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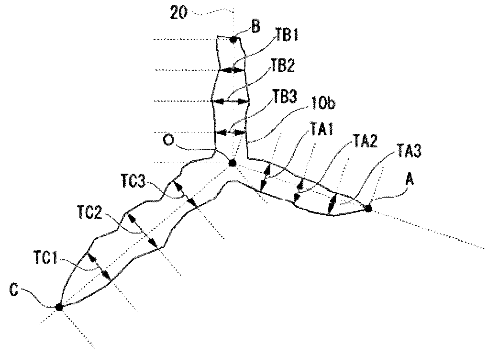
(54) **WIRE ROD AND MANUFACTURING METHOD THEREFOR**

(57) A wire rod according to an embodiment has a predetermined chemical composition, in which, in a structure observed in a central part of a cross section of the wire rod, the area fraction of pearlite is 90.0% or more, the area fraction of pro-eutectoid cementite is 1.00% or less, the average thickness of the pro-eutectoid cementite is 0.25 μm or less, the total length of the pro-eutectoid cementite per unit area is less than 40.0 mm/mm$^2$, the tensile strength satisfies Formula (1), and the diameter is 3.0 to 5.5 mm.

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 70 \leq TS \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 160 \ldots \text{Formula (1)}$$

[FIG. 3]

FIG. 3

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**Description**

[Technical Field of the Invention]

**[0001]** The present invention relates to a wire rod and a manufacturing method thereof.

**[0002]** Priority is claimed on Japanese Patent Application No. 2016-211590, filed on October 28, 2016, the content of which is incorporated herein by reference.

[Related Art]

**[0003]** High strength steel wires such as steel cords and sawing wires are typically manufactured by wire-drawing a high carbon steel wire rod having a C content of about 0.7% to 0.9%. Since high carbon steel has high strength, wire breaks tend to occur during wire-drawing. When the working strain is increased by wire-drawing, the drawn wire undergoes high-strengthening and decreases in ductility, and thus wire breaks particularly tend to occur. Wire breaks during wire-drawing significantly reduce productivity. Therefore, there is a demand for a high carbon steel wire rod (that is, a high carbon steel wire rod having good drawability) which is less likely to break during wire-drawing.

**[0004]** On the other hand, high strength is required for steel wires. For example, steel cords require high-strengthening for a weight reduction of tires and improvement of fuel economy of automobiles. Sawing wires require high-strengthening and a reduction in diameter in order to prevent wire breaks during cutting of a silicon wafer and reduce a cutting margin. In order to meet the demand of steel wires for strength, as a steel material, high carbon steel, particularly hyper-eutectoid steel containing C in an amount more than that of eutectoid steel is used.

**[0005]** In hyper-eutectoid steel, in general, pro-eutectoid cementite precipitates in a hot rolled wire rod, so that the drawability of the wire rod significantly decreases. Therefore, it is desirable to limit the amount of pro-eutectoid cementite precipitated in the hot rolled wire rod of the hyper-eutectoid steel. Here, in this specification, the "hot rolled wire rod" means the wire rod as hot-rolled after hot rolling which has not been subjected to a reheating treatment.

**[0006]** Patent Document 1 discloses that the drawability of a hot rolled wire rod is improved by defining the pearlite lamellar spacing of the hot rolled wire rod. However, in Patent Document 1, the influence of pro-eutectoid cementite on drawability is not examined. In addition, in Patent Document 1, a step of setting a cooling rate from winding to a predetermined temperature to 20 °C/s or more and thereafter performing heating is provided, and thus the manufacturing process is complex. Furthermore, there are problems that the load on the cooling capacity after the winding is large and the manufacturing costs increase.

**[0007]** Patent Document 2 aims at improving the drawability of a hot rolled wire rod by limiting the tensile strength, reduction in area after breaking, nodule diameter, and the like of the hot rolled wire rod. However, as in Patent Document 1, in Patent Document 2, the influence of pro-eutectoid cementite on the drawability is not examined. If the reduction in area after breaking, nodule diameter, and the like limited in Patent Document 2 are realized in a wire rod having a large C content, a large amount of pro-eutectoid cementite precipitates, and there may be a case that the drawability decreases.

**[0008]** In Patent Document 3, the drawability of a wire rod is improved by refining austenite grains of the wire rod after hot rolling and causing the area fraction, aspect ratio, and the like of pro-eutectoid cementite after cooling to be in predetermined ranges. By further reducing the tensile strength of the wire rod disclosed in Patent Document 3, the improvement of drawability and a reduction in manufacturing costs due to a reduction in the load during wire-drawing are expected.

[Prior Art Document]

[Patent Documents]

**[0009]**

[Patent Document 1] Japanese Patent No. 5179331
[Patent Document 2] Japanese Patent No. 4088220
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2001-181789

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

**[0010]** The present invention has been made to solve the above problems. That is, an object of the present invention is to provide a wire rod which contains C in an amount more than that of eutectoid steel, is obtained without a reheating treatment after hot rolling, and has excellent drawability, and a manufacturing method thereof.

[Means for Solving the Problem]

**[0011]** The present inventors produced high carbon steel hot rolled wire rods (hereinafter, sometimes referred to as "wire rods") in which the metallographic structure and tensile strength were controlled under various manufacturing conditions, using steels having a C content of 0.90% to 1.15%. The inventors evaluated the drawability of the wire rods, and examined the influence of the structure and tensile strength of the wire rods on the drawability. As a result, the inventors obtained findings that the drawability of a wire rod is improved by controlling the tensile strength in a predetermined range depending on the C content and the Cr content, limiting the area fraction and thickness of pro-eutectoid cementite, and furthermore controlling the total length of the pro-eutectoid cementite per unit area. In this specification, "drawability" refers to a property that can be drawn without wire breaks. In this specification, the drawability of a wire rod is evaluated by true strain at the time of occurrence of breaking during wire-drawing.

**[0012]** The present invention has been completed on the basis of the above findings, and the summary thereof is as follows.

(1) According to an aspect of the present invention, a wire rod includes, by mass%: C: 0.90% to 1.15%; Si: 0.10% to 0.50%; Mn: 0.10% to 0.80%; Cr: 0.10% to 0.50%; Ni: 0% to 0.50%; Co: 0% to 1.00%; Mo: 0% to 0.20%; B: 0% to 0.0030%; P: limited to 0.020% or less; S: limited to 0.010% or less; and a remainder including of Fe and impurities, in which, when a radius of the wire rod is assumed to be R, in a structure observed in a central part within (1/5)R from a center of a cross section of the wire rod, an area fraction of pearlite is 90.0% or more, and an area fraction of pro-eutectoid cementite is 1.00% or less, an average thickness of the pro-eutectoid cementite in the central part is 0.25 $\mu$m or less, a total length of the pro-eutectoid cementite per unit area in the central part is less than 40.0 mm/mm$^2$, a tensile strength of the wire rod satisfies Formula (1), and a diameter of the wire rod is 3.0 to 5.5 mm,

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 70 \leq \text{TS} \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 160 \ldots \text{Formula (1)}$$

where the total length of the pro-eutectoid cementite per unit area (mm/mm$^2$) is a sum of lengths of pro-eutectoid cementite observed per unit area, TS in Formula (1) represents the tensile strength of the wire rod when a unit of TS is MPa, "C content (%)" in Formula (1) represents an amount of C contained in the wire rod by mass%, and "Cr content (%)" represents an amount of Cr contained in the wire rod by mass%.

(2) The wire rod according to (1) may contain any one or two or more of, by mass%: Ni: 0.10% to 0.50%; Co: 0.10% to 1.00%; Mo: 0.05% to 0.20%; and B: 0.0002% to 0.0030%.

(3) In the wire rod according to (1) or (2), the area fraction of the pro-eutectoid cementite may be more than 0% to 1.00%.

(4) In the wire rod according to any one of (1) to (3), the wire rod may contain one or two or more of pro-eutectoid cementite, intergranular ferrite, and bainite in the structure observed in the central part.

(5) According to another aspect of the present invention, a manufacturing method of the wire rod wherein a steel piece having a composition according to (1) is subject to: a hot rolling into a diameter of 3.0 to 5.5 mm; a winding at 940°C to 800°C; and a cooling at an average cooling rate of 6.0 to 15.0 °C/s to 650°C after the winding, at an average cooling rate of 1.0 to 3.0 °C/s at 650°C to 600°C, and at an average cooling rate of 10.0 °C/s or more at 600°C to 300°C.

[Effects of the Invention]

**[0013]** According to the aspects, it is possible to provide a wire rod which contains C in an amount more than that of eutectoid steel, is obtained without a reheating treatment after hot rolling, and has excellent drawability, and a manufacturing method thereof. In addition, according to the above aspects, it is possible to improve the drawability of a wire rod having a hyper-eutectoid steel composition without extra facility costs. In addition, according to the above aspects, it is possible to limit cost increasing factors (an increase in the wire breaking rate during wire-drawing, execution of intermediate patenting, an increase in wear of a die, an increase in load during wire-drawing, and the like) caused by high-strengthening of a steel cord and a sawing wire. Therefore, the wire rod according to the aspects is useful as a material of a high strength steel wire such as a steel cord used as a reinforcing material for tires and hoses, and a sawing wire used for cutting a silicon wafer or the like.

[Brief Description of the Drawings]

**[0014]**

FIG. 1 is a schematic view showing the state of pro-eutectoid cementite precipitated at a prior austenite grain boundary.
FIG. 2 is a view showing a method of measuring the thickness and length of pro-eutectoid cementite.
FIG. 3 is a view showing a method of measuring the thickness and length of pro-eutectoid cementite.
FIG. 4 is a view showing a method of measuring the thickness and length of pro-eutectoid cementite.

[Embodiments of the Invention]

**[0015]** Hereinafter, a wire rod according to an embodiment will be described. This embodiment is described in detail in order to achieve better understanding of the gist of the present invention, and does not limit the present invention unless otherwise specified.
**[0016]** First, the steel composition of the wire rod according to this embodiment will be described. Hereinafter, unless otherwise specified, % regarding the steel composition indicates mass%.

C: 0.90% to 1.15%

**[0017]** C is an essential element for securing the strength of a steel wire. When the C content is less than 0.90%, the strength of the steel wire decreases. Therefore, the lower limit of the C content is set to 0.90%. A preferable lower limit of the C content is 0.96%, or 1.00%. On the other hand, when the C content exceeds 1.15%, a large amount of pro-eutectoid cementite is precipitated in the wire rod, and wire breaks easily occur. In addition, when the C content exceeds 1.15%, the strength of the wire rod and the steel wire excessively increases, and the drawability of the wire rod and the steel wire decreases. Therefore, the upper limit of the C content is set at 1.15%. A preferable upper limit of the C content is 1.10% or 1.08%.

Si: 0.10% to 0.50%

**[0018]** Si has an effect of increasing the strength of ferrite in pearlite. In order to effectively exhibit the above effect, the lower limit of the Si content is set to 0.10%. A preferable lower limit of the Si content is 0.15%, or 0.20%. However, when Si is excessively contained, $SiO_2$-based inclusions which are harmful to the drawability of the wire rod may be generated in some cases. Therefore, the upper limit of the Si content is set to 0.50%. A preferable upper limit of the Si content is 0.40%, or 0.35%.

Mn: 0.10% to 0.80%

**[0019]** Mn has an effect of delaying the transformation from austenite to pro-eutectoid cementite and pro-eutectoid ferrite, and is an element useful for obtaining a structure primarily containing pearlite. In order to effectively exhibit the above effect, the lower limit of the Mn content is set to 0.10%. A preferable lower limit of the Mn content is set to 0.20% or 0.30%. However, even if Mn is excessively contained, the above effect is saturated. Furthermore, Mn has an effect of improving the hardenability of steel. Therefore, in a case where the wire rod excessively contains Mn, a supercooled structure such as bainite and martensite is generated in the wire rod in a cooling process after hot rolling, or the strength of the wire rod excessively increases, resulting in the deterioration of drawability. Therefore, the upper limit of the Mn content is set to 0.80%. A preferable upper limit of the Mn content is 0.70%, 0.60%, or 0.50%.

Cr: 0.10% to 0. 50%

**[0020]** Cr has an effect of increasing the work hardening rate of pearlite in steel. As the work hardening rate of the pearlite increases, higher tensile strength can be obtained in wire-drawing with low strain. In addition, since Cr has an effect of delaying the transformation from austenite to pro-eutectoid cementite and pro-eutectoid ferrite, Cr is an element useful for obtaining a structure primarily containing pearlite. In order to effectively exhibit the above effect, the lower limit of the Cr content is set to 0.10%. A preferable lower limit of the Cr content is 0.15% or 0.20%. However, in a case where the Cr content exceeds 0.50%, the hardenability of the wire rod increases, and a supercooled structure such as bainite and martensite is generated in a cooling process after hot rolling, or the wire rod undergoes excessive high-strengthening, resulting in the decrease in the drawability. Therefore, the upper limit of the Cr content is set at 0.50%. A preferable upper limit of the Cr content is 0.40% or 0.35%.

**[0021]** Both Mn and Cr are elements having effects of improving the hardenability of steel and delaying the transformation to pro-eutectoid cementite. In order to limit the generation of a non-pearlite structure (such as pro-eutectoid cementite, bainite, and martensite) in the wire rod, it is preferable to control the total amount of Mn and Cr. The lower limit of the total amount of Mn and Cr is preferably 0.40% or 0.45%. The upper limit of the total amount of Mn and Cr is preferably 0.60% or 0.55%.

**[0022]** In addition to the above-described base elements, the wire rod according to this embodiment may further selectively contain one or two or more of Ni, Co, Mo and B described below. In a case where these elements are not contained, the amount of these elements is 0%.

Ni: 0% to 0.50%

**[0023]** Ni has an effect of delaying the transformation from austenite to pro-eutectoid cementite and pro-eutectoid ferrite and is thus an element useful for obtaining a structure primarily containing pearlite. Ni is also an element having an effect of increasing the toughness of a drawn wire. In order to obtain the above effect, it is preferable to set the lower limit of the Ni content to 0.10%. A more preferable lower limit of the Ni content is 0.15% or 0.20%. On the other hand, when Ni is excessively contained, hardenability becomes excessive, and supercooled structures such as bainite and martensite are generated in the wire rod in a cooling process after hot rolling, so that there may be a case where the drawability of the wire rod decreases. Therefore, it is preferable to set the upper limit of the Ni content to 0.50%. A more preferable upper limit of the Ni content is 0.30% or 0.25%.

Co: 0% to 1.00%

**[0024]** Co has an effect of limiting precipitation of pro-eutectoid ferrite in a rolled wire rod. In addition, Co has an effect of improving the ductility of the drawn wire. In order to effectively exhibit the above effect, it is preferable to set the lower limit of the Co content set to 0.10%. A more preferable lower limit of the Co content is 0.20%, 0.30%, or 0.40%. On the other hand, even if Co is excessively contained, the above effect is saturated, so that the cost increases. Therefore, it is preferable to set the upper limit of the Co content to 1.00%. A more preferable upper limit of the Co content is 0.90% or 0.80%.

Mo: 0% to 0.20%

**[0025]** Mo has an effect of delaying the transformation from austenite to pro-eutectoid cementite and pro-eutectoid ferrite and is an element useful for obtaining a structure primarily containing pearlite. In order to obtain the above effect, it is preferable to set the lower limit of the Mo content to 0.05%. A more preferable lower limit of the Mo content is 0.08%. However, when the Mo content exceeds 0.20%, the hardenability becomes excessive, and a supercooled structure such as bainite and martensite is generated in a cooling process after hot rolling, or the drawability of the wire rod decreases in some cases. Therefore, it is preferable to set the upper limit of the Mo content to 0.20%. A more preferable upper limit of the Mo content is 0.15% or 0.11%.

B: 0% to 0.0030%

**[0026]** B has an effect of being concentrated at grain boundaries and thus limiting precipitation of pro-eutectoid ferrite. In order to obtain the above effect, it is preferable to set the lower limit of the B content to 0.0002%. A more preferable lower limit of the B content is 0.0005%, 0.0007%, 0.0008%, or 0.0009%. On the other hand, when B is excessively contained, B may form carbides such as $Fe_{23}(CB)_6$ in austenite, so that there may be a case where the drawability of the wire rod decreases. Therefore, it is preferable to set the upper limit of the B content to 0.0030%. A more preferable upper limit of the B content is 0.0020%.

**[0027]** The wire rod according to this embodiment contains the above-described base elements and one or two or more of Ni, Co, Mo, and B as necessary, and the remainder substantially consists of Fe and impurities. There may be a case where P and S are contained in the wire rod according to this embodiment as impurities incorporated during the production of molten steel.

P: 0.020% or Less

**[0028]** P is an element that segregates at the grain boundaries and thus reduces the drawability of the wire rod. Therefore, it is preferable to reduce the P content as much as possible. In order to secure the drawability of the wire rod, the upper limit of the P content is set to 0.020%. A preferable upper limit of the P content is 0.014%, or 0.010%. P may be incorporated as impurities during the production of molten steel in some cases, but there is no need to particularly limit the lower limit thereof, and the lower limit thereof is 0%. When the P content is excessively reduced, there may be a case where the melting cost increases, so that the lower limit of the P content may be set to 0.003% or 0.005%.

S: 0.010% or Less

**[0029]** S is an element that precipitates with Mn or the like and thus reduces the drawability of the wire rod. Therefore, it is preferable to reduce the S content as much as possible. In order to secure the drawability of the wire rod, the upper limit of the S content is set to 0.010%. A preferable upper limit of the S content is 0.008%, 0.007%, or 0.005%. S may be incorporated as impurities during the production of molten steel in some cases, but there is no need to particularly limit the lower limit thereof, and the lower limit thereof is 0%. When the S content is excessively reduced, there may be a case where the melting cost increases, so that the lower limit of the S content may be set to 0.001% or 0.003%.

**[0030]** The wire rod according to this embodiment contains pearlite as the primary structure, and the residual structure contains any one or two or more of pro-eutectoid cementite, intergranular ferrite, and bainite. The pro-eutectoid cementite, intergranular ferrite, and bainite as the residual structures may become the propagation path of fracture in some cases, and as the area fraction of the residual structures increases, the drawability of the wire rod decreases in some cases. Therefore, in the wire rod according to this embodiment, when the radius of the wire rod is assumed to be R, in a structure observed in a central part within (1/5)R from the center of a cross section of the wire rod, the area fraction of the pearlite is set to 90.0% or more and the area fraction of the pro-eutectoid cementite is set to 1.00% or less. A preferable area fraction of the pearlite is 93.0% or more, 95.0% or more, or 97.0% or more. A preferable area fraction of the pro-eutectoid cementite is 0.50% or less, or 0.20% or less.

**[0031]** In the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, the area fraction of the pearlite may be 100%. However, in the chemical composition of the wire rod according to this embodiment, it is difficult to completely limit precipitation of pro-eutectoid cementite, intergranular ferrite, and bainite. In order to cause the area fraction of the pearlite to be 100% in the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, superior cooling capacity is required, and there are a case where the facility cost increases, a case where the drawability decreases due to an increase in the tensile strength of the wire rod, and a case where the cost increases due to secondary work caused by an increase in the load during wire-drawing. Therefore, in the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, the area fraction of the pearlite may be less than 100%.

**[0032]** When the amount of precipitated pro-eutectoid cementite is small, the pro-eutectoid cementite does not reduce the drawability of the wire rod. On the other hand, in the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, in order to cause the area fraction of the pro-eutectoid cementite to be 0%, excellent cooling capacity is required, and there may be a case where the facility cost increases. Therefore, in the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, the area fraction of the pro-eutectoid cementite may be more than 0%.

**[0033]** In the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, it is preferable to reduce the area fraction of the intergranular ferrite and bainite as much as possible. It is preferable to set the total area fraction of the intergranular ferrite and bainite to 5.0% or less, or 4.5% or less. Setting the total area fraction of the intergranular ferrite and bainite to 0% may increase the manufacturing cost in some cases, so that the total area fraction of the intergranular ferrite and bainite may be more than 0%.

**[0034]** The pro-eutectoid cementite in the wire rod is a cause of wire breaks during wire-drawing. However, when the amount of precipitated pro-eutectoid cementite is small, a decrease in the drawability can be limited by appropriately adjusting the relationship with prior austenite grain boundaries. Specifically, by reducing the thickness of the pro-eutectoid cementite and shortening the total length of the pro-eutectoid cementite per unit area, a decrease in the drawability of the wire rod can be limited.

**[0035]** The thickness and the total length of the pro-eutectoid cementite will be described with reference to FIGS. 1 to 4. FIG. 1 is a schematic view showing the state of pro-eutectoid cementite precipitated at a prior austenite grain boundary. FIG. 2 is a view showing a method of measuring the thickness and length of pro-eutectoid cementite 10a in FIG. 1. FIGS. 3 and 4 are views showing methods of measuring the thickness and length of pro-eutectoid cementite 10b and 10c in FIG. 1, respectively.

**[0036]** Pro-eutectoid cementite precipitates in a shape along the prior austenite grain boundary. Specifically, as shown in FIG. 1, pro-eutectoid cementite 10a to 10d precipitate along a prior austenite grain boundary 20. For each of the pro-eutectoid cementite, the length is defined in a direction along the prior austenite grain boundary, and the thickness is defined in a direction perpendicular to the prior austenite grain boundary. Regarding the thickness of the pro-eutectoid cementite, the thickness is measured at three points at intervals at which the length is quartered in the direction along the prior austenite grain boundary, and the average of the measured values is defined as the thickness of the pro-eutectoid cementite. In the measurement of the thickness of the pro-eutectoid cementite, in a case where measurement points are different from typical cases, for example, in a case of branch points and end portions, these points are not included in the average. That is, in FIG 2, the length of the pro-eutectoid cementite 10a is L1, and the thickness of the pro-eutectoid cementite 10a is the average of T1, T2, and T3. Like the pro-eutectoid cementite 10b in FIG. 1, in pro-eutectoid cementite having branches, the sum of the lengths of the branches is defined as the length of the pro-eutectoid cementite. That is, in FIG. 3, the length of the pro-eutectoid cementite 10b is the sum of OA, OB and OC. In addition, the thickness of the pro-eutectoid cementite is measured in each of the branches at three points at intervals at which the length is quartered in the direction along the prior austenite grain boundary as described above, and the average of the measured values is defined as the thickness of the pro-eutectoid cementite. That is, in FIG. 3, the thickness of the pro-eutectoid cementite 10b is the average of TA1, TA2, TA3, TB1, TB2, TB3, TC1, TC2, and TC3. Like the pro-eutectoid cementite 10c in FIG. 1, the length of pro-eutectoid cementite having a shape bent along the prior austenite grain boundary is measured along the prior austenite grain boundary. That is, in FIG. 4, the length of the pro-eutectoid cementite 10c is the sum of O'D and O'E. In addition, the thickness is divided at the bent part and is measured at three points in each part at intervals at which the length is quartered in the direction along the prior austenite grain boundary, and the average of the measured values is defined as the thickness of the pro-eutectoid cementite. That is, in FIG. 4, the thickness of the pro-eutectoid cementite 10c is the average of TD1, TD2, TD3, TE1, TE2, and TE3. The total length of the pro-eutectoid cementite in FIG. 1 is the sum of the lengths of the pro-eutectoid cementite 10a to 10d.

**[0037]** In the wire rod according to this embodiment, in the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, the average thickness of the pro-eutectoid cementite is set to 0.25 μm or less, and the total length of the pro-eutectoid cementite per unit area is set to be less than 40.0 mm/mm$^2$ A preferable average thickness of the pro-eutectoid cementite is 0.20 μm or less. A preferable total length of the pro-eutectoid cementite per unit area is 30.0 mm/mm$^2$ or less, 20.0 mm/mm$^2$ or less, or 10.0 mm/mm$^2$ or less. When the average thickness of the pro-eutectoid cementite exceeds 0.25 μm or the total length of the pro-eutectoid cementite per unit area becomes 40.0 mm/mm$^2$ or more, defects of the wire rod increase during wire-drawing, which may cause wire breaks in some cases.

**[0038]** In the wire rod according to this embodiment, in the structure observed in the central part within (1/5)R from the center of the cross section of the wire rod, the drawability of the wire rod may be further reduced by reducing the degree of occupation of the pro-eutectoid cementite in the prior austenite grain boundary. The degree of occupation of the pro-eutectoid cementite in the prior austenite grain boundary is evaluated by the product of the total length of the pro-eutectoid cementite per unit area and the prior austenite grain size as shown on the left side of Formula (A). It is preferable that the left side of Formula (A) is less than 1.2. More preferably, the left side of Formula (A) is less than 1.0.

$$\text{Total length (mm/mm}^2\text{) of pro-eutectoid cementite per unit area} \times \text{prior austenite grain size (mm)} < 1.2 \quad \text{...Formula (A)}$$

**[0039]** The tensile strength (MPa) of the wire rod according to this embodiment is defined by Formula (1) according to the C content (mass%) and Cr content (mass%).

**[0040]** When the tensile strength of the wire rod is lower than the lower limit value (left side) shown in Formula (1), coarsening of the pro-eutectoid cementite, and an increase in the area fraction of the pro-eutectoid cementite, or an increase in the thickness of lamellar cementite are incurred, so that there may be a case where the drawability of the wire rod decreases. On the other hand, when the tensile strength of the wire rod exceeds the upper limit value (right side) shown in Formula (1), the amout of work hardening by wire-drawing becomes large, and the tensile strength of the drawn wire increases while the ductility thereof decreases, so that there may be a case where the drawability of the drawn wire decreases. When the tensile strength of the wire rod exceeds the upper limit value (right side) shown in Formula (1), the load on a die and a wire-drawing machine increases, so that there may be a case where the manufacturing cost increases.

**[0041]** A preferable constant term of the right side of Formula (1) is +150 (MPa). In other words, it is preferable that the tensile strength of the wire rod satisfies Formula (2). A more preferable constant term of the left side of Formula (1) is +80 (MPa), and a more preferable constant term of the right side is +150 (MPa). In other words, it is more preferable that the tensile strength of the wire rod satisfies Formula (3). A more preferable constant term of the left side of Formula (1) is +90 (MPa), and a more preferable constant term of the right side is +140 (MPa). In other words, it is more preferable that the tensile strength of the wire rod satisfies Formula (4). In Formulas (1) to (4), TS represents the tensile strength of the wire rod, "C content (%)" represents the amount of C contained in the wire rod by mass%, and "Cr content (%)" represents the amount of Cr contained in the wire rod by mass%.

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 70 \leq \text{TS} \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 160 \ldots \text{Formula (1)}$$

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 70 \leq \text{TS} \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 150 \ldots \text{Formula (2)}$$

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 80 \leq \text{TS} \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 150 \ldots \text{Formula (3)}$$

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 90 \leq \text{TS} \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 140 \ldots \text{Formula (4)}$$

**[0042]** The diameter of the wire rod affects the cooling rate after winding, and accordingly affects the metallographic structure, tensile strength, and the like of the wire rod. When the diameter of the wire rod exceeds 5.5 mm, the cooling rate at the central part of the wire rod becomes slow, so that there may be a case where pro-eutectoid cementite is generated in a large amount in the wire rod. On the other hand, when the diameter of the wire rod is less than 3.0 mm, it becomes difficult to manufacture the wire rod, and the production efficiency decreases, so that there may be a case where the cost of the wire rod increases. Therefore, the wire diameter of the wire rod according to this embodiment is set to 3.0 to 5.5 mm.

**[0043]** The area fraction of pearlite and pro-eutectoid cementite is measured by the following method.

**[0044]** First, the wire rod is cut, and the wire rod is embedded in a resin so that a cross section perpendicular to the longitudinal direction of the wire rod can be observed. The wire rod embedded in the resin is polished with abrasive paper and alumina abrasive grains, and is further mirror-finished to obtain a sample. The observed section of the sample (that is, the cross section of the wire rod) is corroded with a nital solution or a picral solution and then the observed section of the sample is observed with a scanning electron microscope (SEM).

**[0045]** The nital solution is a mixed solution of nitric acid and ethyl alcohol. Corrosion of the observed section of the sample is performed by a method of immersing the observed section in the nital solution having a concentration of 5% or less and a temperature of about 15°C to 30°C for several seconds to one minute, a method of wiping the observed section with absorbent cotton soaked with the nital solution having the above concentration and temperature, or the like. The picral solution is a mixed solution of picric acid and ethyl alcohol. Corrosion of the observed section of the sample is performed by a method of immersing the observed section in the picral solution having a concentration of about 5% and a temperature of about 40°C to 60°C for 30 seconds to two minutes. After the corrosion, the observed section of the sample is immediately washed with water thoroughly, and is quickly dried with cold air or hot air.

**[0046]** Subsequently, using a photographing device attached to the SEM, a central part (a region within (1/5)R from the center of the wire rod with the radius of the wire rod as R) of the sample is photographed in a plurality of visual fields at a magnification of 2,000-fold or more so that the total observation visual field area is 0.08 $mm^2$ or more. Using the SEM photographs thereof and image analysis software such as particle analysis software, the area fractions of the pearlite and pro-eutectoid cementite of the central part of the wire rod are obtained.

**[0047]** The average thickness and length of the pro-eutectoid cementite are measured using the SEM photographs. The average thickness of the pro-eutectoid cementite is obtained by obtaining the thicknesses of all pro-eutectoid cementite in the SEM photographs and calculating the average value thereof. The thickness of the pro-eutectoid cementite is obtained by measuring the thickness in a direction perpendicular to a prior austenite grain boundary. In the case of the cementite 10a in FIG. 2, the thicknesses T1, T2, and T3 are measured, and the average thereof is taken as the thickness of the pro-eutectoid cementite. The length (mm) of the pro-eutectoid cementite is measured by drawing a line imaging the prior austenite grain boundary based on the shapes of the pro-eutectoid cementite in the SEM photographs and measuring the length along the line. Like the cementite 10a in FIG 2, in a case of cementite that does not have a particularly bent shape, a straight line imaging the prior austenite grain boundary is drawn along the major axis direction thereof and the length L1 is measured along the straight line. Like the cementite 10c in FIG. 4, in a case of pro-eutectoid cementite having a unique bent part, a line imagining the prior austenite grain boundary is drawn according to the shape, and the length of the pro-eutectoid cementite is measured along the line. Like the cementite 10b in FIG 3, in a case of pro-eutectoid cementite having branches, the lengths of the branches are added. The total length (mm/mm$^2$) of the pro-eutectoid cementite per unit area is set to a value obtained by dividing the sum of the lengths of pro-eutectoid cementite in a measurement visual field which is measured, by the area of the visual field. That is, the total length (mm/mm$^2$) of the pro-eutectoid cementite per unit area is the sum of the lengths of the pro-eutectoid cementite observed per unit area. Upon measurement, if necessary, a region including the pro-eutectoid cementite may be photographed at a higher magnification and the average thickness and length of the pro-eutectoid cementite may be measured.

**[0048]** The prior austenite grain size is measured using a wire rod which is quenched by water-cooling several rings from the final end of a coil immediately after winding after hot rolling. The quenched wire rod is cut, and the wire rod is embedded in a resin so that a cross section thereof can be observed. The wire rod embedded in the resin is polished with abrasive paper and alumina, and is further mirror-finished to obtain a sample. The observed section of the sample (that is, the cross section of the wire rod) is corroded with an alkaline picric acid solution to reveal prior austenite grain boundaries. Corrosion of the observed section of the sample is performed by immersing the observed section of the sample in the alkaline picric acid solution having a temperature of about 75°C to 90°C for 10 to 20 minutes. After the corrosion, the observed section of the sample is immediately washed with water thoroughly, and is quickly dried with cold air or hot air. The alkaline picric acid solution used for the corrosion of the observed section is a mixed solution of 2 parts of picric acid, 5 parts of sodium hydroxide, and 100 parts of water by weight.

**[0049]** After corroding the observed section, using an optical microscope, a central part (a region within (1/5)R from the center of the wire rod with the radius of the wire rod as R) of the observed section of the sample is photographed in a plurality of visual fields at a magnification of 400-fold or more so that the total observation visual field area is 0.15 mm$^2$ or more. Using the taken photographs and the cutting method described in JIS G 0551: 2013, prior austenite grain sizes are measured. In the cutting method, ten or more straight lines with a length of 400 μm are drawn at intervals of 100 μm so as not to overlap each other, and the grain sizes are evaluated by the number of grains trapped by straight lines of 4 mm or more in total.

**[0050]** The tensile strength of the wire rod is measured by the following method. In the wire rod, excluding unsteady parts, three or more samples are taken from a front part, a middle part, and a tail part of the wire rod coil. Using the taken samples, a tension test is conducted according to JIS Z 2241: 2011. The tensile strength of the wire rod is obtained by calculating the average value of the tensile strengths of all the samples.

**[0051]** Next, a manufacturing method of the wire rod according to this embodiment will be described. The manufacturing method described below is merely an example, and is not limited by the following procedures and methods, and any method can be adopted as long as the method can realize the configuration of the wire rod according to this embodiment.

**[0052]** Materials to be subjected to hot rolling can be obtained under typical manufacturing conditions. For example, steel having the above-mentioned elements is cast, and the cast piece is subjected to a soaking treatment (a heat treatment for reducing segregation occurring in casting) to be retained at about 1100°C to 1200°C for 10 to 20 hours, and the cast piece is subjected to blooming, thereby obtaining a steel piece having a suitable size for hot rolling (a steel piece before hot rolling generally called a billet).

**[0053]** Next, hot rolling is performed under the following conditions. First, the steel piece is heated to 900°C to 1200°C and the start temperature of finish rolling is controlled to 750°C to 950°C. The temperature of the wire rod during the hot rolling indicates the surface temperature of the wire rod. The temperature of the wire rod during the hot rolling can be measured using a radiation thermometer.

**[0054]** The temperature of the wire rod after the finish rolling is higher than the start temperature of the finish rolling due to deformation heating. In this embodiment, the winding temperature is controlled to 800°C to 940°C. When the winding temperature is lower than 800°C, austenite grain sizes of the wire rod are refined, so that there are a case where pro-eutectoid cementite, intergranular ferrite, and bainite tend to precipitate, and a case where the mechanical descaling properties of the wire rod decrease. On the other hand, when the winding temperature exceeds 940°C, the austenite grain sizes of the wire rod become excessively large, so that there may be a case where the drawability of the wire rod decreases. A preferable winding temperature is 830°C to 920°C. A more preferable winding temperature is 850°C to 900°C.

**[0055]** It is preferable that the prior austenite grain size of the wire rod is caused to be 15 to 60 μm by controlling the start temperature of the finish rolling and the winding temperature as described above. A more preferable prior austenite grain size is 20 to 45 μm.

**[0056]** The austenite in the wire rod transforms into pearlite during cooling after the winding. Therefore, the cooling rate after the winding is an important factor for controlling the structure and tensile strength of the wire rod. In this embodiment, the cooling after the winding is divided into three temperature ranges and the average cooling rate in each of the temperature ranges is controlled.

**[0057]** When the average cooling rate to 650°C after the winding is less than 6.0 °C/s, there may be a case where it is difficult to limit the precipitation of pro-eutectoid cementite. On the other hand, when the average cooling rate to 650°C after the winding exceeds 15.0 °C/s, there may be a case where transformation from austenite to bainite, a decrease in drawability due to high-strengthening, and a decrease in the mechanical descaling properties of the wire rod are incurred.

Furthermore, when the average cooling rate to 650°C after the winding exceeds 15.0 °C/s, large-scale cooling facilities are necessary, so that there may be a case where the facility cost increases. Therefore, after the winding, the average cooling rate to 650°C is set to 6.0 to 15.0 °C/s. After the winding, a preferable average cooling rate to 650°C is 7.0 to 10.0°C/s.

**[0058]** In a temperature range of 650°C to 600°C, the average cooling rate is controlled to 1.0 to 3.0 °C/s in order to transform austenite in the wire rod into pearlite. When the average cooling rate at 650°C to 600°C is less than 1.0 °C/s, there may be a case where the drawability of the wire rod decrease due to a decrease in the tensile strength of the wire rod or an increase in the thickness of the pro-eutectoid cementite. On the other hand, when the average cooling rate at 650°C to 600°C exceeds 3.0 °C/s, transformation from austenite to pearlite is not completed until 600°C, and the tensile strength of the wire rod increases, so that there are a case where the drawability decreases and a case where the service life of a drawing die decreases. A preferable average cooling rate at 650°C to 600°C is 1.5 to 2.8 °C/s.

**[0059]** In a temperature range of 600°C or less, the average cooling rate is set to 10.0 °C/s or more for cooling to 300°C or less. This is because the tensile strength of the wire rod decreases in some cases when the wire rod is retained at a temperature near the transformation temperature even after the transformation from austenite to pearlite. A preferable average cooling rate at 600°C to 300°C is 15.0°C/s or more. When the average cooling rate at 600°C to 300°C is set to be higher than 50 °C/s, excellent cooling facilities are necessary, resulting in an increase in facility costs. Therefore, the upper limit of the average cooling rate at 600°C to 300°C may be set to 50°C/s or less.

**[0060]** The temperature of the wire rod during the cooling may be measured with the radiation thermometer. In general, cooling of the wire rod after hot rolling is performed after winding in a coil form. The wire rod wound in a coil form has a dense part where there are many overlaps of the wire rod and a sparse part where there are few overlaps of the wire rod. In the manufacturing method of the wire rod according to this embodiment, the temperature of the wire rod after being wound is measured at a part of the wire rod wound in a coil form, where there are many overlaps of the wire rod (dense part).

**[0061]** By adjusting the manufacturing conditions as described above with the above-described composition, the structure and tensile strength of the wire rod can be within the ranges of the present invention.

[Examples]

**[0062]** Hereinafter, the present invention will be described in more detail with reference to examples of the wire rod according to the present invention. However, the present invention is not limited to the following examples as a matter of course, and can be performed with appropriate modifications within a scope conforming to the gist of the present invention, all of which are included in the technical scope of the present invention.

**[0063]** Table 1 shows the chemical compositions of steels and manufacturing conditions. Table 2 shows the evaluation results of the structures of wire rods and the evaluation results of tensile properties and drawability. Cooling rates 1 to 3 in Table 1 are as follows. The average cooling rate was controlled by adjusting the air volume of a blast. In Tables 1 and 2, numerical values outside the ranges of the present invention are underlined.

**[0064]**

Cooling rate 1: Average cooling rate to 650°C after winding
Cooling rate 2: Average cooling rate from 650°C to 600°C
Cooling rate 3: Average cooling rate from 600°C to 300°C

[Table 1]

| No. | Composition (mass%) remainder including of Fe and impurities | | | | | | | | | | Manufacturing conditions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Cr | Ni | Co | Mo | B (ppm) | Wire diameter (mm) | Winding temperature (°C) | Cooling rate 1 (°C/s) | Cooling rate 2 (°C/s) | Cooling rate 3 (°C/s) |
| A1 | 0.93 | 0.21 | 0.30 | 0.008 | 0.008 | 0.19 | | | | | 5.5 | 805 | 6.4 | 1.8 | 13.5 |
| A2 | 0.96 | 0.19 | 0.30 | 0.012 | 0.008 | 0.20 | | | | | 5.5 | 871 | 9.8 | 2.5 | 11.4 |
| A3 | | | | | | | | | | | 5.5 | 815 | 6.3 | 1.9 | 12.3 |
| A4 | | | | | | | | | | | 4.0 | 915 | 10.5 | 2.2 | 10.9 |
| A5 | | | | | | | | | | | 5.0 | 889 | 6.2 | 1.5 | 11.1 |
| A6 | 1.02 | 0.19 | 0.31 | 0.013 | 0.005 | 0.19 | | | | | 5.5 | 878 | 7.3 | 2.6 | 10.6 |
| A7 | | | | | | | | | | | 4.5 | 853 | 9.9 | 2.4 | 12.6 |
| A8 | | | | | | | | | | | 3.8 | 903 | 11.5 | 2.7 | 11.8 |
| A9 | 1.00 | 0.48 | 0.30 | 0.010 | 0.007 | 0.15 | | | | | 5.5 | 890 | 8.9 | 2.1 | 10.9 |
| A10 | 1.01 | 0.21 | 0.53 | 0.012 | 0.009 | 0.11 | | | | | 5.5 | 861 | 6.9 | 1.9 | 10.5 |
| A11 | 0.97 | 0.15 | 0.28 | 0.011 | 0.008 | 0.45 | | | | | 5.5 | 905 | 10.3 | 1.7 | 11.9 |
| A12 | 1.05 | 0.21 | 0.30 | 0.012 | 0.009 | 0.21 | | | | | 5.5 | 911 | 7.5 | 2.6 | 10.9 |
| A13 | | | | | | | | | | | 5.5 | 872 | 7.4 | 2.1 | 10.5 |
| A14 | 1.13 | 0.19 | 0.29 | 0.014 | 0.010 | 0.18 | | | | | 5.5 | 931 | 9.1 | 2.5 | 11.0 |
| A15 | | | | | | | | | | | 5.5 | 886 | 8.2 | 2.3 | 10.7 |
| A16 | 0.97 | 0.15 | 0.28 | 0.011 | 0.008 | 0.11 | 0.21 | | | | 5.5 | 835 | 7.5 | 1.2 | 10.2 |
| A17 | 1.02 | 0.19 | 0.31 | 0.013 | 0.005 | 0.19 | | 0.89 | | | 5.5 | 886 | 8.3 | 2.5 | 11.0 |
| A18 | 0.97 | 0.18 | 0.28 | 0.011 | 0.008 | 0.20 | | | 0.11 | | 5.5 | 874 | 6.4 | 1.7 | 10.6 |
| A19 | 1.00 | 0.22 | 0.50 | 0.011 | 0.007 | 0.18 | | | | 15 | 5.5 | 881 | 8.8 | 2.6 | 10.8 |
| A20 | 1.06 | 0.19 | 0.31 | 0.008 | 0.007 | 0.31 | | | 0.08 | 7 | 5.5 | 904 | 6.7 | 2.1 | 11.4 |
| A21 | 1.09 | 0.21 | 0.25 | 0.009 | 0.008 | 0.29 | | | | 9 | 5.5 | 811 | 7.3 | 1.3 | 10.3 |
| A22 | 1.05 | 0.20 | 0.33 | 0.008 | 0.007 | 0.30 | | 0.21 | | 8 | 5.5 | 918 | 9.5 | 2.9 | 10.5 |
| B1 | 1.19 | 0.19 | 0.35 | 0.010 | 0.004 | 0.21 | | | | | 5.5 | 883 | 7.2 | 2.3 | 10.6 |
| B2 | 1.00 | 0.75 | 0.32 | 0.015 | 0.009 | 0.19 | | | | | 5.5 | 885 | 8.2 | 2.8 | 10.5 |
| B3 | 1.00 | 0.26 | 1.05 | 0.012 | 0.008 | 0.18 | | | | | 5.5 | 888 | 11.5 | 2.7 | 11.3 |
| B4 | 1.05 | 0.21 | 0.31 | 0.018 | 0.005 | 0.71 | | | | | 5.5 | 876 | 7.9 | 2.2 | 11.4 |
| B5 | 0.96 | 0.19 | 0.30 | 0.012 | 0.008 | 0.20 | | | | | 5.5 | 889 | 9.5 | 6.5 | 11.8 |
| B6 | 0.97 | 0.15 | 0.28 | 0.011 | 0.008 | 0.45 | | | | | 5.5 | 856 | 4.1 | 1.5 | 10.9 |
| B7 | 1.02 | 0.19 | 0.31 | 0.013 | 0.005 | 0.19 | | | | | 5.5 | 810 | 7.5 | 0.8 | 10.3 |
| B8 | | | | | | | | | | | 3.8 | 902 | 16.8 | 2.6 | 12.6 |
| B9 | 1.05 | 0.21 | 0.30 | 0.012 | 0.009 | 0.21 | | | | | 5.5 | 778 | 5.8 | 2.1 | 12.6 |
| B10 | | | | | | | | | | | 5.5 | 863 | 7.5 | 1.8 | 6.5 |
| B11 | | | | | | | | | | | 5.5 | 912 | 8.1 | 4.3 | 11.1 |
| B12 | 1.11 | 0.19 | 0.31 | 0.014 | 0.010 | 0.18 | | | | | 5.5 | 989 | 6.5 | 1.6 | 10.9 |
| B13 | | | | | | | | | | | 5.5 | 841 | 4.8 | 2.5 | 11.9 |

[Table 2]

| No. | Wire rod | | | | | | | | | Drawability evaluation results | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Prior γ grain size (μm) | Pearlite area ratio (%) | Pro-eutectoid cementite area ratio (%) | Pro-eutectoid cementite average thickness (μm) | Total length of pro-eutectoid cementite per unit area (mm/mm$^2$) | Left side of Formula (A) | Tensile strength (MPa) | Left side of Formula (1) | Right side of Formula (1) | Wire diameter at wire break (mm) | True strain at wire break |
| A1 | 20.8 | 96.5 | 0.03 | 0.16 | 1.9 | 0.04 | 1120 | 1057 | 1147 | 0.84 | 3.8 |
| A2 | 23.4 | 95.6 | 0.05 | 0.15 | 3.5 | 0.08 | 1148 | 1090 | 1180 | 1.10 | 3.2 |
| A3 | 21.5 | 92.6 | 0.08 | 0.17 | 4.4 | 0.09 | 1123 | 1090 | 1180 | 1.10 | 3.2 |
| A4 | 38.2 | 98.2 | 0.00 | 0.00 | 0.0 | 0.00 | 1155 | 1090 | 1180 | 0.77 | 3.3 |
| A5 | 28.6 | 96.4 | 0.07 | 0.16 | 4.5 | 0.13 | 1104 | 1090 | 1180 | 0.77 | 3.7 |
| A6 | 27.8 | 95.6 | 0.09 | 0.15 | 6.2 | 0.17 | 1211 | 1147 | 1237 | 1.20 | 3.0 |
| A7 | 24.2 | 93.4 | 0.12 | 0.19 | 6.0 | 0.15 | 1194 | 1147 | 1237 | 0.84 | 3.4 |
| A8 | 25.6 | 97.6 | 0.00 | 0.00 | 0.0 | 0.00 | 1221 | 1147 | 1237 | 0.75 | 3.2 |
| A9 | 28.9 | 93.4 | 0.11 | 0.13 | 8.8 | 0.25 | 1180 | 1115 | 1205 | 1.10 | 3.2 |
| A10 | 26.1 | 95.6 | 0.14 | 0.20 | 7.6 | 0.20 | 1159 | 1113 | 1203 | 1.10 | 3.2 |
| A11 | 31.5 | 92.3 | 0.05 | 0.23 | 2.3 | 0.07 | 1178 | 1175 | 1265 | 1.20 | 3.0 |
| A12 | 35.4 | 93.6 | 0.12 | 0.18 | 6.9 | 0.24 | 1218 | 1183 | 1273 | 1.20 | 3.0 |
| A13 | 26.7 | 91.6 | 0.45 | 0.16 | 28.6 | 0.76 | 1194 | 1183 | 1273 | 1.20 | 3.0 |
| A14 | 39.4 | 94.6 | 0.46 | 0.20 | 23.5 | 0.93 | 1301 | 1254 | 1344 | 1.30 | 2.9 |
| A15 | 30.1 | 92.8 | 0.83 | 0.23 | 36.1 | 1.09 | 1293 | 1254 | 1344 | 1.20 | 3.0 |
| A16 | 22.3 | 95.3 | 0.08 | 0.18 | 4.8 | 0.11 | 1085 | 1073 | 1163 | 1.10 | 3.2 |
| A17 | 25.9 | 97.8 | 0.11 | 0.19 | 6.0 | 0.16 | 1209 | 1147 | 1237 | 1.10 | 3.2 |
| A18 | 25.0 | 95.6 | 0.08 | 0.20 | 4.6 | 0.12 | 1121 | 1100 | 1190 | 1.10 | 3.2 |
| A19 | 26.1 | 96.4 | 0.12 | 0.19 | 6.2 | 0.16 | 1195 | 1124 | 1214 | 1.10 | 3.2 |
| A20 | 33.4 | 94.4 | 0.71 | 0.21 | 28.4 | 0.95 | 1256 | 1223 | 1313 | 1.10 | 3.2 |
| A21 | 19.8 | 90.9 | 0.84 | 0.21 | 38.4 | 0.76 | 1285 | 1247 | 1337 | 1.30 | 2.9 |
| A22 | 41.1 | 98.6 | 0.28 | 0.18 | 10.8 | 0.44 | 1293 | 1210 | 1300 | 1.20 | 3.0 |
| B1 | 28.7 | 93.9 | 1.19 | 0.28 | 42.9 | 1.23 | 1384 | 1323 | 1413 | 1.55 | 2.5 |
| B2 | 26.2 | 94.5 | 0.09 | 0.18 | 5.2 | 0.14 | 1251 | 1127 | 1217 | 1.73 | 2.3 |
| B3 | 24.9 | 91.2 | 0.09 | 0.19 | 4.9 | 0.12 | 1294 | 1124 | 1214 | 1.55 | 2.5 |
| B4 | 23.8 | 88.6 | 0.12 | 0.21 | 6.1 | 0.15 | 1509 | 1333 | 1423 | 1.94 | 2.1 |
| B5 | 25.5 | 96.8 | 0.00 | 0.00 | 0.0 | 0.00 | 1256 | 1090 | 1180 | 1.73 | 2.3 |
| B6 | 24.7 | 90.8 | 0.91 | 0.35 | 26.5 | 0.65 | 1184 | 1175 | 1265 | 1.73 | 2.3 |
| B7 | 21.5 | 87.6 | 0.11 | 0.24 | 4.9 | 0.11 | 1054 | 1147 | 1237 | 1.55 | 2.5 |
| B8 | 29.8 | 96.3 | 0.00 | 0.00 | 0.0 | 0.00 | 1352 | 1147 | 1237 | 1.10 | 2.5 |
| B9 | 17.8 | 92.3 | 1.82 | 0.22 | 82.8 | 1.47 | 1196 | 1183 | 1273 | 1.73 | 2.3 |
| B10 | 27.4 | 85.6 | 0.68 | 0.21 | 32.7 | 0.90 | 1113 | 1183 | 1273 | 1.55 | 2.5 |
| B11 | 31.8 | 95.6 | 0.34 | 0.20 | 18.4 | 0.59 | 1285 | 1183 | 1273 | 1.55 | 2.5 |
| B12 | 45.3 | 92.6 | 0.88 | 0.21 | 42.6 | 1.93 | 1259 | 1234 | 1324 | 1.73 | 2.3 |
| B13 | 29.7 | 93.8 | 1.15 | 0.28 | 41.8 | 1.24 | 1284 | 1234 | 1324 | 1.94 | 2.1 |

**[0065]** Nos. A1 to A22 in Table 1 are examples of the present invention. Nos. B1 to B13 in Table 1 are comparative examples in which one or more of the compositions and the manufacturing conditions were outside appropriate ranges.

**[0066]** In both the example of the present invention and the comparative examples, a billet was heated to 1000°C to 1200°C in a heating furnace, and thereafter the start temperature of finish rolling was set to 750°C to 950°C. During the finish rolling, the temperature of a wire rod increased by deformation heating was controlled and wound into a coil form at a winding temperature shown in Table 1. Cooling after the winding was performed at an average cooling rate to 650°C after the winding (cooling rate 1 in Table 1), an average cooling rate from 650°C to 600°C (cooling rate 2 in Table 1), and an average cooling rate from 600°C to 300°C (cooling rate 3 in Table 1) under conditions shown in Table 1. By the above method, a wire rod having the wire diameter shown in Table 1 was obtained.

**[0067]** The area fraction of the pearlite and the area fraction of the pro-eutectoid cementite of the wire rod were measured by the following method.

**[0068]** First, the wire rod was cut, and the wire rod was embedded in a resin so that a cross section perpendicular to the longitudinal direction could be observed. The wire rod embedded in the resin was polished with abrasive paper and alumina abrasive grains, and was further mirror-finished to obtain a sample. The observed section of the sample (that is, the cross section of the wire rod) was corroded with a nital solution or a picral solution and then the observed section of the sample was observed with a scanning electron microscope (SEM). The nital solution used was a mixed solution of nitric acid and ethyl alcohol. Corrosion of the observed section of the sample was performed by a method of immersing the observed section in the nital solution having a concentration of 5% or less and a temperature of about 15°C to 30°C for several seconds to one minute, a method of wiping the observed section with absorbent cotton soaked with the nital solution having the above concentration and temperature, or the like. The picral solution used was a mixed solution of picric acid and ethyl alcohol. Corrosion of the observed section of the sample was performed by a method of immersing the observed section in the picral solution having a concentration of about 5% and a temperature of about 40°C to 60°C for 30 seconds to two minutes. After the corrosion, the observed section of the sample was immediately washed with water thoroughly, and was quickly dried with cold air or hot air.

**[0069]** Subsequently, using a photographing device attached to the SEM, a central part (a region within (1/5)R from the center of the wire rod with the radius of the wire rod as R) of the sample was photographed in a plurality of visual fields at a magnification of 2,000-fold or more so that the total observation visual field area was 0.08 $mm^2$ or more. Using the SEM photographs thereof and image analysis software such as particle analysis software, the area fraction of the pearlite and pro-eutectoid cementite of the central part of the wire rod was obtained. As the image analysis software, Luzex (registered trademark, manufactured by NIRECO CORPORATION.) was used.

**[0070]** In both the examples of the present invention and the comparative examples, the metallographic structure observed in the central part was a composite structure of one or two or more of pearlite, pro-eutectoid cementite, intergranular ferrite, and bainite.

**[0071]** The average thickness and length of the pro-eutectoid cementite were measured using the SEM photographs. The average thickness of the pro-eutectoid cementite was obtained by measuring the thicknesses of all pro-eutectoid cementite in the SEM photographs and calculating the average value thereof. The thickness of the pro-eutectoid cementite was obtained by measuring the thickness in a direction perpendicular to a prior austenite grain boundary. In a case of cementite having the same shape as the cementite 10a in FIG. 2, the thicknesses T1, T2, and T3 were measured, and the average thereof was taken as the thickness of the pro-eutectoid cementite. The length of the pro-eutectoid cementite was measured by drawing a line imaging the prior austenite grain boundary based on the shapes of the pro-eutectoid cementite in the SEM photographs and measuring the length along the line. Like the cementite 10a in FIG. 2, in a case of cementite without a particularly bent shape, a straight line imaging the prior austenite grain boundary was drawn along the major axis direction thereof and the length L1 was measured along the straight line. Like the cementite 10c in FIG. 4, in a case of pro-eutectoid cementite having a unique bent part, a line imagining the prior austenite grain boundary was drawn according to the shape, and the length of the pro-eutectoid cementite was measured along the line. Like the cementite 10b in FIG. 3, in a case of pro-eutectoid cementite having branches, the lengths of the branches were added. The total length of the pro-eutectoid cementite per unit area was set to the value obtained by dividing the sum of the lengths of pro-eutectoid cementite in a measurement visual field which was measured, by the area of the visual field. That is, the total length ($mm/mm^2$) of the pro-eutectoid cementite per unit area was the sum of the lengths of the pro-eutectoid cementite observed per unit area. Upon measurement, if necessary, a region including the pro-eutectoid cementite was photographed at a magnification of 3,000 to 5,000-fold and the average thickness and length of the pro-eutectoid cementite were measured.

**[0072]** The prior austenite grain size was measured using a wire rod which was quenched by water-cooling several rings from the final end of a coil immediately after winding after hot rolling. The quenched wire rod was cut, was embedded in a resin so as to observe a cross section thereof, and thereafter polished with alumina to obtain a sample. Thereafter, the polished sample was corroded with an alkaline picric acid solution to reveal prior austenite grain boundaries. Corrosion of the observed section of the sample was performed by immersing the observed section of the sample in the alkaline picric acid solution having a temperature of about 75°C to 90°C for 10 to 20 minutes. After the corrosion, the observed section of the sample was immediately washed with water thoroughly, and was quickly dried with cold air or hot air. The alkaline picric acid solution used for the corrosion of the observed section was a mixed solution of 2 parts of picric acid, 5 parts of sodium hydroxide, and 100 parts of water by weight.

**[0073]** The observed section of the sample was corroded by immersing the observed section of the sample in the alkaline picric acid solution having a temperature of about 75°C to 90°C for 10 to 20 minutes. After the corrosion, the observed section of the sample was immediately washed with water thoroughly, and was quickly dried with cold air or hot air. Thereafter, using an optical microscope, a central part (a region within (1/5)R from the center of the wire rod with the radius of the wire rod as R) of the observed section of the sample was photographed in a plurality of visual fields at a magnification of 400-fold or more so that the total observation visual field area was 0.18 $mm^2$ or more. Using the SEM photographs and the cutting method described in JIS G 0551: 2013, prior austenite grain sizes were measured. In the cutting method, 15 or more straight lines with a length of 400 μm were drawn at intervals of 100 μm so as not to overlap each other, and the grain sizes were evaluated by the number of grains trapped by straight lines of 6 mm or more in total.

**[0074]** The tensile strength was measured by the following method. In the wire rod, three rings were taken from each of a front part (a place closer to the tail end side than the front end side by 50 rings), a middle part (within 100 rings from the middle between the front end and the tail end in the coil), and a tail part (a place closer to the front end side than the tail end by 50 rings), and eight samples were taken from each ring at equal intervals, so that a total of 72 samples were taken. Using the samples, a tension test was conducted according to JIS Z 2241: 2011. The tensile strength of the wire rod was obtained by calculating the average value of the tensile strengths obtained from the 72 samples. The tension test was conducted with a sample length of 400 mm, a crosshead speed of 10 mm/min, and a chuck distance of 200 mm.

**[0075]** The drawability of the wire rod was evaluated by the following method. Ten rings were taken from the wire rod, were pickled to remove scale, and were subjected to a lime coating treatment. Thereafter, wire-drawing (dry wire-drawing) was performed thereon without a patenting treatment. The reduction of area per one pass during the wire-drawing was set to 17% to 23%. A case where wire-drawing was performed and the true strain at the time of a wire break was 2.9 or more was determined as passed due to excellent drawability. On the other hand, a case where wire-drawing was performed and the true strain at the time of a wire break was less than 2.9 was determined as failed due to poor drawability. The true strain was obtained by calculating -2 × In (diameter of drawn wire / diameter of wire rod). Here, "In" is the natural logarithm.

**[0076]** All of Nos. A1 to A22 are examples of the present invention, and showed excellent drawability that enables wire-drawing with a true strain of 2.9 or more without a patenting treatment.

**[0077]** On the other hand, since Nos. B1 to B13 did not satisfy some of the requirements of the present invention, the true strain at the time of a wire break was less than 2.9, and the drawability was inferior to the examples of the present invention.

**[0078]** Since No. B1 had a large C content, the area fraction of the pro-eutectoid cementite of the wire rod increased, the average thickness of the pro-eutectoid cementite increased, and furthermore, the total length of the pro-eutectoid cementite per unit area increased, so that the drawability of the wire rod decreased.

**[0079]** Since No. B2 had a large Si content and No. B3 had a large Mn content, the tensile strength of both the wire rods increased, so that the drawability decreased.

**[0080]** Since No. B4 had a large Cr content, the area fraction of the pearlite decreased, and the tensile strength increased, so that the drawability of the wire rod decreased.

**[0081]** Since Nos. B5 and B11 had large average cooling rates (cooling rate 2) at 650°C to 600°C, the tensile strength increased, so that the drawability of the wire rod decreased.

**[0082]** Since No. B6 had a small average cooling rate (cooling rate 1) to 650°C after winding, the average thickness of the pro-eutectoid cementite increased, resulting in a decrease in the drawability of the wire rod.

**[0083]** Since No. B7 had a small average cooling rate (cooling rate 2) at 650°C to 600°C, the tensile strength decreased, so that the drawability of the wire rod decreased.

**[0084]** Since No. B8 had a large average cooling rate (cooling rate 1) to 650°C after winding, the wire rod was excessively cooled, and the tensile strength increased, so that the drawability of the wire rod decreased.

**[0085]** Since No. B9 had a low winding temperature and a small average cooling rate (cooling rate 1) to 650°C after winding, the prior austenite grain size was refined, and the pro-eutectoid cementite precipitated in a large amount, so that the total length of the pro-eutectoid cementite per unit area increased and the drawability of the wire rod decreased.

**[0086]** Since No. B10 had a small average cooling rate (cooling rate 3) at 600°C to 300°C, the tensile strength of the wire rod decreased, so that the drawability of the wire rod decreased.

**[0087]** Since No. B12 had a high winding temperature, the prior austenite grain size increased, and furthermore, the total length of the pro-eutectoid cementite per unit area increased, so that the drawability of the wire rod decreased.

**[0088]** Since No. B13 had a small average cooling rate (cooling rate 1) to 650°C after winding, the area fraction of the pro-eutectoid cementite increased, the average thickness of the pro-eutectoid cementite increased, and furthermore, the total length of the pro-eutectoid cementite per unit area increased, so that the drawability of the wire rod decreased.

## Claims

**1.** A wire rod comprising, by mass%:

C: 0.90% to 1.15%;
Si: 0.10% to 0.50%;
Mn: 0.10% to 0.80%;
Cr: 0.10% to 0.50%;

Ni: 0% to 0.50%;
Co: 0% to 1.00%;
Mo: 0% to 0.20%;
B: 0% to 0.0030%;
P: limited to 0.020% or less;
S: limited to 0.010% or less; and
a remainder including of Fe and impurities,
wherein, when a radius of the wire rod is assumed to be R, in a structure observed in a central part within (1/5)R from a center of a cross section of the wire rod, an area fraction of pearlite is 90.0% or more, and an area fraction of pro-eutectoid cementite is 1.00% or less,
an average thickness of the pro-eutectoid cementite in the central part is 0.25 μm or less,
a total length of the pro-eutectoid cementite per unit area in the central part is less than 40.0 $mm/mm^2$,
a tensile strength of the wire rod satisfies Formula (1), and
a diameter of the wire rod is 3.0 to 5.5 mm,

$$1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 70 \leq TS \leq 1000 \times \text{C content (\%)} + 300 \times \text{Cr content (\%)} + 160 \ldots \text{Formula (1)}$$

where the total length of the pro-eutectoid cementite per unit area ($mm/mm^2$) is a sum of lengths of pro-eutectoid cementite observed per unit area, TS in Formula (1) represents the tensile strength of the wire rod when a unit of TS is MPa, "C content (%)" in Formula (1) represents an amount of C contained in the wire rod by mass%, and "Cr content (%)" represents an amount of Cr contained in the wire rod by mass%.

**2.** The wire rod according to claim 1,
wherein the wire rod contains any one or two or more of, by mass%:

Ni: 0.10% to 0.50%;
Co: 0.10% to 1.00%;
Mo: 0.05% to 0.20%; and
B: 0.0002% to 0.0030%.

**3.** The wire rod according to claim 1 or 2,
wherein the area fraction of the pro-eutectoid cementite is more than 0% to 1.00%.

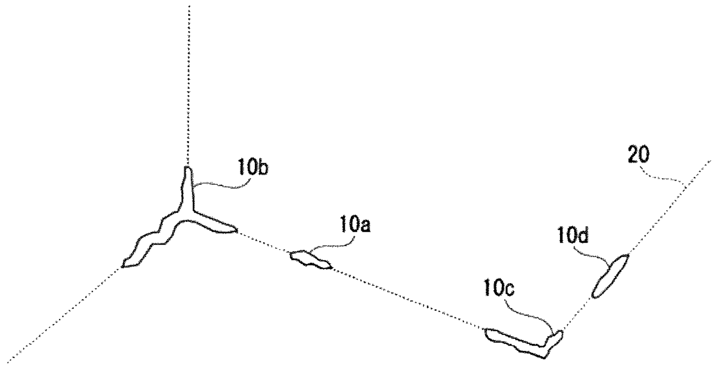
**4.** The wire rod according to any one of claims 1 to 3,
wherein the wire rod contains one or two or more of pro-eutectoid cementite, intergranular ferrite, and bainite in the structure observed in the central part.

**5.** A manufacturing method of the wire rod according to any one of claims 1 to 4, wherein a steel piece having a composition according to claim 1 is subject to:

a hot rolling into a diameter of 3.0 to 5.5 mm;
a winding at 940°C to 800°C; and
a cooling at an average cooling rate of 6.0 to 15.0 °C/s to 650°C after the winding, at an average cooling rate of 1.0 to 3.0 °C/s at 650°C to 600°C, and at an average cooling rate of 10.0 °C/s or more at 600°C to 300°C.

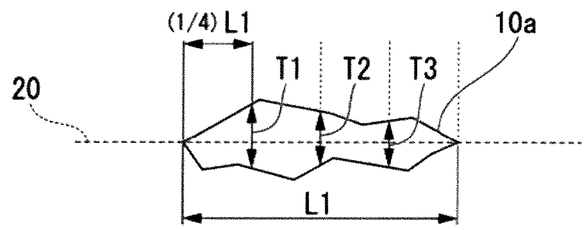
[FIG. 1]

FIG. 1



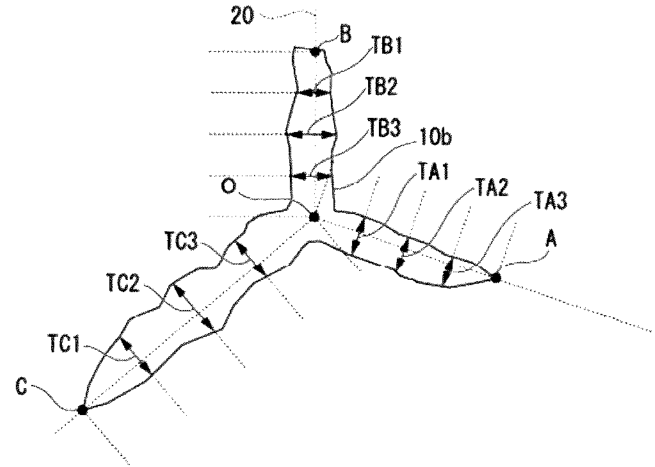

[FIG. 2]

FIG. 2



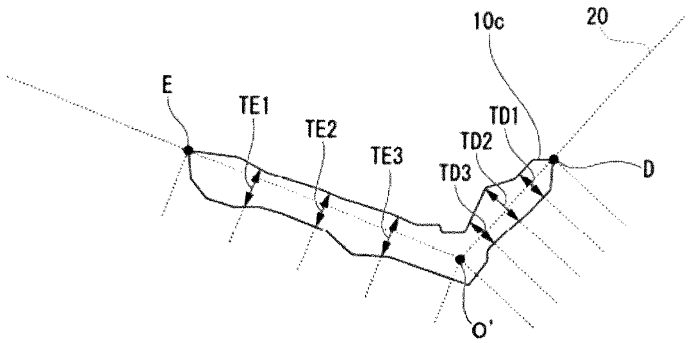

[FIG. 3]

FIG. 3




[FIG. 4]

FIG. 4



## INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/039166

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/18(2006.01)i, C22C38/54(2006.01)i, C21D8/06(2006.01)i, C21D9/52(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)
Int.Cl. C22C38/00-38/60, C21D8/06, C21D9/52

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

| | |
|---|---|
| Published examined utility model applications of Japan | 1922-1996 |
| Published unexamined utility model applications of Japan | 1971-2018 |
| Registered utility model specifications of Japan | 1996-2018 |
| Published registered utility model applications of Japan | 1994-2018 |

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | JP 2003-183778 A (SUMITOMO METAL INDUSTRIES, LTD.) 03 July 2003, claims, paragraphs [0001], [0009], [0063], [0072]-[0074], tables 1, 2 (Family: none) | 1-5 |
| A | JP 4-254526 A (NIPPON STEEL CORP.) 09 September 1992, claims, paragraphs [0001], [0008], tables 1, 2 (Family: none) | 1-5 |
| A | JP 5-295436 A (NIPPON STEEL CORP.) 09 November 1993, claims, paragraphs [0001], [0004], tables 1, 2 (Family : none) | 1-5 |
| A | JP 8-295933 A (NIPPON STEEL CORP.) 12 November 1996, claims, paragraphs [0001], [0009], tables 1, 2 (Family: none) | 1-5 |

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

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 16 January 2018 (16.01.2018) | 30 January 2018 (30.01.2018) |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Japan Patent Office<br>3-4-3, Kasumigaseki, Chiyoda-ku,<br>Tokyo 100-8915, Japan | Telephone No. |

Form PCT/ISA/210 (second sheet) (January 2015)

## REFERENCES CITED IN THE DESCRIPTION

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- JP 5179331 B **[0009]**
- JP 4088220 B **[0009]**
- JP 2001181789 A **[0009]**