cannot be imparted to the wire rod without spheroidizing annealing.

Prior Art Document

Patent Document

[0013]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2006-200039

[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2004-100016

[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2003-129176

[Patent Document 4] Japanese Unexamined Patent Application, First Publication No. 2003-171737

[Patent Document 5] Japanese Unexamined Patent Application, First Publication No. H08-260046

[Patent Document 6] Japanese Unexamined Patent Application, First Publication No. 2001-234286

[Patent Document 7] Pamphlet of International Publication No. WO2013/108828

[Patent Document 8] Japanese Unexamined Patent Application, First Publication No. 2003-49226

[Patent Document 9] Japanese Unexamined Patent Application, First Publication No. 2012-233254

Disclosure of the Invention

FIG. 2B is a schematic view showing an inner area.

FIG. 2C is a schematic view showing a center portion.

FIG. 2D is a view showing a C cross section of a wire rod.

FIG. 3 is a graph showing the relationship between the area ratio of pro-eutectoid cementite in a surface area and coil formability of a drawn wire.

FIG. 4 is a graph showing the relationship between the hardness in a surface area and coil formability of a drawn wire.

FIG. 5 is a graph showing the relationship between the difference between the hardness in a surface area and the hardness in a center portion and coil formability of a drawn wire.

Embodiments of the Invention

[0020]

Hereinafter, a steel wire rod for bearings having excellent drawability and excellent coil formability after drawing according to an embodiment of the present invention will be described. Since the embodiment is merely described in detail in order to afford a better understanding of the point of the present invention, the present invention is not limited by the embodiment unless otherwise specified.

[0021]

First of all, the steel composition of a wire rod according to the embodiment will be described. Hereinafter, % and ppm regarding units of amounts of chemical elements mean mass% and mass ppm, respectively.

[0022]

C: 0.95 - 1.10%

C is indispensable for imparting required strength to steel for bearings.

the hardenability of steel. Therefore, it is necessary that the amount of Mn be 0.20% or more. The amount of Mn is preferably 0.23% or more, and more preferably more than 0.25% in order to further enhance the hardenability. However, when steel includes an excessive amount of Mn, it wastes money because the above-described effects of Mn have been maximized. Furthermore, supercooled structures such as martensite tend to form in a cooling step after hot rolling, and cause harm to the drawability. Therefore, it is necessary that the upper limit of the amount of Mn be 1.20%. The amount of Mn is preferably 1.00% or less, and more preferably 0.80% or less or less than 0.50%.

[0025]

Cr: 0.90 - 1.60%

Cr heightens the hardenability, and accelerates spheroidizing during a heat treatment of a drawn wire and increases the amount of carbides. In addition, Cr is highly effective at inhibiting the size of pearlite blocks from increasing during slow cooling after rolling. However, when the amount of Cr is less than 0.90%, Cr does not produce the above-described effects sufficiently, and thereby the product characteristics of bearing parts decreases. Therefore, it is necessary that the amount of Cr be 0.90% or more. The amount of Cr is preferably more than 1.00% or 1.10% or more, and more preferably 1.20% or more or 1.30% or more in order to obtain a higher hardenability. On the other hand, when the amount of Cr is more than 1.60%, the hardenability is excessive, and supercooled structures such as martensite and bainite tend to form in a cooling step after hot rolling. Therefore, it is necessary that the upper limit of the amount of Cr be 1.60%. The amount of Cr is preferably less than 1.50%, and more preferably 1.40% or less in order to secure more stable drawability.

[0026]

P: 0 - 0.020%

N: 0 - 0.030%

N is an impurity. When the amount of N is more than 0.030%, large size inclusions form, and the drawability of a wire rod and the product characteristics of bearing parts deteriorate. Therefore, the amount of N is 0.030% or less. N combines with Al or B to form nitrides, and the nitrides reduce the size of crystal grains by acting as pinning particles. Therefore, when the amount of N is small, steel may include N. For example, the lower limit of the amount of N may be 0.003%. The lower limit of the amount of N may be 0.005% in order to further enhance the effect of N on grain refining.

[0032]

Al: 0.010 -0.100%

Al is a deoxidizing element. When the amount of Al is less than 0.010%, the drawability of a wire rod and the product characteristics of bearing parts deteriorate because oxides precipitate as a result of insufficient deoxidation. When the amount of Al is more than 0.100%, Al_2O_3-based inclusions form, and thereby the drawability of a wire rod and the product characteristics of bearing parts deteriorate. Therefore, the amount of Al is 0.010% to 0.100%. It is preferable that the amount of Al be 0.015% to 0.078% in order to prevent the drawability and the quality of products from deteriorating more reliably. More preferably, the amount of Al may be 0.018% to 0.050%.

[0033]

Though steel may include chemical elements other than the above-described chemical elements as impurities, the amounts of such impurities are limited in the manner described in JIS G 4805. That is, the amount of Cu is limited to 0.20% or less, and the amounts of elements other than the above-described elements are limited to 0.25% or less.

[0034]

precipitated pro-eutectoid cementite is small. However, when a large amount of pro-eutectoid cementite precipitates so as to enclose prior austenite grains, the pro-eutectoid cementite hampers the prior austenite grains from deforming during drawing, and thereby the drawability decreases. Therefore, it is necessary that the area ratio of pro-eutectoid cementite be limited to 5.0% or less in the inner area. The area ratio of pro-eutectoid cementite is preferably limited to 3.0% or less, and more preferably limited to less than 3.0% or 2.8% or less in order to more consistently secure the drawability. The structures (the balance) except pearlite and pro-eutectoid cementite are at least one selected from the group consisting of bainite, ferrite, and spheroidal cementite, and it is necessary to limit the area ratio of the balance to 10% or less. The area ratio of the balance is preferably limited to 8.0% or less, and more preferably limited to less than 5.0% or 3.0% or less in order to more consistently secure the drawability.

[0039]

Thus, in the embodiment, a small amount of pro-eutectoid cementite is allowed to precipitate, but it is desirable that pro-eutectoid cementite does not precipitate, unlike the above-described Patent Document 2.

[0040]

The diameter (grain size) of pearlite blocks has a very strong correlation with ductility, and when the grain size of pearlite blocks is reduced, the drawability is improved. In particular, the grain size of pearlite blocks is coarse, the pearlite blocks increase the possibility that internal cracks appear during drawing, and the drawn wire is broken. Therefore, it is important to limit the grain size of pearlite blocks so as not to be excessively large. Accordingly, the maximum grain size of pearlite blocks is limited to 40 μm or less in order to improve the drawability sufficiently by inhibiting internal cracks from appearing. That is, it is necessary that the area ratio of pearlite blocks

having an equivalent circle diameter of more than 40 μm be 0.62% or less. In addition, it is more preferable that the maximum grain size of pearlite blocks be limited to 35 μm or less. That is, it is more preferable that the area ratio of pearlite blocks having an equivalent circle diameter of more than 35 μm or less be 0.48% or less.

[0041]

Next, the structure of the surface area will be described.

[0042]

When a drawn wire is formed into a coil, flexure and torsion are applied to the drawn wire. Since the extent of deformation caused by the flexure and torsion is the largest in the surface area, it is important to control the microstructure (the amount of pearlite, the amount of pro-eutectoid cementite, hardness, and difference in hardness between the surface area and a center portion) in the surface area. For example, when the amount of pearlite is small, the wire breaking occurs during winding the drawn wire into a coil. In addition, for example, as shown in FIG. 3, when the amount of pro-eutectoid cementite is large and a network pro-eutectoid cementite exists, the wire breaking occurs during winding the drawn wire into a coil. Therefore, it is necessary that the area ratio of pearlite be 80% or more and the area ratio of pro-eutectoid cementite be limited to 2.0% or less in the surface area in order to secure the coil formability. The area ratio of pearlite in the surface area is preferably 85% or more or 90% or more, and more preferably more than 95% or 97% or more in order to further enhance the coil formability. Here, pearlite includes degenerated pearlite. The structures (the balance) except pearlite and pro-eutectoid cementite are at least one selected from the group consisting of bainite, ferrite, and spheroidal cementite, and it is necessary to limit the area ratio of the balance to 20% or less. The area ratio of the balance is preferably limited to 15% or less or 10% or less, and more preferably limited to less

[0044]

Furthermore, the difference in structure between a surface area and an inner area decreases the coil formability. The structure in each position varies with, for example, chemical composition, a cooling control after hot rolling, and the microscopic distribution of chemical elements, and the difference in structure reaches a maximum between the surface of a wire rod and the center of the wire rod. Therefore, the difference between the structure in a surface area and the structure in an inner area is defined as the difference between the hardness in the surface area and the hardness in a center portion. When the difference between the hardness in a surface area and the hardness in a center portion is higher than HV 20.0, a wire breaking occurs during winding the drawn wire into a coil, as shown in FIG. 5. Therefore, it is necessary that the difference in hardness between a surface area and a center portion be limited to HV 20.0 or lower. That is, the range of the difference in hardness between a surface area and a center portion is HV 0 to HV 20.0.

[0045]

The measurement method of the above-described structures will be described.

The area ratios of pro-eutectoid cementite and pearlite are measured as follows. A sample is cut out from a wire rod at an unprescribed position, is embedded in a resin, and is polished with a coarse abrasive so that the C cross section of a wire rod (a cross section perpendicular to a center line of the wire rod) is a surface (cutting surface). Next, the sample is polished with alumina for the final polish, and is etched using 3% nital solution or picral. After that, the etched surface is observed under a scanning electron microscope (SEM) in order to identify the phase and structure. Furthermore, photographic images are obtained in 10 points each of the surface area and the inner area under a magnification of 2,000-fold using the SEM (the field of the SEM per one image:

by the finish rolling from growing with generation of processing heat (increase in temperature) during the finish rolling. When the size of austenite grains increases, the size of pearlite blocks increases, and variations in hardness increases. Therefore, it is necessary that the average cooling rate be 5 °C/s or higher in a temperature range of 700°C or higher in order to decrease the amount of pro-eutectoid cementite in the surface area sufficiently and more consistently secure fine pearlite blocks and uniform hardness in a C cross section. On the other hand, when the average cooling rate is higher than 20 °C/s at a temperature range of 700°C or higher, the manufacturing cost increases with an increase in facility cost, and the coil formability decreases with an increase in hardness in the surface area. Therefore, it is necessary that the upper limit of the average cooling rate be 20 °C/s. It is preferable that the average cooling rate be 15 °C/s or lower in order to further decrease the hardness in the surface area. When the wire rod is wound into a ring shape at a temperature range of less than 700°C, flaws tend to form on the surface of the wire rod. Therefore, the wire rod is wound at 700°C or higher.

[0057]

When the hot-rolled wire rod is cooled to 700°C at an average cooling rate of 5 to 20 °C/s, and then the hot-rolled wire rod is cooled to a temperature range of 700°C or lower, austenite is transformed to pearlite. Therefore, the average cooling rate in a temperature range of 700°C or lower is a factor for controlling the pearlite transformation temperature. When the average cooling rate is higher than 1.0 °C/s, the pearlite transformation temperature decreases to lower than 650°C. As a result, the drawability and coil formability after drawing decrease because the hardness increases in a surface area and/or the difference in hardness between a surface area and a center portion increases. Therefore, it is necessary that the average cooling rate be 1.0 °C/s or lower in

then was hot rolled so that the finish rolling started from a temperature range of 700 to 800°C. After that, the cooling condition was controlled step by step as follows: the average cooling rate was 5 to 20 °C/s in a temperature range from a temperature at which the hot rolling was completed to 700°C, the average cooling rate was 0.1 to 1 °C/s in a temperature range from 650 to 700°C, and the pearlite transformation temperature was 650 to 700°C. The diameters of the wire rods were 3.6 to 5.5 mm.

[0064]

In the wire rods of Nos. 15 to 21, the following partial modification was made to the above-described basic method. In addition, in the wire rod of No. 22, the above-described basic method was not used, but the following method was used instead. That is, a hot-rolled wire rod having a grain size number of austenite of 9.5 and a diameter of wire rod of 3.0 mm was obtained by controlling the hot rolling conditions of a billet. After that, the obtained hot-rolled wire rod was cooled to 650°C at a constant cooling rate of 9 °C/s, and then was cooled to from 650°C to 400°C at a constant rate of 1.0 °C/s so as to have a lamellar spacing of pearlite of 0.08 μm.

[0065]

The area ratio of pro-eutectoid cementite and the area ratio of pearlite were determined in a surface area (area in a range of a depth 0.1 × r (mm) from the surface of a wire rod (r: radius of the steel wire rod)) and an inner area (area other than the surface area), and then the maximum size of pearlite blocks was determined in the inner area.

[0066]

The obtained wire rod was embedded in a resin, and was polished with a coarse abrasive so that the C cross section of the wire rod was a surface. The surface was polished with alumina for the final polish, and then was etched using 3% nital or picral. After that, the phase and structure were identified by an observation using a SEM, and