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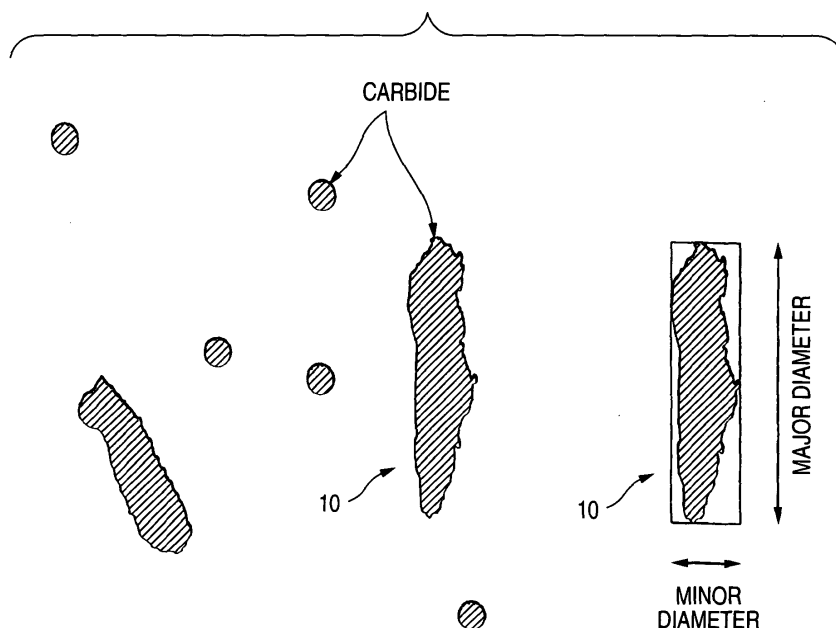
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(54) **Bearing steel excellent in corrosion resistance**

(57) Bearing steel containing 0.10 wt% to 0.35 wt% of C, less than 0.5 wt% of Si, 0.3 wt% to 1.5 wt% of Mn, 0.03 wt% or less of P, 0.03 wt% or less of S, 1.0 wt% to 3.5 wt% of Ni, 1.0 wt% to 5.0 wt% of Cr, 0.03 wt% to 2.5 wt% of Mo, 0.005 wt% to 0.050 wt% of Al, 0.003 wt% or less of Ti, 0.0015 wt% or less of O, 0.025 wt% or less of N, and a substantially residual part of Fe, wherein the

bearing steel after carburizing or carbonitriding treatment exhibits a surface C concentration of not lower than 0.9 %, contains 15 % by area or less of carbide and contains 0.1 % by area or less of rod-like carbide 10 having an aspect ratio of not lower than 3 in terms of the ratio of major diameter to minor diameter and having a minor diameter of not smaller than 2  $\mu\text{m}$ .

**FIG. 1**



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**Description****BACKGROUND OF THE INVENTION**

**[0001]** The present invention relates to bearing steel and particularly to bearing steel which is excellent in corrosion resistance, surface fatigue strength and rolling fatigue life and which is adapted for large-size bearing parts in a rolling machine (mill), a thermal power generator, a hydraulic powder generator, etc.

**[0002]** A carburized material of case-hardened steel such as JIS SCr, JIS SCM or JIS SNCM has been heretofore used as bearing steel for large-size bearing parts.

There has been however an increasing demand for long-lived bearing parts in recent years. Under such circumstances, attempt to add alloy elements such as Si, Ni, Mo, etc. to thereby improve rolling fatigue strength has been made.

**[0003]** For example, Japanese Patent Publication 14416/1990 has disclosed bearing steel adapted for large-size bearing parts and containing JIS SNCM 815 as a base material, and an appropriate amount of Si and Ni added to the base material.

**[0004]** Incidentally, for example, in the case of bearing parts used in a rolling machine, rust may be formed due to penetration of rolling water in accordance with the rolling machine. There is a problem that the rust brings about reduction in rolling fatigue life.

Therefore, development of bearing steel more excellent in corrosion resistance is required newly so that the bearing steel can be adapted for large-size bearing parts.

**[0005]** On the other hand, it has been obvious that carbonitriding treatment is more effective than ordinary carburizing treatment because nitriding improves heat resistance and because stability of residual austenite improves rolling fatigue strength against contaminants (rolling fatigue strength under an environment contaminated with dust). Accordingly, development of bearing steel excellent in carbonitriding characteristic is also required.

**SUMMARY OF THE INVENTION**

**[0006]** The invention is developed to solve the problem and an object of the invention is to provide bearing steel which is excellent in corrosion resistance, surface fatigue strength and rolling fatigue life and excellent in carbonitriding characteristic and which is particularly adapted for large-size bearing parts.

**[0007]** In order to solve the aforesaid object, the invention is characterized by having the following arrangement.

(1) Bearing steel excellent in corrosion resistance comprising:

0.10 wt% to 0.35 wt% of C;  
less than 0.5 wt% of Si;  
0.2 wt% to 1.5 wt% of Mn;  
0.03 wt% or less of P;  
0.03 wt% or less of S;  
1.0 wt% to 3.5 wt% of Ni;  
1.0 wt% to 5.0 wt% of Cr;  
0.03 wt% to 2.5 wt% of Mo;  
0.005 wt% to 0.050 wt% of Al;  
0.003 wt% or less of Ti;  
0.0015 wt% or less of O;  
0.025 wt% or less of N; and

a substantially residual part of Fe,

wherein the bearing steel after carburizing or carbonitriding treatment exhibits a surface C concentration of not lower than 0.7 %, contains 15 % or less by area of carbide and contains 0.1 % or less by area of carbide having an aspect ratio of not lower than 3 in terms of the ratio of major diameter to minor diameter and having a minor diameter of not smaller than 2  $\mu$ m.

(2) The bearing steel according to claim 1 further comprising at least one of 0.05 wt% to 1.0 wt% of V, and 0.1 wt% or less of Nb as an alloy component.

(3) The bearing steel according to (1), wherein Ni is set from 2.0 wt% to 3.0 wt%.

(4) The bearing steel according to (1), wherein Cr is set from 1.0 wt% to 2.0 wt%.

(5) The bearing steel according to (1), wherein Mo is set from 0.3 wt% to 1.0 wt%.

(6) The bearing steel according to (1), wherein Ni is set from 2.0 wt% to 3.0 wt%, Cr is set from 1.0 wt% to 2.0 wt% and Mo is set from 0.3 wt% to 1.0 wt%.

With this aspect, the corrosion resistance thereof is remarkably improved and the rod-like carbide is hard to be generated thereby enhancing the life of the bearing steel. Further, the bearing steel according to this aspect has good balance between the corrosion resistance and the life.

(7) The bearing steel according to (1), wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of lower than 0.9 %.

(8) The bearing steel according to (2), wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of lower than 0.9 %.

(9) The bearing steel according to (6), wherein the bearing steel after carburizing treatment exhibits the surface C concentration of lower than 0.9 %.

(10) The bearing steel according to (1), wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of from 0.79 to 0.82 %.

(11) The bearing steel according to (6), wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of from 0.79 to 0.82 %.

(12) The bearing steel according to (1), wherein the bearing steel after carburizing exhibits the surface C concentration of not lower than 0.9 %.

(13) The bearing steel according to (2), wherein the bearing steel after carburizing exhibits the surface C concentration of not lower than 0.9 %.

#### BRIEF DESCRIPTION OF THE DRAWING

**[0008]** FIG. 1 is a view typically showing rod-like carbide existing in steel.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

##### Operation of the Invention

**[0009]** The inventors have examined various alloy elements. As a result, it has been found that both reduction in the amount of added Si and addition of an appropriate amount of Ni and Cr are effective in improving corrosion resistance.

**[0010]** It has been also apparent that the surface C concentration, the area percentage of carbide and the presence of rod-like carbide after carburizing or carbonitriding treatment have large influence on corrosion resistance and rolling fatigue life.

That is, it has been apparent that a surface C concentration high enough to be not lower than a certain degree is required for improving rolling fatigue life but increase in C concentration causes increase in area percentage of carbide to thereby deteriorate corrosion resistance and causes production of rod-like carbide to thereby deteriorate both rolling fatigue life and impact resistance remarkably.

**[0011]** The reason why the presence of rod-like carbide deteriorates both rolling fatigue life and impact resistance can be conceived as follows. That is, the bearing steel cracks along a surface of rod-like carbide which is an inclusion, or the rod-like carbide is apt to operate as a start point of the crack.

It is further conceived that corrosion resistance also deteriorates because the bearing steel is apt to corrode along the surface of the rod-like carbide.

In the invention, it has been found that those properties deteriorate particularly when rod-like carbide having an aspect ratio of not lower than 3 and having a minor diameter of not larger than 2  $\mu\text{m}$  is produced.

**[0012]** The inventors have also found that carbonitriding treatment improves both corrosion resistance and rolling fatigue life and that addition of an appropriate amount of Ni and Mo is effective in improving rolling fatigue life.

The invention is based on the aforementioned knowledge.

**[0013]** In the invention, the size of each oxide inclusion in the steel before carburizing or carbonitriding treatment is preferably selected to be not larger than 50  $\mu\text{m}$  in terms of the maximum diameter. That is, the inventors have found that corrosion resistance can be improved when the size of each oxide inclusion in the steel is reduced to be not larger than 50  $\mu\text{m}$ .

**[0014]** It has become also apparent that evaluation of acid-dissolved extract by a pore electrical resistance method is effective in guaranteeing the size of the oxide inclusion.

**[0015]** It has further become apparent that both corrosion resistance and rolling fatigue life can be improved when intermediate annealing and secondary quenching/tempering are performed successively after carburizing or carbonitriding treatment.

**[0016]** That is, in the invention, after steel containing oxide inclusions each having a maximum diameter of not larger than 50  $\mu\text{m}$  is carburized or carbonitrided, the steel is preferably subjected to intermediate annealing and secondary quenching/tempering successively so that the steel exhibits a surface C concentration of not lower than 0.7 %, contains carbide having an area percentage of not higher than 15 % and contains 0.1 % by area or less of carbide having an aspect ratio of not lower than 3 and having a minor diameter of not smaller than 2  $\mu\text{m}$ .

**[0017]** In the invention, the steel may further contain 0.05 wt% to 1.0 wt% of V, and 0.1 wt% or less of Nb as alloy components.

When these components are contained in the steel, crystal grains can be made so fine that characteristic of the bearing steel can be improved.

**[0018]** The reason why each of the chemical components in the invention is limited will be described below in detail.

C: 0.10 % to 0.35 %

The amount of C needs to be not smaller than 0.10 % in order to obtain required strength as bearing steel and keep sufficient surface hardness after carburizing or carbonitriding treatment. If the content of C is larger than 0.35 %, both toughness and machinability are reduced. Accordingly, the content of C is selected to be in a range of from 0.10 % to 0.35 %.

Si: < 0.5 %

Si is effective in making a quench-hardened martensitic structure dense to thereby improve toughness and fatigue resistance of steel. In this sense, Si is a significant component in the invention. Corrosion resistance of steel, however, deteriorates remarkably if the amount of added Si is not smaller than 0.5 %. Furthermore, both toughness and processability deteriorate. Accordingly, the content of Si is selected to be smaller than 0.5 %.

Mn: 0.2 % to 1.5 %

Mn is an element which operates as a deacidifying and desulfurizing element at the time of melting steel and which is effective in improving hardenability of steel. In this invention, therefore, the steel contains 0.2 % or more of Mn. Both processability and machinability, however, deteriorate if the content of Mn is larger than 1.5 %. Accordingly, the upper limit of the content of Mn is set at 1.5 %.

P: S 0.03 %

S:  $\leq$  0.03 %

Each of P and S causes deterioration of strength of bearing steel. In the invention, therefore, the amount of each of P and S is limited to be not larger than 0.03 %.

Ni: 1.0 % to 3.5 %

Ni is a significant component in the invention and has a great effect on improvement in corrosion resistance of steel. Ni is an element effective in improving hardenability of steel and toughness of steel after quenching/tempering. In the invention, therefore, the steel contains 1.0 % or more of Ni. Both toughness and processability of steel, however, deteriorate if the content of Ni is larger than 3.5 %. Accordingly, the upper limit of the content of Ni is set at 3.5 %. Preferably, the content of Ni is set from 2.0 to 3.0%.

Cr: 1.0 % to 5.0 %

Cr is also a significant component in the invention and has a great effect on improvement in corrosion resistance of steel. Cr is an element effective in improving hardenability of steel and strength and toughness of steel after quenching/tempering. In the invention, therefore, the steel contains 1.0 % or more of Cr. If the content of Cr is larger than 5.0 %, both hardenability and machinability, however, deteriorate while the effect on improvement in corrosion resistance is saturated. Accordingly, the upper limit of the content of Cr is set at 5.0 %. Preferably, the content of Cr is set from 1.0 to 2.0 %.

Mo: 0.03 % to 2.5 %

Mo is an element effective in improving strength of steel. In the invention, therefore, the steel contains 0.03 % or more of Mo. Both hardenability and machinability, however, deteriorate simultaneously if the content of Mo is larger than 2.5 %. Accordingly, the upper limit of the content of Mo is set at 2.5 %. Preferably, the contents of Mo is set from 0.3 to 1.0 %.

Al: 0.005 % to 0.050 %

Al forms AlN effective in making crystal grains fine. In the invention, therefore, the steel contains 0.005 % or more

of Al. The effect on prevention of production of coarse crystal grains is however reduced as well as cleanliness of steel deteriorates if the content of Al is larger than 0.050 %. Accordingly, the upper limit of the content of Al is set at 0.050 %.

Ti:  $\leq 0.003$  %

Ti generates a hard precipitate TiN which operates as a fracture start point of rolling fatigue fracture and which causes reduction in rolling fatigue life. In the invention, therefore, the content of Ti is limited to be not larger than 0.003 %.

O:  $\leq 0.0015$  %

O reduces cleanliness of steel to cause reduction in rolling fatigue life. In the invention, therefore, the content of O is limited to be not larger than 0.0015 %.

N:  $\leq 0.025$  %

N is bonded to Al to generate AlN which operates to make crystal grains fine. Strength of steel, however, deteriorates if a large amount of N is contained. In the invention, therefore, the upper limit of the content of N is set at 0.025 %. More preferably, the content of N is in a range of from 0.01 % to 0.02 %.

V: 0.05 % to 1.0 %

Nb:  $\leq 0.1$  %

Each of V and Nb is an element that contributes to making crystal grains fine. The effect on making crystal grains fine is reduced if the content of each of V and Nb is too large. Accordingly, when each of V and Nb needs to be added as a selected element, the steel contains 0.05 % to 1.0 % of V, and 0.1 % or less of Nb.

Surface C Concentration

Surface C concentration after heat treatment is important in order to keep strength of steel. A surface C concentration of not lower than 0.7 % is required for obtaining required hardness and rolling fatigue life.

In the case of carburizing processing, when the C concentration increases, the percentage of carbide is increased thereby not only deteriorating resistance of corrosion but also deteriorating both rolling fatigue life and impact resistance. Therefore, surface C concentration is preferably set from 0.7 % to 0.9 %.

Carbide

Fine carbide is required for ensuring rolling fatigue life. If the area percentage of carbide is higher than 15 %, strength of steel is reduced in reverse.

**[0019]** Particularly, if the alloy elements and the heating treatment condition are inappropriate, rod-like carbide having an aspect ratio of not lower than 3 in terms of the ratio of major diameter to minor diameter and having a minor diameter of not smaller than 2  $\mu\text{m}$  is produced as shown in Fig. 1. If the area percentage of the rod-like carbide produced thus is higher than 0.1 %, both rolling fatigue life and impact resistance are reduced remarkably.

Oxide Inclusion

The presence of an oxide inclusion reduces rolling fatigue life because the oxide inclusion serves as a start point of rolling fatigue fracture. In addition, the presence of such an oxide inclusion large in size reduces corrosion resistance because the interface between the oxide inclusion and a matrix is preferentially corroded under a corrosive environment.

The maximum diameter of the oxide inclusion is preferably controlled to be not larger than 50  $\mu\text{m}$  in order to obtain bearing steel excellent in corrosion resistance and rolling fatigue life.

Heat Treatment

When the amount of added alloy elements is large after carburizing or carbonitriding, there is the possibility that required surface hardness cannot be obtained because the martensitic transformation point ( $M_s$  point) of steel becomes so low that a large amount of residual austenite is produced. It is therefore preferable that secondary quenching/tempering is performed.

In this case, intermediate annealing may be preferably performed before the second quenching so that the form of carbide is made appropriate to improve hardenability of the matrix. Further, addition of nitrogen is effective in improving corrosion resistance.

## EMBODIMENT

**[0020]** An embodiment according to the invention will be described below in detail.

<Material>

**[0021]** In a vacuum induction melting furnace, 150 g of steel having chemical components shown in Table 1 was melted and hot-forged at 1200°C to produce a round bar having a diameter of 32 mm or 65 mm. After the round bar was normalized at 900°C, the round bar was subjected to spheroidizing treatment as softening treatment at 760°C to prepare a test material.

For evaluation of cleanliness of the material, a size distribution of oxide inclusion particles was measured by an acid dissolution extraction-pore electrical resistance method (method for measuring volume of particles on the basis

of change in electrical resistance at the time of passage of the particles through pores).

**[0022]** A round bar of  $\Phi 20$  mm was cut out of an R/2 portion of the material. After the round bar was quenched from  $850^{\circ}\text{C}$ , about 30 g of a 1 mm-thick thin plate was cut out of the round bar and subjected to acid dissolution.

Extraction of oxide inclusions by acid dissolution was performed with a solution of sulfuric acid and permanganic acid.

The extracted oxide inclusions were dispersed into 200 cc of an electrolytic solution. A size distribution of particles in 500  $\mu\text{l}$  of the dispersed solution was measured in the condition of an aperture size (pore size) of 100  $\mu\text{m}$  by the Multisizer made by Beckman Coulter, Inc.

**[0023]** Table 1 shows the measured maximum diameter of the oxide inclusions.

In any test material of steel according to the invention, the maximum diameter of the oxide inclusions was not larger than 50  $\mu\text{m}$ .

Table 1

|                                        | No. | Chemical Component (wt%) |      |      |       |       |      |      |      |
|----------------------------------------|-----|--------------------------|------|------|-------|-------|------|------|------|
|                                        |     | C                        | Si   | Mn   | P     | S     | Ni   | Cr   | Mo   |
| Steel according to the invention       | 1   | 0.17                     | 0.26 | 0.59 | 0.011 | 0.006 | 1.51 | 1.10 | 0.29 |
|                                        | 2   | 0.21                     | 0.27 | 0.75 | 0.015 | 0.007 | 1.75 | 1.05 | 0.45 |
|                                        | 3   | 0.19                     | 0.31 | 0.35 | 0.013 | 0.005 | 1.15 | 1.96 | 1.66 |
|                                        | 4   | 0.20                     | 0.45 | 0.61 | 0.017 | 0.007 | 1.95 | 3.25 | 0.25 |
|                                        | 5   | 0.21                     | 0.28 | 1.10 | 0.012 | 0.006 | 3.25 | 1.63 | 0.33 |
|                                        | 6   | 0.17                     | 0.21 | 0.98 | 0.011 | 0.005 | 2.05 | 2.25 | 0.95 |
|                                        | 7   | 0.27                     | 0.11 | 1.45 | 0.013 | 0.007 | 1.00 | 4.51 | 0.19 |
|                                        | 8   | 0.32                     | 0.27 | 0.68 | 0.024 | 0.025 | 1.50 | 2.02 | 0.55 |
|                                        | 9   | 0.19                     | 0.25 | 0.45 | 0.016 | 0.015 | 2.50 | 1.07 | 2.24 |
|                                        | 10  | 0.29                     | 0.31 | 0.33 | 0.015 | 0.009 | 3.05 | 1.22 | 1.09 |
|                                        | 11  | 0.20                     | 0.26 | 0.81 | 0.011 | 0.006 | 1.30 | 1.18 | 0.54 |
|                                        | 12  | 0.18                     | 0.22 | 0.55 | 0.013 | 0.010 | 1.75 | 1.75 | 0.42 |
|                                        | 13  | 0.20                     | 0.31 | 0.97 | 0.013 | 0.005 | 2.05 | 1.10 | 0.64 |
|                                        | 14  | 0.20                     | 0.25 | 1.05 | 0.012 | 0.007 | 2.55 | 1.89 | 0.81 |
|                                        | 15  | 0.22                     | 0.25 | 0.23 | 0.014 | 0.008 | 1.66 | 1.51 | 0.75 |
|                                        | 16  | 0.20                     | 0.24 | 0.28 | 0.018 | 0.006 | 2.19 | 1.78 | 0.81 |
|                                        | 17  | 0.19                     | 0.31 | 0.56 | 0.020 | 0.007 | 2.94 | 1.17 | 0.30 |
| Steel according to Comparative Example | 1   | 0.20                     | 0.21 | 0.75 | 0.013 | 0.011 | 0.02 | 1.05 | 0.01 |
|                                        | 2   | 0.15                     | 0.25 | 0.45 | 0.014 | 0.014 | 4.25 | 0.85 | 0.25 |
|                                        | 3   | 0.20                     | 1.00 | 0.34 | 0.016 | 0.007 | 0.75 | 0.98 | 0.01 |
|                                        | 4   | 0.18                     | 0.75 | 0.78 | 0.020 | 0.016 | 0.03 | 1.14 | 0.31 |

|                                  | No. | Chemical Component (wt%) |        |        |       |         | Maximum Inclusion Diameter (μm) |
|----------------------------------|-----|--------------------------|--------|--------|-------|---------|---------------------------------|
|                                  |     | Al                       | Ti     | O      | N     | Others  |                                 |
| Steel according to the invention | 1   | 0.024                    | 0.0021 | 0.0008 | 0.011 | -       | 25                              |
|                                  | 2   | 0.023                    | 0.0020 | 0.0009 | 0.012 | -       | 40                              |
|                                  | 3   | 0.025                    | 0.0023 | 0.0007 | 0.014 | -       | 25                              |
|                                  | 4   | 0.028                    | 0.0019 | 0.0010 | 0.011 | -       | 27                              |
|                                  | 5   | 0.024                    | 0.0002 | 0.0008 | 0.010 | -       | 29                              |
|                                  | 6   | 0.010                    | 0.0024 | 0.0009 | 0.003 | -       | 25                              |
|                                  | 7   | 0.024                    | 0.0021 | 0.0008 | 0.011 | Nb:0.05 | 28                              |
|                                  | 8   | 0.026                    | 0.0024 | 0.0007 | 0.013 | -       | 33                              |
|                                  | 9   | 0.025                    | 0.0019 | 0.0010 | 0.010 | -       | 27                              |
|                                  | 10  | 0.024                    | 0.0021 | 0.0009 | 0.009 | -       | 31                              |
|                                  | 11  | 0.027                    | 0.0023 | 0.0008 | 0.012 | -       | 25                              |
|                                  | 12  | 0.029                    | 0.0022 | 0.0007 | 0.011 | V:0.5   | 26                              |
|                                  | 13  | 0.024                    | 0.0020 | 0.0009 | 0.009 | -       | 20                              |
|                                  | 14  | 0.023                    | 0.0022 | 0.0002 | 0.010 | -       | 21                              |
|                                  | 15  | 0.025                    | 0.019  | 0.0009 | 0.011 | -       | 23                              |
|                                  | 16  | 0.023                    | 0.025  | 0.0008 | 0.011 | -       | 29                              |

|                                                    |    |       |        |        |       |   |    |
|----------------------------------------------------|----|-------|--------|--------|-------|---|----|
|                                                    | 17 | 0.025 | 0.021  | 0.0009 | 0.013 | - | 24 |
| Steel<br>according<br>to<br>Comparative<br>Example | 1  | 0.026 | 0.0021 | 0.0007 | 0.011 | - | 43 |
|                                                    | 2  | 0.024 | 0.0023 | 0.0008 | 0.012 | - | 27 |
|                                                    | 3  | 0.027 | 0.0020 | 0.0009 | 0.009 | - | 55 |
|                                                    | 4  | 0.025 | 0.0023 | 0.0008 | 0.010 | - | 27 |

## &lt;Corrosion Test&gt;

**[0024]** For evaluation of corrosion resistance, a corrosion test was performed in a humid condition and in a crevice corrosion condition.

Specifically, a roughly processed test specimen having a diameter of 20 mm and a length of 36 mm was cut out of each of the materials. The test specimen was carburized at 960°C for 22 hours in a furnace in an atmosphere of 1.2 % carbon potential as a carburizing condition. After quenched from 860°C, the test specimen was intermediately annealed at 660°C for 4 hours, secondarily quenched at 790°C and tempered at 180°C. After a cylindrical surface of the test specimen was then ground-finished, the test specimen was subjected to the corrosion test.

**[0025]** On the other hand, the roughly processed test specimen provided in the aforementioned manner was carburized in the same condition as described above and then carbonitrided at 850°C for 7 hours in a furnace in an atmosphere of 1.2 % carbon potential and 5 % ammonia addition as a carbonitriding condition. The test specimen was intermediately annealed and secondarily quenched in the same manner as described above. After a cylindrical surface of the test specimen was finished in the same manner as described above, the test specimen was subjected to the corrosion test.

A combined cycle testing machine was used in the corrosion test. The state of corrosion was examined after each test specimen was left at a test temperature of 49°C ± 1°C with 95 % or higher relative humidity for 24 hours.

With respect to crevice corrosion, the test specimen was placed quietly on a V block so that a contact portion between the V block and the test specimen was in the crevice corrosion condition.

## &lt;Measurement of C Concentration&gt;

**[0026]** A center portion of the test specimen was cut with a micro-cutter and ground-finished. Then, a C concentration distribution from a surface layer of the test specimen was measured by an electron probe microanalyser (EPMA) to thereby obtain the surface C concentration.

## &lt;Measurement of Carbide&gt;

**[0027]** Carbide was measured as follows. A center portion of the test specimen was cut with a micro-cutter and ground-finished. Then, the test specimen was corroded by picral so that carbide came out from the test specimen. The carbide was observed in five visual fields by a 5000-power scanning electron microscope (SEM), so that the area percentage of carbide and the major and minor diameters of all carbide particles as shown in Fig. 1 were measured by image analysis.

## &lt;Rolling Fatigue Test&gt;

**[0028]** A thrust type rolling fatigue test was performed in order to examine rolling fatigue strength of bearing parts.

A ring-like test specimen having an outer diameter of 63 mm, an inner diameter of 28.7 mm and a thickness of 9 mm was cut out of each material so that it was used as a roughly processed test specimen.

**[0029]** The test specimen was subjected to carburizing treatment and quenching/tempering treatment as heat treatment.

The carburizing condition was the same as in the corrosion test specimen.

After the heat treatment, one test surface of the test specimen was ground-finished by 0.15 mm and the other test surface of the test specimen was lapped so that the test specimen was used as a thrust type rolling fatigue test specimen.

**[0030]** On the other hand, the roughly processed test specimen provided in the aforementioned manner was subjected to carbonitriding treatment and quenching/tempering treatment.

The carbonitriding condition was the same as in the corrosion test specimen.

After the heat treatment, the test specimen was subjected to the same ground finish so that the test specimen was used as a thrust type rolling fatigue test specimen.

**[0031]** A thrust type rolling fatigue testing machine was used in the test. The test was performed in the test condition shown in Table 2.

High-speed steel gas atomized powder having a hardness of 750 Hv and having a particle size of 100  $\mu\text{m}$  to 180  $\mu\text{m}$  obtained by classification was used in the test under a contamination environment.

The rolling fatigue life was evaluated on the basis of the number ( $L_{10}$ ) of cycles in which the probability of accumulated breakage reached 10 % in a Weibull distribution and the number ( $L_{50}$ ) of cycles in which the probability of accumulated breakage reached 50 % in a Weibull distribution when the test was repeated by 16 cycles in the same test condition.

Table 2:

| Rolling Fatigue Life Test Condition                                                 |                                                  |
|-------------------------------------------------------------------------------------|--------------------------------------------------|
| Testing Machine                                                                     | Thrust Type Rolling Fatigue Life Testing Machine |
| Contact Surface Pressure                                                            | 5.5 (4.9) GPa                                    |
| Rotational Speed                                                                    | 1800 rpm                                         |
| Test Temperature                                                                    | Ordinary Temperature                             |
| Lubricating                                                                         | Turbine #68                                      |
| Dirt Content                                                                        | No Dirt (0.25 g/l)                               |
| Note) Values put in parentheses show a contaminated rolling fatigue test condition. |                                                  |

#### <Charpy Impact Test>

**[0032]** A Charpy impact test was performed in order to examine toughness of bearing parts.

A roughly processed test specimen which was 12 mm wide, 14 mm high and 55 mm long and in which a notch having a depth of 1.8 mm and a curvature radius of 10 mm was formed in the lengthwise center of the test specimen was cut out of each of the materials.

**[0033]** The test specimen was subjected to carburizing and quenching/tempering treatment as heat treatment.

The carburizing condition was as follows. The test specimen was carburized at 930°C for 4 hours in a furnace in an atmosphere of 1.2 % carbon potential. After quenched from 850°C, the test specimen was intermediately annealed at 660°C for 4 hours, secondarily quenched from 790°C and tempered at 180°C.

After the heat treatment, the test specimen was ground into a test specimen which was 10 mm wide and 10 mm high and in which a notch having a depth of 2 mm and a curvature radius of 10 mm was formed in the test specimen. The test specimen was subjected to the Charpy test.

**[0034]** On the other hand, the roughly processed test specimen provided in the aforementioned manner was carbonitrided and quenched/tempered.

The carbonitriding condition was as follows. After carburized in the same manner as described above, the test specimen was carbonitrided at 850°C for 5 hours in a furnace in an atmosphere of 1.2 % carbon potential and 5% ammonia addition. Then, the test specimen was intermediately annealed and secondarily quenched/tempered in the same manner as described above.

After the heat treatment, the test specimen was ground-finished in the same manner as described above. The test specimen was subjected to the Charpy test.

A Charpy testing machine was used in the test. Energy absorbed at breakage of the test specimen was measured at ordinary temperature.

#### <Results>

**[0035]** Table 3 shows test results of the carburized materials.

Table 3

|                                        | No. | Heat Treatment | Surface C Concentration (%) | Area Percentage of Carbide (%) |                                | Corrosion Resistance <sup>2)</sup> |         |
|----------------------------------------|-----|----------------|-----------------------------|--------------------------------|--------------------------------|------------------------------------|---------|
|                                        |     |                |                             | Total                          | Rod-Like Carbide <sup>1)</sup> | Humid                              | Crevice |
| Steel according to the invention       | 1   | Carburizing    | 1.20                        | 8.3                            | ≤0.1                           | ○                                  | ○       |
|                                        | 2   | Carburizing    | 1.13                        | 7.9                            | ≤0.1                           | ○                                  | ○       |
|                                        | 3   | Carburizing    | 1.18                        | 7.3                            | ≤0.1                           | ○                                  | ○       |
|                                        | 4   | Carburizing    | 0.93                        | 5.8                            | ≤0.1                           | ⊗                                  | ○       |
|                                        | 5   | Carburizing    | 1.10                        | 7.4                            | ≤0.1                           | ○                                  | ○       |
|                                        | 6   | Carburizing    | 1.21                        | 6.3                            | ≤0.1                           | ○                                  | ○       |
|                                        | 7   | Carburizing    | 1.07                        | 7.1                            | ≤0.1                           | ⊗                                  | ⊗       |
|                                        | 8   | Carburizing    | 1.03                        | 8.8                            | ≤0.1                           | ○                                  | ○       |
|                                        | 9   | Carburizing    | 1.22                        | 6.7                            | ≤0.1                           | ⊗                                  | ○       |
|                                        | 10  | Carburizing    | 1.11                        | 7.4                            | ≤0.1                           | ○                                  | ○       |
|                                        | 11  | Carburizing    | 1.18                        | 7.1                            | ≤0.1                           | ○                                  | ○       |
|                                        | 12  | Carburizing    | 0.98                        | 6.6                            | ≤0.1                           | ⊗                                  | ○       |
|                                        | 13  | Carburizing    | 1.21                        | 7.3                            | ≤0.1                           | ⊗                                  | ○       |
|                                        | 14  | Carburizing    | 1.17                        | 8.1                            | ≤0.1                           | ⊗                                  | ○       |
|                                        | 15  | Carburizing    | 0.95                        | 6.5                            | ≤0.1                           | ○                                  | ○       |
|                                        | 16  | Carburizing    | 0.94                        | 7.3                            | ≤0.1                           | ⊗                                  | ○       |
|                                        | 17  | Carburizing    | 0.91                        | 6.4                            | ≤0.1                           | ○                                  | ○       |
| Steel according to Comparative Example | 1   | Carburizing    | 0.82                        | 7.1                            | ≤0.1                           | △                                  | ×       |
|                                        | 2   | Carburizing    | 0.79                        | 6.2                            | ≤0.1                           | △                                  | △       |
|                                        | 3   | Carburizing    | 0.99                        | 7.3                            | 0.2                            | ×                                  | ×       |
|                                        | 4   | Carburizing    | 1.12                        | 16.5                           | ≤0.1                           | ×                                  | ×       |

|                                        | No. | Impact Value<br>(J/cm <sup>2</sup> ) | Ordinary Temperature<br>Rolling Fatigue Life<br>(X 10 <sup>6</sup> Times) |                 | Contaminated Rolling Fatigue Life<br>(X 10 <sup>5</sup> Times) |                 |
|----------------------------------------|-----|--------------------------------------|---------------------------------------------------------------------------|-----------------|----------------------------------------------------------------|-----------------|
|                                        |     |                                      | L <sub>10</sub>                                                           | L <sub>50</sub> | L <sub>10</sub>                                                | L <sub>50</sub> |
| Steel according to the invention       | 1   | 64                                   | 15.3                                                                      | 26.5            | 6.5                                                            | 15.4            |
|                                        | 2   | 64                                   | 15.0                                                                      | 28.5            | 7.4                                                            | 16.6            |
|                                        | 3   | 55                                   | 17.1                                                                      | 25.9            | 6.3                                                            | 14.6            |
|                                        | 4   | 64                                   | 14.5                                                                      | 26.4            | 6.9                                                            | 15.7            |
|                                        | 5   | 65                                   | 17.8                                                                      | 25.9            | 5.9                                                            | 14.9            |
|                                        | 6   | 66                                   | 18.1                                                                      | 29.1            | 8.3                                                            | 15.4            |
|                                        | 7   | 57                                   | 16.6                                                                      | 25.4            | 7.6                                                            | 14.4            |
|                                        | 8   | 63                                   | 14.7                                                                      | 26.8            | 5.9                                                            | 14.9            |
|                                        | 9   | 63                                   | 16.2                                                                      | 25.8            | 7.6                                                            | 16.4            |
|                                        | 10  | 68                                   | 16.2                                                                      | 28.8            | 6.6                                                            | 14.7            |
|                                        | 11  | 54                                   | 15.4                                                                      | 31.1            | 6.9                                                            | 16.1            |
|                                        | 12  | 64                                   | 18.0                                                                      | 34.2            | 7.4                                                            | 15.7            |
|                                        | 13  | 64                                   | 14.4                                                                      | 28.5            | 7.3                                                            | 15.5            |
|                                        | 14  | 66                                   | 16.1                                                                      | 31.9            | 6.9                                                            | 14.9            |
|                                        | 15  | 62                                   | 16.8                                                                      | 27.3            | 7.1                                                            | 15.1            |
|                                        | 16  | 63                                   | 17.6                                                                      | 27.1            | 7.8                                                            | 16.2            |
|                                        | 17  | 69                                   | 14.7                                                                      | 30.4            | 6.5                                                            | 15.1            |
| Steel according to Comparative Example | 1   | 42                                   | 9.0                                                                       | 15.6            | 4.0                                                            | 10.9            |
|                                        | 2   | 40                                   | 8.5                                                                       | 18.0            | 4.1                                                            | 8.4             |
|                                        | 3   | 42                                   | 3.7                                                                       | 15.5            | 2.6                                                            | 5.9             |
|                                        | 4   | 49                                   | 8.9                                                                       | 19.0            | 4.4                                                            | 10.2            |

\*1) Carbide having a major diameter/minor diameter ratio of not lower than 3 and having a minor diameter of not smaller than 2  $\mu\text{m}$ .

\*2) The quantity of corrosion:

⊙ very small

○ small

△ slightly large

× large

[0036] In steel according to the invention, the surface C concentration was not lower than 0.7 %, the area percentage of carbide was not higher than 15 %, and the area percentage of rod-like carbide was not higher than 0.1 %. The term "rod-like carbide" used herein means carbide having a major diameter/minor diameter ratio (aspect ratio) of not lower than 3 and having a minor diameter of not smaller than 2  $\mu\text{m}$ .

[0037] As is obvious from the test results, corrosion resistance of steel according to the invention in both humid condition and crevice corrosion condition is more excellent than that of steel according to Comparative Examples.

[0038] It is obvious from results of the rolling fatigue test that the life of steel according to the invention in a detergent oil condition is longer than that of steel according to Comparative Examples. Although the rolling fatigue life of steel in a contamination condition is reduced by at least one figure compared with that in the detergent oil condition, the life of steel according to the invention is still longer than that of steel according to Comparative Examples.

[0039] The Charpy impact value of steel according to the invention is equal to or greater than that of steel according to Comparative Examples. It is obvious that the steel according to the invention is excellent in crushing strength as

bearing parts.

[0040] Next, Table 4 shows test results of the carbonitrided materials.

Table 4

|                                        | No. | Heat Treatment | Surface C Concentration (%) | Area Percentage of Carbide (%) |                                | Corrosion Resistance <sup>2)</sup> |         |
|----------------------------------------|-----|----------------|-----------------------------|--------------------------------|--------------------------------|------------------------------------|---------|
|                                        |     |                |                             | Total                          | Rod-Like Carbide <sup>1)</sup> | Humid                              | Crevice |
| Steel according to the invention       | 1   | Carbonitriding | 1.22                        | 8.1                            | ≤0.1                           | ⊙                                  | ○       |
|                                        | 2   | Carbonitriding | 1.20                        | 8.3                            | ≤0.1                           | ○                                  | ○       |
|                                        | 3   | Carbonitriding | 1.10                        | 7.6                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 4   | Carbonitriding | 0.98                        | 6.8                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 5   | Carbonitriding | 1.12                        | 8.4                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 6   | Carbonitriding | 1.08                        | 7.7                            | ≤0.1                           | ○                                  | ○       |
|                                        | 7   | Carbonitriding | 0.94                        | 6.3                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 8   | Carbonitriding | 1.11                        | 8.3                            | ≤0.1                           | ⊙                                  | ○       |
|                                        | 9   | Carbonitriding | 1.20                        | 8.5                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 10  | Carbonitriding | 1.15                        | 7.5                            | ≤0.1                           | ⊙                                  | ○       |
|                                        | 11  | Carbonitriding | 1.12                        | 7.7                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 12  | Carbonitriding | 1.09                        | 6.8                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 13  | Carbonitriding | 1.12                        | 8.2                            | ≤0.1                           | ⊙                                  | ○       |
|                                        | 14  | Carbonitriding | 1.18                        | 7.4                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 15  | Carbonitriding | 0.95                        | 7.2                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 16  | Carbonitriding | 0.82                        | 8.0                            | ≤0.1                           | ⊙                                  | ⊙       |
|                                        | 17  | Carbonitriding | 0.79                        | 6.6                            | ≤0.1                           | ⊙                                  | ○       |
| Steel according to Comparative Example | 1   | Carbonitriding | 0.82                        | 7.5                            | ≤0.1                           | △                                  | △       |
|                                        | 2   | Carbonitriding | 0.80                        | 7.1                            | ≤0.1                           | △                                  | △       |
|                                        | 3   | Carbonitriding | 0.96                        | 8.9                            | 0.3                            | △                                  | ×       |
|                                        | 4   | Carbonitriding | 1.13                        | 17.1                           | 0.2                            | △                                  | ×       |

|                                        | No. | Impact Value<br>(J/cm <sup>2</sup> ) | Ordinary Temperature Rolling Fatigue Life<br>(X 10 <sup>6</sup> Times) |                 | Contaminated Rolling Fatigue Life<br>(X 10 <sup>5</sup> Times) |                 |
|----------------------------------------|-----|--------------------------------------|------------------------------------------------------------------------|-----------------|----------------------------------------------------------------|-----------------|
|                                        |     |                                      | L <sub>10</sub>                                                        | L <sub>50</sub> | L <sub>10</sub>                                                | L <sub>50</sub> |
| Steel according to the invention       | 1   | 65                                   | 21.1                                                                   | 39.6            | 13.4                                                           | 32.2            |
|                                        | 2   | 64                                   | 19.9                                                                   | 40.6            | 14.9                                                           | 32.6            |
|                                        | 3   | 64                                   | 22.1                                                                   | 39.3            | 13.8                                                           | 33.0            |
|                                        | 4   | 66                                   | 21.9                                                                   | 41.5            | 15.1                                                           | 31.9            |
|                                        | 5   | 64                                   | 20.5                                                                   | 41.0            | 14.6                                                           | 33.5            |
|                                        | 6   | 63                                   | 19.9                                                                   | 40.5            | 15.2                                                           | 33.8            |
|                                        | 7   | 55                                   | 20.4                                                                   | 40.1            | 14.3                                                           | 32.7            |
|                                        | 8   | 63                                   | 21.3                                                                   | 39.7            | 15.6                                                           | 32.1            |
|                                        | 9   | 63                                   | 21.9                                                                   | 41.7            | 14.9                                                           | 33.0            |
|                                        | 10  | 55                                   | 20.8                                                                   | 42.0            | 13.5                                                           | 32.8            |
|                                        | 11  | 64                                   | 22.4                                                                   | 40.6            | 14.0                                                           | 31.8            |
|                                        | 12  | 66                                   | 23.1                                                                   | 41.9            | 15.4                                                           | 34.0            |
|                                        | 13  | 54                                   | 23.0                                                                   | 41.1            | 15.6                                                           | 33.4            |
|                                        | 14  | 65                                   | 22.6                                                                   | 40.8            | 14.3                                                           | 32.9            |
|                                        | 15  | 61                                   | 21.5                                                                   | 40.3            | 15.0                                                           | 33.4            |
|                                        | 16  | 73                                   | 28.6                                                                   | 50.3            | 19.6                                                           | 39.8            |
|                                        | 17  | 69                                   | 25.4                                                                   | 48.7            | 17.4                                                           | 40.1            |
| Steel according to Comparative Example | 1   | 41                                   | 10.8                                                                   | 19.6            | 7.9                                                            | 27.9            |
|                                        | 2   | 42                                   | 11.6                                                                   | 20.1            | 8.1                                                            | 28.4            |
|                                        | 3   | 49                                   | 6.5                                                                    | 15.2            | 5.6                                                            | 21.9            |
|                                        | 4   | 49                                   | 10.6                                                                   | 23.2            | 8.4                                                            | 30.2            |

\*1) Carbide having a major diameter/minor diameter ratio of not lower than 3 and having a minor diameter of not smaller than 2  $\mu\text{m}$ .

\*2) The quantity of corrosion:

⊙ very small

○ small

△ slightly large

× large

[0041] Similarly to the carburized materials, in steel according to the invention, the surface C concentration was not lower than 0.7 %, the area percentage of carbide was not higher than 15 %, and the area percentage of rod-like carbide was not higher than 0.1 %. Accordingly, it is obvious that steel according to the invention is more excellent in corrosion resistance, rolling fatigue life and impact value than steel according to Comparative Examples.

It is further obvious that the carbonitrided materials are more excellent in corrosion resistance than the carburized materials, and that the rolling fatigue life of steel made of any one of the carbonitrided materials is improved under the contamination condition.

[0042] As described above, alloy components are added while balanced according to the invention. In addition, the surface C concentration, the area percentage of carbide and the area percentage of rod-like carbide after carburizing or carbonitriding treatment are made appropriate. As a result, there can be provided bearing steel which exhibits excellent corrosion resistance even in the case where the bearing steel is adapted to bearing parts in a rolling machine,

a thermal power generator, a hydraulic power generator, etc. and which is excellent in surface fatigue strength and rolling fatigue life and also excellent in carbonitriding characteristic.

## Claims

### 1. Bearing steel excellent in corrosion resistance comprising:

0.10 wt% to 0.35 wt% of C;  
less than 0.5 wt% of Si;  
0.2 wt% to 1.5 wt% of Mn;  
0.03 wt% or less of P;  
0.03 wt% or less of S;  
1.0 wt% to 3.5 wt% of Ni;  
1.0 wt% to 5.0 wt% of Cr;  
0.03 wt% to 2.5 wt% of Mo;  
0.005 wt% to 0.050 wt% of Al;  
0.003 wt% or less of Ti;  
0.0015 wt% or less of O;  
0.025 wt% or less of N; and

a substantially residual part of Fe,  
wherein the bearing steel after carburizing or carbonitriding treatment exhibits a surface C concentration of not lower than 0.7 %, contains 15 % or less by area of carbide and contains 0.1 % or less by area of carbide having an aspect ratio of not lower than 3 in terms of the ratio of major diameter to minor diameter and having a minor diameter of not smaller than 2  $\mu\text{m}$ .

2. The bearing steel according to claim 1 further comprising at least one of 0.05 wt% to 1.0 wt% of V, and 0.1 wt% or less of Nb as an alloy component.

3. The bearing steel according to claim 1, wherein Ni is set from 2.0 wt% to 3.0 wt%.

4. The bearing steel according to claim 1, wherein Cr is set from 1.0 wt% to 2.0 wt%.

5. The bearing steel according to claim 1, wherein Mo is set from 0.3 wt% to 1.0 wt%.

6. The bearing steel according to claim 1, wherein Ni is set from 2.0 wt% to 3.0 wt%, Cr is set from 1.0 wt% to 2.0 wt% and Mo is set from 0.3 wt% to 1.0 wt%.

7. The bearing steel according to claim 1, wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of lower than 0.9 %.

8. The bearing steel according to claim 2, wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of lower than 0.9 %.

9. The bearing steel according to claim 6, wherein the bearing steel after carburizing treatment exhibits the surface C concentration of lower than 0.9 %.

10. The bearing steel according to claim 1, wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of from 0.79 to 0.82 %.

11. The bearing steel according to claim 6, wherein the bearing steel after carbonitriding treatment exhibits the surface C concentration of from 0.79 to 0.82 %.

12. The bearing steel according to claim 1, wherein the bearing steel after carburizing exhibits the surface C concentration of not lower than 0.9 %.

13. The bearing steel according to claim 2, wherein the bearing steel after carburizing exhibits the surface C concen-

tration of not lower than 0.9 %.

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