(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 955 242 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
16.12.2015 Bulletin 2015/51

(21) Application number: **14779834.2**

(22) Date of filing: **20.03.2014**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***C21D 9/46*** *(2006.01)*
C22C 38/38 *(2006.01)*

(86) International application number:
PCT/JP2014/001603

(87) International publication number:
WO 2014/162677 (09.10.2014 Gazette 2014/41)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **02.04.2013 JP 2013076824**

(71) Applicant: **JFE Steel Corporation**
Tokyo 100-0011 (JP)

(72) Inventors:
- **KOBAYASHI, Takashi**
  Tokyo 100-0011 (JP)
- **SAITO, Hayato**
  Tokyo 100-0011 (JP)
- **FUNAKAWA, Yoshimasa**
  Tokyo 100-0011 (JP)

(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(54) STEEL SHEET FOR NITRIDING AND PRODUCTION METHOD THEREFOR

(57) Provided is a steel sheet for nitriding having excellent formability and punchability. A steel sheet for nitriding has a composition including, in percent by mass, 0.02% to 0.08% of C, 0.1% or less of Si, 0.2% to 1.8% of Mn, 0.05% or less of P, 0.02% or less of S, 0.01% to 0.06% of Al, 0.5% to 1.5% of Cr, 0.01% or less of N, and the balance being Fe and incidental impurities; and has a microstructure including ferrite as a main phase and pearlite and/or bainite as a secondary phase. The ferrite has a fraction of 70% or more in the entire microstructure and an average grain diameter of 5 to 25 μm. An average length of the major axis of cementite present in the secondary phase in a cross section in the rolling direction of the steel sheet is 3.0 μm or less.

Printed by Jouve, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to a steel sheet for nitriding which is used by being subjected to nitriding treatment in order to improve durability and which is suitable as a material for machine parts, in particular, a steel sheet for nitriding having excellent formability and punchability before nitriding treatment, and a method for producing the same.

Background Art

[0002] In machine parts used for automotive transmissions and the like, in order to improve fatigue strength and abrasion resistance, steel as a material is formed into a desired part shape and is then often subjected to a surface-hardening treatment before use. Typical examples of such a surface-hardening treatment are carburizing treatment and nitriding treatment.

[0003] Carburizing treatment is the most common surface-hardening treatment. However, in carburizing treatment, usually, carbon is diffused and infiltrated (carburized) into the surface portion of steel at a temperature of the A_3 transformation point or more, and then the steel is subjected to quenching. Consequently, under the influence of distortion caused by quenching from the high temperature, a decrease in shape accuracy of parts is unavoidable. Furthermore, in the as-quenched state after carburizing, the toughness of the steel is markedly decreased. Accordingly, after quenching, it is necessary to perform tempering in order to recover toughness and to perform correction of the shape of parts. Therefore, when a carburizing treatment is employed, the number of processes required for manufacturing parts increases, resulting in an increase in manufacturing costs, which is disadvantageous.

[0004] In contrast, in nitriding treatment, usually, steel is heated to a temperature of about 500°C to 600°C that is lower than the A_1 transformation temperature so that nitrogen is diffused and infiltrated (nitrided) into the surface portion of steel, and the surface of steel is hardened without quenching, unlike the carburizing treatment. That is, in nitriding treatment, the treatment temperature is relatively low, and treatment is not accompanied by phase transformation of steel during cooling. Therefore, a decrease in shape accuracy of parts due to transformation strain does not occur, which is advantageous. Furthermore, the volume variation of the surface portion of steel due to nitriding is small, and it is easy to maintain good shape accuracy of parts, which is also advantageous.

[0005] In the case of nitriding using ammonia gas, according to existing techniques, since the time required for nitriding is significantly long, the nitriding treatment is not suitable for automotive parts and the like that are supposed to be mass-produced. However, in recent years, a nitriding treatment referred to as nitrocarburizing in which a nitriding reaction is allowed to proceed rapidly by utilizing a carburizing atmosphere has become common. Thus, the significantly long treatment time, which is the problem in the existing techniques, is in the process of being solved.

[0006] In nitrocarburizing treatment, by holding an object to be treated in a treatment atmosphere at 550°C to 600°C for several hours, nitrogen is diffused and introduced into steel from the surface of steel by means of an iron carbide generating reaction. In accordance with the nitrocarburizing treatment, although the surface hardness obtained after the treatment is lower than that in the existing nitriding treatment, the time required for nitriding can be markedly reduced. For the reason described above, in recent years, the number of cases in which nitrocarburizing treatment is employed as the surface-hardening treatment, as an alternative to carburizing treatment, has been increasing.

[0007] On the other hand, according to existing techniques, machine parts used for automotive transmissions and the like are generally manufactured by subjecting intermediate products obtained by casting or forging to machining. However, in recent years, thin steel sheets have been positively used as a material for machine parts, and machine parts have been manufactured by subjecting thin steel sheets to press working or the like so as to have a desired shape. The reason for this is that, by replacing parts manufactured by subjecting intermediate products obtained by casting or forging to machining in the existing techniques with sheet-metal working products of steel sheets, shortening of manufacturing processes and reduction in manufacturing costs can be achieved. Under such a background, there has been an increased demand for a steel sheet for nitriding having excellent formability as a steel material for the machine parts.

[0008] Regarding a steel sheet for nitriding having excellent formability, various techniques have been proposed. For example, Patent Literature 1 and Patent Literature 2 propose techniques for producing a steel sheet for nitriding in which a steel having a composition including, in weight ratio, 0.01% to less than 0.08% of C, 0.005% to 1.00% of Si, 0.010% to 3.00% of Mn, 0.001% to 0.150% of P, 0.0002% to 0.0100% of N, more than 0.15% to 5.00% of Cr, more than 0.060% to 2.00% of Al, and one or two of Ti and V is hot-rolled, followed by coiling at 500°C or higher, and then optionally subjected to cold rolling at a rolling reduction of 50% or more and subjected to perform recrystallization annealing. In accordance with these techniques, by producing a low-carbon steel sheet in which the content of C that adversely affects formability is suppressed to less than 0.08% and, at the same time, which contains Al, Cr, Ti and/or V which are nitriding accelerating elements, it is possible to obtain a steel sheet for nitriding having excellent formability and nitriding property.

[0009] Furthermore, Patent Literature 3 proposes a technique on a steel sheet for nitrocarburizing in which the steel sheet has a composition including 0.01% to 0.10% by mass of C, 0.1% by mass or less of Si, 0.1% to 1.0% by mass of Mn, 0.05% by mass or less of P, 0.01% by mass or less of S, 0.01% to 0.06% by mass of Al, 0.05% to 0.50% by mass of Cr, 0.01% to 0.30% by mass of V, 0.01% by mass or less of N, and the balance being Fe and incidental impurities. In accordance with the technique proposed in Patent Literature 3, it is possible to obtain a steel sheet for nitrocarburizing in which the production cost is low because of reduced amounts of alloy elements, which has excellent formability, and which can be used for producing a steel sheet having an excellent surface hardening property by nitrocarburizing treatment because of simultaneous addition of Cr and V which are nitriding accelerating elements.

Citation List

Patent Literature

[0010]

PTL 1: Japanese Unexamined Patent Application Publication No. 9-25513
PTL 2: Japanese Unexamined Patent Application Publication No. 9-25543
PTL 3: Japanese Unexamined Patent Application Publication No. 2005-171331

Summary of Invention

Technical Problem

[0011] When machine parts used for automotive transmissions and the like are manufactured by subjecting a thin steel sheet to forming, in many cases, the thin steel sheet is blanked to a predetermined size prior to forming, and holes with various shapes are pierced after forming. Accordingly, the steel sheet as the material for the parts is required to have excellent formability and excellent punchability. When the punchability of the steel sheet is degraded, occurrence of sags, burrs, and the like in punched surfaces during punching increases markedly, which impairs the dimensional accuracy of the machine parts. There may be cases where microcracks are likely to occur in punched surfaces, thus adversely affecting the strength property of the machine parts.
[0012] However, in any of the existing techniques described above, no consideration is given to the punchability of steel sheets. Furthermore, the problems described below remain.
[0013] In the techniques proposed in Patent Literature 1 and 2, the composition includes a large amount of Al as a nitriding accelerating element. Therefore, there is a concern that inner defects and surface defects resulting from Al-containing inclusions may occur, and generation of a large amount of Al-containing slag increases refining costs during smelting.
[0014] In accordance with the technique proposed in Patent Literature 3, even if the amounts of alloy elements for nitriding acceleration are decreased, a sufficient hardening property can be imparted to a steel sheet for nitrocarburizing. However, the resulting steel sheet has insufficient strength, and it is difficult to apply the technique to heavily-loaded parts.
[0015] It is an object of the present invention to solve the problems in the existing techniques described above and to provide a steel sheet for nitriding which can be widely used as a material for parts, such as automotive transmissions, and which has excellent formability and excellent punchability before nitriding treatment, and a method for producing the same.

Solution to Problem

[0016] In order to solve the problems described above, the present inventors have performed thorough studies on the surface hardening property by nitriding treatment of steel sheets, and various factors affecting formability and punchability of steel sheets. As a result, it has been found that by adjusting the chemical composition and microstructure of a steel sheet to certain ranges, a good hardening property can be provided by nitriding treatment, and it is possible to impart sufficient formability and punchability to a steel sheet before nitriding treatment.
[0017] The present invention has been completed by further conducting studies on the basis of such findings. That is, the gist of the present invention is as follows:

[1] A steel sheet for nitriding having a composition and microstructure; the composition including, in percent by mass, 0.02% to 0.08% of C, 0.1% or less of Si, 0.2% to 1.8% of Mn, 0.05% or less of P, 0.02% or less of S, 0.01% to 0.06% of Al, 0.5% to 1.5% of Cr, 0.01% or less of N, and the balance being Fe and incidental impurities, and the microstructure including ferrite as a main phase and pearlite and/or bainite as a secondary phase, wherein the ferrite has an area fraction of 70% or more in the entire microstructure and an average grain diameter of 5 to 25 μm, and

cementite present in the secondary phase has an average length of the major axis of 3.0 μm or less in a cross section in the rolling direction of the steel sheet.

[2] The steel sheet for nitriding according to [1], wherein the composition further includes, in percent by mass, at least one selected from the group consisting of 0.005% to 0.075% of V, 0.005% to 0.025% of Nb, and 0.005% to 0.025% of Ti.

[3] A method for producing a steel sheet for nitriding including:

heating a steel slab having a composition including, in percent by mass, 0.02% to 0.08% of C, 0.1% or less of Si, 0.2% to 1.8% of Mn, 0.05% or less of P, 0.02% or less of S, 0.01% to 0.06% of Al, 0.5% to 1.5% of Cr, 0.01% or less of N, and the balance being Fe and incidental impurities, to 1,050°C to 1,250°C;
hot rolling the heated steel slab at a finishing temperature ranging from the Ar_3 transformation temperature to (the Ar_3 transformation temperature + 100°C);
cooling the hot rolled steel sheet at a cooling rate of 40°C/s to 80°C/s in the temperature range from the finishing temperature to 750°C and at a cooling rate of 15°C/s to 35°C/s in the temperature range from 750°C to a cooling stop temperature of 500°C to 650°C; and
coiling the cooled steel sheet at a coiling temperature of 500°C to 650°C.

[4] The method for producing a steel sheet for nitriding according to [3], wherein the composition of the steel slab further includes, in percent by mass, at least one selected from the group consisting of 0.005% to 0.075% of V, 0.005% to 0.025% of Nb, and 0.005% to 0.025% of Ti.

Advantageous Effects of Invention

[0018] According to the present invention, it is possible to obtain a steel sheet having excellent formability and punchability and a good hardening property by nitriding treatment. The steel sheet of the present invention is very suitable as a material for formed parts to be subjected to nitriding treatment, such as automotive transmission parts, thus exhibiting industrially marked effects. Furthermore, the steel sheet of the present invention is not limited to being used for gas nitrocarburizing treatment and salt bath nitrocarburizing treatment, but can also be suitably used as any of various steel sheets for nitriding, such as plasma nitriding, gas nitriding, carbonitriding, and nitrosulphurizing.

Description of Embodiments

[0019] First, the microstructure of a steel sheet for nitriding according to the present invention will be described. The steel sheet of the present invention has a microstructure including ferrite (which may also be referred to as "polygonal ferrite"), which is a main phase, and a secondary phase. The secondary phase includes pearlite and/or bainite. Furthermore, the fraction of the ferrite in the entire microstructure is 70% or more, the average grain diameter of the ferrite is 5 to 25 μm, and the average length of the major axis of cementite present in the secondary phase in a cross section in the rolling direction of the steel sheet is 3.0 μm or less.

Main phase: ferrite

[0020] In the steel sheet of the present invention, by using soft ferrite as a main phase, formability of the steel sheet can be secured. In the case where a material other than ferrite is used as a main phase, it is not possible to impart good formability to the steel sheet. However, in a steel sheet having a ferrite single-phase microstructure, it is not possible to secure sufficient strength as a steel sheet material that can be widely used for automotive transmission parts and the like. Therefore, the steel sheet of the present invention has a microstructure including ferrite as the main phase, and the secondary phase described below.

Secondary phase: pearlite and/or bainite

[0021] The secondary phase, which is the remainder other than ferrite, includes one or two selected from the group consisting of pearlite and bainite. The secondary phase in the steel sheet microstructure has a role in reinforcing the strength of the steel sheet having soft ferrite as the main phase. In the case where reinforcement of a microstructure having martensite as the secondary phase is employed, martensite is softened by an increase in temperature during nitriding treatment, resulting in an increased variation in the strength of the steel sheet. Therefore, in order to maintain the strength of the steel sheet stably even after being subjected to nitriding treatment in which the steel sheet is held at about 500°C to 600°C, the secondary phase in the steel sheet microstructure is required to be composed of pearlite and/or bainite.

Area fraction of ferrite in the entire microstructure: 70% or more

[0022] In order to impart good formability to the steel sheet, it is necessary to set the area fraction of the ferrite, which is the main phase, to be 70% or more. In the case where the area fraction of the ferrite is less than 70%, the formability of the steel sheet is likely to be at an insufficient level. Furthermore, the punchability of the steel sheet decreases. For example, during punching of the steel sheet, the sheared surface ratio of punched surfaces decreases. On the other hand, in the case where the area fraction of the ferrite is excessively high, the strength of the steel sheet may not reach the necessary level. Therefore, the area fraction of the ferrite is preferably set at 97% or less, and more preferably 95% or less.

Average grain diameter of ferrite: 5 to 25 μm

[0023] In the case where the average grain diameter of the ferrite is more than 25 μm, the surface properties of the steel sheet may be degraded during forming, and the smoothness of punched surfaces may be degraded, resulting in degradation of punchability of the steel sheet. Furthermore, when the grain diameter of the ferrite becomes coarse, the number of grain boundaries decreases. Consequently, grain boundary diffusion of N during nitriding treatment is suppressed, and there is a concern that the time required for the nitriding treatment may be elongated. On the other hand, in the case where the average grain diameter of the ferrite is less than 5 μm, the steel sheet hardens, and formability is likely to be degraded. Therefore, the average grain diameter of the ferrite is set at 5 to 25 μm, and preferably 5 to 15 μm.

Average length of the major axis of cementite present in the secondary phase in a cross section in the rolling direction of the steel sheet: 3.0 μm or less

[0024] When the average length of the major axis of cementite present in the secondary phase in a cross section in the rolling direction of the steel sheet exceeds 3.0 μm, the stress concentration ratio increases at the interface between the cementite and the ferrite during punching of the steel sheet, which makes it easy to cause microcracks, and the fracture surface ratio at punched surfaces increases. Thus, the punchability of the steel sheet is degraded. Therefore, the average length of the major axis is set at 3.0 μm or less. However, when the cementite becomes extremely small, microcracks are likely to occur in punched surfaces of the steel sheet. Therefore, the average length of the major axis is preferably 1.0 μm or more.

[0025] Reasons for limiting the chemical composition of the steel sheet for nitriding of the present invention will be described below. Hereinafter, "%", which is the unit of measure for the constituent element content, means "percent by mass" unless otherwise indicated.

C: 0.02% to 0.08%

[0026] C is an element that has an effect of increasing the strength of steel through solid solution strengthening and formation of the secondary phase. When the C content is less than 0.02%, it is not possible to secure a sufficient strength of the steel sheet as a material for parts. On the other hand, when the C content is exceeded 0.08%, the strength of the steel sheet increases excessively, resulting in a decrease in formability. Furthermore, the fraction of the secondary phase increases, and it is difficult to obtain cementite having a desired form. Therefore, the C content is set at 0.02% to 0.08%, and preferably 0.04% to 0.06%.

Si: 0.1% or less

[0027] Si is an element that is effective in deoxidizing steel, and also has an effect of strengthening steel by means of solid solution strengthening. In order to obtain these effects, the Si content is preferably set at 0.01% or more. However, when the Si content exceeds 0.1%, hardly eliminable scale is generated during hot rolling, and surface properties of the steel sheet degrade markedly. Therefore, the Si content is set at 0.1% or less, and preferably 0.05% or less.

Mn: 0.2% to 1.8%

[0028] Mn is an element that strengthens steel by means of solid solution strengthening. Furthermore, Mn has an effect of fixing, as precipitates, S which is present as an impurity in the steel, thus reducing adverse effects caused by S. When the Mn content is less than 0.2%, the effects cannot be obtained sufficiently, and it is not possible to secure the required strength of the steel sheet. On the other hand, when the Mn content is more than 1.8%, the strength of the steel sheet increases excessively, and a band-like microstructure due to microsegregation is likely to be formed, resulting in degradation in the formability and punchability of the steel sheet. Therefore, the Mn content is set at 0.2% to 1.8%, and preferably 0.2% to 1.2%.

P: 0.05% or less

[0029] P is an element that is present as an impurity in the steel, and when the P content is large, the formability and toughness of the steel sheet degrade. Therefore, the P content is set at 0.05% or less, and preferably 0.03% or less.

S: 0.02% or less

[0030] S is also an element that is present as an impurity in the steel, and when the S content is large, the formability and toughness of the steel sheet degrade. Therefore, the S content is set at 0.02% or less, and preferably 0.01% or less.

Al: 0.01% to 0.06%

[0031] Al is an element that is added for the purpose of deoxidizing steel. When the Al content in the steel is less than 0.01%, it is not possible to obtain a sufficient deoxidizing effect. On the other hand, when the Al content in the steel is more than 0.06%, the deoxidizing effect is saturated, and there is a possibility that inner defects and surface defects will increase due to an increase in inclusions in the steel. Therefore, the Al content is set at 0.01% to 0.06%, and preferably 0.02% to 0.05%.

Cr: 0.5% to 1.5%

[0032] Cr has an effect of increasing the hardness of the surface portion of the steel sheet by forming nitrides in the steel by nitriding treatment, and is an important alloy element in the present invention. Cr also has an effect of refining cementite in the steel. In terms of sufficient exhibition of such effects, it is necessary to set the Cr content at 0.5% or more. However, when the Cr content exceeds 1.5%, the hardened portion of the outermost layer is embrittled significantly by nitriding treatment, and the depth of the hardened portion may be decreased in some cases. Therefore, the Cr content is set at 0.5% to 1.5%, and preferably 0.5% to 1.0%.

N: 0.01% or less

[0033] N is an element that is present as an impurity in the steel. A large amount of N degrades the formability of the steel sheet, and there is a possibility that N will combine with nitriding accelerating elements, such as Cr, before nitriding treatment, thus degrading the hardening property due to nitriding. Therefore, the N content is set at 0.01% or less, and preferably 0.005% or less.

[0034] The steel sheet of the present invention may contain, in addition to the composition described above, one or two or more selected from the group consisting of 0.005% to 0.075% of V, 0.005% to 0.025% of Nb, and 0.005% to 0.025% of Ti.

V: 0.005% to 0.075%

[0035] V is an element that has an effect of increasing the hardness of the surface portion of the steel sheet by forming nitrides in the steel by nitriding treatment. Furthermore, since V is a carbide/nitride forming element, V also has an effect of increasing the strength of steel by means of particle dispersion strengthening (precipitation strengthening). Accordingly, in the steel sheet of the present invention, V can be incorporated for the purpose of controlling the hardening property due to nitriding treatment and adjusting the level of strength of the steel sheet. In terms of sufficient exhibition of such effects, the V content is preferably set at 0.005% or more. On the other hand, when the V content is excessively large, formability is decreased by the excessive increase in the strength of the steel sheet, the hardened portion is embrittled by nitriding treatment, and also an economical disadvantage is caused. Therefore, the V content is preferably set at 0.005% to 0.075%, and more preferably 0.025% to 0.075%.

Nb: 0.005% to 0.025%

[0036] Nb is a carbide/nitride forming element and has an effect of increasing the strength of steel by means of particle dispersion strengthening (precipitation strengthening). When the Nb content is less than 0.005%, such an effect cannot be obtained sufficiently. On the other hand, when the Nb content is more than 0.025%, there is a concern that the strength of the steel sheet will increase excessively, resulting in a decrease in formability. Therefore, the Nb content is preferably set at 0.005% to 0.025%, and more preferably 0.005% to 0.015%.

Ti: 0.005% to 0.025%

[0037] Ti is also a carbide/nitride forming element and has an effect of increasing the strength of steel by means of particle dispersion strengthening (precipitation strengthening). When the Ti content is less than 0.005%, such an effect cannot be obtained sufficiently. On the other hand, when the Ti content is more than 0.025%, there is a concern that the strength of the steel sheet may increase excessively, resulting in a decrease in formability. Therefore, the Ti content is preferably set at 0.005% to 0.025%, and more preferably 0.005% to 0.015%.
[0038] The balance other than the components described above includes Fe and incidental impurities. As the incidental impurities, 0.03% or less of Cu, 0.03% or less of Ni, 0.03% or less of Mo, 0.003% or less of Sn, 0.003% or less of Sb, 0.005% or less of O, and the like are permissible.
[0039] A method for producing a steel sheet for nitriding according to the present invention will be described below.
[0040] A steel sheet according to the present invention can be obtained by heating, hot rolling, cooling, and coiling steel having the chemical composition described above.
[0041] The steel used in the present invention can be refined by any of known refining processes, such as a converter process or an electric furnace process. The refined steel is formed into a steel (slab) by continuous casting or ingot casting and bloom rolling or the like. As necessary, preliminary treatments, secondary smelting, cleaning of the steel surface can be performed.

Heating temperature of steel: 1,050°C to 1,250°C

[0042] When the heating temperature of the steel is lower than 1,050°C, it is difficult to secure a desired finishing temperature during hot rolling. On the other hand, when the heating temperature of the steel exceeds 1,250°C, energy required for heating increases, and defects in the surface properties of the steel sheet are likely to occur. Therefore, the heating temperature of the steel before hot rolling is set at 1,050°C to 1,250°C, and preferably 1,100°C to 1,200°C.
[0043] When the steel is heated, the steel cooled to normal temperature may be reheated, or the steel being cooled after casting may be subjected to additional heating or heat-retained.
[0044] In the present invention, after the steel is heated to the temperature range described above, rough rolling and finish rolling (hot rolling) are performed. The rough rolling may be performed under ordinary conditions, and rough rolling conditions are not particularly limited.

Finishing temperature: Ar_3 transformation temperature to (the Ar_3 transformation temperature + 100°C)

[0045] When the finishing temperature in the hot rolling step is lower than the Ar_3 transformation temperature, an unrecrystallized ferrite microstructure which is elongated in the rolling direction and a pancake-shaped, coarse ferrite microstructure are formed, and it is not possible to obtain ferrite with a desired grain diameter. Furthermore, the formability and punchability of the steel sheet are degraded. Moreover, the in-plane anisotropy of mechanical properties of the steel sheet is increased. On the other hand, when the finishing temperature exceeds (the Ar_3 transformation temperature + 100°C), surface properties of the steel sheet are likely to be degraded, the ferrite microstructure is likely to be coarsened, and it is difficult to obtain ferrite with a desired grain diameter. Therefore, the finishing temperature is set in the range of the Ar_3 transformation temperature to (the Ar_3 transformation temperature + 100°C), and preferably (the Ar_3 transformation temperature + 20°C) to (the Ar_3 transformation temperature + 100°C). In order to secure a necessary finishing temperature, the steel sheet under rolling may be subjected to additional heating using a heating device, such as a sheet bar heater or an edge heater.

Cooling rate from finishing temperature to 750°C: 40°C/s to 80°C/s

[0046] The steel sheet which has been subjected to hot rolling is cooled (forced cooled) in the temperature range from the finishing temperature to 750°C at a cooling rate of 40°C/s to 80°C/s, and preferably 45°C/s to 75°C/s. In the case where the cooling rate in the temperature range is less than 40°C/s, the microstructure of the hot-rolled steel sheet is likely to be coarsened, and it is not possible to obtain ferrite or cementite having a desired shape. On the other hand, in the case where the cooling rate in the temperature range is more than 80°C/s, martensite or excessively large amounts of bainite and pearlite are likely to be generated in the hot-rolled steel sheet, and it is difficult to obtain ferrite with a desired fraction or a desired secondary phase.

Cooling rate from 750°C to cooling stop temperature: 15°C/s to 35°C/s

Cooling stop temperature: 500°C to 650°C

[0047] In the temperature range from 750°C to a cooling stop temperature, cooling (forced cooling) is performed at a cooling rate of 15°C/s to 35°C/s, and preferably 15°C/s to 25°C/s. In the case where the cooling rate in the temperature range is less than 15°C/s, the microstructure of the hot-rolled steel sheet is likely to be coarsened, and it is difficult to obtain ferrite or cementite having a desired shape. On the other hand, in the case where the cooling rate in the temperature range is more than 35°C/s, progression of ferrite transformation is suppressed, and it is not possible to obtain ferrite with a desired fraction.

[0048] In the case where the cooling stop temperature is lower than 500°C, the steel sheet is hardened because martensite and an excessively large amount of bainite are generated. As a result, the formability of the steel sheet is degraded, and the strength of the steel sheet after nitriding treatment becomes unstable. On the other hand, in the case where the cooling stop temperature is higher than 650°C, pearlite is coarsened, and it is not possible to obtain cementite having a desired shape. Therefore, the cooling stop temperature is set at 500°C to 650°C, and preferably 500°C to 600°C.

[0049] The steel sheet cooled to the cooling stop temperature may be directly coiled, or may be allowed to cool for a short period of time until it is coiled with a coiler. Here, the term "being allowed to cool" refers to air cooling in the air in which forced cooling by pouring water is not performed. However, in order to remove cooling water remaining on the steel sheet, it is permissible to spray high-pressure water or compressed air for a very short period of time onto the steel sheet which are being allowed to cool because a decrease in the temperature of the steel sheet due to this is very small.

Coiling temperature: 500°C to 650°C

[0050] In the case where the coiling temperature is lower than 500°C, the steel sheet is hardened because martensite and an excessively large amount of bainite are generated. As a result, the formability of the steel sheet is degraded, and the strength of the steel sheet after nitriding treatment becomes unstable. On the other hand, in the case where the coiling temperature is higher than 650°C, pearlite is coarsened, and it is not possible to obtain cementite having a desired shape. Therefore, the coiling temperature is set at 500°C to 650°C, and preferably 500°C to 600°C.

[0051] The coiled steel sheet is used after scale is removed by pickling or shot peening. Furthermore, the steel sheet may be subjected to temper rolling for the purpose of shape straightening and adjusting surface roughness. Performing such descaling or temper rolling does not impair the advantages of the present invention.

EXAMPLES

[0052] Steels A to L containing constituent elements shown in Table 1 and the balance being Fe and incidental impurities were prepared in molten state. The resulting slabs were subjected to hot rolling under the conditions shown in Table 2, and thus hot-rolled steel sheets with a thickness of 2.3 mm were formed. Subsequently, the resulting hot-rolled steel sheets were descaled by pickling, and then subjected to temper rolling with an elongation of 0.5%. Specimens were taken from the hot-rolled steel sheets after the temper rolling, and microstructure observation, a tensile test, and a punching test were performed. Furthermore, the hot-rolled steel sheets after the temper rolling was subjected to nitriding treatment, and a hardness test was performed on the hot-rolled steel sheets after the nitriding treatment.

(1) Microstructure observation

[0053] A specimen of a cross section in the thickness direction parallel to the rolling direction at the 1/4 width position was taken from each of the steel sheets before the nitriding treatment, and the specimen was subjected to mirror polishing and etched with nital. Using an image obtained by photographing the 1/4 thickness position at an appropriate magnification of 500 to 5,000 times with an optical microscope or a scanning electron microscope, the microstructure was confirmed.

[0054] Regarding the fraction of ferrite in the microstructure, using the image described above, the area ratio of ferrite was obtained by image analysis, which was defined as the fraction of ferrite.

[0055] Regarding the average grain diameter of ferrite, using the image described above, grain diameters were determined in accordance with the method stipulated in Japan Industrial Standard JIS G 0551-2005, and the average grain diameter was calculated from the grain size number.

[0056] Regarding the average length of the major axis of cementite present in the secondary phase (pearlite and/or bainite), using the image described above, the length of the major axis of each of grains of cementite in the observation range was obtained, and the average was calculated by arithmetic average. These results are also shown in Table 2.

(2) Tensile test (evaluation of formability)

[0057] The formability of the steel sheet was evaluated on the basis of ductility determined by a tensile test. The tensile test was carried out in accordance with JIS Z 2241-2011 using a No. 5 test specimen stipulated in JIS Z 2241-2011 which was taken at the 1/4 width position of a steel sheet such that the testing direction corresponded to the rolling direction. Tensile strength (TS) and elongation after fracture (EL) were measured, and a strength-elongation balance (TS × EL) was calculated. The steel sheet having a strength-elongation balance value of 16 GPa·% or more was evaluated as having good formability.

(3) Punching test (evaluation of punchability)

[0058] A disk-shaped test specimen with a diameter of 50 mm was punched out from a steel sheet before nitriding treatment (clearance: 5% of steel sheet thickness), the sheared surface ratio at the punched surface of the test specimen was measured, and presence or absence of microcracks in the fracture surface region was confirmed. In the case where the sheared surface ratio was 60% or more, and no cracks were observed in the fracture surface region, the steel sheet was evaluated as having good punchability.

(4) Hardness test (evaluation of surface hardening property due to nitriding treatment)

[0059] A hot-rolled steel sheet after temper rolling was subjected to gas nitrocarburizing treatment, and the cross section hardness of the steel sheet after the gas nitrocarburizing treatment (nitrided layer cross section hardness) was measured. Gas obtained by mixing ammonia (NH_3) and endothermic converted gas at the equal volume ratio was used as nitriding gas. The gas nitrocarburizing treatment temperature was set at 570°C, and the holding time at the gas nitrocarburizing treatment temperature was set at 150 minutes. After the holding, oil cooling was performed. Regarding the cross section hardness of the steel sheet, a specimen of a cross section in the thickness direction parallel to the rolling direction was taken from the steel sheet after the gas nitrocarburizing treatment, and the Vickers hardness (HV0.1) at a depth of 0.2 mm from the surface of the steel sheet was measured in accordance with JIS Z 2244-2009. In the case where the measured Vickers hardness was 250 or more, the surface hardening property of the steel sheet by nitriding treatment was evaluated to be good.

[0060] The results thereof are shown in Table 3.

[Table 1]

Steel	Chemical composition (mass%)										
	C	Si	Mn	P	S	Al	Cr	N	V	Nb	Ti
A	0.02	0.08	1.8	0.02	0.007	0.02	1.5	0.003	-	-	-
B	0.04	0.05	0.3	0.02	0.010	0.05	0.9	0.002	-	-	-
C	0.04	0.03	0.2	0.02	0.005	0.04	0.8	0.002	0.005	-	-
D	0.05	0.03	0.6	0.03	0.005	0.06	1.0	0.002	-	-	-
E	0.05	0.03	0.8	0.05	0.005	0.03	1.0	0.002	-	0.005	0.008
F	0.06	0.04	1.2	0.02	0.005	0.04	0.7	0.002	-	-	-
G	0.06	0.02	1.0	0.01	0.005	0.05	0.8	0.001	0.065	-	-
H	0.06	0.05	1.2	0.03	0.005	0.05	0.6	0.001	0.050	0.008	-
I	0.08	0.06	1.4	0.01	0.020	0.03	1.2	0.005	-	-	-
<u>J</u>	0.05	0.03	0.7	0.04	0.005	0.04	<u>0.4</u>	0.002	-	-	-
<u>K</u>	0.05	0.03	0.7	0.04	0.005	0.05	<u>1.6</u>	0.002	-	-	-
<u>L</u>	<u>0.12</u>	0.03	1.2	0.02	0.005	0.03	0.6	0.002	-	-	-

[Table 2]

Steel sheet No.	Steel	Ar_3 transformation point(°C)	Hot rolling conditions						Steel sheet microstructure *3			
			Heating temperature (°C)	Finishing temperature (°C)	Cooling rate 1 *1 (°C)	Cooling rate 2 *2 (°C)	Cooling stop temperature (°C)	Coiling temperature (°C)	Type	F fraction (%)	F average grain diameter (μm)	C average length of major axis (μm)
1	A	761	1100	860	70	15	650	650	F, P	95	18	3.0
2	A	761	1250	920	70	15	650	650	F, P	95	28	3.5
3	A	761	1100	860	70	10	650	650	F, P	96	27	3.2
4	A	761	1100	860	60	15	690	680	F, P	96	29	3.8
5	B	812	1150	900	75	20	600	600	F, P	92	12	2.6
6	B	812	1000	760	40	20	610	600	F, P	94	26	2.8
7	C	811	1150	900	65	25	600	600	F, P	94	11	2.5
8	C	811	1150	900	35	20	610	600	F, P	93	16	3.1
9	D	807	1250	840	40	30	560	550	F, P	90	9	2.0
10	D	807	1250	840	80	45	550	540	F, P	68	8	1.6
11	E	806	1250	840	45	30	550	550	F, P	89	7	1.9
12	F	773	1200	860	60	25	580	580	F, P	82	7	1.7
13	F	773	1200	860	100	35	550	540	F, P, B	66	5	1.3
14	G	781	1200	860	60	25	590	580	F, P	78	7	1.5
15	G	781	1200	860	60	35	470	460	F, B, M	62	7	1.2
16	H	791	1200	860	55	25	550	540	F, P	74	6	1.4
17	I	744	1050	820	70	35	500	500	F, B	70	5	1.0
18	I	744	1050	840	65	25	520	520	F, P, B	72	6	1.2
19	J	810	1250	840	45	30	550	550	F, P	89	10	2.4
20	K	800	1250	840	45	30	550	550	F, P	91	8	1.6

(continued)

Steel sheet No.	Steel	Ar_3 transformation point(°C)	Hot rolling conditions						Steel sheet microstructure *3			
			Heating temperature (°C)	Finishing temperature (°C)	Cooling rate 1 *1 (°C)	Cooling rate 2 *2 (°C)	Cooling stop temperature (°C)	Coiling temperature (°C)	Type	F fraction (%)	F average grain diameter (μm)	C average length of major axis (μm)
21	L	749	1050	840	45	30	560	550	F, P	80	6	3.3

*1) Average cooling rate in the temperature range from the finishing temperature to 750°C
*2) Average cooling rate in the temperature range from 750°C to the cooling stop temperature
*3) F: ferrite, P: pearlite, B: bainite, M: martensite, C: cementite present in pearlite and/or bainite

[Table 3]

Steel sheet No.	Steel	Formability				Punchability			Hardening property		Remarks
		Tensile strength TS (MPa)	Elongation after fracture EL (%)	Strength-elongation balance TS × EL(GPa·%)	Evaluation *4	Sheared surface ratio (%)	Cracks in fracture surface	Evaluation *4	Nitrided layer cross section hardness HV0.1 (HV0.1)	Evaluation *4	
1	A	384	43.3	16.6	○	68	Absent	○	262	○	Example of invention
2	A	371	41.8	15.5	×	63	Present	×	249	×	Comparative example
3	A	377	42.9	16.2	○	64	Present	×	256	○	Comparative example
4	A	369	43.1	15.9	×	65	Present	×	243	×	Comparative example
5	B	358	46.2	16.5	○	65	Absent	○	285	○	Example of invention
6	B	345	39.7	13.7	×	48	Present	×	278	○	Comparative example
7	C	362	45.6	16.5	○	63	Absent	○	281	○	Example of invention
8	C	356	46.3	16.5	○	61	Present	×	273	○	Comparative example
9	D	379	43.9	16.6	○	64	Absent	○	275	○	Example of invention
10	D	394	41.6	16.4	○	58	Absent	×	277	○	Comparative example
11	E	411	40.7	16.7	○	66	Absent	○	287	○	Example of invention
12	F	409	42.8	17.5	○	61	Absent	○	276	○	Example of invention
13	F	440	40.6	17.9	○	56	Absent	×	280	○	Comparative example

(continued)

Steel sheet No.	Steel	Formability				Punchability			Hardening property		Remarks
		Tensile strength TS (MPa)	Elongation after fracture EL (%)	Strength-elongation balance TS × EL(GPa·%)	Evaluation *4	Sheared surface ratio (%)	Cracks in fracture surface	Evaluation *4	Nitrided layer cross section hardness HV0.1 (HV0.1)	Evaluation *4	
14	G	458	40.2	18.4	○	62	Absent	○	319	○	Example of invention
15	G	522	34.7	18.1	○	55	Present	×	328	○	Comparative example
16	H	531	34.5	18.3	○	60	Absent	○	337	○	Example of invention
17	I	603	27.6	16.6	○	62	Absent	○	274	○	Example of invention
18	I	598	27.9	16.7	○	63	Absent	○	271	○	Example of invention
19	J	371	44.4	16.5	○	59	Absent	×	171	×	Comparative example
20	K	395	43.0	17.0	○	65	Absent	○	222	×	Comparative example
21	L	587	27.5	16.1	○	60	Present	×	269	○	Comparative example

*4) O : Good, × : Poor

[0061] The steel sheets which conform to the present invention (examples of invention) have good formability, excellent punchability of the steel sheet, and an excellent surface hardening property due to nitriding treatment. On the other hand, in other steel sheets which are out of the ranges of the present invention in terms of the chemical composition and microstructure (comparative examples), any of or all of the formability, punchability, and surface hardening property due to nitriding treatment are at insufficient levels.

[0062] This application claims the benefit of Japanese Patent Application No. 2013-076824, filed April 2, 2013, which is hereby incorporated by reference herein in its entirety.

Claims

1. A steel sheet for nitriding having a composition and a microstructure:

the composition comprising in percent by mass,

0.02% to 0.08% of C,	0.1% or less of Si;
0.2% to 1.8% of Mn,	0.05% or less of P;
0.02% or less of S,	0.01% to 0.06% of Al;
0.5% to 1.5% of Cr,	0.01% or less of N; and

the balance being Fe and incidental impurities; and

the microstructure including ferrite as a main phase and pearlite and/or bainite as a secondary phase, wherein the ferrite has a fraction of 70% or more in the entire microstructure and an average grain diameter of 5 to 25 μm, and cementite present in the secondary phase has an average length of the major axis of 3.0 μm or less in a cross section in the rolling direction of the steel sheet.

2. The steel sheet for nitriding according to Claim 1, wherein the composition further comprises, in percent by mass, at least one selected from the group consisting of 0.005% to 0.075% of V, 0.005% to 0.025% of Nb, and 0.005% to 0.025% of Ti.

3. A method for producing a steel sheet for nitriding, comprising:

heating a steel slab having a composition including, in percent by mass, 0.02% to 0.08% of C, 0.1% or less of Si, 0.2% to 1.8% of Mn, 0.05% or less of P, 0.02% or less of S, 0.01% to 0.06% of Al, 0.5% to 1.5% of Cr, 0.01% or less of N, and the balance being Fe and incidental impurities, to 1,050°C to 1,250°C;
hot rolling the heated steel slab at a finishing temperature ranging from the Ar_3 transformation temperature to (the Ar_3 transformation temperature + 100°C);
cooling the hot rolled steel sheet at a cooling rate of 40°C/s to 80°C/s in the temperature range from the finishing temperature to 750°C at a cooling rate of 15°C/s to 35°C/s in the temperature range from 750°C to a cooling stop temperature of 500°C to 650°C; and
coiling the cooled steel sheet at a coiling temperature of 500°C to 650°C.

4. The method for producing a steel sheet for nitriding according to Claim 3, wherein the composition of the steel slab further includes, in percent by mass, at least one selected from the group consisting of 0.005% to 0.075% of V, 0.005% to 0.025% of Nb, and 0-005% to 0.025% of Ti.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/001603

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/38*(2006.01)i

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)
C22C1/00-49/14, C21D9/46

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

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	JP 2012-177176 A (JFE Steel Corp.), 13 September 2012 (13.09.2012), (Family: none)	1-4
A	JP 2012-177167 A (JFE Steel Corp.), 13 September 2012 (13.09.2012), (Family: none)	1-4
A	WO 2008/123366 A1 (Nippon Steel Corp.), 16 October 2008 (16.10.2008), & JP 4874333 B & US 2010/0108201 A1 & EP 2130938 A1 & CA 2681748 A & KR 10-2009-0115877 A & CN 101646794 A	1-4

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 June, 2014 (11.06.14)	24 June, 2014 (24.06.14)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/001603

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	WO 2013/047755 A1 (Nippon Steel & Sumitomo Metal Corp.), 04 April 2013 (04.04.2013), & TW 201329252 A	1-4

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 9025513 A **[0010]**
- JP 9025543 A **[0010]**
- JP 2005171331 A **[0010]**
- JP 2013076824 A **[0062]**