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(54) SOFT-NITRIDING STEEL AND SOFT-NITRIDED COMPONENT USING STEEL AS MATERIAL

(57) According to the present invention, it is possible to obtain steel for nitrocarburizing having a predetermined chemical composition, a bainite area ratio exceeding 50 % and excellent machinability by cutting before nitrocarburizing, and having strength and toughness equivalent to conventional steel, such as SCr420 carburized steel material, and excellent fatigue properties after nitrocarburizing.

EP 2 816 128 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to steel for nitrocarburizing and to nitrocarburized components using the steel as material. In particular, the present invention relates to steel for nitrocarburizing that has excellent fatigue properties after nitrocarburizing and is suitable for use in automobiles and construction equipment and to nitrocarburized components using the steel as a material.

BACKGROUND ART

[0002] Since excellent fatigue properties are desired for machine structural components, such as automobile gears, surface hardening is generally performed. Carburizing treatment, induction quench hardening and nitriding treatment are well-known forms of surface hardening.

[0003] With carburizing treatment, carbon is caused to infiltrate and diffuse in a high-temperature austenite region, yielding a deep hardening depth. Carburizing treatment is thus useful for improving fatigue strength.

[0004] However, since heat treatment distortion occurs, it is difficult to apply carburizing treatment to components that, from the perspective of noise or the like, require high dimensional accuracy.

[0005] Induction quench hardening is a process for quenching a surface part by high frequency induction heating and, like carburizing treatment, causes degradation of dimensional accuracy.

[0006] Nitriding treatment is a process to harden a surface by causing nitrogen to infiltrate and diffuse in a high-temperature region at or below the Ac_1 critical point. The treatment is long, taking 50 to 100 hours, and requires removal of a brittle compound layer on the surface after treatment.

[0007] Therefore, nitrocarburizing treatment has been developed for nitriding at approximately the same treatment temperature as nitriding treatment yet in a short time. In recent years, nitrocarburizing treatment has become commonly used on machine structural components and the like. During nitrocarburizing treatment, nitrogen and carbon are simultaneously caused to infiltrate and diffuse in a temperature region in a range of 500 °C to 600 °C in order to harden the surface, making it possible to reduce the treatment time to half or less that of conventional nitriding treatment.

[0008] However, whereas it is possible to increase the core hardness by quench hardening during carburizing treatment, nitrocarburizing treatment is performed at a temperature at or below the critical point of steel, thus causing the core hardness not to increase and yielding nitrocarburized material with poorer fatigue strength than carburized material.

[0009] In order to improve the fatigue strength of nitrocarburized material, quenching and tempering are generally performed before nitrocarburizing to increase the core hardness. The resulting fatigue properties, however, cannot be considered sufficient. Furthermore, this approach increases manufacturing costs and reduces mechanical workability.

[0010] To address these problems, it has been proposed to form steel with a chemical composition including Ni, Al, Cr and Ti, to age-harden the core during nitrocarburizing by Ni-Al and Ni-Ti intermetallic compounds or by Cu compounds, and to precipitation-harden nitrides and carbides such as Cr, Al and Ti in a nitrided layer of the surface (PTL 1, PTL 2).

[0011] PTL 3 discloses cogging steel that contains 0.5 % to 2 % of Cu by hot forging and then air cooling the steel to provide a ferrite-based microstructure with solute Cu, precipitating the Cu during nitrocarburizing treatment at 580 °C for 120 minutes, and furthermore concurrently precipitation-hardening Ti, V and Nb carbonitrides to yield a steel that, after the nitrocarburizing treatment, has excellent bending fatigue properties. PTL 4 discloses steel for nitrocarburizing having dispersed therein Ti-Mo carbides and carbides including at least one element selected from the group consisting of Nb, V and W.

CITATION LIST

Patent Literature

[0012]

PTL 1 : JP 5-59488 A
PTL 2: JP 7-138701 A
PTL 3: JP 2002-69572 A
PTL 4: JP 2010-163671 A

SUMMARY OF INVENTION

(Technical Problem)

[0013] While the nitrocarburizing steel recited in PLT 1 and PLT 2 improves bending fatigue strength through precipitation-hardening of Cu and the like, the resulting workability cannot be considered sufficient. By requiring the addition of a relatively large amount of Cu, Ti, V and Nb, the nitrocarburizing steel recited in PLT 3 has a high production cost. The steel for nitrocarburizing recited in PTL 4 has the problem of high production cost due to the inclusion of a relatively large amount of Ti and Mo.
[0014] In view of the foregoing, an object of the present invention is to provide steel for nitrocarburizing and a nitrocarburized component using the steel as material, the steel having a low hardness and excellent mechanical workability before nitrocarburizing while allowing for an increase in core hardness via nitrocarburizing treatment and allowing for relatively inexpensive manufacture of nitrocarburized components with excellent fatigue properties.

(Solution to Problem)

[0015] To achieve the above object, the inventors intensely studied the effects of the microstructure and composition of steel on the fatigue properties after nitrocarburizing of steel. As a result, the inventors discovered that with a steel material provided with a specific amount of V and Nb in the steel composition and a bainite-based microstructure before nitrocarburizing, excellent fatigue properties are obtained after nitrocarburizing by performing nitrocarburizing treatment on the steel material while utilizing the rise in temperature to increase the core hardness by age precipitating fine precipitates in the core structure other than the nitrocarburized surface part.
[0016] The present invention is the result of further study based on the above discovery and is characterized as follows.

[1] A steel for nitrocarburizing comprising, in mass%, C: 0.01 % or more and less than 0.10 %, Si: 1.0 % or less, Mn: 0.5 % to 3.0 %, Cr: 0.30 % to 3.0 %, Mo: 0.005 % to 0.4 %, V: 0.02 % to 0.5 %, Nb: 0.003 % to 0.15 %, Al: 0.005 % to 0.2 %, S: 0.06 % or less, P: 0.02 % or less, B: 0.0003 % to 0.01 %, and the balance being Fe and incidental impurities, and including a microstructure with a bainite area ratio exceeding 50 % before nitrocarburizing.
[2] The steel for nitrocarburizing according to [1], wherein after nitrocarburizing, precipitates including V and Nb are dispersed in a bainite phase.
[3] A nitrocarburized component using the steel for nitrocarburizing according to [1] or [2] as material.

(Advantageous Effect of Invention)

[0017] According to the present invention, it is possible to obtain steel for nitrocarburizing, and nitrocarburized components using the steel as material, that has excellent machinability by cutting before nitrocarburizing, and that after nitrocarburizing has strength and toughness equivalent to conventional steel, such as SCr420 carburized steel material, and excellent fatigue properties, thus proving extremely useful in industrial terms.

BRIEF DESCRIPTION OF DRAWINGS

[0018] The present invention will be further described below with reference to the accompanying drawings, wherein:

FIG. 1 is a schematic diagram illustrating the manufacturing process for manufacturing a nitrocarburized component using steel for nitrocarburizing according to the present invention.

DESCRIPTION OF EMBODIMENTS

[0019] The microstructure, chemical composition and manufacturing conditions of the steel for nitrocarburizing according to the present invention will be described.

1. Microstructure

[0020] The microstructure before nitrocarburizing is set to have a bainite area ratio exceeding 50 %, and the microstructure after nitrocarburizing is set to have V and Nb precipitates dispersed in a bainite phase. When a matrix phase before nitrocarburizing is a bainite-based microstructure with a bainite area ratio exceeding 50 %, formation of V and Nb precipitates in the matrix phase is drastically inhibited as compared to a ferrite-pearlite microstructure. As a result, formation of the V and Nb precipitates before nitrocarburizing and consequent increased hardness of the steel can be prevented, thereby improving workability of cutting generally performed before nitrocarburizing. Furthermore, applying nitrocarburizing treatment to the steel causes the surface part to be nitrided and simultaneously age precipitates the V and Nb precipitates in the core bainite phase other than the nitrided surface part, thereby increasing the core hardness. Both the fatigue properties and the strength after nitrocarburizing therefore dramatically improve.

[0021] Note that the "microstructure with a bainite area ratio exceeding 50 %" contemplated by the present invention refers to the area ratio of the bainite microstructure (phase) exceeding 50 % under cross-sectional microstructure observation (microstructure observation with a 200x optical microscope). The area ratio of the bainite phase preferably exceeds 60 % and even more preferably exceeds 80 %. Moreover, the V and Nb precipitates in the bainite phase are preferably a dispersion of fine precipitates having a grain size of less than 10 nm. Furthermore, for sufficient strengthening by precipitation, 500 or more of the V and Nb precipitates with the grain size of less than 10 nm preferably exist per 1 μm^2.

2. Chemical Composition

[0022] Reasons for the limitations of the chemical composition in the steel for nitrocarburizing according to the present invention will now be described. The fraction of each steel component represents mass%.

C: 0.01 % or more and less than 0.10 %

[0023] Carbon (C) is added for bainite phase formation and to ensure strength. When the amount of C added is less than 0.01 %, the amount of bainite formed decreases, as does the amount of V and Nb precipitates, thus making it difficult to ensure strength. On the other hand, when 0.10 % or greater of C is added, the bainite phase becomes harder, thereby reducing the mechanical workability. Accordingly, the amount of C added is set in a range of 0.01 % or more and less than 0.10 %. C is preferably 0.03 % or more and less than 0.10 %.

Si: 1.0 % or less

[0024] Silicon (Si) is added for its usefulness in deoxidizing and bainite phase formation. Adding an amount of Si exceeding 1.0 %, however, deteriorates mechanical workability and cold-rolling workability due to solid solution hardening of ferrite and bainite phases. Accordingly, the amount of Si added is set to be 1.0 % or less. The amount is preferably 0.5 % or less and more preferably 0.3 % or less. Note that for Si to contribute effectively to deoxidation, the amount of Si added is preferably set to be 0.01 % or more.

Mn: 0.5 % to 3.0 %

[0025] Manganese (Mn) is added for its usefulness in bainite phase formation and in increasing strength. When the amount of Mn added is less than 0.5 %, the formed amount of bainite phase decreases, and V and Nb precipitates are formed, causing the hardness before nitrocarburizing to increase and the formed amount of V and Nb precipitates after nitrocarburizing treatment to decrease. In turn, this lowers the hardness after nitrocarburizing and makes it difficult to ensure strength. On the other hand, adding an amount of Mn exceeding 3.0 % deteriorates mechanical workability and cold-rolling workability. Accordingly, the amount of Mn added is set to be in a range of 0.5 % to 3.0 %. The amount is preferably 0.5 % or more and 2.5 % or less, and more preferably 0.6 % or more and 2.0 % or less.

Cr: 0.30 % to 3.0 %

[0026] Chromium (Cr) is added for its usefulness in bainite phase formation. When the amount of Cr added is less than 0.30 %, the formed amount of bainite phase decreases, and V and Nb precipitates are formed, causing the hardness before nitrocarburizing to increase and the formed amount of V and Nb precipitates after nitrocarburizing treatment to decrease. In turn, this lowers the hardness after nitrocarburizing and makes it difficult to ensure strength. On the other hand, adding an amount of Cr exceeding 3.0 % deteriorates mechanical workability and cold-rolling workability. Accordingly, the amount of Cr added is set to be in a range of 0.30 % to 3.0 %. The amount is preferably 0.5 % or more and 2.0 % or less, and more preferably 0.5 % or more and 1.5 % or less.

V: 0.02 % to 0.5 %

[0027] Vanadium (V) forms fine precipitates along with Nb due to the rise in temperature during nitrocarburizing and is therefore an important element for increasing core hardness and improving strength. An added amount of V less than 0.02 % does not satisfactorily achieve these effects. On the other hand, adding an amount of V exceeding 0.5 % causes the precipitates to coarsen. Accordingly, the amount of V added is set to be in a range of 0.02 % to 0.5 %. The amount is preferably 0.03 % or more and 0.3 % or less, and more preferably 0.03 % or more and 0.25 % or less.

Nb: 0.003 % to 0.15 %

[0028] Niobium (Nb) forms fine precipitates along with V due to the rise in temperature during nitrocarburizing and is therefore an extremely effective element for increasing core hardness and improving fatigue strength. An added amount of Nb less than 0.003 % does not satisfactorily achieve these effects. On the other hand, adding an amount of Nb exceeding 0.15 % causes the precipitates to coarsen. Accordingly, the amount of Nb added is set to be in a range of 0.003 % to 0.15 %. The amount is preferably 0.02 % or more and 0.12 % or less.

Mo: 0.005 % to 0.4 %

[0029] Molybdenum (Mo) causes fine V and Nb precipitates to form and is effective for improving the strength of the nitrocarburized material. Mo is therefore an important element for the present invention. Mo is also useful for bainite phase formation. To improve strength, 0.005 % or more is added, but since Mo is an expensive element, adding more than 0.4 % leads to increased component cost. Accordingly, the amount of Mo added is set to be in a range of 0.005 % to 0.4 %. The amount is preferably 0.01 % to 0.3 % and more preferably 0.04 % to 0.2 %.

Al: 0.005 % to 0.2 %

[0030] Aluminum (Al) is a useful element for improving surface hardness and effective hardened case depth after nitrocarburizing and is therefore intentionally added. Al also yields a finer microstructure by inhibiting the growth of austenite grains during hot forging and is thus a useful element for improving toughness. Therefore, 0.005 % or more is added. On the other hand, including over 0.2 % does not increase this effect, but rather causes the disadvantage of higher component cost. Accordingly, the amount of Al added is set to be in a range of 0.005 % to 0.2 %. The amount is preferably over 0.020 % and 0.1 % or less, and more preferably over 0.020 % and 0.040 % or less.

S: 0.06 % or less

[0031] Sulfur (S) forms MnS in the steel and is a useful element for improving the machinability by cutting. Including over 0.06 %, however, lessens toughness. Accordingly, the amount of S added is set to be 0.06 % or less. The amount is preferably 0.04 % or less. Note that for S to achieve the effect of improving machinability by cutting, the amount of S added is preferably set to be 0.002 % or more.

P: 0.02 % or less

[0032] Phosphorus (P) exists in a segregated manner at austenite grain boundaries and lowers the grain boundary strength, thereby lowering strength and toughness. Accordingly, the P content is preferably kept as low as possible, but a content of up to 0.02 % is tolerable. The P content is therefore set to be 0.02 % or less. Note that setting the content of P to be less than 0.001 % requires a high cost. Therefore, it suffices in industrial terms to reduce the content of P to 0.001 %.

B: 0.0003 % to 0.01 %

[0033] Boron (B) effectively promotes bainite phase formation. An added amount of B less than 0.0003 % does not satisfactorily achieve this effect. On the other hand, adding over 0.01 % does not increase this effect and only leads to higher component cost. Accordingly, the amount of B added is set to be in a range of 0.0003 % to 0.01 %. The amount is preferably set to be 0.0010 % or more and 0.01 % or less.

[0034] Note that in order to achieve the effect of promoting bainite phase formation, it is preferable that B be present in the steel as a solute. When solute N is present in the steel, however, the B in the steel is consumed by formation of BN. B does not contribute to improved quench hardenability when existing in the steel as BN. Accordingly, when solute N exists in the steel, B is preferably added in an amount greater than that consumed by formation of BN, and the amounts of B (%B) and of N (%N) in the steel preferably satisfy the relationship in formula (1) below.

$$\%B \geq \%N/14 \times 10.8 + 0.0003 \cdots\cdots (1)$$

[0035] In the steel for nitrocarburizing according to the present invention, after subjection to forging or when improving the machinability by cutting of the nitrocarburized material, one or more selected from the group of Pb ≤ 0.2 % and Bi ≤ 0.02 % may be added. Note that the effects achieved according to the present invention are not diminished regardless of whether these elements are added and regardless of their content.
[0036] Furthermore, in the steel for nitrocarburizing according to the present invention, the balance other than the above added elements consists of Fe and incidental impurities. In particular, however, Ti not only adversely affects the strengthening by precipitation of V and Nb but also lowers the core hardness and therefore is not to be included insofar as possible. The amount of Ti is preferably less than 0.010 % and more preferably less than 0.005 %.

3. Manufacturing Conditions

[0037] FIG. 1 is a schematic diagram illustrating the manufacturing process for manufacturing a nitrocarburized component using steel for nitrocarburizing according to the present invention.
[0038] In FIG. 1, S1 indicates a manufacturing process of a steel bar as a material, S2 indicates a transportation process, and S3 indicates the process of finishing the product (nitrocarburized component).
[0039] Specifically, in the steel bar manufacturing process (S1), a steel ingot is hot rolled into a steel bar and shipped after quality inspection. After shipping, the steel bar is transported (S2), and during the process (S3) of finishing the product (nitrocarburized component), the steel bar is cut to predetermined dimensions and subjected to hot forging or cold forging. After cutting the steel bar into a predetermined shape by drill boring, lathe turning or the like as necessary, nitrocarburizing treatment is performed, yielding the final product.
[0040] Alternatively, hot rolling material may be directly cut into a predetermined shape by lathe turning, drill boring or the like, with nitrocarburizing treatment then being performed to yield the final product. In the case of hot forging, cold straightening may be performed afterwards. Coating treatment, such as painting or plating, may also be applied to the final product. Preferable manufacturing conditions will now be described.

Rolling Heating Temperature

[0041] The rolling heating temperature is preferably set in a range of 950 °C to 1250 °C. In the steel for nitrocarburizing according to the present invention, this range is adopted to cause carbides remaining after melting to be present as a solute during hot rolling, so as not to diminish forgeability due to formation of fine precipitates in the rolling material (the steel bar which is the material for the hot forging component).
[0042] In other words, when the rolling heating temperature is set to be less than 950 °C, it becomes difficult for the carbides remaining after melting to form a solute. On the other hand, a temperature exceeding 1250 °C facilitates coarsening of the crystal grains, thus reducing forgeability. Accordingly, the rolling heating temperature is preferably set in a range of 950 °C to 1250 °C.

Rolling Finishing Temperature

[0043] The rolling finishing temperature is preferably set to be 800 °C or more. This temperature is adopted because at a rolling finishing temperature of less than 800 °C, a ferrite phase forms. Particularly when the next process is nitrocarburizing after cold forging or cutting, such a ferrite phase is disadvantageous for obtaining a bainite phase with an area ratio exceeding 50 % of the matrix phase after nitrocarburizing. Moreover, at a rolling finishing temperature of less than 800 °C, the rolling load increases, which degrades the out-of-roundness of the rolling material. Accordingly, the rolling finishing temperature is preferably set to be 800 °C or more.

Cooling Rate

[0044] In order to prevent fine precipitates from forming before forging, thereby reducing forgeability, it is preferable to specify the cooling rate after rolling. In the precipitation temperature range of fine precipitates of 700 °C to 550 °C, it is preferable to cool the steel bar faster than the critical cooling rate at which fine precipitates are produced (0.5 °C/s).

Nitrocarburizing Treatment (Precipitation Treatment)

[0045] The resulting steel bar is then used as material that is forged and shaped into components by cutting and the like. Nitrocarburizing treatment is then performed. The temperature for nitrocarburizing treatment is preferably set to be in a range of 550 °C to 700 °C in order to yield fine precipitates including V and Nb, and the treatment time is preferably 10 minutes or more. This range is adopted because at less than 550 °C, insufficient precipitates are obtained, whereas over 700 °C, the temperature enters the austenite region, making nitrocarburizing difficult. A more preferable range is

550 °C to 630 °C. Furthermore, the treatment time is set to be 10 minutes or more to obtain a sufficient amount of V and Nb precipitates.

[0046] Note that when hot forging is used, the hot forging is preferably performed with the heating temperature during hot forging in a range of 950 °C to 1250 °C, with the forging finishing temperature at 800 °C or more and the cooling rate after forging exceeding 0.5 °C/s in order for the bainite phase to exceed 50 % in area ratio of the matrix phase after nitrocarburizing and in order to prevent formation of fine precipitates from the standpoints of cold straightening and workability of cutting after hot forging.

EXAMPLES

[0047] Next, the present invention is further described through examples.

[0048] Steel samples with the composition shown in Table 1 (steel samples No. 1 to 17) were obtained by steelmaking in a 150 kg vacuum melting furnace, then rolling by heating at 1150 °C, finishing at 970 °C, and subsequently cooling to room temperature at a cooling rate of 0.9 °C/s to prepare steel bars with ø 50 mm. No. 17 is a conventional material, JIS SCr420. Note that P was not intentionally added to any of the steel samples in Table 1. Accordingly, the content of P in Table 1 indicates the amount mixed in as an incidental impurity. Furthermore, Ti was added to steel samples No. 14 and No. 15 but not intentionally added to steel samples No. 1 to 13 and No. 16 to 17 in Table 1. Accordingly, the content of Ti in steel samples No. 1 to 13 and No. 16 to 17 in Table 1 indicates the amount mixed in as an incidental impurity.

[0049] These materials were then heated to 1200 °C and subsequently hot forged at 1100 °C to a size of ø 30 mm. The materials were cooled to room temperature at a cooling rate of 0.8 °C/s, with a portion being cooled at 0.1 °C/s for the sake of comparison.

Table 1

(mass%)

Steel Sample No.	C	Si	Mn	P	S	Cr	Mo	V	Nb	Al	Ti	B	N	Category
1	0.038	0.07	1.82	0.012	0.020	0.61	0.20	0.18	0.09	0.032	0.001	0.0051	0.0056	Inventive Example
2	0.049	0.18	1.14	0.010	0.017	1.13	0.13	0.13	0.04	0.025	0.002	0.0074	0.0084	Inventive Example
3	0.077	0.24	0.73	0.015	0.020	1.42	0.07	0.29	0.12	0.024	0.002	0.0050	0.0055	Inventive Example
4	0.086	0.29	0.64	0.018	0.034	1.20	0.10	0.14	0.03	0.029	0.003	0.0078	0.0090	Inventive Example
5	0.089	0.16	0.85	0.013	0.019	0.79	0.20	0.11	0.10	0.037	0.001	0.0068	0.0061	Inventive Example
6	0.050	0.25	1.35	0.019	0.031	1.01	0.05	0.14	0.06	0.025	0.004	0.0055	0.0055	Inventive Example
7	0.170	0.22	0.70	0.017	0.025	1.13	0.19	0.13	0.06	0.024	0.002	0.0069	0.0077	Comparative Example
8	0.081	1.10	3.15	0.014	0.015	0.64	0.14	0.14	0.05	0.029	0.002	0.0055	0.0057	Comparative Example
9	0.079	0.28	0.34	0.018	0.027	1.20	0.07	0.19	0.10	0.028	0.003	0.0053	0.0056	Comparative Example
10	0.069	0.23	1.01	0.016	0.022	0.27	0.09	0.14	0.06	0.028	0.001	0.0057	0.0059	Comparative Example
11	0.048	0.08	1.04	0.011	0.018	0.85	0.003	0.13	0.06	0.026	0.003	0.0059	0.0064	Comparative Example
12	0.073	0.11	0.94	0.011	0.016	1.08	0.12	0.01	0.001	0.025	0.003	0.0060	0.0061	Comparative Example
13	0.040	0.06	1.68	0.014	0.019	1.15	0.10	0.12	0.001	0.030	0.001	0.0049	0.0051	Comparative Example
14	0.039	0.08	1.65	0.014	0.022	1.20	0.08	0.12	0.04	0.029	0.030	0.0048	0.0053	Comparative Example
15	0.037	0.09	1.66	0.012	0.018	1.16	0.12	0.16	0.05	0.025	0.100	0.0045	0.0054	Comparative Example
16	0.065	0.15	1.13	0.010	0.016	0.85	0.10	0.14	0.05	0.004	0.002	0.0058	0.0062	Comparative Example
17	0.220	0.27	0.79	0.014	0.018	1.18	0.001	0.005	0.001	0.027	0.004	0.0001	0.0105	Conventional Example

[0050] The microstructure of the above materials was observed, hardness was measured, and machinability by cutting was tested. During microstructure observation, a cross-section was observed under an optical microscope, and the core microstructure was identified. For samples in which a bainite phase was present in the core, the area fraction of the bainite phase in the core was calculated. Machinability by cutting was assessed by a drill cutting test. Specifically, hot forging material was sliced to yield 20 mm thick pieces of test material in which through holes were bored in five locations per cross section using a JIS high-speed tool steel SKH51 straight drill with ø 6 mm, under the following conditions: feed rate, 0.15 mm/rev; revolution speed, 795 rpm. Machinability by cutting was assessed by the total number of holes before the drill could no longer cut.

[0051] Hardness was measured by testing the hardness of the core using a Vickers hardness tester, with a test force of 100 g.

[0052] For steel samples No. 1 to 16, gas nitrocarburizing treatment was further applied to the hot forging material, and for steel sample No. 17, gas carburizing treatment was applied to the hot forging material. The gas nitrocarburizing treatment was performed by heating to 570 °C to 620 °C and retaining for 3.5 h under an atmosphere of NH_3:N_2:CO_2 = 50:45:5. The gas carburizing treatment was performed by carburizing at 930 °C for 3 h, then oil quenching after retaining at 850 °C for 40 minutes, and furthermore tempering at 170 °C for 1 h.

[0053] The microstructure of these heat treatment materials was observed, hardness was measured, precipitates were observed, and impact properties and fatigue properties were tested.

[0054] During microstructure observation, a cross-section was observed under an optical microscope, and the core microstructure was identified. For samples in which a bainite phase was present in the core, the area fraction of the bainite phase was calculated.

[0055] To measure the hardness of the nitrocarburized material and the carburized material, the core hardness and surface hardness were measured. The surface hardness was measured at a position 0.02 mm from the surface, and the effective hardened case depth was measured as the depth from the surface at a hardness of HV 400. Samples for transmission electron microscopy observation were created from the cores of the nitrocarburized material and the carburized material by Twin-jet electropolishing. Precipitates were observed in the resulting samples using a transmission electron microscope with an acceleration voltage of 200 kV. Furthermore, the composition of the observed precipitates was calculated with an energy-dispersive X-ray spectrometer (EDX).

[0056] The assessment of impact properties was made by performing a Charpy impact test and calculating the impact value (J/cm^2). Notched test pieces (R: 10 mm, depth: 2 mm) were used as test pieces. The notched test pieces were collected from the hot forging material, and after performing the above-described nitrocarburizing treatment or carburizing treatment, the collected test pieces were used in the Charpy impact test.

The assessment of fatigue properties was made by an Ono-type rotary bending fatigue test, and the fatigue limit was calculated. Notched test pieces (notch R: 1.0 mm; notch diameter: 8 mm; stress concentration factor: 1.8) were used as test pieces. The test pieces were collected from the hot forging material and, after the above-described nitrocarburizing treatment or carburizing treatment, were used in the fatigue test.

[0057] Table 2 shows the test results. No. 1 to 6 are inventive examples, No. 7 to 17 are comparative examples, and No. 18 is a conventional example provided by JIS SCr420 steel.

[Table 2]

Table 2

No.	Steel Sample No.	Cooling Rate After Heat Treatment Corresponding to Hot Forging (°C/s)	Characteristics Before Nitrocarburizing				Characteristics After Nitrocarburizing Treatment								Category
			Core Hardness HV	Core Structure (1)	Bainite Phase Area Ratio (%)	Drill Hole Count	Nitrocarburizing Treatment Temperature (°C)	Surface Hardness HV	Effective Hardened Case Depth (mm)	Core Hardness HV	Core Structure (1)	Bainite Phase Area Ratio (%)	Impact Value (J/cm^2)	Fatigue Strength (MPa)	
1	1	0.8	240	B-based	98	496	605	787	0.15	295	B-based	98	12	512	Inventive Example
2	2	0.8	244	B-based	92	487	570	795	0.17	277	B-based	92	12	476	Inventive Example
3	3	0.8	264	B-based	96	441	620	805	0.19	324	B-based	96	11	577	Inventive Example
4	4	0.8	268	B-based	97	431	590	796	0.17	300	B-based	97	12	525	Inventive Example
5	5	0.8	266	B-based	92	436	590	784	0.15	294	B-based	92	13	509	Inventive Example
6	6	0.8	240	B-based	90	495	590	790	0.16	277	B-based	90	12	474	Inventive Example
7	2	0.1	228	F+P	0	524	590	787	0.15	226	F+P	0	13	347	Comparative Example
8	7	0.8	290	B-based	94	200	590	799	0.17	319	B-based	94	11	566	Comparative Example
9	8	0.8	323	M+B	38	89	590	786	0.15	353	M+B	38	12	640	Comparative Example
10	9	0.8	290	F+P+B	12	193	590	801	0.17	298	F+P+B	12	13	527	Comparative Example
11	10	0.8	284	F+P+B	15	198	590	837	0.17	295	F+P+B	15	13	514	Comparative Example
12	11	0.8	213	B-based	65	577	590	787	0.18	232	B-based	65	12	373	Comparative Example
13	12	0.8	252	B-based	96	470	590	795	0.16	250	B-based	96	12	416	Comparative Example
14	13	0.8	242	B-based	97	491	590	790	0.17	253	B-based	97	13	423	Comparative Example
15	14	0.8	241	B-based	97	499	590	788	0.17	251	B-based	97	3	418	Comparative Example
16	15	0.8	244	B-based	98	492	590	795	0.19	260	B-based	98	2	450	Comparative Example
17	16	0.8	249	B-based	96	479	590	724	0.12	279	B-based	96	9	395	Comparative Example
18	17	0.8	248	F+P+B	85	449	930 °C × 3 h carburizing, 850 °C × 40 m retaining then oil quenching, 170 °C × 1 h tempering	730	1.05	360	Tempered M+B	50	15	470	Conventional Example

(1) F: Ferrite, P: Pearlite, B: Bainite, M: Martensite

[0058] As is clear from Table 2, nitrocarburized materials No. 1 to 6 have better fatigue strength than the material resulting from carburizing, quenching, and tempering the conventional example (No. 18). As for workability of drill cutting, the material before nitrocarburizing treatment in No. 1 to 6 (hot forging material) has a level equivalent to or greater than the conventional material in practical terms. Furthermore, the results of transmission electron microscopy observation and of testing the precipitate composition by EDX confirm that the nitrocarburized materials No. 1 to 6 contain 500 or more fine precipitates, including V and Nb, with a grain size of less than 10 nm dispersed per 1 μm^2 in the bainite phase. Based on these results, it can be concluded that the nitrocarburized material according to the present invention exhibits a high fatigue strength due to strengthening by precipitation based on the above fine precipitates.

[0059] By contrast, comparative examples No. 7 to 17 have a chemical composition or a resulting microstructure that are outside of the scope of the present invention and thus have worse fatigue strength or drill workability.

[0060] In particular, No. 7 has low fatigue strength as compared to the inventive examples due to the slow cooling rate after hot forging. For No. 7, the results of transmission electron microscopy observation showed no dispersion of fine precipitates with a grain size of less than 10 nm, whereas course precipitates with a grain size greatly exceeding 10 nm were observed. Based on these results, the coarseness of such resulting precipitates can be considered the cause of the reduction in fatigue strength. In other words, it is thought that if the cooling rate after hot forging is slow and the desired bainite phase is not obtained, course precipitates are formed before nitrocarburizing. The amount of fine precipitates that form after nitrocarburizing treatment then decreases, resulting in insufficient strengthening by precipitation.

[0061] No. 8 includes a high amount of C, outside of the range of the present invention. The hardness of the bainite phase therefore increases, reducing drill workability.

[0062] No. 9 includes high amounts of Si and Mn, outside of the range of the present invention. The hardness of the hot forging material is therefore high, reducing the drill workability to approximately 1/5 that of conventional material.

[0063] No. 10 includes a low amount of Mn, outside of the range of the present invention. A ferrite-pearlite microstructure thus forms before nitrocarburizing (after hot forging), lowering the area ratio of the bainite phase and forming V and Nb precipitates in the microstructure. The hardness before nitrocarburizing thus increases, reducing the drill workability.

[0064] No. 11 includes a low amount of Cr, outside of the range of the present invention. A ferrite-pearlite microstructure thus forms before nitrocarburizing (after hot forging), lowering the area ratio of the bainite phase and forming V and Nb precipitates in the microstructure. The hardness before nitrocarburizing thus increases, reducing the drill workability.

[0065] No. 12 includes a low amount of Mo, outside of the range of the present invention. Therefore, few fine precipitates exist after the nitrocarburizing treatment, and the resulting core hardness is insufficient. The fatigue strength is therefore lower than the conventional example.

[0066] No. 13 includes low amounts of V and Nb, outside of the range of the present invention. Therefore, few fine precipitates exist after the nitrocarburizing treatment, and the resulting core hardness is insufficient. The fatigue strength is therefore lower than the conventional material.

[0067] No. 14 includes a low amount of Nb, outside of the range of the present invention. Therefore, few fine precipitates exist after the nitrocarburizing treatment, and the resulting core hardness is insufficient. The fatigue strength is therefore lower than the conventional material.

[0068] Ti was added to No. 15 and No. 16, thus yielding few precipitates including V and Nb after the nitrocarburizing treatment. The resulting core hardness is therefore insufficient, and the fatigue strength is lower than the conventional material. Furthermore, the impact value is low.

[0069] No. 17 includes a low amount of Al, outside of the range of the present invention. The surface hardness after the nitrocarburizing treatment and the effective hardened case depth are therefore insufficient, resulting in a lower fatigue strength than the conventional material.

Claims

1. A steel for nitrocarburizing comprising, in mass%,

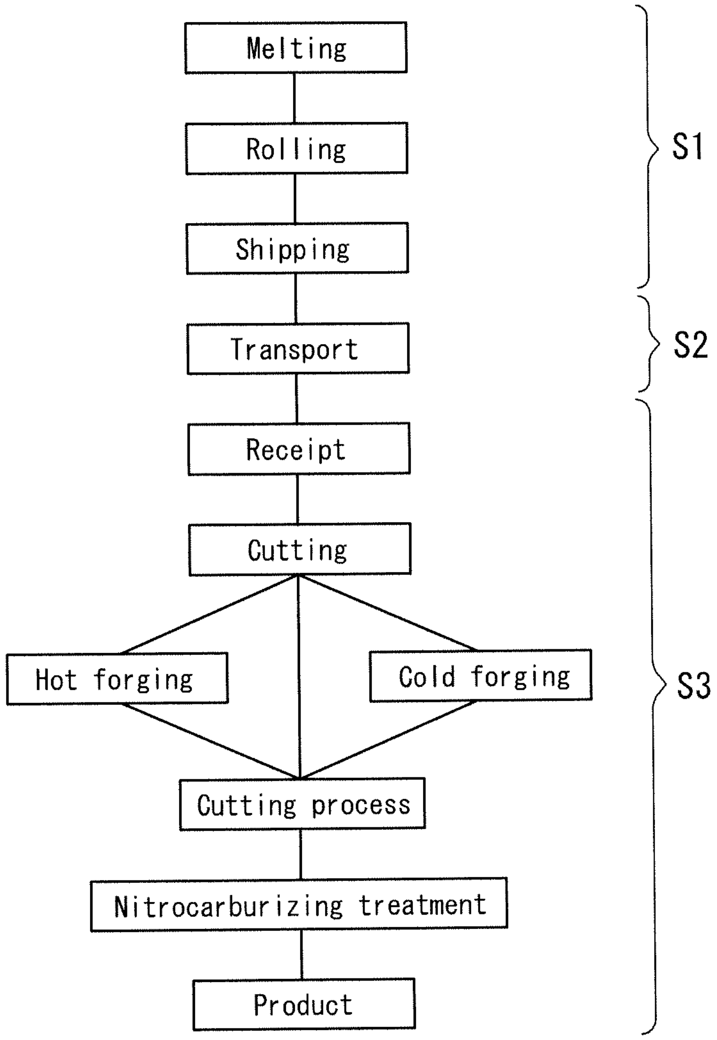
C: 0.01 % or more and less than 0.10 %,
Si: 1.0 % or less,
Mn: 0.5 % to 3.0 %,
Cr: 0.30 % to 3.0 %,
Mo: 0.005 % to 0.4 %,
V: 0.02 % to 0.5 %,
Nb: 0.003 % to 0.15 %,
Al: 0.005 % to 0.2 %,
S: 0.06 % or less,
P: 0.02 % or less,
B: 0.0003 % to 0.01 %, and
the balance being Fe and incidental impurities, and

including a microstructure with a bainite area ratio exceeding 50 % before nitrocarburizing.

2. The steel for nitrocarburizing according to claim 1, wherein after nitrocarburizing, precipitates including V and Nb are dispersed in a bainite phase.

3. A nitrocarburized component using the steel for nitrocarburizing according to claim 1 or 2 as material.

FIG. 1


Melting
Rolling
Shipping
Transport
Receipt
Cutting
Hot forging
Cold forging
Cutting process
Nitrocarburizing treatment
Product
S1
S2
S3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/000838

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/60*(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)
C22C38/00, C22C38/60

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	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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 8-134585 A (Nippon Steel Corp., Babcock-Hitachi Kabushiki Kaisha, Toshio FUJITA), 28 May 1996 (28.05.1996), entire text (Family: none)	1-3
A	JP 2006-193827 A (Sumitomo Metal Industries, Ltd.), 27 July 2006 (27.07.2006), entire text (Family: none)	1-3
A	JP 2011-231375 A (Sumitomo Metal Industries, Ltd.), 17 November 2011 (17.11.2011), entire text (Family: none)	1-3

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Date of the actual completion of the international search	Date of mailing of the international search report
09 May, 2013 (09.05.13)	21 May, 2013 (21.05.13)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
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INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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REFERENCES CITED IN THE DESCRIPTION

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