US 20240011137A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2024/0011137 A1

(43) Pub. Date: Jan. 11, 2024

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(54) **STAINLESS STEEL BAR MATERIAL AND ELECTROMAGNETIC COMPONENT**

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(21) Appl. No.: **18/037,694**

(22) PCT Filed: **Nov. 16, 2021**

(86) PCT No.: **PCT/JP2021/042062**

§ 371 (c)(1),
(2) Date: **May 18, 2023**

(30) **Foreign Application Priority Data**

Nov. 19, 2020 (JP) 2020-192251

Publication Classification

(51) **Int. Cl.**

C22C 38/60	(2006.01)
C22C 38/58	(2006.01)
C22C 38/54	(2006.01)
C22C 38/52	(2006.01)
C22C 38/50	(2006.01)
C22C 38/48	(2006.01)
C22C 38/46	(2006.01)
C22C 38/44	(2006.01)
C22C 38/42	(2006.01)
C22C 38/06	(2006.01)
C22C 38/04	(2006.01)
C22C 38/02	(2006.01)
C22C 38/00	(2006.01)
C22C 33/04	(2006.01)
C21D 9/08	(2006.01)
C21D 8/12	(2006.01)
C21D 6/00	(2006.01)

(52) **U.S. Cl.**

CPC ***C22C 38/60*** (2013.01); ***C22C 38/58*** (2013.01); ***C22C 38/54*** (2013.01); ***C22C 38/52*** (2013.01); ***C22C 38/50*** (2013.01); ***C22C 38/48*** (2013.01); ***C22C 38/46*** (2013.01); ***C22C 38/44*** (2013.01); ***C22C 38/42*** (2013.01); ***C22C 38/06*** (2013.01); ***C22C 38/04*** (2013.01); ***C22C 38/02*** (2013.01); ***C22C 38/008*** (2013.01); ***C22C 38/005*** (2013.01); ***C22C 38/004*** (2013.01); ***C22C 38/002*** (2013.01); ***C22C 38/001*** (2013.01); ***C22C 33/04*** (2013.01); ***C21D 9/08*** (2013.01); ***C21D 8/1222*** (2013.01); ***C21D 8/1261*** (2013.01); ***C21D 6/004*** (2013.01); ***C21D 6/005*** (2013.01); ***C21D 6/007*** (2013.01); ***C21D 6/008*** (2013.01); *C22C 2202/02* (2013.01)

(57) **ABSTRACT**

A bar-shaped stainless steel product having a chemical composition that contains, by mass %: 0.001 to 0.030% of C; 0.01 to 4.00% of Si; 0.01 to 2.00% of Mn; 0.01 to 4.00% of Ni; 8.0 to 35.0% of Cr; 0.01 to 5.00% of Mo; 0.01 to 2.00% of Cu; 0.001 to 0.030% of N; 7.000% or less of Al; 0 to 2.00% of Ti; 0 to 2.00% of Nb; and 0 to 0.1% of B; one or more elements selected from 0.001% or more of Ti, **0.001**% or more of Nb, and 0.0001% or more of B being contained, a balance consisting of Fe and impurities, an average particle size of nitrides being 10 μm or less, and a solute N content in steel being 0.020 mass % or less.

STAINLESS STEEL BAR MATERIAL AND ELECTROMAGNETIC COMPONENT

TECHNICAL FIELD

[0001] The present invention relates to an electromagnetic stainless steel, in particular, a bar-shaped stainless steel product excellent in high-speed cold forging properties, machinability, and soft magnetic properties, and an electromagnetic component using the same.

BACKGROUND ART

[0002] Electromagnetic stainless steel products, as represented by an injector, a solenoid valve and the like, have been conventionally produced through processing, forming, and heat treatment by using, as a material, a ferritic stainless steel wire rod or steel wire, which are exemplified by SUS430 and SUS410L. However, such stainless steel products processed and manufactured from the above ferritic stainless steel wire rod have insufficient soft magnetic properties for use in high-precision/high-powered components. Further, such stainless steel products fail to cater to enhanced production of components due to insufficient cold forging properties and machinability, leading to limited uses. In order to solve the above problem, a technique of optimizing alloy elements has been studied for the purpose of improving the soft magnetic properties, cold forging properties and machinability (see, Patent Literatures 1 to 3). No invention so far focuses attention on the improvement in soft magnetic properties, high-speed cold forging properties and machinability of ferritic stainless steel bars and wire rods through texture control based on a combination of chemical components and processes.

CITATION LIST

Patent Literature(s)

[0003] Patent Literature 1: JP 06-49606 A
[0004] Patent Literature 2: JP 06-49605 A
[0005] Patent Literature 3: JP 03-44448 A

SUMMARY OF THE INVENTION

Problem(s) to be Solved by the Invention

[0006] In view of the above, an object of the invention is to solve the above problem and provide an electromagnetic stainless steel excellent in high-speed cold forging properties, machinability, and soft magnetic properties, in particular, a bar-shaped stainless steel product and an electromagnetic component using the same.

Means for Solving the Problems

[0007] The invention is made to solve the above problem, and provides a bar-shaped stainless steel product and an electromagnetic component below as a gist.

[0008] [1] A bar-shaped stainless steel product having a chemical composition containing, by mass %: 0.001 to 0.030% of C; 0.01 to 4.00% of Si; 0.01 to 2.00% of Mn; 0.01 to 4.00% of Ni; 8.0 to 35.0% of Cr; 0.01 to 5.00% of Mo; 0.01 to 2.00% of Cu; 0.001 to 0.030% of N; 7.000% or less of Al; 0 to 2.00% of Ti; 0 to 2.00% of Nb; 0 to 0.1000% of B; one or more elements selected from 0.001% or more of Ti, 0.001% or more of Nb, and 0.0001% or more of B being contained; 0 to 2.50% of Sn; 0 to 2.0% of V; 0 to 3.00% of W; 0 to 0.05% of Ga; 0 to 2.50% of Co; 0 to 2.50% of Sb; 0 to 2.50% of Ta; 0 to 0.05% of Ca; Oto 0.012% of Mg; Oto 0.012% of Zr; 0 to 0.05% of REM; 0 to 0.30% of Pb; 0 to 0.80% of Se; 0 to 0.30% of Te; 0 to 0.50% of Bi; 0 to 0.50 of S; and 0 to 0.30% of P,

[0009] a balance consisting of Fe and impurities,

[0010] an average particle size of nitrides being 10 μm or less, and

[0011] a solute N content in steel being 0.020 mass % or less.

[0012] [2] A bar-shaped stainless steel product having a chemical composition containing, by mass %: 0.001 to 0.030% of C; 0.01 to 4.00% of Si; 0.01 to 2.00% of Mn; 0.01 to 4.00% of Ni; 8.0 to 35.0% of Cr; 0.01 to 5.00% of Mo; 0.01 to 2.00% of Cu; 0.001 to 0.030% of N; 7.000% or less of Al; 0 to 2.00% of Ti; 0 to 2.00% of Nb; 0 to 0.1000% of B; one or more elements selected from 0.001% or more of Ti, 0.001% or more of Nb, and 0.0001% or more of B being contained; 0 to 2.50% of Sn; 0 to 2.0% of V; 0 to 3.00% of W; 0 to 0.05% of Ga; 0 to 2.50% of Co; 0 to 2.50% of Sb; 0 to 2.50% of Ta; 0 to 0.05% of Ca; 0 to 0.012% of Mg; 0 to 0.012% of Zr; 0 to 0.05% of REM; 0 to 0.30% of Pb; 0 to 0.80% of Se; 0 to 0.30% of Te; 0 to 0.50% of Bi; 0 to 0.50% of S; and 0 to 0.30% of P,

[0013] a balance consisting of Fe and impurities,

[0014] an average particle size of nitrides being 10 μm or less, and

[0015] a solute B content in steel being 0.015 mass % or less.

[0016] [3] The bar-shaped stainless steel product according to [1] or [2], in which the chemical composition further includes, by mass %, one or more groups selected from First Group, Second Group, and Third Group below:

[0017] First Group: one or more elements selected from 0.0001 to 2.5% of Sn; 0.001 to 2.0% of V; 0.05 to 3.0% of W; 0.0004 to 0.05% of Ga; 0.05 to 2.5% of Co; 0.01 to 2.5% of Sb; and 0.01 to 2.5% of Ta,

[0018] Second Group: one or more elements selected from 0.0002 to 0.05% of Ca; 0.0002 to 0.012% of Mg; 0.0002 to 0.012% of Zr; and 0.0002 to 0.05% of REM, and

[0019] Third Group: one or more elements selected from 0.0001 to 0.30% of Pb; 0.0001 to 0.80% of Se; 0.0001 to 0.30% of Te; 0.0001 to 0.50% of Bi; 0.0001 to 0.50% of S; and 0.0001 to 0.30% of P.

[0020] [4] The bar-shaped stainless steel product according to any one of [1] to [3], in which a strain rate without cracking at a compressibility of 70% is 0.1/s or more.

[0021] [5] The bar-shaped stainless steel product according to any one of [1] to [4], in which a hole depth, which represents a tool life, through drilling is 50 mm or more.

[0022] [6] The bar-shaped stainless steel product according to any one of [1] to [5], in which coercive force is 5.0 A/m or less.

[0023] [7] An electromagnetic component using the bar-shaped stainless steel product according to any one of [1] to [6].

[0024] According to the above aspects of the invention, a bar-shaped stainless steel product excellent in high-speed cold forging properties, machinability, and soft magnetic properties and an electromagnetic component are obtainable.

DESCRIPTION OF EMBODIMENT(S)

[0025] The inventors conducted various studies to obtain a bar-shaped stainless steel product excellent in high-speed cold forging properties, machinability, and soft magnetic properties and an electromagnetic component. As a result, the following findings (a) to (c) have been obtained.

[0026] (a) An average particle size of nitrides, a solute N content in steel (a content of N forming a solid solution in steel), and a solute B content in steel (a content of B forming a solid solution in steel) are reducible by a combination of ferritic stainless steel of which components are adjusted with one or more of B, Ti, and Nb and a hot- rolling process (a temperature at a finish rolling entering side, a rolling diameter of finish rolling, and a heat treatment temperature).

[0027] (b) As a result, it has been found a new method capable of improving all of the high-speed cold forging properties, machinability, and soft magnetic properties where the strain rate without cracking at a compressibility of 70% is 0.1/s or more for the high-speed cold forging properties, the cutting resistance is 50 mm or more for the machinability, and the coercive force is 5.0 Nm or less for the soft magnetic properties.

[0028] The invention has been made on the basis of the above findings. A preferable exemplary embodiment of the invention will be described in detail. In the following description, the preferable exemplary embodiment of the invention will be described as the invention. Requirements of the invention will be described in detail below. Regarding steel products having a bar-shape according to the invention, examples of a "bar-shaped steel product" include a "steel bar", a "wire rod", a "steel wire", a "deformed wire", and a "deformed steel bar".

[0029] 1. Average Particle Size of Nitrides In the "bar-shaped steel product" according to the invention, an average particle size of nitrides is controlled. Specifically, the average particle size of nitrides is 10 μm or less, because coarse nitrides having an average particle size exceeding 10 μm decrease high-speed cold forging properties. The average particle size of nitrides is more preferably 7 μm or less, still more preferably 5 μm or less. When the average particle size of nitrides is too small, soft magnetic properties and machinability decrease. The average particle size of nitrides is thus preferably 0.01 μm or more. Note that the nitrides include carbonitrides.

[0030] The average particle size of nitrides can be determined by measuring at least one field of view at 400-fold magnification at each of a surface layer portion, a center portion, and a ¼-depth-position existing between the surface layer portion and the center portion in an L-cross section of the bar-shaped steel product (cross-section including a central axis of the bar-shaped steel product); identifying the nitrides in the observation visual field(s) with FE-SEM/ESD; measuring equivalent circle diameters of the nitrides in the observation visual field(s); and calculating an average value of the equivalent circle diameters.

[0031] 2. Solute N Content and Solute B Content in Steel

[0032] In the bar-shaped steel product according to the invention, soft magnetic properties and high-speed cold forging properties are improved by making the solute

[0033] N content in steel 0.020 mass % or less or making the solute B content in steel 0.015 mass % or less. Hereinafter, an invention, in which a later-described chemical composition preferable for the invention is satisfied, the above-described average particle size of nitrides is satisfied, and the solute N content in steel is 0.020 mass % less, is referred to as "Invention 1". Further, an invention, in which a chemical composition preferable for the invention is satisfied, the above average particle size of nitrides is satisfied, and the solute B content in steel is 0.015 mass % less, is referred to as "Invention 2".

[0034] 2-1. Solute N Content in Steel

[0035] In a bar-shaped steel product according to Invention 1, the solute N content in steel is controlled. Specifically, the solute N content in steel is 0.020 mass % or less. This is because, lattice strain is caused at a solute N content in steel exceeding mass %, which would decrease soft magnetic properties and high-speed cold forging properties. The solute N content in steel is more preferably 0.015 mass % or less, still more preferably 0.01 mass % or less. When the solute N content in steel is too small, machinability decreases. The solute N content in steel is thus preferably mass % or more. The steel of the invention has a crystal structure formed from ferrite, and thus the solute N content in steel corresponds to a solute N content in a ferrite phase.

[0036] The solute N content in steel ($=N_0-N_{pre}$) is obtainable by performing an electrolytic extraction residue method on the bar-shaped steel product to extract nitrides, measuring an N content (N_{pre}) in the nitrides, and subtracting the N content (N_{pre}) from a total N content (N_0) in steel.

[0037] 2-2. Solute B Content in Steel

[0038] In a bar-shaped steel product according to Invention 2, the problem to be solved by the invention can also be solved by controlling the solute B content in steel. Specifically, the solute B content in steel is controlled to be 0.015 mass % or less. This is because, lattice strain is caused at a solute B content in steel exceeding 0.015 mass %, which would decrease soft magnetic properties and high-speed cold forging properties. The solute B content in steel is more preferably 0.010 mass % or less, still more preferably 0.005% or less. When the solute B content in steel is too small, machinability decreases. The solute B content in steel is thus preferably 0.00001 mass % or more. The steel of the invention has a crystal structure formed from ferrite, and thus the solute B content in steel corresponds to a solute B content in a ferrite phase.

[0039] The solute B content in steel ($=B_0-B_{pre}$) is obtainable by performing an electrolytic extraction residue method on the bar-shaped steel product to extract nitrides, measuring a B content (B_{pre}) in the nitrides, and subtracting the B content (B_{pre}) from a total B content (B_0) in steel.

[0040] 3. Chemical Composition

[0041] Reasons for limiting elements are as follows. It should be noted that the unit "%" for a content of each element means "mass %" in the following description.

[0042] C: 0.001 to 0.030%

[0043] C increases strength and machinability of the steel product. The C content is thus 0.001% or more. However, an excessive C content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The C content is thus 0.030% or less. The C content is preferably 0.020% or less, more preferably 0.015% or less.

[0044] Si: 0.01 to 4.00%

[0045] Si, which is contained as a deoxidizing element, improves soft magnetic properties and machinability. The Si content is thus 0.01% or more, preferably 0.10% or more. However, an excessive Si content decreases high-speed cold forging properties, soft magnetic properties, and machinability. The Si content is thus 4.00% or less. The Si content is preferably 3.00% or less, more preferably 1.50% or less.

[0046] Mn: 0.01 to 2.00%

[0047] Mn improves strength, soft magnetic properties, and machinability of the steel product. The Mn content is thus 0.01% or more, preferably 0.05% or more. However, an excessive Mn content decreases soft magnetic properties, high-speed cold forging properties, and machinability. Further, corrosion resistance may also be decreased. The Mn content is thus 2.00% or less. The Mn content is preferably 1.00% or less, more preferably 0.50% or less.

[0048] Ni: 0.01 to 4.00%

[0049] Ni improves toughness, soft magnetic properties, high-speed cold forging properties, and machinability of the steel product. The Ni content is thus 0.01% or more, preferably 0.05% or more. However, an excessive Ni content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The Ni content is thus 4.00% or less. The Ni content is preferably 3.00% or less, more preferably 1.00% or less, and still more preferably 0.50% or less.

[0050] Cr: 8.0 to 35.0%

[0051] Cr improves corrosion resistance, soft magnetic properties, high-speed cold forging properties, and machinability. The Cr content is thus 8.0% or more. The Cr content is preferably 10.0% or more. However, an excessive Cr content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The Cr content is thus 35.0% or less. The Cr content is preferably 21.0% or less, more preferably 20.0% or less.

[0052] Mo: 0.01 to 5.00%

[0053] Mo improves corrosion resistance, soft magnetic properties, high-speed cold forging properties, and machinability. The Mo content is thus 0.01% or more. However, an excessive Mo content decreases high-speed cold forging properties, soft magnetic properties, and machinability. The Mo content is thus 5.00% or less.

[0054] The Mo content is preferably 3.00% or less, more preferably 2.00% or less, and still more preferably 1.50% or less.

[0055] Cu: 0.01 to 2.00%

[0056] Cu improves corrosion resistance, soft magnetic properties, high-speed cold forging properties, and machinability. The Cu content is thus 0.01% or more, preferably 0.05% or more. However, an excessive Cu content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The Cu content is thus 2.00% or less. The Cu content is preferably 1.00% or less, more preferably 0.80% or less, and still more preferably 0.40% or less.

[0057] N:0.001 to 0.030%

[0058] N increases strength and machinability of the steel product. Further, N is an element forming nitrides. The N content is thus 0.001% or more, preferably 0.002% or more. However, an excessive N content decreases soft magnetic properties, machinability, and high-speed cold forging properties. Further, an excessive N content makes the average particle size of nitrides large, increasing the solute N content. The N content is thus 0.030% or less. The N content is preferably 0.025% or less, more preferably 0.020% or less.

[0059] Al: 7.000% or less

[0060] Al has an effect of promoting deoxidation to improve a cleanliness level of inclusions. Further, Al improves soft magnetic properties, high-speed cold forging properties, and machinability. However, an excessive Al content saturates the effect, decreasing soft magnetic properties, high-speed cold forging properties, and machinability. Further, coarse inclusions decrease toughness. The Al content is thus 7.000% or less. The Al content is preferably 3.000% or less, more preferably 0.100% or less, and still more preferably 0.020% or less. On the other hand, the Al content is preferably 0.001% or more in order to exhibit the above effects.

[0061] The bar-shaped steel product of the invention contains, in addition to the above elements, one or more elements selected from 0.001% or more of Ti, 0.001% or more of Nb, and 0.0001% or more of B to fall within a chemical composition range(s) below. These elements, which are primary elements of nitrides, need to be controlled, because these elements relate to the average particle size of nitrides and the solute N content. Of Ti, Nb, and B, the element(s) not selected may not be contained or be contained to fall within the chemical composition range(s) below.

[0062] Ti: 0 to 2.00% Ti has an effect of improving strength, soft magnetic properties, high-speed

[0063] cold forging properties, and machinability of the steel product. Further, Ti forms nitrides and relates to the solute N content. Furthermore, since Ti forms carbonitrides, formation of Cr carbides is inhibited to inhibit formation of Cr-depletion layers, providing an effect of preventing intergranular corrosion. The Ti content is thus or more. However, an excessive Ti content decreases soft magnetic properties, machinability, and high-speed cold forging properties. Further, an excessive Ti content makes the average particle size of nitrides large. The Ti content is thus 2.00% or less. The Ti content is preferably 1.00% or less, more preferably or less, still more preferably 0.50% or less, and still further more preferably or less. The Ti content is preferably 0.01% or more to exhibit the above effects. The Ti content is more preferably 0.05% or more. The Ti content may be 0.10% or more.

[0064] Nb: 0 to 2.00%

[0065] Nb has an effect of improving strength, soft magnetic properties, high-speed cold forging properties, and machinability of the steel product. Further, Nb forms nitrides and relates to the solute N content. Furthermore, since Nb forms carbonitrides, formation of Cr carbides is inhibited to inhibit formation of Cr-depletion layers, providing an effect of preventing intergranular corrosion. The Nb content is thus 0.001% or more. However, an excessive Nb content decreases soft magnetic properties, machinability, and high-speed cold forging properties. Further, an excessive Nb content makes the average particle size of nitrides large. The Nb content is thus 2.00% or less. The Nb content is preferably 1.00% or less, more preferably 0.80% or less, and still more preferably 0.60% or less. The Nb content is preferably 0.02% or more to exhibit the above effects. The Nb content is more preferably 0.05% or more. The Nb content may be 0.10% or more.

[0066] B:0 to 0.1000%

[0067] B has an effect of improving soft magnetic properties, high-speed cold forging properties, and machinability of the steel product. Further, B forms a boron nitride such as BN and relates to the solute N content and the solute B content. BN especially contributes to the improvement in machinability. The B content is thus or more. However, an excessive B content decreases soft magnetic properties, machinability, and high-speed cold forging properties. Further, an excessive B content makes the average particle size of nitrides large. The B content is thus 0.1000% or less. The B content is preferably 0.0200% or less, more preferably or less. The B content is preferably 0.0005% or more to exhibit the above effects. The B content is more preferably 0.0010% or more. The B content may be 0.0020% or more.

[0068] In addition to the above elements, the bar-shaped steel product of the invention may contain, as an element of a first group, one or more elements selected from Sn, V, W, Ga, Co, Sb, and Ta as needed.

[0069] Sn: 0 to 2.50%

[0070] Since Sn has an effect of improving corrosion resistance, soft magnetic properties, high-speed cold forging properties, and machinability, Sn may be contained as needed. However, an excessive Sn content decreases soft magnetic properties, high-speed cold forging properties, and machinability. Further, toughness is decreased by grain boundary segregation of Sn. The Sn content is thus 2.50% or less. The Sn content is more preferably 1.00% or less, still more preferably 0.20% or less. On the other hand, the Sn content is preferably 0.0001% or more, more preferably 0.05% or more, in order to exhibit the above effects.

[0071] V: 0 to 2.0%

[0072] Since V has an effect of improving soft magnetic properties, high-speed cold forging properties, and machinability, V may be contained as needed. However, an excessive V content decreases soft magnetic properties, high-speed cold forging properties, and machinability. Further, coarse carbonitrides decrease toughness. The V content is thus 2.0% or less. The V content is preferably 1.0% or less, more preferably 0.5% or less, and still more preferably 0.1% or less. On the other hand, the V content is preferably 0.001% or more in order to exhibit the above effects.

[0073] W:0 to 3.00%

[0074] Since W has an effect of improving corrosion resistance, W may be contained as needed. However, an excessive W content decreases soft magnetic properties, high-speed cold forging properties, and machinability. Further, coarse carbonitrides decrease toughness. The W content is thus 3.00% or less. The W content is preferably 2.00% or less, more preferably 1.50% or less. On the other hand, the W content is preferably 0.05% or more, more preferably 0.10% or more, in order to exhibit the above effects.

[0075] Ga: 0 to 0.05%

[0076] Since Ga has an effect of improving corrosion resistance, Ga may be contained as needed. However, an excessive Ga content decreases hot workability. The Ga content is thus 0.05% or less. On the other hand, the Ga content is preferably or more in order to exhibit the above effects.

[0077] Co: 0 to 2.50%

[0078] Since Co has an effect of improving strength, soft magnetic properties, high-speed cold forging properties, and machinability of the steel product, Co may be contained as needed. Further, a moderate content of Co enhances a saturated magnetic flux density, which improves soft magnetic properties. However, an excessive Co content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The Co content is thus 2.50% or less. The Co content is preferably 1.00% or less, more preferably 0.80% or less. On the other hand, the Co content is preferably 0.05% or more, more preferably 0.10% or more, in order to exhibit the above effects.

[0079] Sb: 0 to 2.50%

[0080] Since Sb has an effect of improving corrosion resistance, Sb may be contained as needed. However, an excessive Sb content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The Sb content is thus 2.50% or less. The Sb content is more preferably 1.00% or less, still more preferably 0.20% or less. On the other hand, the Sb content is preferably 0.01% or more, more preferably 0.05% or more, in order to obtain the above effects.

[0081] Ta: 0 to 2.50%

[0082] Since Ta has an effect of improving corrosion resistance, Ta may be contained as needed. However, an excessive Ta content decreases soft magnetic properties, high-speed cold forging properties, and machinability. The Ta content is thus 2.50% or less. The Ta content is preferably 1.50% or less, more preferably 0.90% or less. On the other hand, the Ta content is preferably 0.01% or more, more preferably 0.04% or more, and still more preferably 0.08% or more, in order to exhibit the above effects.

[0083] In addition to the above elements, the bar-shaped steel product of the invention may contain, as an element of a second group, one or more elements selected from Ca, Mg, Zr, and REM as needed.

[0084] Ca: 0 to 0.05%

[0085] Mg: 0 to 0.012%

[0086] Zr: 0 to 0.012%

[0087] REM: 0 to 0.05%

[0088] Ca, Mg, Zr, and REM may be contained for deoxidation, as needed. However, excessive contents of these elements decrease soft magnetic properties, high-speed cold forging properties, and machinability. Further, coarse inclusions decrease toughness. Thus, the Ca content is 0.05% or less, the Mg content is 0.012% or less, the Zr content is 0.012% or less, and the REM content is 0.05% or less. The Ca content is preferably 0.010% or less, more preferably 0.005% or less. The Mg content is preferably 0.010% or less, more preferably 0.005% or less. The Zr content is preferably 0.010% or less, more preferably 0.005% or less. The REM content is preferably 0.010% or less.

[0089] On the other hand, the Ca content is preferably 0.0002% or more, the Mg content is preferably 0.0002% or more, the Zr content is preferably 0.0002% or more, and the REM content is preferably 0.0002% or more, in order to exhibit the above effects. The Ca content is more preferably 0.0004% or more, still more preferably or more. The Mg content is preferably 0.0004% or more, more preferably or more. The Zr content is more preferably 0.0004% or more, still more preferably 0.001% or more. The REM content is more preferably 0.0004% or more, still more preferably 0.001% or more.

[0090] It should be noted that REM is a general term for 17 elements including Y, Sc, and 15 elements of lanthanoids. One or more of the 17 elements can be contained in steel. The REM content means a total content of these elements.

[0091] In addition to the above elements, the bar-shaped steel product of the invention may contain, as an element of a third group, one or more elements selected from Pb, Se, Te, Bi, S, and P as needed.

[0092] Pb: 0 to 0.30%

[0093] Se: 0 to 0.80%

[0094] Te: 0 to 0.30%

[0095] Bi: 0 to 0.50%

[0096] S: 0 to 0.50%

[0097] P: 0 to 0.30%

[0098] Pb, Se, Te, Bi, S and P may be contained for machinability, as needed. However, excessive contents of these elements decrease soft magnetic properties, high-speed cold forging properties, and toughness. Thus, the Pb content is 0.30% or less, the Se content is 0.80% or less, the Te content is 0.30% or less, the Bi content is 0.50% or less, the S content is 0.50 or less, and the P content is 0.30 or less. The Pb content is preferably 0.1% or less, more preferably 0.05% or less. The Se content is preferably 0.1% or less, more preferably 0.05% or less. The Te content is preferably 0.1% or less, more preferably 0.05% or less. The Bi content is preferably 0.1% or less, more preferably 0.05% or less. The S content is preferably 0.1% or less, more preferably 0.05% or less. The P content is preferably 0.1% or less, more preferably 0.05% or less.

[0099] On the other hand, the Pb content is preferably 0.0001% or more, the Se content is preferably 0.0001% or more, the Te content is preferably 0.0001% or more, the Bi content is preferably 0.0001% or more, the S content is preferably 0.0001% or more, and the P content is preferably 0.0001% or more in order to exhibit the above effects. The Pb content is more preferably 0.0004% or more, still more preferably or more. The Se content is more preferably 0.0004% or more, still more preferably 0.001% or more. The Te content is more preferably 0.0004% or more, still more preferably 0.001% or more. The Bi content is more preferably 0.0004% or more, still more preferably 0.001% or more. The S content is more preferably 0.0001% or more, still more preferably 0.0002% or more. The P content is more preferably or more, still more preferably 0.001% or more.

[0100] In a chemical composition of the steel sheet of the invention, a balance consists of Fe and impurities. The "impurities" herein mean substances in raw materials such as ore and scrap as well as components mixed in the manufacturing process due to various factors when the steel sheet is industrially manufactured, the substances and the components being allowable within a range that does not adversely affect the invention.

[0101] Examples of the impurities include O, Zn, and H. The impurities are preferably reduced, however, when being contained, the contents of O, Zn, and H are each desirably 0.01% or less.

[0102] 4. Manufacturing Method

[0103] A favorable manufacturing method of an electromagnetic stainless steel (bar-shaped stainless steel product) according to the invention will be described. The bar-shaped stainless steel product according to the invention that satisfies the above features can exhibit the effects irrespective of its manufacturing method. The bar-shaped stainless steel product according to the invention, however, is stably obtainable according to, for instance, a manufacturing method below.

[0104] In the bar-shaped stainless steel product according to the invention, steel having the above chemical composition is melted, the molten steel is casted into a cast steel having a predetermined diameter, the cast steel is subjected to hot steel bar and wire rod rolling or warm steel bar and wire rod rolling including rough rolling, intermediate rolling, and finish rolling to make a bar-shaped steel product, and then the bar-shaped steel product is subjected to a heat treatment. Skew rolling is preferably performed before the rough rolling. Then, pickling or the like may be performed as needed.

[0105] 4-1. Temperature at Finish Rolling Entering Side

[0106] In the hot rolling for the bar-shaped steel product, a temperature at a finish rolling entering side is preferably controlled. The temperature at the finish rolling entering side of the bar-shaped steel product varies the average particle size of nitrides and varies a fraction of the solute N content in steel and a fraction of the solute B content in steel. The temperature at the finish rolling entering side thus affects soft magnetic properties, high-speed cold forging properties, and machinability. When the temperature at the finish rolling entering side of the bar-shaped steel product exceeds 1,200 degrees C., nitrides easily dissolve to increase the solute N content and the solute B content, decreasing soft magnetic properties and high-speed cold forging properties. Further, when the temperature at the finish rolling entering side of the bar-shaped steel product exceeds 1,200 degrees C., the average particle size of nitrides is too small, resulting in poor machinability. Thus, the temperature at the finish rolling entering side is 1,200 degrees C. or less, preferably 1,100 degrees C. or less, and more preferably 1,050 degrees C. or less. On the other hand, when the temperature at the finish rolling entering side is less than 600 degrees C., the solute N content is too small, resulting in poor machinability. Further, when the temperature at the finish rolling entering side is less than 600 degrees C., nitrides not forming a solid solution make the average particle size of nitrides large, decreasing high-speed cold forging properties. The temperature at the finish rolling entering side is thus 600 degrees C. or more. The temperature at the finish rolling entering side is preferably 700 degrees C. or more, more preferably 800 degrees C.

[0107] 4-2. Roll Diameter of Finish Rolling

[0108] A roll diameter of finish rolling affects a strain amount and strain distribution of the bar-shaped steel product, relates to the average particle size of nitrides and the solute N content in steel, and affects soft magnetic properties, high-speed cold forging properties, and machinability. The roll diameter of finish rolling is thus required to be controlled. When the roll diameter of finish rolling is less than 50 mm, no strain is introduced to a center portion of the bar-shaped steel product, failing to facilitate formation of fine nitrides on dislocation and making the average particle size of nitrides large. Further, the solute N content increases at a roll diameter of finish rolling of less than 50 mm, reducing soft magnetic properties and high-speed cold forging properties. Note that the effect of the roll diameter of finish rolling on the solute N content in steel also applies to the solute B content. The solute B content increases when the roll diameter of finish rolling is less than 50 mm. The roll diameter of finish rolling is thus 50 mm or more, preferably 80 mm or more, and still more preferably 100 mm or more. On the other hand, when the roll diameter of finish rolling exceeds 500 mm, nitrides are too fine and the solute N and B contents increase, decreasing machinability and magnetic properties. The roll diameter of finish rolling is thus 500 mm or less, preferably 400 mm or less, and more preferably 300 mm or less.

[0109] 4-3. Heat Treatment Temperature of Bar-shaped Steel Product

[0110] The bar-shaped steel product after hot rolling is preferably subjected to the heat treatment. A heat treatment temperature of the bar-shaped steel product varies the average particle size of nitrides and the fractions of solute contents in steel. Thus, the heat treatment temperature of the bar-shaped steel product affects soft magnetic properties, high-speed cold forging properties, and machinability. When the heat treatment temperature of the bar-shaped steel product exceeds 1,300 degrees C., nitrides easily dissolve to increase the solute N content and the solute B content, decreasing soft magnetic properties and high-speed cold forging properties. Further, the average particle size of nitrides is too small at a heat treatment temperature exceeding 1,300 degrees C., resulting in poor machinability. Thus, the heat treatment temperature is 1,300 degrees C. or less, preferably 1,200 degrees C. or less, and more preferably 1,100 degrees C. or less. On the other hand, when the heat treatment temperature of the bar-shaped steel product is less than 500 degrees C., the solute N content is too small, resulting in poor machinability. Further, when the heat treatment temperature of the bar-shaped steel product is less than 500 degrees C., nitrides not forming a solid solution make the average particle size of nitrides large, decreasing high-speed cold forging properties. The heat treatment temperature is thus 500 degrees C. or more. The heat treatment temperature is preferably 600 degrees C. or more, more preferably 700 degrees C.

[0111] 5. Quality of Bar-shaped Stainless Steel Product

[0112] In the bar-shaped stainless steel product of the invention, the strain rate without cracking at a compressibility of 70% is 0.1/s or more, exhibiting excellent high-speed cold forging properties.

[0113] In the bar-shaped stainless steel product of the invention, a hole depth (tool life) through drilling is 50 mm or more, exhibiting excellent machinability.

[0114] In the bar-shaped stainless steel product of the invention, the coercive force is 5.0 Nm or less, exhibiting excellent soft magnetic properties.

[0115] 6. Electromagnetic Component

[0116] Examples of an electromagnetic component using the bar-shaped stainless steel product of the invention include a core and a connector of an injector and a solenoid valve. Since the bar-shaped steel product used as a material has excellent soft magnetic properties, effects of "improvement in magnetic attractive force", "reduction in a component diameter", and "improvement in responsiveness" can be provided. Further, since the bar-shaped steel product used as a material is excellent in high-speed cold forging properties and machinability, components using the bar-shaped steel product can be produced at low costs with at high productivity and near-net-shape manufacture in cold forging is also possible.

[0117] The invention will be more specifically described below by means of Examples, which are merely exemplary. The invention is not limited thereto.

Example 1

[0118] Steels having chemical compositions shown in Tables 1 and 2 were melted. AOD melting, which was an inexpensive melting process for stainless steel, was assumed for steel melting, where each steel was practically melted in a 100-kg vacuum melting furnace and cast into a cast steel with a diameter of 180 mm. Then, the cast steel was formed into a stainless steel bar or wire rod with a diameter of 20.0 mm under manufacturing conditions below.

[0119] The conditions are described below. Specifically, the cast steel was heated, subjected to skew rolling, rough rolling, and intermediate rolling, and then subjected to finish rolling under the condition of No. 123 in Table 6 (temperature at finish rolling entering side: 1,180 degrees C., roll diameter of finish rolling: 480 mm). After that, the heat treatment was performed under the condition of No. 123 in Table 6 (temperature: 1,290 degrees C.). Accordingly, a bar or a wire rod with a diameter of 20.0 mm (bar-shaped steel product) was provided.

TABLE 1

Class-	Steel	Chemical composition (mass %)												
ification	type	C	Si	Mn	Ni	Cr	Mo	Cu	N	Al	Nb	Ti	B	Others
The invention	A	0.001	2.11	0.01	0.66	10.1	1.75	0.77	0.016	0.045	—	—	0.0027	
	B	0.029	1.72	0.44	0.96	19.7	1.67	0.71	0.012	0.041	—	—	0.0046	
	C	0.011	3.90	0.42	0.99	12.7	1.97	0.64	0.014	0.022	—	—	0.0012	
	D	0.011	1.75	1.90	0.98	15.3	1.70	0.49	0.014	0.088	—	—	0.0046	
	E	0.011	2.12	0.17	3.80	15.2	1.95	0.51	0.015	0.090	—	—	0.0046	
	F	0.011	1.79	0.17	0.77	34.4	1.84	0.60	0.016	0.080	—	—	0.0053	
	G	0.012	2.31	0.16	0.70	8.2	1.88	0.44	0.013	0.088	—	—	0.0065	
	H	0.011	2.43	0.07	0.58	15.2	4.80	0.45	0.011	0.088	0.76	—	0.0077	
	I	0.014	2.17	0.17	0.69	10.7	1.61	1.90	0.018	0.066	0.68	—	0.0029	
	J	0.012	2.37	0.13	0.77	17.9	1.76	0.55	0.029	0.030	—	0.30	0.0093	
	K	0.011	2.85	0.48	0.94	15.4	1.52	0.53	0.014	6.6	—	0.39	0.0059	
	L	0.013	2.22	0.07	0.65	11.3	1.52	0.50	0.011	0.086	1.94	0.40	—	
	M	0.011	1.77	0.39	0.96	11.2	1.96	0.56	0.012	0.090	0.65	1.93	0.0029	
	N	0.012	1.66	0.44	0.94	14.1	1.52	0.63	0.016	0.072	0.61	0.39	0.0001	
	O	0.011	2.35	0.37	0.68	17.2	1.72	0.57	0.017	0.071	0.78	0.43	0.0940	
	P	0.018	0.02	0.90	2.88	20.3	2.01	0.97	0.024	0.603	0.99	0.96	0.0306	
	Q	0.030	3.94	1.22	3.37	23.7	4.47	1.17	0.028	6.247	1.49	1.20	0.0751	
	R	0.004	0.52	0.45	0.07	10.0	1.40	0.09	0.016	0.020	—	0.01	—	
	S	0.013	0.40	0.04	0.15	17.2	0.23	0.22	0.017	0.002	0.03	—	—	
	T	0.008	0.77	0.27	0.13	11.8	0.31	0.14	0.013	0.001	—	—	0.0046	
	U	0.012	1.02	0.07	0.17	19.0	0.71	0.30	0.016	0.006	0.51	0.11	—	
	V	0.012	0.87	0.26	0.33	19.3	0.24	0.08	0.020	0.004	0.54	0.11	0.0021	
	W	0.001	0.53	0.33	0.26	15.4	0.81	0.33	0.017	0.015	—	0.17	—	Pb: 0.12
	X	0.011	0.35	0.31	0.46	12.6	1.18	0.04	0.019	0.005	—	0.17	—	V: 0.1
	Y	0.012	0.61	0.48	0.36	12.5	0.59	0.24	0.018	0.014	—	0.15	—	Sb: 0.01
	Z	0.010	0.80	0.35	0.16	12.3	0.92	0.05	0.014	0.002	—	0.23	—	Ca: 0.01

TABLE 1-continued

Class-ification	Steel type	C	Si	Mn	Ni	Cr	Mo	Cu	N	Al	Nb	Ti	B	Others
	A A	0.010	0.41	0.38	0.37	19.6	1.11	0.21	0.019	0.013	0.35	—	—	Co: 0.2
	A B	0.007	1.04	0.23	0.11	13.8	0.91	0.30	0.019	0.003	0.02	—	—	Te: 0.01
	A C	0.002	1.27	0.47	0.25	14.7	0.85	0.28	0.019	0.009	0.06	—	—	P: 0.01
	A D	0.004	0.45	0.22	0.21	13.6	1.07	0.22	0.019	0.011	0.59	—	—	Se: 0.001
	A E	0.009	1.37	0.22	0.12	11.4	0.19	0.05	0.011	0.003	—	—	0.0075	Bi: 0.001
	A F	0.011	0.90	0.44	0.38	11.0	0.50	0.03	0.017	0.009	—	—	0.0050	Sn: 0.06
	A G	0.007	1.13	0.08	0.27	14.6	1.28	0.35	0.019	0.013	—	0.06	0.0005	W: 0.08
	A H	0.008	0.31	0.37	0.27	12.2	0.96	0.31	0.017	0.017	—	0.24	0.0028	Ta: 0.07
	A I	0.006	0.39	0.08	0.33	19.7	1.32	0.21	0.016	0.006	0.49	—	0.0093	Zr: 0.007
	A J	0.012	0.29	0.01	0.09	15.1	0.14	0.17	0.020	0.006	0.13	—	0.0069	Mg: 0.008
	A K	0.003	1.48	0.25	0.22	15.0	0.03	0.20	0.012	0.014	0.26	0.10	—	REM: 0.002
	A L	0.004	0.78	0.06	0.25	11.2	0.99	0.15	0.018	0.010	0.16	0.14	—	Ga: 0.01
	A M	0.003	0.11	0.33	0.43	19.4	1.33	0.28	0.020	0.019	0.07	0.19	0.0020	S: 0.5
	A N	0.010	0.41	0.38	0.37	19.6	1.11	0.21	0.019	0.013	0.35	—	—	
	A O	0.007	1.04	0.23	0.11	13.8	0.91	0.30	0.019	0.0034	0.02	—	—	
	A P	0.002	1.27	0.47	0.25	14.7	0.85	0.28	0.019	0.0094	0.06	—	—	
	A Q	0.004	0.45	0.22	0.21	13.6	1.07	0.22	0.019	0.0107	0.59	—	—	
	A R	0.009	1.37	0.22	0.12	11.4	0.19	0.05	0.011	0.0034	0.31	—	—	
	A S	0.011	0.90	0.44	0.38	11.0	0.50	0.03	0.017	0.0089	0.25	—	—	
	A T	0.007	1.13	0.08	0.27	14.6	1.28	0.35	0.019	0.0126	—	0.06	—	
	A U	0.008	0.31	0.37	0.27	12.2	0.96	0.31	0.017	0.0168	—	0.24	—	
	A V	0.006	0.39	0.08	0.33	19.7	1.32	0.21	0.016	0.0061	0.49	—	—	
	A W	0.012	0.29	0.01	0.09	15.1	0.14	0.17	0.020	0.006	0.13	—	—	

TABLE 2

Classification	Steel type	C	Si	Mn	Ni	Cr	Mo	Cu	N	A	Nb	Ti	B	Others
Comparative product	A X	0.0004	2.72	0.11	0.91	13.9	1.90	0.41	0.017	0.051	—	—	0.0068	
	A Y	0.0350	2.35	0.42	0.60	12.1	1.59	0.72	0.018	0.053	—	—	0.0096	
	A Z	0.014	4.50	0.14	0.93	18.3	1.99	0.56	0.010	0.022	—	—	0.0067	
	B A	0.011	2.79	2.40	0.89	14.4	1.68	0.42	0.016	0.055	—	—	0.0015	
	B B	0.013	2.86	0.21	4.30	10.4	1.53	0.59	0.012	0.039	—	—	0.0020	
	B C	0.011	1.76	0.18	0.89	7.0	1.91	0.46	0.020	0.080	0.76	—	—	
	B D	0.012	2.28	0.43	0.80	37.0	1.96	0.65	0.014	0.088	0.70	—	—	
	B E	0.014	1.92	0.38	0.79	12.6	6.00	0.46	0.011	0.026	0.70	—	—	
	B F	0.011	1.95	0.49	0.75	15.9	1.88	2.50	0.010	0.026	0.72	—	—	
	B G	0.010	2.24	0.16	0.95	13.6	1.86	0.68	0.0003	0.100	—	0.48	—	
	B H	0.014	2.10	0.24	0.51	11.4	1.93	0.41	0.0500	0.044	0.69	—	0.0094	
	B I	0.013	2.00	0.09	0.85	12.9	1.86	0.51	0.030	8.0	0.71	0.34	—	
	B J	0.011	2.74	0.45	0.50	12.3	1.95	0.61	0.021	0.061	2.30	0.38	0.0016	
	B K	0.011	1.93	0.19	0.53	10.2	1.73	0.67	0.023	0.040	0.61	2.20	0.0003	
	B L	0.014	2.05	0.17	0.94	19.5	1.66	0.69	0.025	0.089	—	0.44	0.2000	

[0120] For the obtained bar or wire rod (bar-shaped steel product), the average particle size of nitrides, the solute N content in steel, the solute B content in steel, high-speed cold forging properties, soft magnetic properties, and machinability were evaluated. Tables 3, 4, and 5 collectively show the results. Tables 3 and 4 show the results of examples of the invention corresponding to Invention 1 and comparative examples, where the results of the solute N content in steel are shown. Table 5 shows the results of examples of the invention corresponding to Invention 2 and comparative examples, where the results of the solute B content in steel are shown. The measurements were performed according to the following procedure.

TABLE 3

No.	Class-ification	Steel type	Average particle size of nitrides (μm)	Solute N content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
1	The invention	A	B	B	B	A	B
2		B	B	B	B	A	B
3		C	B	B	B	A	B
4		D	B	B	B	A	B
5		E	B	B	B	A	B

TABLE 3-continued

No.	Classification	Steel type	Average particle size of nitrides (μm)	Solute N content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
6		F	B	B	B	A	B
7		G	B	B	B	A	B
8		H	B	B	B	A	B
9		I	B	B	B	A	B
10		J	B	B	B	A	B
11		K	B	B	B	A	B
12		L	B	B	B	C	B
13		M	B	B	B	A	B
14		N	B	B	B	C	B
15		O	B	B	B	C	B
16		P	C	C	C	C	C
17		Q	C	C	C	C	C
18		R	A	A	A	A	A
19		S	A	A	A	A	A
20		T	A	A	A	A	A
21		U	A	A	A	A	A
22		V	A	A	A	A	A
23		W	B	B	B	A	B
24		X	B	B	B	B	B
25		Y	B	B	B	A	B
26		Z	B	B	B	A	B
27		A A	B	B	B	B	B
28		A B	B	B	B	A	B
29		A C	B	B	B	B	B
30		A D	B	B	B	A	B
31		A E	B	B	B	A	B
32		A F	B	B	B	A	B
33		A G	B	B	B	B	B
34		A H	B	B	B	B	B
35		A I	B	B	B	B	B
36		A J	B	B	B	B	B
37		A K	B	B	B	B	B
38		A L	B	B	B	B	B
39		A M	B	B	B	A	B
40		A N	A	A	A	A	A
41		A O	A	A	A	A	A
42		A P	A	A	A	A	A
43		A Q	A	A	A	A	A
44		A R	A	A	A	A	A
45		A S	A	A	A	A	A
46		A T	A	A	A	A	A
47		A U	A	A	A	A	A
48		A V	A	A	A	A	A
49		A W	A	A	A	A	A

TABLE 4

No.	Classification	Steel type	Average particle size of nitrides (μm)	Solute N content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
50	Comparative product	A X	D	C	D	D	D
51		A Y	D	C	D	D	D
52		A Z	D	C	D	D	D
53		B A	D	C	D	D	D
54		B B	D	C	D	D	D
55		B C	D	C	D	D	D
56		B D	D	C	D	D	D
57		B E	D	C	D	D	D
58		B F	D	C	D	D	D
59		B G	D	A	D	D	D
60		B H	D	D	D	D	D
61		B I	D	D	D	D	D
62		B J	D	D	D	D	D
63		B K	D	D	D	D	D
64		B L	D	D	D	D	D

TABLE 5

No.	Classification	Steel type	Average particle size of nitrides (μm)	Solute B content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
65	The	A	B	B	B	A	B
66	invention	B	B	B	B	A	B
67		C	B	B	B	A	B
68		D	B	B	B	A	B
69		E	B	B	B	A	B
70		F	B	B	B	A	B
71		G	B	B	B	A	B
72		H	B	B	B	A	B
73		I	B	B	B	A	B
74		J	B	B	B	A	B
75		K	B	B	B	A	B
76		L	B	B	B	C	B
77		M	B	B	B	A	B
78		N	B	B	B	C	B
79		P	C	B	C	C	C
80		Q	C	C	C	C	C
81		R	A	B	A	A	A
82		S	A	B	A	A	A
83		T	A	B	A	A	A
84		U	A	B	A	A	A
85		V	A	B	A	A	A
86		W	B	B	B	A	B
87		X	B	B	B	B	B
88		Y	B	B	B	A	B
89		Z	B	B	B	A	B
90		A A	B	B	B	B	B
91		A B	B	B	B	A	B
92		A C	B	B	B	B	B
93		A D	B	B	B	A	B
94		A E	B	B	B	A	B
95		A F	B	B	B	A	B
96		A G	B	B	B	B	B
97		A H	B	B	B	B	B
98		A I	B	B	B	B	B
99		A J	B	B	B	B	B
100		A K	B	B	B	B	B
101		A L	B	B	B	B	B
102		A M	B	B	B	A	B
103		A N	A	B	A	A	A
104		A O	A	B	A	A	A
105		A P	A	B	A	A	A
106		A Q	A	B	A	A	A
107		A R	A	B	A	A	A
108		A S	A	B	A	A	A
109		A T	A	B	A	A	A
110		A U	A	B	A	A	A
111		A V	A	B	A	A	A
112		A W	A	B	A	A	A
113	Comparative	O	B	D	B	C	B
114	Example	B L	D	D	D	D	D

[0121] The average particle size of nitrides was determined by measuring at least one field of view at 400-fold magnification at each of a surface layer portion, a center portion, and a ¼-depth-position existing between the surface layer portion and the center portion in an L-cross section of the bar-shaped steel product (cross-section including a central axis of the bar-shaped steel product). The nitrides in the observation visual field(s) were identified with FE-SEM/ESD, equivalent circle diameters of the nitrides in the observation visual field(s) were measured, an average value of the equivalent circle diameters was calculated. An average particle size of nitrides in a range from 0.01 to 5 μm was evaluated as "A", an average particle size of nitrides in a range from 5 to 7 μm was evaluated as "B", an average particle size of nitrides in a range from 7 to 10 μm was evaluated as "C", and an average particle size of nitrides exceeding 10 μm was evaluated as "D". The bar-shaped steel products of the invention, which were evaluated as "A", "B", and "C", were excellent in the average particle size of nitrides. Note that the nitrides include carbonitrides.

[0122] The solute N content in steel (=N_0−N_{pre}) was determined by performing an electrolytic extraction residue method on the bar-shaped steel product to extract nitrides, measuring an N content (N_{pre}) in the nitrides, and subtracting the N content (N_{pre}) from a total N content (N_0) in steel. A solute N content in steel in a range from to 0.01 mass % was evaluated as "A", a solute N content in steel in a range from 0.01 to 0.015 mass % was evaluated as "B", a solute N content in steel in a range from 0.015 to 0.020 mass % was evaluated as "C", and a solute N content in steel exceeding

0.020 mass % was evaluated as "D". The bar-shaped steel products of the invention, which were evaluated as "A", "B", and "C" as shown in Table 3, were excellent in the solute N content in steel.

[0123] The solute B content in steel ($=B_0-B_{pre}$) was determined by performing an electrolytic extraction residue method on the bar-shaped steel product to extract nitrides, measuring a B content (B_{pre}) in the nitrides, and subtracting the B content (B_{pre}) from a total B content (B_0) in steel. A solute B content in steel of 0.01 mass % or less was evaluated as "B", a solute B content in steel in a range from 0.01 to 0.015 mass % was evaluated as "C", and a solute B content in steel exceeding 0.015 mass % was evaluated as "D". The bar-shaped steel products of the invention, which were evaluated as "B" and "C" as shown in Table 5, were excellent in the solute B content in steel.

[0124] The high-speed cold forging properties were determined from the presence or absence of cracking in end surfaces through a compression test. The high-speed cold forging properties were specifically evaluated as follows: a test piece of 10 mm diameter ×15 mm was prepared; the strain rate was changed at room temperature at a compressibility of 70%; the test piece was compressed; side surfaces of the test piece after the compression test were observed; and the presence or absence of cracking was determined. When the strain rate without cracking at a compressibility of 70% was 10/s or more, the high-speed cold forging properties were evaluated as "A". When the strain rate without cracking at a compressibility of 70% was 1/s or more, the high-speed cold forging properties were evaluated as "B". When the strain rate without cracking at a compressibility of 70% was 0.1/s or more, the high-speed cold forging properties were evaluated as "C". When the strain rate without cracking at a compressibility of 70% was less than 0.1/s, the high-speed cold forging properties were evaluated as "D". The bar-shaped steel products of the invention, which were evaluated as "A", "B", and "C", were excellent in the high-speed cold forging properties.

[0125] The coercive force (A/m) was measured for evaluating soft magnetic properties. A ring-shaped test piece with 3 mm thickness×10 mm outer diameter×8 mm inner diameter was prepared, and the test piece was subjected to a heat treatment at 950 degrees C. for two hours. Then, the coercive force was measured. A coercive force of 2.0 A/m or less was evaluated as "A", a coercive force of 3.5 A/m or less was evaluated as "B", a coercive force of 5.0 A/m or less was evaluated as "C", and a coercive force exceeding 5.0 A/m was evaluated as "D". The bar-shaped steel products of the invention, which were evaluated as "A", "B", and "C", were excellent in the soft magnetic properties.

[0126] Machinability was evaluated based on tool life, as follows: a test piece of 15 mm diameter×30 mm was prepared; drilling in a longitudinal direction (dry type, drill diameter: 4 mm, cutting rate: 25 m/m in, feed: 0.1 mm/rev, tool: SKH9) was performed, and a hole depth at which cutting was impossible was measured. A hole depth (tool life) of 130 mm or more was evaluated as "A", a hole depth (tool life) of 100 mm or more was evaluated as "B", a hole depth (tool life) of 50 mm or more was evaluated as "C", and a hole depth (tool life) of less than 50 mm was evaluated as "D". The bar-shaped steel products of the invention, which were evaluated as "A", "B", and "C", were excellent in the machinability.

Example 2

[0127] Subsequently, bar-shaped steel products with a diameter of 15 mm were prepared using a steel type P in Table 1 under the conditions shown in Tables 6 and 7. Any other history than the temperature at the finish rolling entering side, the roll diameter of finish rolling, and the heat treatment temperature was the same as in Example 1. For the obtained bar or wire rod (bar-shaped steel product), the average particle size of nitrides, the solute N content in steel, the solute B content in steel, high-speed cold forging properties, soft magnetic properties, and machinability were measured according to the above methods. Results are collectively shown in Tables 6 and 7 below. Table 6 shows the results of examples of the invention corresponding to Invention 1 and comparative examples, where the results of the solute N content in steel are shown. Table 7 shows the results of examples of the invention corresponding to Invention 2 and comparative examples, where the results of the solute B content in steel are shown.

TABLE 6

No.	Classification	Steel type	Temperature at finish rolling entering side (° C.)	Rolling diameter of finish rolling (mm)	Heat treatment temperature (° C.)	Average particle size of nitrides (μm)	Solute N content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
115	The	P	1180	320	580	C	C	C	C	C
116	invention		620	95	722	C	C	C	C	C
117			1080	55	928	C	C	C	C	C
118			1090	490	823	C	C	C	C	C
119			1074	340	1290	C	C	C	C	C
120			1064	83	510	C	C	C	C	C
121			774	297.3	771	B	B	B	B	B
122			1065	298	1098	B	B	B	B	B
123			1180	480	1290	C	C	C	C	C
124			942	285	911	A	A	A	A	A
125			1008	240	1007	A	A	A	A	A
126			871	161	862	A	A	A	A	A
127			930	278	705	A	A	A	A	A

TABLE 6-continued

No.	Classification	Steel type	Temperature at finish rolling entering side (° C.)	Rolling diameter of finish rolling (mm)	Heat treatment temperature (° C.)	Average particle size of nitrides (μm)	Solute N content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
128			914	104	795	A	A	A	A	A
129			938	218	827	A	A	A	A	A
130	Comparative	P	1240			C	D	D	D	D
131	product		570			D	C	D	D	D
132			1000	40		D	D	D	D	D
133			850	540		C	D	D	D	D
134			990	167	1350	C	D	D	D	D
135			1080	139	450	D	C	D	D	D

TABLE 7

No.	Classification	Steel type	Temperature at finish rolling entering side (° C.)	Rolling diameter of finish rolling (mm)	Heat treatment temperature (° C.)	Average particle size of nitrides (μm)	Solute B content in steel (mass %)	Strain rate without cracking at compressibility of 70% (/s)	Cutting resistance	Coercive force (A/m)
136	The	P	1180	320	580	C	C	C	C	C
137	invention		620	95	722	C	C	C	C	C
138			1080	55	928	C	C	C	C	C
139			1090	490	823	C	C	C	C	C
140			1074	340	1290	C	C	C	C	C
141			1064	83	510	C	C	C	C	C
142			774	297.3	771	B	B	B	B	B
143			1065	298	1098	B	B	B	B	B
144			1180	480	1290	C	C	C	C	C
145			942	285	911	A	A	A	A	A
146			1008	240	1007	A	A	A	A	A
147			871	161	862	A	A	A	A	A
148			930	278	705	A	A	A	A	A
149			914	104	795	A	A	A	A	A
150			938	218	827	A	A	A	A	A
151	Comparative	P	1240			C	D	D	D	D
152	product		570			D	C	D	D	D
153			1000	40		D	D	D	D	D
154			850	540		C	D	D	D	D
155			990	167	1350	C	D	D	D	D
156			1080	139	450	D	C	D	D	D

INDUSTRIAL APPLICABILITY

[0128] According to the invention, a bar-shaped steel product excellent in soft magnetic properties is obtainable and extremely useful in industry.

1. A bar-shaped stainless steel product comprising a chemical composition comprising, by mass %: 0.001 to 0.030% of C; 0.01 to 4.00% of Si; 0.01 to 2.00% of Mn; 0.01 to 4.00% of Ni; 8.0 to 35.0% of Cr; 0.01 to 5.00% of Mo; 0.01 to 2.00% of Cu; 0.001 to of N; 7.000% or less of Al; 0 to 2.00% of Ti; 0 to 2.00% of Nb; 0 to 0.1000% of B; one or more elements selected from 0.001% or more of Ti, 0.001% or more of Nb, and 0.0001% or more of B being comprised; 0 to 2.50% of Sn; 0 to 2.0% of V; 0 to 3.00% of W; 0 to 0.05% of Ga; 0 to 2.50% of Co; 0 to 2.50% of Sb; 0 to 2.50% of Ta; 0 to 0.05% of Ca; 0 to 0.012% of Mg; 0 to 0.012% of Zr; 0 to 0.05% of REM; 0 to 0.30% of Pb; 0 to 0.80% of Se; 0 to 0.30% of Te; 0 to 0.50% of Bi; 0 to 0.50% of S; and 0 to 0.30% of P,

a balance consisting of Fe and impurities,

an average particle size of nitrides being 10 μm or less, and

a solute N content in steel being 0.020 mass % or less and/or a solute B content in steel being 0.015 mass % or less.

2. (canceled)

3. The bar-shaped stainless steel product according to claim **1**, wherein the chemical composition further comprises, by mass %, one or more groups selected from First Group, Second Group, and Third Group below:

First Group: one or more elements selected from 0.0001 to 2.5% of Sn; 0.001 to 2.0% of V; 0.05 to 3.0% of W; 0.0004 to 0.05% of Ga; 0.05 to 2.5% of Co; 0.01 to 2.5% of Sb; and 0.01 to 2.5% of Ta,

Second Group: one or more elements selected from 0.0002 to 0.05% of Ca; 0.0002 to of Mg; 0.0002 to 0.012% of Zr; and 0.0002 to 0.05% of REM, and

Third Group: one or more elements selected from 0.0001 to 0.30% of Pb; 0.0001 to 0.80% of Se; 0.0001 to

0.30% of Te; 0.0001 to 0.50% of Bi; 0.0001 to 0.50% of S; and 0.0001 to 0.30% of P.

4. The bar-shaped stainless steel product according to claim **1**, wherein a strain rate without cracking at a compressibility of 70% is 0.1/s or more, a hole depth, which represents a tool life, through drilling is 50 mm or more, or coercive force is 5.0 A/m or less.

6. (canceled)

6. (canceled)

7. An electromagnetic component using the bar-shaped stainless steel product according to claim **1**.

8. A bar-shaped stainless steel product, which excludes a steel wire, comprising a chemical composition comprising, by mass %: 0.001 to 0.030% of C; 0.01 to 4.00% of Si; 0.01 to 2.00% of Mn; 0.01 to 4.00% of Ni; 8.0 to 35.0% of Cr; 0.01 to 5.00% of Mo; 0.01 to 2.00% of Cu; 0.001 to 0.030% of N; 7.000% or less of Al; 0 to 2.00% of Ti; 0 to 2.00% of Nb; 0 to 0.1000% of B; one or more elements selected from 0.001% or more of Ti, 0.001% or more of Nb, and 0.0001% or more of B being comprised; 0 to 2.50% of Sn; 0 to 2.0% of V; 0 to 3.00% of W; 0 to 0.05% of Go; 0 to 2.50% of Co; 0 to 2.50% of Sb; 0 to 2.50% of Ta; 0 to 0.05% of Ca; 0 to 0.012% of Mg; 0 to 0.012% of Zr; 0 to 0.05% of REM; 0 to 0.30% of Pb; 0 to 0.80% of Se; 0 to 0.30% of Te; 0 to 0.50% of Bi; 0 to 0.50% of S; and 0 to 0.30% of P,

a balance consisting of Fe and impurities,

an average particle size of nitrides being 10 μm or less, and

a solute N content in steel being 0.020 mass % or less and/or a solute B content in steel comprising 0.015 mass % or less.

9. (canceled)

10. The bar-shaped stainless steel product, which excludes the steel wire, according to claim **8**, wherein the chemical composition further comprises, by mass %, one or more groups selected from First Group, Second Group, and Third Group below:

First Group: one or more elements selected from 0.0001 to 2.5% of Sn; 0.001 to 2.0% of V; 0.05 to 3.0% of W; 0.0004 to 0.05% of Ga; 0.05 to 2.5% of Co; 0.01 to 2.5% of Sb; and 0.01 to 2.5% of Ta,

Second Group: one or more elements selected from 0.0002 to 0.05% of Ca; 0.0002 to of Mg; 0.0002 to 0.012% of Zr; and 0.0002 to 0.05% of REM, and

Third Group: one or more elements selected from 0.0001 to 0.30% of Pb; 0.0001 to 0.80% of Se; 0.0001 to 0.30% of Te; 0.0001 to 0.50% of Bi; 0.0001 to 0.50% of S; and 0.0001 to 0.30% of P.

11. An electromagnetic component using the bar-shaped stainless steel product, which excludes the steel wire, according to claim **8**.

12. The bar-shaped stainless steel product according to claim **3**, wherein a strain rate without cracking at a compressibility of 70% is 0.1/s or more, a hole depth, which represents a tool life, through drilling is 50 mm or more, or coercive force is 5.0 A/m or less.

13. An electromagnetic component using the bar-shaped stainless steel product according to claim **3**.

14. An electromagnetic component using the bar-shaped stainless steel product according to claim **4**.

15. An electromagnetic component using the bar-shaped stainless steel product, which excludes the steel wire, according to claim **10**.

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