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

(11) EP 2 530 178 A1

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

(43) Date of publication:
05.12.2012 Bulletin 2012/49

(21) Application number: **11736785.4**

(22) Date of filing: **26.01.2011**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***C21D 1/06*** *(2006.01)*
C21D 6/00 *(2006.01)* ***C22C 38/32*** *(2006.01)*
C22C 38/54 *(2006.01)*

(86) International application number:
PCT/JP2011/000413

(87) International publication number:
WO 2011/093070 (04.08.2011 Gazette 2011/31)

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

(30) Priority: **27.01.2010 JP 2010015960**

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(54) CASE-HARDENED STEEL AND CARBURIZED MATERIAL

(57) The present invention provides a case hardening steel, comprising a component composition including C: 0.10 mass % to 0.35 mass %; Si: 0.01 mass % to 0.50 mass %; Mn: 0.40 mass % to 1.50 mass %; P: 0.02 mass % or less; S: 0.03 mass % or less; Al: 0.04 mass % to 0.10 mass %; Cr: 0.5 mass % to 2.5 mass %; B: 0.0005 mass % to 0.0050 mass %; Nb: 0.003 mass % to 0.080 mass %; Ti: 0.003 mass % or less; N: less than 0.0080 mass %; and balance as Fe and incidental impurities.

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Description

Technical Field

[0001] The present invention relates to a case hardening steel and a carburized steel material having high fatigue strength, each of which is excellent in cold forgeability, has high fatigue strength after carburization, and suitably serves as a material for mechanical structures in the fields of construction machinery and automobiles.

Prior Art

[0002] A material of a member to be produced by cold forming of a steel bar, e.g. a material of a member of an automobile, is required to have good cold forgeability. In view of this, it has been practiced to subject steel to spheroidizing heat treatment to spheroidize carbide in the steel to improve cold forgeability thereof. It has also been proposed in terms of component composition of steel to decrease content of Si, which significantly affects deformation resistance of the steel. Further, there has been proposed steel in which hardenability-improving properties of boron is effectively utilized.

[0003] JP-B 3551573, for example, proposes carburized steel for gear, in which contents of alloy elements other than boron can be reduced as much as hardenability of the carburized steel improves due to addition of boron, whereby hardness of the steel can be lowered from the normalizing process to make it possible to remarkably improve gear cutting properties of the steel, as compared with conventional steel.

[0004] Further, JP-B 3764586 proposes a case hardening steel which ensures good cold formability thereof by combining compositional advantageous effects of reliably improving hardenability by addition of boron and reducing contents of Si and Mn as solute-strengthening elements with a advantageous effect caused by specific production conditions.

[0005] In recent years, gears of increasing smaller sizes are required for gears used in automobiles or the like as vehicle weight is increasingly reduced for better energy saving and also these gears have to bear increasingly higher load exerted thereon as the engine output is increasingly made higher. Durability of a gear is primarily determined by degrees of gear tooth root fracture caused by bending fatigue and pitting fatigue fracture of gear tooth surface. It is known that reducing an incompletely quench-hardened layer appearing at a surface layer during carburization and making prior austenite grains fine are effective in terms of enhancing strength against bending fatigue of a gear tooth root. Regarding enhancing strength of a gear tooth surface against pitting fracture, correlation between such enhancement and temper softening resistancy has been pointed out and, based thereon, there have been proposed steel having higher Si content, steel having Mo added thereto, and steel having fine carbides dispersed in a carburized surface layer thereof, respectively.

[0006] In this connection, JP-B 3063399, for example, proposes a carburizing steel having improved fatigue strength and toughness by setting diameter of prior austenite grains to be in the range of 7 μm or less. Further, JP-B 4056709 proposes finely dispersing carbides in a carburized layer of a steel surface.

Disclosure of the Invention

[0007] Problems to be solved by the Invention

[0008] However, in the cases of JP-B 3551573 and JP-B 3764586, fatigue properties of the steels hardly improve, although cold formability and impact-related properties thereof are somewhat improved, as compared with the conventional steel. Further, in the cases of JP-B 3063399 and JP-B 4056709, the steels require carbide-generating elements such as Nb, Ti and V by large amounts, thereby causing problems, for example, significantly increasing deformation resistance of the steels during processing when fine carbides are precipitated in the steels.

[0009] The present invention has been developed in view of the situation described above and an object thereof is to provide a case hardening steel and a carburized steel material using the case hardening steel, which exhibit excellent cold forgeability respectively, as well as satisfactory high fatigue strength after being carburized.

Means for solving the Problem

[0010] As a result of a keen study to solve the aforementioned problems, the inventers of the present invention have made discoveries described below.

First, the inventors keenly studied a method for suppressing generation of coarse carbide (mainly cementite) and finely dispersing carbide in a carburized surface layer in a case of forming a carburized surface layer having carbide dispersed therein at relatively high concentration and having carbon concentration of at least 0.85 mass % (which highly carburized layer will be referred to as a "super-carburized layer" hereinafter) in a case hardening steel in order to enhance strength of the steel against fatigue.

Specifically, FIG. 1 shows relationships between contents of Al, B and Ti in steel and the maximum particle size of carbide in a surface layer of a super-carburized layer of a case hardening steel. It is understood from FIG. 1 that specifically controlling contents of Al and B and suppressing addition of Ti are critically important in terms of suppressing generation of coarse carbide and finely dispersing carbide. FIG. 1 also shows the results of pitting fatigue strength measurement conducted for some of the steel examples each having the aforementioned super-carburized layer. It is understood from these results that significantly high pitting fatigue strength of steel can be obtained by suppressing generation of coarse carbide.

Further, relationships between contents of Al, Ti and B and pitting fatigue strength were investigated in the cases of each forming a carburized layer having carbon concentration in the range of 0.70 mass % to 0.84 mass % (which moderately carburized layer will be referred to as a "normally carburized layer" hereinafter) in a case hardening steel. The results of this investigation are also shown in FIG. 1. It is understood from these results that satisfactorily high pitting fatigue strength can be obtained by controlling contents of Al and B within specific ranges and suppressing Ti content to 0.003 mass % or less in a case of forming a normally carburized layer in steel.

[0011] The experiments, of which results are shown in FIG. 1, were conducted by: preparing steel material examples each containing as a base material a steel having the basic composition of 0.2 mass % C, 0.1 mass % Si, 0.6 mass % Mn, 1.5 mass % Cr, 0.02 mass % Nb, with Al and B of specific contents changed between the examples, and the balance as iron and incidental impurities; subjecting these steel material examples to treatments described below; and evaluating the maximum particle diameter (μm) of carbide and pitting fatigue strength (MPa) for each steel material example.

Specifically, each of the steel material samples having "super-carburized layers" was prepared by: forming a corresponding steel material into a round bar (25 mm ϕ); subjecting the round bar to carburization at relatively high carbon concentration (carbon potential: 2%) at 950°C for 5 hours; cooling the bar to 600°C; heating the bar to 850°C and retaining the bar at the temperature for 30 minutes; and subjecting the bar to oil quenching at 60°C and then tempering treatment at 170°C for 2 hours. The steel material sample thus treated was cut and a cut section thereof was then analyzed by: etching the cut section with picral solution; observing an area ranging from a steel surface to 30 μm depth (observed area: 6000 μm^2) by using a scan-type electron microscope; and determining the maximum particle diameter of carbide through image analysis. Further, a roller pitting fatigue test was carried out by: collecting a roller pitting fatigue test piece from the round bar; subjecting the roller pitting fatigue test piece thus collected to the aforementioned respective treatments ranging from the carburization at relatively high carbon concentration to the tempering treatment, to obtain a sample; and subjecting the sample to the protocol of a roller pitting fatigue test under the conditions of slip rate: 40% and oil temperature: 80°C, to evaluate 10^7-cycle strength (the critical strength at which pitting occurs at a surface of the test piece) of the sample.

On the other hand, each of the steel material samples having "normally carburized layers" was prepared as a roller pitting fatigue test sample by forming a corresponding steel material into a round bar (25 mm ϕ) and collecting a roller pitting fatigue test piece from the round bar. The roller pitting fatigue test piece thus collected was subjected to carburization at carbon concentration of 1.1 mass % at 930°C for 7 hours, oil quenching at 60°C and tempering treatment at 170°C for 2 hours. A roller pitting fatigue test was then carried out by using the roller pitting fatigue test piece thus treated, under the conditions of slip rate: 40% and oil temperature: 80°C, to evaluate 10^7-cycle strength (the critical strength at which pitting occurs at a surface of the test piece) of the sample.

[0012] More specifically, primary features of the present invention are as follows.

(1) A case hardening steel having excellent cold forgeability, comprising a component composition including

C: 0.10 mass % to 0.35 mass %;
Si: 0.01 mass % to 0.50 mass %;
Mn: 0.40 mass % to 1.50 mass %;
P: 0.02 mass % or less;
S: 0.03 mass % or less;
Al: 0.04 mass % to 0.10 mass %;
Cr: 0.5 mass % to 2.5 mass %;
B: 0.0005 mass % to 0.0050 mass %;
Nb: 0.003 mass % to 0.080 mass %;
Ti: 0.003 mass % or less;
N: less than 0.0080 mass %; and
balance as Fe and incidental impurities.

[0013] (2) The case hardening steel having excellent cold forgeability of (1) above, wherein the component composition further includes at least one-element selected from

Cu: 1.0 mass % or less;

Ni: 0.50 mass % or less;
Mo: 0.50 mass % or less; and
V: .0.5 mass % or less.

[0014] (3) The case hardening steel having excellent cold forgeability of (1) or (2) above, wherein the component composition further includes at least one element selected from

Ca: 0.0005 mass % to 0.0050 mass %; and
Mg: 0.0002 mass % to 0.0020 mass %.

That is, the case hardening steel of the present invention is a case hardening steel having excellent cold forgeability, comprising a component composition including C: 0.10 mass % to 0.35 mass %, Si: 0.01 mass % to 0.50 mass %, Mn: 0.40 mass % to 1.50 mass %, P: 0.02 mass % or less, S: 0.03 mass % or less, Al: 0.04 mass % to 0.10 mass %, Cr: 0.5 mass % to 2.5 mass %, B: 0.0005 mass % to 0.0050 mass %, Nb: 0.003 mass % to 0.080 mass %, Ti: 0.003 mass % or less, N: less than 0.0080 mass %; optionally at least one element selected from Cu: 1.0 mass % or less, Ni: 0.50 mass % or less, Mo: 0.50 mass % or less, V: .0.5 mass % or less; further optionally at least one element selected from Ca: 0.0005 mass % to 0.0050 mass % and Mg: 0.0002 mass % to 0.0020 mass %; and balance as Fe and incidental impurities.
(4) A carburized steel material having high fatigue strength, as a carburized steel material obtained by subjecting the case hardening steel of any of (1) to (3) above to carburization and having carbon content in a surface layer region ranging from a steel surface to 0.4mm depth, of at least 0.70 mass %.
[0015] (5) A carburized steel material having high fatigue strength, as a carburized steel material obtained by subjecting the case hardening steel of any of (1) to (3) above to carburization and having carbon content in a surface layer region ranging from a steel surface to 0.4mm depth being at least 0.85 mass % and the maximum diameter and the average particle diameter of carbide in the surface layer region being 10 μm or less and 4 μm or less, respectively.

Effect of the Invention

[0016] According to the present invention, there can be provided a case hardening steel exhibiting not only excellent cold forgeability but also satisfactorily high fatigue strength after being carburized, which is industrially very useful.

Brief Description of the Drawings

[0017] FIG. 1 is a graph showing how contents of Al, B and Ti affect a state of carbide precipitation.

Best Embodiment for carrying out the Invention

[0018] The case hardening steel of the present invention will be described in detail hereinafter.
First, reasons why a chemical composition of the steel has been restricted to the aforementioned component ranges will be described in detail for each of the relevant elements.
C: 0.10 mass % to 0.35 mass %
Carbon content in steel needs to be at least 0.10 mass % in order to enhance hardness at the center portion thereof by quenching after carburizing heat treatment. However, carbon content in steel exceeding 0.35 mass % decreases toughness of the core portion of the steel. Accordingly, carbon content in steel is to be in the range of 0.10 mass % to 0.35 mass % and preferably 0.3 mass % or less.

Si: 0.01 mass % to 0.50 mass %

[0019] Silicon is required as a deoxidizing agent and need be added to steel by at least 0.01 mass %. However, silicon is an element which is preferentially oxidized at a carburized surface layer of steel to facilitate oxidization of grain boundaries of the steel. Further, silicon hardens ferrite through solid solution strengthening, thereby increasing deformation resistance of steel and deteriorating cold forgeability of the steel. Accordingly, the upper limit of Si content is to be 0.50 mass % and preferably 0.35 mass %. The lower limit of Si content is preferably 0.03 mass %.

Mn: 0.40 mass % to 1.50 mass %

[0020] Manganese is an element which effectively improves hardenability and need be added to steel by at least 0.40 mass %. However, manganese tends to trigger oxidization of grain boundary and too high content thereof in steel increases retained austenite and lowers surface hardness of the steel. Accordingly, the upper limit of Mn content is 1.50 mass % and preferably 1.40 mass %. The lower limit of Mn content is preferably 0.60 mass %.

P: 0.02 mass % or less

[0021] Phosphorus tends to exist in a segregated manner at crystal grain boundaries and deteriorate toughness of steel. Accordingly, the lower content of phosphorus in steel is the better, although presence of phosphorus in steel is tolerated up to 0.02 mass %. Content of phosphorus in steel is preferably 0.018 mass % or less.

S: 0.03 mass % or less

[0022] Sulfur is an element which exists as sulfide inclusion in steel and effectively improves machinability of the steel. However, too high content of sulfur in steel deteriorates fatigue strength of the steel. Accordingly, the upper limit of sulfur content in steel is to be 0.03 mass %.

Al: 0.04 mass % to 0.10 mass %

[0023] Aluminum is an important element in terms of fixing nitrogen in steel as AlN to ensure a good hardenability-improving effect caused by boron. Content of aluminum in steel need be at least 0.04 mass % in order to sufficiently obtain the good effect of boron. However, content of Al in steel exceeding 0.10 mass % facilitates generation of Al_2O_3 inclusion which harmfully affects fatigue strength of the steel. Accordingly, content of Al in steel is to be restricted to the range of 0.04 mass % to 0.10 mass %.

Cr: 0.5 mass % to 2.5 mass %

[0024] Chromium is a useful element which not only contributes to improving hardenability and temper softening resistancy of steel but also facilitates spheroidization of carbide therein. Content of Cr in steel lower than 0.5 mass % cannot cause such good effects of Cr in a satisfactory manner, while content of Cr in steel exceeding 2.5 mass % possibly facilitates generation of retained austenite in a carburized portion of the steel to adversely affect fatigue strength thereof. Accordingly, Cr content in steel is to be restricted to the range of 0.5 mass % to 2.5 mass %. The lower limit of Cr content in steel is preferably 0.6 mass % and the upper limit thereof is preferably 2.0 mass %.

B: 0.0005 mass % to 0.0050 mass %

[0025] Boron is the most important element in the present invention. Boron exists in a segregated manner at austenite grain boundaries of a steel material during quenching heat treatment, thereby improving hardenability and contributing to increase in hardness of the steel material. These good effects caused by boron allow contents of other hardness-enhancing elements in the steel material to be reduced, whereby deformation resistance is lowered and cold forgeability of the steel material improves. Content of boron in steel need be at least 0.0005 mass % in order to sufficiently cause these good effects of boron. However, too high content of boron in steel deteriorates toughness and forgeability of steel. Accordingly, the upper limit of boron content in steel is to be 0.0050 mass % and preferably 0.0030 mass %.

Nb: 0.003 mass % to 0.080 mass %

[0026] Niobium forms NbC in steel and suppresses, by pinning effects, grain coarsening of austenite grains in the steel during carburizing heat treatment. Content of Nb in steel need be at least 0.003 mass % in order to sufficiently obtain this good effect by niobium. However, Nb content in steel exceeding 0.080 mass % results in precipitation of coarse NbC, thereby possibly deteriorating the effect of suppressing grain coarsening of austenite grains and/or possibly decreasing fatigue strength of the steel. Accordingly, content of Niobium in steel is to be 0.080 mass % or less. The lower limit ofNb in steel is preferably 0.010 mass % and the upper limit thereof is preferably 0.060 mass %.

Ti: 0.003 mass % or less

[0027] Titanium is a component of which inclusion into steel is preferably avoided as best as possible. Titanium tends to be bonded to nitrogen to form coarse TiN. The upper limit of Ti in steel is to be 0.003 mass % because titanium possibly coarsens carbide in a carburized surface layer and decreases fatigue strength of the steel.

N: 0.0080 mass % or less

[0028] Nitrogen is a component of which inclusion into steel is preferably avoided as best as possible. Content of nitrogen in steel is to be less than 0.008 mass % to ensure the good effect of improving hardenability by boron and reliably suppress formation of TiN.

[0029] In the present invention, the component composition of the case hardening steel may further include at least one element selected from Cu: 1.0 mass % or less, Ni: 0.50 mass % or less, Mo: 0.5 mass % or less, and V: .0.5 mass % or less in order to further improve hardenability.

Copper is an element which effectively improves hardenability and content thereof in steel is preferably at least 0.1 mass %. However, too high content of copper in steel deteriorates surface characteristics of a steel material and increases cost for producing alloy. Accordingly, the upper limit of Cu in steel is to be 1.0 mass %.

[0030] Ni, Mo and V are elements which effectively improve hardenability and toughness of steel and contents of Ni, Mo and V in steel are preferably at least 0.1 mass %, 0.05 mass % and 0.02 mass %, respectively. The upper limits of contents of Ni, Mo and V are to be 0.50 mass %, respectively, because these elements are expensive.

[0031] In the present invention, the component composition of the case hardening steel may further include at least one element selected from Ca: 0.0005 mass % to 0.0050 mass % and Mg: 0.0002 mass % to 0.0020 mass % in order to control morphology of sulfide and improve machinability and cold forgeability of steel. Specifically, contents of Ca and Mg in steel need be at least 0.0005 mass % and 0.0002 mass %, respectively, in order to obtain the aforementioned good effects of Ca and Mg. However, too high contents of Ca, Mg in steel result in formation of coarse inclusions, which may adversely affect fatigue strength of the steel. Accordingly, the upper limits of contents of Ca and Mg in steel are to be 0.0050 mass % and 0.0020 mass %, respectively. The remainder of the component composition is iron and incidental impurities.

[0032] A case hardening steel having the component composition described above is subjected to at first cold forming into the product shape and then carburizing treatment. Carburizing treatment may be carried out under the conditions generally applied to a standard case hardening steel (such carburizing treatment will be referred to as "normal carburization" hereinafter). Specifically, the case hardening steel is retained under the conditions of carbon potential: 0.8 mass % to 1.1 mass %, temperature: 900°C or higher, and retention time: 3 to 7 hours, so that a carburized layer having carbon concentration of at least 0.7 mass % is formed in a surface layer ranging from a steel surface to 0.4 mm depth of the case hardening steel. The case hardening steel in which the carburized layer has been formed is subjected to such conventional quench-and-temper process as is generally carried out for a standard case hardening steel. Specifically, the quench-and-temper process includes subjecting the case hardening steel to: quenching in oil at temperature in the range of 60°C to 140°C such that microstructure of the surface layer (the carburized layer) of the steel is rendered to martensite structure including 10% to 40% of retained austenite; and tempering at temperature in the range of 160°C to 200°C for 1 to 2 hours. As a result, there can be obtained a carburized steel material having excellent rotating bending fatigue strength and pitting fatigue strength. The temperature during formation of the carburized layer is preferably 900°C or higher in terms of avoiding prolonging time required for the carburized layer formation and preferably 950°C or lower in terms of avoiding any adverse effect on durability of a carburizing furnace. Further, the temperature of oil during quenching process is preferably 60°C or higher in terms of suppressing deformation of the steel material during the quenching process and preferably 140°C or lower in terms of reliably obtaining targeted microstructure (i.e. martensite structure including 10% to 40% of retained austenite) of steel to ensure satisfactory hardness of the steel. Carbon concentration of a carburized layer obtained by normal carburization is less than 0.85 mass %.

The case hardening steel of the present invention is particularly suitable for super-carburization, in which carbon concentration in a carburized layer is increased to 0.85 mass % or higher to make carbides be precipitated, further harden the carburized layer and improve pitting fatigue strength thereof, rather than normal carburization. The conventional case hardening steel generates too much coarse carbide and fails to further improve pitting fatigue strength after being subjected to super-carburization. In contrast, the case hardening steel of the present invention can suppress precipitation of coarse carbide and improve pitting fatigue strength in a case where carbon concentration in the carburized layer is increased to 0.85 mass % or higher. That is, in the case hardening steel of the present invention, carbon content of the surface layer region ranging from a steel surface to 0.4 mm depth thereof is at least 0.85 mass % and the maximum diameter of carbide formed in the surface layer region is 10μm or less and the average particle diameter of the carbide is 4μm or less after being subjected to carburization. It has been revealed that controlling the maximum diameter and the average particle diameter of carbide in the aforementioned specific ranges significantly improves pitting fatigue strength of the case hardening steel. Such a good effect of improving pitting fatigue strength as this cannot be expected beyond the aforementioned specific diameter ranges of carbide.

[0033] In a case where carbon content in the surface layer region is less than 0.85 mass %, the amount of carbide is not sufficient and additional improvement for pitting fatigue strength of the steel cannot be obtained in a satisfactory manner. In a case where the maximum diameter of carbide exceeds 10μm, fatigue life of the case hardening steel may shrink because coarse carbides serve as origins of fatigue cracks. The average particle diameter of carbide exceeding

4μm also shortens fatigue life of the case hardening steel.

[0034] The carburizing heat treatment is preferably conducted under following conditions in order to obtain carbide satisfying the aforementioned requirements. That is, the carburizing heat treatment preferably includes: carburizing the case hardening steel by retaining the steel at carbon potential of 1.2 mass % to 2.5 mass % at temperature in the range of 930°C to 1050°C for 1 to 5 hours; then subjecting the case hardening steel to cooling to 550°C to 650°C, retention at temperature in the range of 830°C to 880°C for 30 minutes to 60 minutes, quenching in oil at temperature in the range of 60°C to 140°C, and preferably conducting tempering at temperature preferably in the range of 170°C to 200°C. It is possible to form by carrying out the processes described above a carburized layer as a surface layer of the case hardening steel, the carburized layer having the aforementioned steel microstructure constituted of martensite structure including 10% to 40% of retained austenite and also including finely dispersed carbide having the maximum diameter of 10μm or less and the average particle diameter of 4μm or less.

Examples

[0035] Next, Examples of the present invention will be described.
Each of steel samples having respective component compositions shown in Table 1 (the balance of each component composition is iron and incidental impurities) was processed by ingot casting, heated to temperature at 1150°C or higher, and formed into an intermediate material member having a square cross section (170mm x 170mm). The intermediate material member was heated to temperature equal to or higher than (Ac_3 + 100°C) and hot rolled to a round bar having diameter of 60mm. Cold forgeability was then evaluated for the round bar sample thus obtained.

[0036] Table 1

Table 1

Steel type	Chemical Component (mass %)																Note
	C	Si	Mn	P	S	Al	N	Cr	B	Nb	Ti	Cu	Ni	Mo	V	Ca	Mg	
A	0,21	0,08	0,83	0,012	0,011	0,071	0,0032	1,06	0,0018	0,032	0,001	—	—	—	0,02	—	—	Present Example
B	0,19	0,07	0,86	0,017	0,016	0,065	0,0046	1,02	0,0021	0,014	0,002	0,11	—	—	—	—	—	Present Example
C	0,19	0,18	0,87	0,016	0,014	0,077	0,0041	1,10	0,0016	0,022	0,001	—	—	—	—	—	—	Present Example
D	0,22	0,14	0,54	0,008	0,024	0,068	0,0044	1,45	0,0009	0,016	0,002	—	0,1	—	—	—	—	Present Example
E	0,17	0,22	0,40	0,011	0,018	0,059	0,0039	1,65	0,0016	0,016	0,003	—	—	0,09	—	—	—	Present Example
F	0,20	0,20	0,56	0,012	0,022	0,050	0,0035	1,30	0,0015	0,019	0,001	—	—	—	—	—	0,0006	Present Example
G	0,19	0,18	0,97	0,017	0,016	0,081	0,0065	1,20	0,0025	0,008	0,002	—	—	—	—	0,0012	—	Present Example
H	0,27	0,19	0,65	0,011	0,014	0,026	0,0064	1,10	0,0022	0,012	0,15	—	—	—	—	—	—	Comp. Example
I	0,21	0,63	0,56	0,013	0,029	0,079	0,0055	1,12	0,0011	0,011	0,003	—	0,09	—	—	—	—	Comp. Example
J	0,22	0,38	0,92	0,009	0,018	0,015	0,0045	0,87	0,0025	0,005	0,001	—	—	0,08	—	—	—	Comp. Example
K	0,17	0,22	0,88	0,008	0,012	0,160	0,0071	1,40	0,0031	0,006	0,001	—	—	—	—	—	0,0011	Comp. Example
L	0,22	0,11	0,93	0,014	0,029	0,067	0,0115	1,31	0,0029	0,010	0,002	—	—	—	—	—	—	Comp. Example
M	0,16	0,26	0,77	0,014	0,016	0,066	0,0046	1,78	0,0002	0,015	0,001	0,07	0,08	—	—	0,0017	—	Comp. Example
N	0,24	0,06	0,79	0,015	0,017	0,064	0,0045	1,22	0,0016	0,114	0,002	—	—	—	—	—	—	Comp. Example

(continued)

Steel type	Chemical Component (mass %)																	Note
	C	Si	Mn	P	S	Al	N	Cr	B	Nb	Ti	Cu	Ni	Mo	V	Ca	Mg	
P	0,22	0,12	0,88	0,016	0,022	0,064	0,0022	1,11	0,0045	0,021	0.027	—	—	0,15	—	—	—	Comp. Example
Q	0,16	0,07	0,42	0,012	0,011	0,085	0,0035	3,31	0,0022	0,016	0,002	—	—	—	—	—	—	Comp. Example
R	0,22	0,21	1,55	0,016	0,019	0,074	0,0059	0,33	0,0019	0,019	0,001	—	0,10	—	—	0,0012	—	Comp. Example
S	0,22	0,11	0,98	0,014	0,015	0,077	0,0051	1,32	0.0084	0,012	0,002	—	—	—	—	—	—	Comp. Example
T	0,19	0,12	0,84	0,015	0,013	0,074	0,0043	1,45	0,0016	0,028	0,001	—	0,11	—	—	—	—	Present Example
U	0,18	0,23	0,55	0,015	0,013	0,074	0,0034	2,81	0,0012	0,022	0,001	0,13	—	—	—	—	—	Comp. Example

* Underlined values: beyond the present invention

[0037] Cold formability of the round bar sample was evaluated in terms of limit upset ratio and deformation resistance. Specifically, deformation resistance was determined by: collecting a test piece (diameter: 10mm, height: 15mm) from a region ranging from a steel surface to a diameter/4 position in the radial direction (a D/4 position) of each round bar sample; and then measuring compression load at 60% upset forging by using a 300t press according to the deformation resistance measuring method recommended by The Japan Society for Technology of Plasticity, based on end face confined compression.

The limit upset ratio was determined by carrying out compression processing of the test piece according to the method for measuring deformation resistance described above and regarding the upset ratio when an end portion of the test piece was cracked as "the limit upset ratio". Cold forgeability of a sample is evaluated to be good when the deformation resistance value is 899 MPa or less and the limit upset ratio (the limit cracking ratio) is at least 74%.

[0038] Next, fatigue properties of each sample were evaluated in terms of rotating bending fatigue and pitting fatigue. Specifically, rotating bending fatigue test pieces and roller pitting fatigue test pieces were collected from the aforementioned D/4 position of each round bar sample. The rotating bending fatigue test pieces were subjected to two different types of thermal processes, i.e. normal carburization and super-carburization for generating lots of carbide. The roller pitting fatigue test pieces were also subjected to the two different types of thermal processes described above. The normal carburization included: carburization at carbon potential of 1.1 mass % at 930°C for 7 hours; oil quenching at 60°C; and tempering at 170°C for 2 hours. On the other hand, the super-carburization included: carburization at carbon potential of 2 mass % at 950°C for 5 hours; cooling to 600°C; retention at 850°C for 30 minutes; oil quenching at 60°C; and tempering at 170°C for 2 hours.

[0039] In the present embodiment, measurement of carbide after carburization included: etching a cut section with picral solution; observing an area ranging from a steel surface to 30 μm depth (6000 μm^2) by using a scanning electron microscope; and determining the maximum particle diameter and the average diameter of carbide through image analysis. Specifically, each carbide image was converted into a circle having the equal area and the maximum diameter and the average diameter of the circles thus obtained were regarded as "the maximum particle diameter" and "the average particle diameter" of the carbide, respectively. Carbide present in another depth range, i.e. a steel surface to the 0.4mm depth, of each sample was also observed. It was confirmed that "the largest particle diameter" and "the average particle diameter" are both largest in the region ranging from a steel surface to the 30μm depth position. Carbide particle having diameter of at least 0.5μm when converted into a circle having the same area was identified as "a carbide particle" in the observation described above.

Measurement of carbon concentration was carried out through EPMA line analysis of the region ranging from a steel surface to the 0.4mm depth of each sample.

A rotating bending fatigue test and a roller pitting fatigue test were carried out for each of the test pieces after carburization. The rotating bending fatigue test was conducted at 3500 rpm to evaluate the fatigue strength after 10^7 cycles. Further, the roller pitting fatigue test was conducted at slip rate: 40% and oil temperature: 80°C to evaluate the 10^7-cycle strength (the critical strength when pitting occurs at a surface of the test piece). The evaluation results thus obtained are shown in Table 2.

[0040] Table 2

Table 2

Example No.	Steel type	Cold formability		Carburization condition	Carbide particle diameter (μm)		C concentration in a region from steel surface to 04mm depth (mass%)	Fatigue strength (10^7-cycle strength)		
		Deformation resistance (MPa)	Limit upset ratio (%)		Maximum	Average		Rotating bending fatigue strength (MPa)	Pitting fatigue strength (MPa)	
1	A	875	78	Normal carurization	-	-	0,83	796	-	Present Example
2	B	856	75	Normal carurization	-	-	0,82	786	-	Present Example
3	C	867	76	Normal carurization	-	-	0,84	816	-	Present Example
4	A	875	78	Super-carburization	7,8	3,2	1,10	796	3250	Present Example
5	B	856	75	Super-carburization	6,5	2,8	1,11	786	3130	Present Example
6	C	867	76	Super-carburization	7,7	3,4	1,09	816	3250	Present Example
7	D	876	75	Super-carburization	6,5	2,4	1,12	821	3250	Present Example
8	E	899	74	Super-carburization	8,1	2,6	1,14	826	3130	Present Example
9	F	895	75	Super-carburization	7,5	3,4	1,16	816	3340	Present Example
10	G	877	76	Super-carbunzation	7,9	2,5	1,12	796	3130	Present Example
11	H	922	75	Super-carburization	12,5	4,8	1,13	766	2890	Comp Example
12	I	956	70	Super-carburization	7,7	3,4	1,08	756	3440	Comp. Example

(continued)

Example No.	Steel type	Cold formability		Carburization condition	Carbide particle diameter (μm)		C concentration in a region from steel surface to 04mm depth (mass%)	Fatigue strength (10^7-cycle strength)		
		Deformation resistance (MPa)	Limit upset ratio (%)		Maximum	Average		Rotating bending fatigue strength (MPa)	Pitting fatigue strength (MPa)	
13	J	883	74	Super-carburization	13,1	4,5	1,15	748	2770	Comp. Example
14	K	873	76	Super-carburization	14,2	4,8	1,11	756	2770	Comp. Example
15	L	890	72	Super-carburization	9,8	3,2	1,06	736	2890	Comp. Example
16	M	877	76	Super-carburization	11,5	3,8	1,18	726	2770	Comp. Example
17	N	933	71	Super-carburization	9,4	3,4	1,15	746	2890	Comp Example
18	P	846	76	Super-carburization	15,1	4,9	1,13	746	2770	Comp. Example
19	Q	975	68	Super-carburization	7,8	3,8	1,21	766	2890	Comp. Example
20	R	889	75	Super-carburization	9,4	4,9	1,19	756	2890	Comp. Example
21	S	902	69	Super-carburization	16,2	5,1	1,22	726	2770	Comp Example
22	T	847	77	Normal carurization	-	-	0,74	786	3010	Present Example
23	U	957	71	Normal carurization	-	-	0,72	746	2770	Comp. Example

* Underlined values: beyond the present invention or failing to meet the target values

[0041] It is understood from Table 2 that Examples according to the present invention are unanimously excellent in both cold forgeability and fatigue strength.

Claims

1. A case hardening steel, comprising a component composition including
   C: 0.10 mass % to 0.35 mass %;
   Si: 0.01 mass % to 0.50 mass %;
   Mn: 0.40 mass % to 1.50 mass %;
   P: 0.02 mass % or less;
   S: 0.03 mass % or less;
   Al: 0.04 mass % to 0.10 mass %;
   Cr: 0.5 mass % to 2.5 mass %;
   B: 0.0005 mass % to 0.0050 mass %;
   Nb: 0.003 mass % to 0.080 mass %;
   Ti: 0.003 mass % or less;
   N: less than 0.0080 mass %; and
   balance as Fe and incidental impurities.

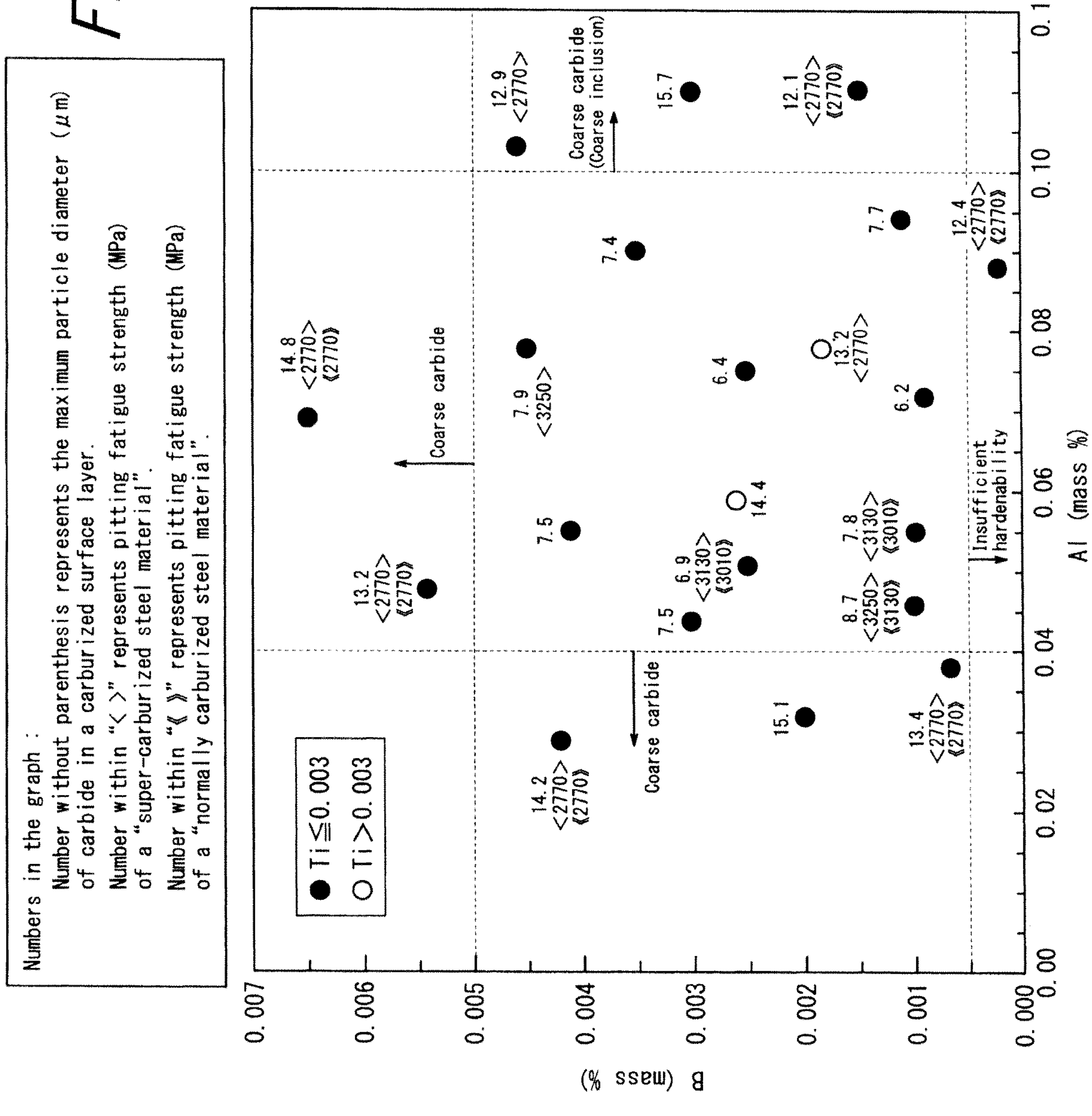
2. The case hardening steel of claim 1, wherein the component composition further includes at least one element selected from
   Cu: 1.0 mass % or less;
   Ni: 0.50 mass % or less;
   Mo: 0.50 mass % or less; and
   V: .0.5 mass % or less.

3. The case hardening steel of claim 1 or 2, wherein the component composition further includes at least one element selected from
   Ca: 0.0005 mass % to 0.0050 mass %; and
   Mg: 0.0002 mass % to 0.0020 mass %.

4. A carburized steel material, obtained by subjecting the case hardening steel of any of claims 1 to 3 to carburization, the carburized steel material having carbon content in a surface layer region ranging from a steel surface to 0.4mm depth of at least 0.70 mass %.

5. A carburized steel material, obtained by subjecting the case hardening steel of any of claims 1 to 3 to carburization, the carburized steel material having carbon content in a surface layer region ranging from a steel surface to 0.4mm depth being at least 0.85 mass % and the maximum diameter and the average particle diameter of carbide in the surface layer region being 10 μm or less and 4 μm or less, respectively.

FIG. 1


Numbers in the graph :
Number without parenthesis represents the maximum particle diameter (μm) of carbide in a carburized surface layer.
Number within "< >" represents pitting fatigue strength (MPa) of a "super-carburized steel material".
Number within "《 》" represents pitting fatigue strength (MPa) of a "normally carburized steel material".
● Ti≦0.003
○ Ti>0.003
B (mass %)
Al (mass %)
Coarse carbide
Coarse carbide
Coarse carbide (Coarse inclusion)
Insufficient hardenability
14.2 <2770> 《2770》
15.1
13.4 <2770> 《2770》
13.2 <2770> 《2770》
7.5
6.9 <3130> 《3010》
8.7 <3250> 《3130》
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7.5
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6.2
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7.7
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12.9 <2770>
15.7
12.1 <2770> 《2770》
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0.003
0.004
0.005
0.006
0.007
0.00
0.02
0.04
0.06
0.08
0.10
0.12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/000413

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D1/06*(2006.01)i, *C21D6/00*(2006.01)i, *C22C38/32*(2006.01)i, *C22C38/54*(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)
C22C38/00-38/60, C21D1/06, C21D6/00

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	1996-2011
Kokai Jitsuyo Shinan Koho	1971-2011	Toroku Jitsuyo Shinan Koho	1994-2011

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.
X Y A	JP 2006-299383 A (Kobe Steel, Ltd.), 02 November 2006 (02.11.2006), claims; paragraphs [0043] to [0053] (Family: none)	1-3 4 5
X Y A	JP 2008-179849 A (JFE Bars & Shapes Corp.), 07 August 2008 (07.08.2008), claims; paragraphs [0044] to [0067]; fig. 1 (Family: none)	2 4 1,3,5
X Y A	JP 2001-240941 A (Nippon Steel Corp.), 04 September 2001 (04.09.2001), claims; paragraphs [0055] to [0067] & US 6602359 B1 & EP 1178126 A1 & WO 01/48258 A1 & DE 60034943 T2	2,4 4 1,3,5

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

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Date of the actual completion of the international search	Date of mailing of the international search report
11 April, 2011 (11.04.11)	26 April, 2011 (26.04.11)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/000413

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 11-71654 A (Sumitomo Metal Industries, Ltd.), 16 March 1999 (16.03.1999), claims; paragraphs [0051] to [0078]; fig. 1 (Family: none)	2,4 4 1,3,5
X Y A	JP 9-241821 A (Sumitomo Metal Industries, Ltd.), 16 September 1997 (16.09.1997), claims; paragraphs [0047] to [0074]; fig. 1 (Family: none)	2,4 4 1,3,5

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REFERENCES CITED IN THE DESCRIPTION

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