/mm^2 or more is preferred. The coarse carbides may be present at crystal grain boundaries or within crystal grains.

• Fine carbides

[0051] The fine carbides stabilize dislocation microstructure and help prevent dislocation recovery when temperature rises due to frictional heat. Accordingly, by precipitating the fine carbides, softening due to frictional heat may be inhibited and wear resistance under a hot environment may be improved. The effect of inhibiting dislocation recovery increases with a smaller average particle size of the fine carbides. The average particle size of the fine carbides is therefore 0.05 μm or less. On the other hand, excessively fine carbides lead to excessive hardness and embrittlement. The average particle size of the fine carbides is therefore 0.005 μm or more. The fine carbides are more effective when formed within crystal grains than at crystal grain boundaries. The number density of the fine carbides is not particularly limited. The higher the number density, the greater the effect, and 0.11/μm^2 or more is preferred.

[0052] Further, the microstructure of the steel component according to the present disclosure is not particularly limited. Desired properties are obtainable as long as the conditions described above are met. Typically, the microstructure of the steel component according to the present disclosure may consist of tempered martensite, cementite, and carbides containing at least one of Nb, Ti, or V. The cementite and the carbides containing at least one of Nb, Ti, or V are preferably spheroidized. Specifically, the spheroidization ratio of the carbides, defined by the following expression using average major axis length La and average minor axis length Lb of the carbides, is preferably 0.71 or more.

$$\text{Spheroidization ratio} = Lb/La$$

[0053] La is obtained by dividing the sum of the major axis length of all carbides in a 100 μm^2 range by the number of such carbides. Further, Lb is obtained by dividing the sum of the minor axis length of all carbides in a 100 μm^2 range by the number of such carbides.

[Sheet thickness]

[0054] The sheet thickness of the cold-rolled steel sheet is not particularly limited and may be any thickness. The sheet thickness is preferably 0.1 mm or more. The sheet thickness is more preferably 0.2 mm or more. Further, an upper limit of the sheet thickness is not particularly limited. The sheet thickness is particularly 2.5 mm or less. The sheet thickness is more preferably 1.6 mm or less. The sheet thickness is even more preferably 0.8 mm or less. When the sheet thickness is 0.2 mm or more and 0.8 mm or less, the cold-rolled steel sheet is particularly suitable for use as a material for knitting needles and the like.

[Method for producing cold-rolled steel sheet]

[0055] The following describes a method for producing a cold-rolled steel sheet according to an embodiment.
[0056] The cold-rolled steel sheet may be produced by performing the following processes in sequence, starting with a steel slab having the chemical composition described above.

(1) Heating
(2) Hot rolling
(3) Cooling
(4) Coiling
(5) First annealing
(6) Cold rolling
(7) Second annealing
(8) Final cold rolling
(9) Machining and heat treatment

[0057] The processes (6) and (7) above are applied two or more times. The following describes each of the processes.

(1) Heating

[0058] First, a steel slab having the chemical composition described above is heated. A method for producing the steel slab is not particularly limited, and any method may be used. For example, composition adjustment of the steel slab may be performed by a blast furnace converter steelmaking process or by an electric furnace steelmaking process. Further, for example, casting from molten steel into a slab may be done by continuous casting or by blooming.

Slab heating temperature: 1,100 °C or more
Holding time: 1.0 h or more

[0059] In the heating, the steel slab is heated under a set of conditions including: a slab heating temperature of 1,100 °C or more and a holding time of 1.0 h or more, in order to homogenize the steel microstructure and to allow some carbides in the steel to be solid-dissolved and the rest to be precipitated.
[0060] Some C combined with Nb, Ti, V to form the coarse carbides needs to be precipitated at the slab heating stage described above, while other undissolved carbides are dissolved at the slab heating stage in order to precipitate to desired dimensions at a later annealing stage. When the slab heating temperature is lower than 1,100 °C or when the holding time is shorter than 1 h, coarse Nb, Ti, V carbides are not precipitated, and later, coarse Nb, Ti, V carbides to increase resistance to static wear are not obtainable. On the other hand, when the slab heating temperature is too high, Nb, Ti, V solid-solubilize, decreasing a precipitation amount, and therefore the slab heating temperature is preferably 1,380 °C or less.

(2) Hot rolling

[0061] The heated slab is then hot rolled to obtain a hot-rolled steel sheet. In the hot rolling, rough rolling and finishing rolling may be performed according to conventional methods.

Finishing start temperature: Ac3 or more

[0062] When the finishing start temperature of the hot rolling is less than Ac3, stretched ferrite is formed in the steel sheet after hot rolling, and this stretched ferrite remains in the finally obtainable cold-rolled steel sheet. As a result, the formation of carbides at grain boundaries and within grains, which is effective in improving wear resistance, is inhibited. The finishing start temperature of the hot rolling is therefore Ac3 or more. An upper limit of the finishing start temperature is not particularly limited. The finishing start temperature is preferably 1,200 °C or less.

[0063] The Ac3 temperature (°C) is obtained by the following Formula (1).

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

[0064] Here, the element symbols denote the content in mass% of the respective elements, and the content of any element not contained is assumed to be 0.

(3) Cooling

Time from end of hot rolling to start of cooling: 2.0 s or less

[0065] The hot-rolled steel sheet is then cooled. When a long time elapses between the end of hot rolling and the start of cooling, coarse ferrite grains are formed in a surface layer of the steel sheet and remain until later processing. As a result, the precipitation of carbides to grain boundaries and into grains, which is effective in improving wear resistance, is inhibited. The time between the end of hot rolling and the start of cooling is therefore 2.0 s or less. In view of the above, the shorter the time between the end of hot rolling and the start of cooling, the better, and therefore a lower limit is not particularly limited. However, from an industrial production viewpoint, the time may be 0.5 s or more, or even 0.8 s or more.

Average cooling rate: 25 °C/s or more

[0066] Similarly, when the average cooling rate during the cooling is less than 25 °C/s, coarse ferrite grains are formed in a surface layer of the steel sheet, and precipitation of carbides that are effective in improving wear resistance is inhibited. The average cooling rate in the cooling is therefore 25 °C/s or more. An upper limit of the average cooling rate is not particularly limited. When the cooling rate is excessively high, volume expansion caused by transformation during subsequent coiling results in a poor coiling shape. Therefore, from the viewpoint of achieving a good coiling shape, the average cooling rate is preferably 160 °C/s or less. The average cooling rate is more preferably 150 °C/s or less.

Cooling stop temperature: 640 °C to 720 °C

[0067] When the cooling stop temperature is too high during the cooling, a non-uniform microstructure consisting of abnormally coarse portions and fine portions is formed, which inhibits subsequent carbide formation. The cooling stop temperature is therefore 720 °C or less. On the other hand, when the cooling stop temperature is too low, coiling shape defects occur due to volume expansion caused by transformation during coiling. As a result, non-uniform strain is introduced into the steel sheet during subsequent cold rolling, and therefore carbides of the desired particle size are not obtained, and wear resistance is not improved. The cooling stop temperature is therefore 640 °C or more.

(4) Coiling

[0068] After the cooling is stopped, the cooled hot-rolled steel sheet is coiled. At this time, the coiling temperature is not particularly limited. The coiling temperature is preferably 600 °C to 700 °C.

(5) First annealing

[0069]

Annealing temperature: 650 °C or more and 720 °C or less

Annealing time: 3 h or more

[0070] The hot-rolled steel sheet after the coiling is subjected to the first annealing under a set of conditions including: an annealing temperature of 650 °C or more and 720 °C or less, and an annealing time of 3 h or more. The microstructure of the hot-rolled steel sheet after the coiling is a pearlitic microstructure lined with plate-like cementite and ferrite. When the microstructure is pearlitic, strain is not introduced stably during subsequent cold rolling, and the cold-rolled steel sheet may be defective in shape. Accordingly, breaking up the pearlitic microstructure and spheroidizing the carbides is necessary. However, the pearlitic microstructure is stable to heat, and therefore tends to maintain plate shapes. The plate-like microstructure needs to be broken up by holding at a high temperature for a long time to increase interface area. The first annealing is therefore performed at a temperature of 650 °C or more for 3 h or more. After the first annealing, further cold rolling and second annealing helps to break up plate-like cementite. On the other hand, when the annealing temperature is higher than 720 °C, microstructure change proceeds preferentially from one portion, resulting in a mixed microstructure of coarse and fine microstructures, and ultimately carbides of the desired size are not obtained, and wear resistance is not improved. An upper limit of the annealing time is not particularly limited. An excessively long annealing time reduces productivity and also saturates the effect. Therefore, the annealing time is preferably 20 h or less.
[0071] Prior to the first annealing, the hot-rolled steel sheet is preferably pickled.

(6) Cold rolling

(7) Second annealing

[0072] Cold rolling is an important process for improving wear resistance, as the plate-like carbides broken up in the first annealing process are further broken up and dispersed throughout the steel sheet, and dispersed at the desired dimensions by the second annealing process. Plate-like carbides formed after hot rolling and coiling are stable, and therefore tend to remain until later stages of production. Plate-like carbide formation may cause void formation and cracking. Further, wear progresses unilaterally in portions of the microstructure where carbide formation does not occur due to not being dispersed throughout the steel sheet.
[0073] Therefore, in order to precipitate carbides having a particle size effective for improving wear resistance, the hot-rolled steel sheet after the first annealing is subjected to two or more cycles of cold rolling and second annealing. The cold rolling is used to break up the plate-like carbides formed in the steel sheet, and the second annealing is used to distribute the carbides of the desired dimensions throughout the steel sheet. To achieve these effects, the rolling ratio in the cold rolling is 15 % or more and the annealing temperature in the second annealing is 600 °C or more. On the other hand, when the annealing temperature is higher than 800 °C, prior austenite grains in the finally obtained microstructure become coarser, resulting in decreased wear resistance during friction heat generation. The annealing temperature is therefore 800 °C or less.
[0074] When the heating rate in the second annealing is too slow, local coarsening of the carbides occurs, and the fine carbides necessary to inhibit the softening of the steel sheet as temperature rises during friction are not obtained. The heating rate is therefore 50 °C/h or more. An upper limit of the heating rate is not particularly limited. The heating rate is preferably 200 °C/s or less.
[0075] Although a higher rolling ratio in the cold rolling is better, when the rolling ratio is 65 % or more, the shape of a resulting cold-rolled steel sheet may become unstable. The rolling ratio is therefore preferably less than 65 %.
[0076] The number of cycles of the cold rolling and the second annealing is two or more. Two or more cycles of the cold rolling and the annealing refines the microstructure and distributes carbides throughout the steel sheet to achieve the final desired carbide sizes. A large number of cycles is preferable to consistently obtain good steel sheet shape and thickness accuracy, and an upper limit of the number of cycles is not particularly limited. However, when the number of cycles exceeds five, the effect saturates, and therefore the number of cycles is preferably five or less.

(8) Final cold rolling

Rolling ratio: 30 % or more

[0077] After the cycle of the cold rolling and the second annealing is performed two or more times as described above, final cold rolling at a rolling ratio of 30 % or more is further applied. According to the final cold rolling at a rolling ratio of 30 % or more, the fine carbides are produced during final quenching and tempering, which improves wear resistance during frictional heat generation. Further, final cold rolling at a rolling ratio of 30 % or more refines prior austenite grain size, and therefore further improves wear resistance. The larger the rolling ratio in the final cold rolling, the better, but the shape of the steel sheet may become unstable when the rolling ratio is 65 % or more. The rolling ratio is therefore preferably less than 65 %.

[0078] Further, the final cold-rolled steel sheet may be subjected to further optional surface treatment.

(9) Machining and heat treatment

[0079] The resulting cold-rolled steel sheet is then machined into component shapes and heat-treated to produce the final steel component. The method of machining is not particularly limited and any method may be applied. The machining may be, for example, at least one of blanking, cutting work, drawing, bending, or polishing.

[0080] The heat treatment includes quenching under a set of conditions including: a quenching temperature of 700 °C or more and 950 °C or less and a holding time of 1.0 min or more to 60 min or less, and tempering under a set of conditions including: a tempering temperature of 100 °C to 400 °C and a holding time of 20 min or more to 3 h or less. The quenching and tempering conditions are important to control carbide particle size and prior austenite grain size, in order to obtain excellent wear resistance.

[0081] In order to produce the fine carbides, the quenching temperature (heating temperature during quenching) needs to be high. The quenching temperature is therefore 700 °C or more. The quenching temperature is preferably 720 °C or more. On the other hand, when the quenching temperature is too high, prior austenite grain size increases and wear resistance decreases. The quenching temperature is therefore 950 °C or less. The quenching temperature is preferably 920 °C or less.

[0082] In order to produce carbides of the desired dimensions during the quenching, holding at the heating temperature for 1.0 min or more is necessary. The holding time is therefore 1.0 min or more. On the other hand, when the holding time exceeds 60 min, prior austenite grains become coarser and wear resistance decreases. The holding time is therefore 60 min or less. Cooling in the quenching process is preferably performed by cooling to room temperature using oil or other coolant.

[0083] In order to improve hardness and obtain high wear resistance, tempering temperature needs to be low. The tempering temperature is therefore 400 °C or less. The tempering temperature is preferably 380 °C or less. On the other hand, when the tempering temperature is too low, the fine carbides do not grow to the desired dimensions. Further, hardness becomes too high and the material is embrittled. The tempering temperature is therefore 100 °C or more. The tempering temperature is preferably 130 °C or more.

[0084] When the holding time during the tempering is less than 20 min, the fine carbides do not grow to the desired dimensions, and hardness increases too much, causing embrittlement, and therefore the holding time is 20 min or more. On the other hand, when the holding time exceeds 3 h, the fine carbides become too coarse to achieve the desired dimensions. The holding time is therefore 3 h or less.

[0085] The heat treatment may be performed after the machining or during the machining.

[0086] According to the above method, a steel component having excellent wear resistance may be produced. Applications of the steel component are not particularly limited. The steel component is particularly suitable for applications requiring wear resistance, such as components for textile machinery, bearing components, and blades for machinery.

EXAMPLES

[0087] Steels having the chemical compositions listed in Table 1 were melted in a converter and made into steel slabs by continuous casting. Each steel slab was then heated, hot rolled, cooled, coiled, first annealed, cold rolled, second annealed, and finally cold rolled in sequence to produce a cold-rolled steel sheet having a final sheet thickness of about 0.4 mm. Each process was carried out under the conditions listed in Tables 2 and 3. The cycle of cold rolling and second annealing was applied a number of times listed in Table 3. The cold-rolled steel sheets were then subjected to heat treatment consisting of quenching and tempering under the conditions listed in Table 3 to obtain samples. In the Examples, the process of machining to a component shape was omitted.

[0088] For each sample, the average grain size of prior austenite grains, the average particle size of the coarse carbides, and the average particle size of the fine carbides were measured by the following procedures.

(Prior austenite grain size)

[0089] Test pieces for microstructure observation were taken from the samples obtained. For each test piece, after polishing a rolling direction cross section (L-section) of the test piece for microstructure observation, final polishing was performed with colloidal silica, and electron backscatter diffraction (EBSD) measurements were performed to identify prior austenite grain boundaries. After identifying prior austenite grain boundaries, individual grain sizes and the number of grains were determined, and the equivalent circular diameter was calculated and used as the average grain size. The evaluation results are listed in Table 4.

(Coarse carbides)

[0090] Test pieces for carbide observation were taken from the samples obtained. For each test piece, after polishing a rolling direction cross section (L-section) of the test piece for carbide observation, the polished surface was corroded with 1 vol% to 3 vol% nital solution to reveal the microstructure. The surface of the test piece for carbide observation was then imaged using scanning electron microscopy (SEM) at a magnification of 3,000× to obtain a microstructure image. The particle size of each carbide containing at least one of Nb, Ti, or V in the microstructure image obtained was measured by a cutting method, and the average particle size of the carbides was calculated. Nb, Ti, V carbides were identified using SEM energy dispersive X-ray spectroscopy (EDS) analysis. Elemental mapping was performed with respect to the observed fields of view to separate cementite from other carbides, and the other carbides were considered to be Nb, Ti, V carbides. The evaluation results are listed in Table 4. The column was left blank (-) when no coarse carbides were observed.

(Fine carbides)

[0091] Test pieces for carbide observation were taken from the samples obtained, thinned to a thickness of about 70 μm, and then observation samples were prepared by electropolishing. For each observation sample, carbides containing at least one of Nb, Ti, or V were observed by transmission electron microscopy (TEM) at 150,000× to 250,000× magnification and analyzed by TEM-EDS. The diameter of each carbide was determined by the cutting method, and the arithmetic mean of the obtained diameters was calculated to obtain the average particle size of the fine carbides. The evaluation results are listed in Table 4. The column was left blank (-) when no fine carbides were observed.

(Wear resistance)

[0092] The wear resistance of the resulting steel sheets after quenching and tempering was evaluated under the following two conditions.

[0093] First, the wear resistance under static conditions, where temperature rise due to friction hardly occurs, was evaluated using the following procedure.

[0094] From each test piece, a wear test piece 10 was taken having the shape illustrated in FIG. 1. Each of the wear test pieces 10 was provided with four holes 11 for threading.

[0095] Wear tests were conducted using the wear test pieces 10 and a wear test apparatus 20 illustrated in FIG. 2. Specifically, an amount of wear was measured by running a yarn S fed from a yarn unwinder 21 for 100,000 m per hole with the yarn S in contact with the side of the hole 11 of the wear test piece 10. Full dull polyester knitting yarn was used as the yarn S. The running speed of the yarn S was 5 m/min. Further, the tension of the yarn was adjusted to 10 ± 2 N/cm using a tension regulator 22.

[0096] As illustrated in FIG. 3, a groove 12 was formed by wear at a point where the hole 11 was in contact with the yarn. After running the yarn 100,000 m, the running was stopped and a depth d (wear depth) of the groove 12 was measured using optical microscopy.

[0097] The same test was performed on each of the four holes 11 and the average of the four wear depths obtained was taken as the wear depth of the wear test piece 10. When the wear depth was less than 490 μm, the wear resistance was judged to be good (O), and when 490 μm or more, wear resistance was judged to be poor (X). The evaluation results are listed in Table 4.

[0098] Next, in order to evaluate wear resistance under conditions with a temperature increase caused by friction, the same procedure was used as in the static condition test above, except that the yarn running speed was set to 180 m/min, and wear resistance was evaluated using the same criteria. The evaluation results are listed in Table 4.

[Table 1]

[0099]

Table 1

Steel sample ID	Chemical composition (mass%) *												Ac3	Remarks
	C	Si	Mn	P	S	Al	N	Cr	Ti	Nb	V	Other		
A	0.95	0.22	0.71	0.018	0.0010	0.002	0.003	0.40	-	0.11	-	-	748	Conforming steel
B	0.90	0.24	0.81	0.010	0.0030	0.003	0.003	0.50	0.07	0.10	-	-	773	Conforming steel
C	0.68	0.21	1.05	0.015	0.0100	0.004	0.005	0.55	0.01	0.08	0.04	-	769	Conforming steel
D	0.79	0.22	0.90	0.010	0.0020	0.003	0.002	0.40	0.08	0.21	002	-	786	Conforming steel
E	0.95	0.25	0.55	0.031	0.0100	0.002	0.001	0.44	-	0.11	-	-	763	Conforming steel
F	0.88	0.24	0.77	0.028	0.0022	0.030	0.002	0.55	-	0.10	-	-	773	Conforming steel
G	0.95	0.44	0.61	0.042	0.0026	0.002	0.006	0.32	0.10	-	-	-	818	Conforming steel
H	1.18	0.15	0.70	0.017	0.0080	0.020	0.003	0.55	0.38	-	0.30	Mo:0.01	880	Conforming steel
I	1.11	0.3	0.86	0.018	0.0020	0.040	0.002	0.41	-	-	0.06	Ni:0.01, Cu:0.01	748	Conforming steel
J	0.80	0.5	0.81	0.022	0.0030	0.003	0.001	0.20	-	0.18	0.00	Sb:0.005, Sn:0.002, Hf0.001, REM:0.001, Zr:0.003, B:0.001, W:0.001	779	Conforming steel
K	<u>0.530</u>	0.51	0.38	0.016	0.0030	0.003	0.001	0.22	0.05	0.18	0.05	-	842	Comparative steel
L	<u>1.52</u>	0.24	0.66	0.012	0.0040	0.004	0.002	0.09	0.04	0.22	0.06	-	714	Comparative steel
M	0.88	<u>0.07</u>	0.58	0.012	0.0050	0.002	0.003	0.31	0.04	0.27	0.9	-	765	Comparative steel

(continued)

Steel sample ID	Chemical composition (mass%) *												Ac3	Remarks
	C	Si	Mn	P	S	Al	N	Cr	Ti	Nb	V	Other		
N	0.90	0.68	0.55	0.014	0.0080	0.002	0.002	0.28	0.05	0.38	0.42	-	797	Comparative steel
O	0.91	0.21	0.17	0.013	0.0100	0.003	0.002	0.44	0.82	0.12	0.02	-	1092	Comparative steel
P	1.11	0.24	2.22	0.016	0.0030	0.003	0.004	0.50	0.41	0.19	0.03	-	849	Comparative steel
Q	0.68	0.25	1.23	0.08	0.0100	0.004	0.004	0.51	0.3	0.2	0.03	-	927	Comparative steel
R	0.79	0.30	1.00	0.023	0.0300	0.005	0.003	0.47	0.11	0.29	0.08	Mo:0.03	808	Comparative steel
S	0.90	0.41	0.69	0.033	0.0060	0.16	0.005	0.49	0.78	0.24	002	-	1156	Comparative steel
T	0.90	0.20	0.58	0.027	0.0030	0.003	0.022	0.50	0.07	0.14	0.01	-	790	Comparative steel
U	0.95	0.40	1.88	0.028	0.0030	0.007	0.002	0.03	0.13	0.5	0.07	-	786	Comparative steel
V	0.92	0.33	0.77	0.011	0.0010	0.003	0.003	0.92	0.04	0.38	0.61	-	760	Comparative steel
W	0.99	0.28	0.45	0.042	0.0020	0.003	0.006	0.38	0.01	-	-	-	776	Comparative steel
X	0.70	0.25	0.40	0.039	0.0080	0.004	0.005	0.29	-	-	1.1	-	803	Comparative steel
Y	1.25	0.49	0.61	0.015	0.0003	0.002	0.003	0.30	-	-	-	-	733	Comparative steel

* The balance being Fe and inevitable impurity

[Table 2]

[0100]

Table 2

No.	Steel sample ID	Ac3	Heating		Hot rolling	Cooling			First annealing		Remarks
			Slab heating temp.	Holding time	Finishing start temp.	Time to start *	Cooling rate	Cooling stop temp.	Annealing temp.	Annealing time	
		°C	°C	h	°C	s	°C/s	°C	°C	h	
1	A	748	1108	1.0	1010	1.3	50	685	700	6	Example
2	B	773	1180	2.0	1120	1.5	30	700	705	4	Example
3	C	769	1220	1.5	1190	1.4	30	690	695	8	Example
4	D	786	1190	6.0	1110	1.0	50	690	680	6	Example
5	E	763	1220	4.0	1200	1.5	45	685	710	10	Example
6	F	773	1250	4.5	1180	2.0	60	690	720	15	Example
7	G	818	1310	3.0	1230	1.7	105	690	720	6	Example
8	H	880	1370	6.0	1305	0.9	90	705	700	6	Example
9	I	748	1200	2.0	1090	1.5	40	685	730	10	Example
10	J	779	1150	4.0	1015	1.5	85	680	660	12	Example
11	K	842	1270	3.0	1050	1.0	30	690	680	4	Comparative Example
12	L	714	1160	4.5	1080	2.0	28	690	690	5	Comparative Example
13	M	765	1130	2.0	1050	1.8	85	700	700	6	Comparative Example
14	N	797	1180	4.0	1100	1.9	55	705	680	6	Comparative Example
15	O	1092	1200	3.0	1120	1.5	65	710	690	6	Comparative Example
16	P	849	1280	5.0	1200	2.0	60	700	700	8	Comparative Example

(continued)

No.	Steel sample ID	Ac3	Heating		Hot rolling	Cooling			First annealing		Remarks
			Slab heating temp.	Holding time	Finishing start temp.	Time to start *	Cooling rate	Cooling stop temp.	Annealing temp.	Annealing time	
		°C	°C	h	°C	s	°C/s	°C	°C	h	
17	Q	927	1290	4.0	1210	1.5	70	680	710	10	Comparative Example
18	R	808	1170	3.5	1090	2.0	50	650	690	8	Comparative Example
19	S	1156	1290	1.0	1210	1.8	50	700	660	8	Comparative Example
20	I	790	1080	2.5	1000	1.5	55	690	650	6	Comparative Example
21	U	786	1140	3.0	1060	1.8	25	680	700	6	Comparative Example
22	V	760	1160	3.5	1080	2.0	30	680	690	8	Comparative Example
23	W	776	1130	4.5	1050	2.0	70	650	680	8	Comparative Example
24	X	803	1120	4.0	1040	1.8	65	640	680	10	Comparative Example
25	Y	733	1100	5.0	1100	1.5	50	680	680	6	Comparative Example
26	C	769	990	8.0	1040	1.5	30	690	700	5	Comparative Example
27	C	769	1390	5.0	1110	1.8	41	700	700	8	Example
28	C	769	1180	0.5	1010	2.0	40	660	710	10	Comparative Example
29	C	769	1100	3.0	760	1.0	25	640	680	12	Comparative Example

(continued)

No.	Steel sample ID	Ac3	Heating		Hot rolling	Cooling			First annealing		Remarks
			Slab heating temp.	Holding time	Finishing start temp.	Time to start *	Cooling rate	Cooling stop temp.	Annealing temp.	Annealing time	
		°C	°C	h	°C	s	°C/s	°C	°C	h	
30	F	773	1210	4.0	1180	5.0	38	700	720	4	Comparative Example
31	F	773	1190	5.0	1120	1.5	10	690	660	9	Comparative Example
32	F	773	1180	8.0	1010	0.9	40	610	680	8	Comparative Example
33	F	773	1100	1.0	1000	1.8	55	730	710	3	Comparative Example
34	D	786	1110	4.0	1060	1.5	60	680	620	5	Comparative Example
35	D	786	1180	8.0	1020	2.0	49	690	750	4	Comparative Example
36	D	786	1200	3.0	1080	1.7	34	710	700	1	Comparative Example
37	D	786	1110	5.5	1305	1.6	90	690	700	5	Comparative Example
38	D	786	1150	5.5	1090	1.5	50	700	690	4	Comparative Example
39	D	786	1200	9.0	1070	1.0	40	660	710	8	Comparative Example
40	D	786	1210	6.0	1050	1.3	45	680	720	9	Comparative Example
41	C	769	1230	4.5	1030	1.5	48	700	680	10	Comparative Example
42	G	818	1210	6.0	1090	1.7	40	680	710	6	Comparative Example

(continued)

No.	Steel sample ID	Ac3	Heating		Hot rolling	Cooling			First annealing		Remarks
			Slab heating temp.	Holding time	Finishing start temp.	Time to start *	Cooling rate	Cooling stop temp.	Annealing temp.	Annealing time	
		°C	°C	h	°C	s	°C/s	°C	°C	h	
43	G	818	1105	4.0	1100	1.6	30	650	720	4	Comparative Example
44	G	818	1310	8.5	1040	1.0	25	690	700	7	Comparative Example
45	G	818	1150	5.0	990	2.0	48	640	720	5	Comparative Example
46	I	748	1350	6.0	1070	1.2	70	710	700	10	Comparative Example
47	I	748	1230	8.0	1050	1.1	100	670	690	12	Comparative Example
48	I	748	1210	6.0	1000	2.0	50	690	720	8	Comparative Example
49	C	769	1150	3.5	990	1.4	45	690	695	6	Comparative Example

* Time from end of hot rolling to start of cooling

[Table 3]

[0101]

Table 3

No.	Cold rolling and second annealing				Cold rolling	Quenching		Tempering		Remarks
	Cold rolling	Second annealing		No. of cycles	Rolling ratio	Quenching temp.	Holding time	Tempering temp.	Holding time	
	Rolling ratio	Annealing temp.	Heating rate							
	%	°C	°C/h	Times	%	°C	min	°C	min	
1	48	680	120	3	35	810	100	250	60	Example
2	50	690	100	3	40	770	5.0	200	120	Example
3	55	680	110	2	30	830	15.0	300	120	Example
4	20	700	140	3	35	850	15.0	290	60	Example
5	44	710	190	2	30	780	250	280	30	Example
6	35	690	90	3	32	800	200	180	20	Example
7	55	730	100	5	35	750	250	170	150	Example
8	32	780	130	3	30	910	5.0	200	100	Example
9	40	725	80	4	35	900	100	210	110	Example
10	35	700	100	2	40	850	15.0	300	60	Example
11	37	710	150	3	30	760	450	190	80	Comparative Example
12	30	680	100	3	35	760	100	230	60	Comparative Example
13	35	700	100	2	30	780	100	200	30	Comparative Example
14	40	680	80	2	35	800	200	260	30	Comparative Example
15	25	710	70	4	30	810	200	280	45	Comparative Example
16	30	720	120	4	30	780	300	300	60	Comparative Example

(continued)

No.	Cold rolling and second annealing				Cold rolling	Quenching		Tempering		Remarks
	Cold rolling	Second annealing		No. of cycles	Rolling ratio	Quenching temp.	Holding time	Tempering temp.	Holding time	
	Rolling ratio	Annealing temp.	Heating rate							
	%	°C	°C/h	Times	%	°C	min	°C	min	
17	35	700	150	3	30	780	300	260	80	Comparative Example
18	30	690	50	3	35	800	100	250	80	Comparative Example
19	35	720	180	4	30	820	15.0	260	60	Comparative Example
20	40	680	90	3	30	820	15.0	280	90	Comparative Example
21	45	700	110	4	30	800	15.0	300	90	Comparative Example
22	50	720	110	3	35	810	200	240	50	Comparative Example
23	55	750	130	2	30	790	15.0	250	60	Comparative Example
24	35	750	100	3	35	780	100	260	45	Comparative Example
25	30	750	150	4	35	780	300	280	50	Comparative Example
26	38	710	130	3	40	800	100	190	70	Comparative Example
27	40	770	150	2	30	910	5.0	280	60	Example
28	35	800	90	3	35	810	600	240	120	Comparative Example
29	20	630	110	2	30	850	15.0	250	100	Comparative Example

(continued)

No.	Cold rolling and second annealing				Cold rolling	Quenching		Tempering		Remarks
	Cold rolling	Second annealing		No. of cycles	Rolling ratio	Quenching temp.	Holding time	Tempering temp.	Holding time	
	Rolling ratio	Annealing temp.	Heating rate							
	%	°C	°C/h	Times	%	°C	min	°C	min	
30	35	690	120	2	30	770	100	300	20	Comparative Example
31	30	700	120	2	35	800	160	240	30	Comparative Example
32	28	730	150	3	40	820	35.0	160	70	Comparative Example
33	29	710	200	4	30	920	15.0	210	90	Comparative Example
34	19	700	160	3	35	900	100	280	30	Comparative Example
35	25	750	190	3	40	800	300	210	60	Comparative Example
36	20	660	60	5	55	810	600	300	50	Comparative Example
37	10	700	110	4	30	900	15.0	180	60	Comparative Example
38	30	580	80	2	40	850	25.0	200	90	Comparative Example
39	50	810	150	2	35	880	15.0	260	80	Comparative Example
40	45	800	130	1	35	750	400	300	100	Comparative Example
41	40	790	190	3	25	830	300	210	70	Comparative Example

(continued)

No.	Cold rolling and second annealing				Cold rolling	Quenching		Tempering		Remarks
	Cold rolling	Second annealing		No. of cycles	Rolling ratio	Quenching temp.	Holding time	Tempering temp.	Holding time	
	Rolling ratio	Annealing temp.	Heating rate							
	%	°C	°C/h	Times	%	°C	min	°C	min	
42	20	700	100	3	40	<u>670</u>	450	220	150	Comparative Example
43	50	710	100	3	30	<u>970</u>	5.0	200	60	Comparative Example
44	45	730	80	2	35	810	<u>0.5</u>	190	100	Comparative Example
45	42	800	80	2	40	830	<u>800</u>	280	70	Comparative Example
46	48	780	120	2	50	900	15.0	<u>410</u>	90	Comparative Example
47	38	720	130	3	45	880	35.0	240	<u>5</u>	Comparative Example
48	34	690	120	5	35	850	200	250	<u>200</u>	Comparative Example
49	25	680	40	3	35	760	100	230	80	Comparative Example

[Table 4]

[0102]

Table 4

No.	Steel sample ID	Prior austenite grain size	Average particle size of coarse carbides	Average particle size of fine carbides	Wear resistance				Remarks
					Wear test (1) (Running speed 5 m/min)		Wear test (2) (Running speed 180 m/min)		
		μm	μm	μm	μm	Evaluation	μm	Evaluation	
1	A	15	0.5	0.005	420	O	455	O	Example
2	B	12	0.3	0.010	430	O	456	O	Example
3	C	12	0.3	0.023	420	O	457	O	Example
4	D	18	0.8	0.011	440	O	450	O	Example
5	E	15	0.5	0.016	440	O	451	O	Example
6	F	10	1.0	0.020	430	O	461	O	Example
7	G	13	1.2	0.010	415	O	446	O	Example
8	H	15	0.4	0.009	455	O	468	O	Example
9	I	20	0.3	0.008	450	O	450	O	Example
10	J	14	0.6	0.009	440	O	460	O	Example
11	K	28	0.1	-	510	X	495	X	Comparative Example
12	L	20	2.4	0.050	530	X	550	X	Comparative Example
13	M	18	0.8	0.011	500	X	520	X	Comparative Example
14	N	18	0.1	0.004	515	X	505	X	Comparative Example
15	O	15	0.3	0.021	480	O	505	X	Comparative Example
16	P	25	0.1	0.004	505	X	520	X	Comparative Example

(continued)

No.	Steel sample ID	Prior austenite grain size	Average particle size of coarse carbides	Average particle size of fine carbides	Wear resistance				Remarks
					Wear test (1) (Running speed 5 m/min)		Wear test (2) (Running speed 180 m/min)		
		µm	µm	µm	µm	Evaluation	µm	Evaluation	
17	Q	12	0.3	0.010	515	X	515	X	Comparative Example
18	R	15	0.2	0.030	520	X	520	X	Comparative Example
19	S	10	0.1	0.011	500	X	515	X	Comparative Example
20	I	10	0.3	0.023	510	X	520	X	Comparative Example
21	U	15	0.1	0.008	495	X	510	X	Comparative Example
22	V	18	0.1	0.004	505	X	510	X	Comparative Example
23	W	15	0.1	0.003	500	X	515	X	Comparative Example
24	X	18	2.8	0.010	520	X	525	X	Comparative Example
25	Y	25	0.1	0.001	525	X	550	X	Comparative Example
26	C	15	-	0.028	490	X	479	O	Comparative Example
27	C	13	1.5	0.005	480	O	472	O	Example
28	C	10	-	0.021	495	X	471	O	Comparative Example
29	C	17	3.2	0.001	500	X	552	X	Comparative Example

(continued)

No.	Steel sample ID	Prior austenite grain size	Average particle size of coarse carbides	Average particle size of fine carbides	Wear resistance				Remarks
					Wear test (1) (Running speed 5 m/min)		Wear test (2) (Running speed 180 m/min)		
		μm	μm	μm	μm	Evaluation	μm	Evaluation	
30	F	15	-	0.003	510	X	521	X	Comparative Example
31	F	13	-	0.002	515	X	520	X	Comparative Example
32	F	10	-	0.002	510	X	539	X	Comparative Example
33	F	14	-	0.001	530	X	545	X	Comparative Example
34	D	10	-	0.015	500	X	501	X	Comparative Example
35	D	18	1.5	-	480	O	536	X	Comparative Example
36	D	19	-	0.005	490	X	478	O	Comparative Example
37	D	20	4.2	0.005	515	X	480	O	Comparative Example
38	D	18	4.0	0.005	495	X	532	X	Comparative Example
39	D	38	1.0	0.008	500	X	515	X	Comparative Example
40	D	18	2.7	-	520	X	546	X	Comparative Example
41	C	15	2.8	-	515	X	551	X	Comparative Example
42	G	15	0.9	0.002	480	O	563	X	Comparative Example

(continued)

No.	Steel sample ID	Prior austenite grain size	Average particle size of coarse carbides	Average particle size of fine carbides	Wear resistance				Remarks
					Wear test (1) (Running speed 5 m/min)		Wear test (2) (Running speed 180 m/min)		
		μm	μm	μm	μm	Evaluation	μm	Evaluation	
43	G	<u>40</u>	1.1	0.013	540	X	525	X	Comparative Example
44	G	15	1.0	<u>0.001</u>	480	O	571	X	Comparative Example
45	G	<u>35</u>	1.3	0.042	525	X	530	X	Comparative Example
46	I	18	1.5	<u>0.092</u>	475	X	522	X	Comparative Example
47	I	14	0.6	<u>0.002</u>	480	O	491	X	Comparative Example
48	I	19	0.8	<u>0.061</u>	470	O	555	X	Comparative Example
49	C	13	2.2	<u>-</u>	420	O	528	X	Comparative Example

REFERENCE SIGNS LIST

[0103]

10	wear test piece
11	hole
12	groove
20	wear test apparatus
21	yarn unwinder
22	tension adjuster
23	yarn winder
S	yarn
d	wear depth

Claims

1. A steel component comprising a chemical composition containing, in mass%,

C: 0.6 % to 1.25 %,
Si: 0.10 % to 0.55 %,
Mn: 0.20 % to 2.0 %,
P: 0.0005 % to 0.05 %,
S: 0.01 % or less,
Al: 0.001 % to 0.1 %,
N: 0.001 % to 0.009 %,
Cr: 0.05 % to 0.55 %, and
at least one of Ti: 0.05 % to 1.0 %, Nb: 0.1 % to 0.5 %, or V: 0.01 % to 1.0 %,
with the balance being Fe and inevitable impurity,
wherein the average grain size of prior austenite grains is 25 μm or less,
further comprising carbides containing at least one of Nb, Ti, or V, wherein
among the carbides, the average particle size of particles having a particle size of 0.1 μm or more is 0.15 μm to 2.5 μm, and
among the carbides, the average particle size of particles having a particle size less than 0.1 μm is 0.005 μm to 0.05 μm.

2. The steel component 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,
Zr: 0.5 % or less,
B: 0.005 % or less, and
W: 0.01 % or less.

3. The steel component according to claim 1 or 2, wherein the steel component is any one of a component for textile machinery, a bearing component, or a blade for machinery.

4. A method of producing a steel component, the method comprising:

heating a steel slab comprising the chemical composition according to claim 1 or 2 under a set of conditions including: a slab heating temperature of 1,100 °C or more and a holding time of 1.0 h or more;
processing the heated steel slab into a hot-rolled steel sheet under a set of conditions including a finishing start temperature of Ac3 or more;
cooling the hot-rolled steel sheet under a set of conditions including: a time from end of hot rolling to start of cooling of 2.0 s or less, an average cooling rate of 25 °C/s or more, and a cooling stop temperature of 640 °C to 720 °C;
coiling the cooled hot-rolled steel sheet;
applying, to the hot-rolled steel sheet after coiling, first annealing under a set of conditions including: an annealing temperature of 650 °C or more and 720 °C or less, and an annealing time of 3 h or more;
applying, to the hot-rolled steel sheet after the first annealing, a cycle applied twice or more of cold rolling at a rolling ratio of 15 % or more and second annealing at an annealing temperature of 600 °C to 800 °C and a heating rate of 50 °C/h or more;
final cold rolling at a rolling ratio of 30 % or more; and
applying, to the cold-rolled steel sheet:

machining into a component shape, and
heat treatment including quenching under a set of conditions including: a quenching temperature of 700 °C or more and 950 °C or less and a holding time of 1.0 min or more to 60 min or less, and tempering under a set of conditions including: a tempering temperature of 100 °C to 400 °C and a holding time of 20 min or more to 3 h or less.

FIG. 1

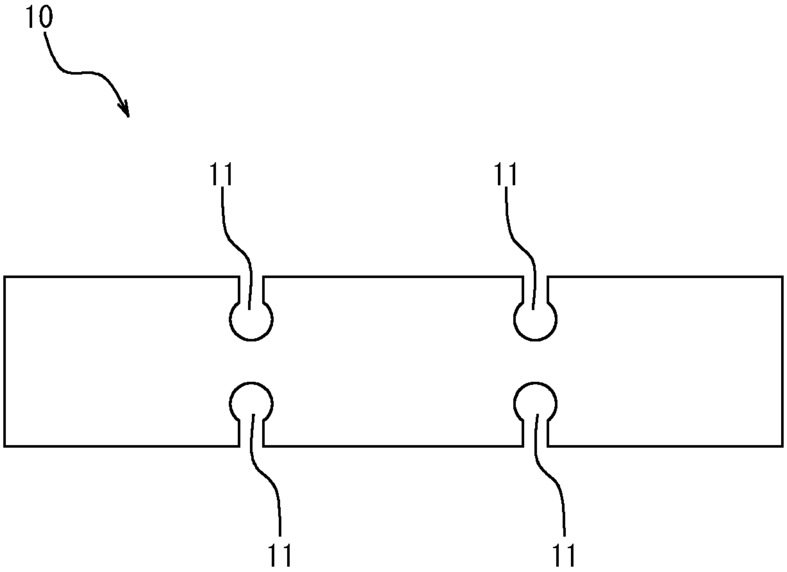


FIG. 2

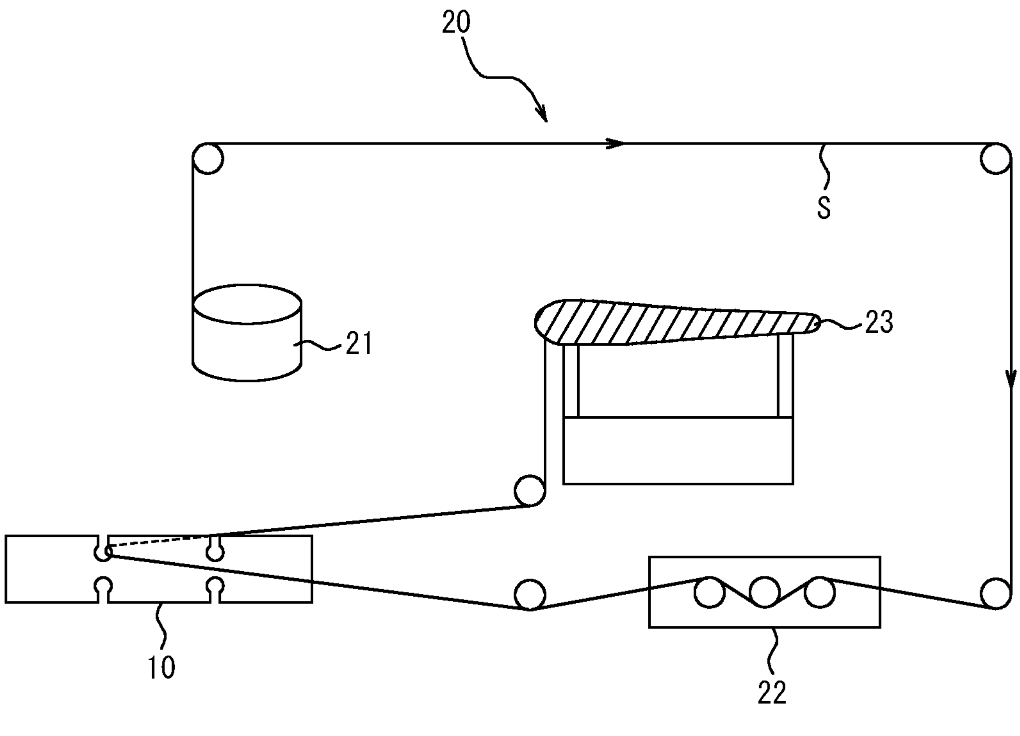
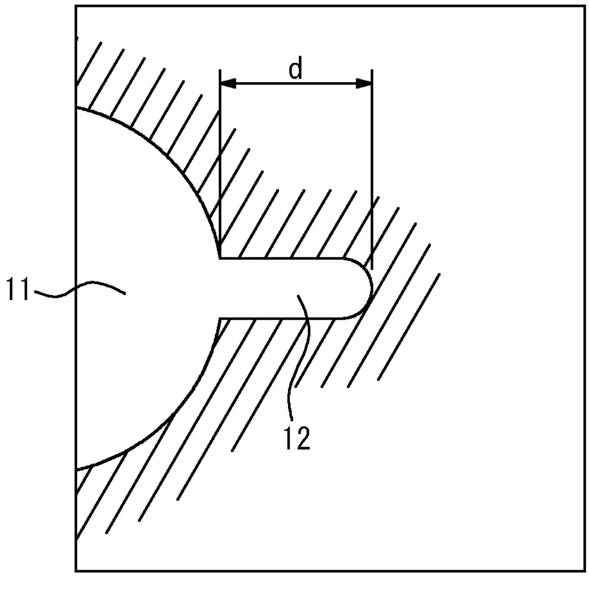


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/023540

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/00(2006.01)i; ***C21D 9/00***(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/38***(2006.01)i; ***C22C 38/60***(2006.01)i
FI: C22C38/00 301Z; C21D9/00 A; C21D9/46 F; C22C38/00 301H; C22C38/00 301U; 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)

C22C38/00-38/60; C21D9/00; C21D9/46-9/48; C21D8/00-8/04

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2021/090472 A1 (TOKUSHU KINZOKU EXCEL CO LTD) 14 May 2021 (2021-05-14) claims, paragraphs [0054]-[0064], table 2	1-4
A	JP 2017-190494 A (NISSHIN STEEL CO LTD) 19 October 2017 (2017-10-19) claims, paragraphs [0041]-[0042]	1-4
A	JP 2015-190036 A (NISSHIN STEEL CO LTD) 02 November 2015 (2015-11-02) claims, paragraphs [0086]-[0090]	1-4
A	JP 2010-138453 A (NISSHIN STEEL CO LTD) 24 June 2010 (2010-06-24) claims, paragraphs [0033], [0035]	1-4

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Date of the actual completion of the international search	Date of mailing of the international search report
18 August 2022	**30 August 2022**

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/023540

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