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

(11) EP 3 228 721 A1

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

(43) Date of publication:
11.10.2017 Bulletin 2017/41

(21) Application number: **15865720.5**

(22) Date of filing: **02.12.2015**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***C22C 38/38*** *(2006.01)*
C21D 8/06 *(2006.01)* ***C21D 9/52*** *(2006.01)*

(86) International application number:
PCT/JP2015/083879

(87) International publication number:
WO 2016/088803 (09.06.2016 Gazette 2016/23)

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

(30) Priority: **05.12.2014 JP 2014247258**

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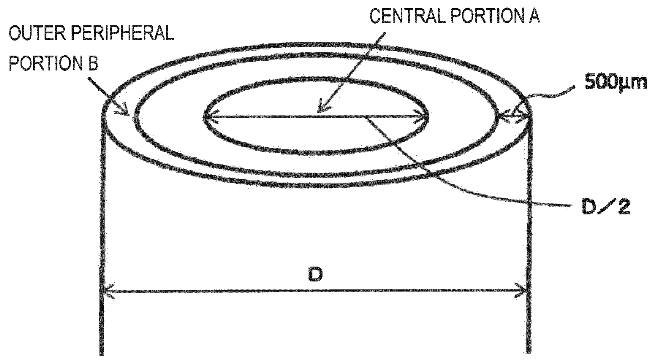
(54) HIGH-CARBON-STEEL WIRE ROD HAVING EXCELLENT WIRE DRAWING PROPERTIES

(57) Provided is a high-carbon steel wire rod after hot rolling, having a steel composition comprising, in mass%, C: 0.60% to 1.10%, Si: 0.02% to 2.0%, Mn: 0.1% to 2.0%, Cr: 0.3% to 1.6%, Al: 0.001% to 0.05%, N: limited to 0.008% or less, P: limited to 0.020% or less, S: limited to 0.020% or less, and a balance: Fe and unavoidable impurities. The high-carbon steel wire rod has a structure containing 95% or more pearlite in an area ratio in a cross section perpendicular to a wire rod longitudinal direction, wherein an average lamellar spacing of the pearlite is 50 to 100 nm, and an average value of a pearlite block size of a central portion that is an area within a circle with a diameter of D/2 with respect to a diameter D of the wire rod from a center of a cross section perpendicular to a wire rod longitudinal direction is as follows, 5 μm < pearlite block size < 15 μm.

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a high-carbon steel wire rod used for, after wire drawing, various wire ropes such as cables for power transmission lines and cables for suspension bridges, etc.

Background Art

[0002] A high-carbon steel wire rod used for various wire ropes such as cables for power transmission lines and cables for suspension bridges, etc., is required to have, after wire drawing, not only high strength and high ductility but also good wire drawability from the viewpoint of productivity. Thus far, high-quality high-carbon wire rods have been variously developed from such requirements.

[0003] For example, Patent Literature 1 proposes a technology to obtain good wire drawability by the reduction in the amount of solid solution N by the addition of Ti and the reduction in strain aging by solid solution Ti. Further, Patent Literature 2 proposes a technology to obtain low strength and good wire drawability by controlling the cementite form to a spheroidized form. Patent Literature 3 proposes a technology that specifies the amount of each of C, Si, Mn, P, S, N, Al, and O contained in a steel material and controls the area ratio of the second phase, ferrite, and the pearlite lamellar spacing, to obtain a wire rod excellent in wire drawability in which wire breaking is less likely to occur and by which die wear is suppressed to allow the life of the die to be extended. Patent Literature 4 proposes a high-carbon steel wire rod with high ductility that contains C: 0.6 to 1.1% and contains 95% or more of the pearlite structure, wherein the maximum value of the pearlite block grain size of pearlite of a central portion of a hot rolled wire rod measured by an EBSP apparatus is 45 μm or less and the average value thereof is 10 to 25 μm.

Citation List

Patent Literature

[0004]

Patent Literature 1: JP 2012-097300A
Patent Literature 2: JP 2004-300497A
Patent Literature 3: JP 2007-327084A
Patent Literature 4: JP 2008-007856A

Summary of Invention

Technical Problem

[0005] However, according to an experiment by the present inventors, it has been found that, even by the technologies described above, a distinctive effect such as an improvement in wire drawability was not always able to be obtained by the addition of Ti or the reduction in the amount of solid solution N in the case of a high strength rod of more than 1300 MPa. Furthermore, spheroidization heat treatment yields only low strength after wire drawing, and is not suitable for use as high-carbon steel wires.

[0006] The present invention has been made in view of such circumstances, and the present invention addresses an issue to provide a steel wire rod serving as a material for obtaining a steel wire having high strength and good wire drawability.

Solution to Problem

[0007] The present invention provides a high-carbon steel wire rod serving as a material of a high strength steel wire, and a gist of the present invention is as follows.

[0008]

(1) A high-carbon steel wire rod after hot rolling, having a steel composition containing, in mass%,
C: 0.60% to 1.10%,
Si: 0.02% to 2.0%,
Mn: 0.1% to 2.0%,

Cr: 0.3% to 1.6%,
Al: 0.001 % to 0.05%,
N: limited to 0.008% or less,
P: limited to 0.020% or less,
S: limited to 0.020% or less, and
a balance: Fe and unavoidable impurities, and
a structure containing 95% or more pearlite in an area ratio in a cross section perpendicular to a wire rod longitudinal direction,
wherein an average lamellar spacing of the pearlite is 50 to 100 nm, and
an average value of a pearlite block size of a central portion that is an area within a circle with a diameter of D/2 with respect to a diameter D of the wire rod from a center of a cross section perpendicular to a wire rod longitudinal direction is as follows, 5 μm < pearlite block size < 15 μm.

(2)
The high-carbon steel wire rod according to (1), in which, in an outer peripheral portion that is an area within 500 μm from an outer layer of the cross section perpendicular to the wire rod longitudinal direction, a degree of accumulation of crystal orientations <110> of ferrite in the pearlite structure is 1.3 or more.

(3)
The high-carbon steel wire rod according to (1), further containing, in mass%, Mo: 0.01% to 0.2%.

(4)
The high-carbon steel wire rod according to (1), further containing, in mass%, one or two of
Nb: 0.01% to 0.2%, and
V: 0.01% to 0.2%.

(5)
The high-carbon steel wire rod according to (1), further containing, in mass%, B: 0.0003% to 0.003%.

(6)
The high-carbon steel wire rod according to (1), containing Si: 0.02% to 1.0%.

(7)
The high-carbon steel wire rod according to (1), in which the average value of the pearlite block size is specified by a following expression, 5 μm < pearlite block size < 12 μm.

Advantageous Effects of Invention

[0009] According to the present invention, a high-carbon steel wire rod that has a tensile strength of 1300 MPa or more and yet has high ductility etc. can be provided; thus, the industrial contribution is very significant.

Brief Description of Drawings

[0010]

[FIG. 1] FIG. 1 is a diagram showing a central portion A and an outer peripheral portion B of a cross section perpendicular to the wire rod longitudinal direction.
[FIG. 2] FIG. 2 is a diagram showing the relationship between the wire drawing true strain and the cumulative rate of breaking.

Description of Embodiments

[0011] To solve problems like those described above, the present inventors conducted extensive investigation and research variously on the structure of the steel wire rod and the heat treatment method. As a result, the findings of (a) and (b) below have been obtained.

(a) The addition of Cr promotes the fine-making of the prior γ grain size, and makes fine the pearlite block size after transformation.
(b) The finer the average value of the pearlite block size observed in a central portion A (specified) of the wire rod, the better the wire drawability is.
(c) When <110> orientations of ferrite crystal orientation observed in an outer peripheral portion B (specified) of a cross section perpendicular to the wire rod longitudinal direction are gathered, crystal rotation during wire drawing is lessened, and therefore the occurrence of voids due to shear stress can be suppressed.

[0012] The ferrite crystal orientation in the wire rod longitudinal direction and the block size of pearlite of a steel wire rod have a distribution with variation from the center to the outer layer. FIG. 1 shows a central portion A and an outer peripheral portion B of a cross section perpendicular to the wire rod longitudinal direction. In the present specification, as shown in FIG. 1, for a wire rod with a diameter of D mm, the area within a circle with a diameter of 1/2D from the center is defined as a central portion A, and the area within 500 μm from the outer layer is defined as an outer peripheral portion B.

[0013] The pearlite block size can be measured by the electron back scatter diffraction (referred to as EBSD) method using the central portion A of FIG. 1 as the measurement site. For example, a cross section perpendicular to the wire rod longitudinal direction is mirror-polished with colloidal silica particles, and measurement by the EBSD method is performed around the center in the diameter direction; thus, a map of ferrite crystal orientations is created. The area of mapping is set to a rectangular area of which all the sides have a length of 500 μm or more, the pixel configuration is set to a regular hexagonal element array, and the measurement interval is set to 0.5 μm, for example.

[0014] The degree of accumulation of ferrite crystal orientations <110> in the wire rod longitudinal direction can be measured by using the outer peripheral portion B of FIG. 1 as the measurement site and plotting the crystal orientation of each pixel on a {110} pole figure. More specifically, the degree of accumulation of ferrite crystal orientations <110> can be measured by using the measurement result of the EBSD method to create a {110} pole figure and performing texture analysis or the like on the obtained pole figure. The degree of accumulation is expressed as the intensity ratio on the assumption that the case of the crystal orientation being random orientations is 1.

[0015] When the ferrite crystal orientation is identified by the EBSD method, the information of the crystal orientation of ferrite is given to each hexagonal pixel; as a result, the information of the angular difference of crystal orientation is defined at the boundary between adjacent pixels. When a pixel boundary with an inclination difference of 9° or more appears successively, such as when there is a ferrite crystal orientation inclination difference of 9° or more at the boundary between two pixels and there is 9° or more also at the pixel boundary adjacent to that boundary, they are combined together and defined as a pearlite block grain boundary.

[0016] When all the pixel boundaries extending from a triple junction of pixels have 9° or more, the pearlite block grain boundary branches. When the condition of the crystal orientation difference of the pixel boundary being 9° or more comes to an end on the way, the last pixel boundary is not regarded as a pearlite block grain boundary, and is not taken into account. In accordance with the above way of thinking, a pixel boundary having a ferrite orientation difference of 9° or more is defined over the entire rectangular area; when pixel boundaries surround one closed area, the area is defined as one pearlite block, and the pixel boundaries are defined as the pearlite block grain boundary. Pearlite block grain boundaries are described on the map of ferrite crystal orientation in this way, and the block size of pearlite is measured. However, the case where one grain of the defined pearlite block is formed of 25 or less pixels is treated as noise, and is not taken into account. Here, the pearlite block and the pearlite nodule are synonymous. Further, the pearlite is lamellar pearlite.

[0017] The lamellar spacing can be found by corroding a cross section perpendicular to the wire rod longitudinal direction with nital, drawing a line perpendicularly for 5 lamellar spacings at a place where the lamellar spacing is smallest in the photographed visual field with a SEM at a magnification of 10,000 times, and dividing the length of the 5 lamellar spacings by 5. The photographing with a SEM is performed on 10 or more visual fields, and the sum total of the lamellar spacings found in the visual fields is divided by the number of visual fields; thus, the average value is obtained.

[0018] The wire drawability is evaluated by dipping a test material with a length of 10 m in hydrochloric acid to remove scales, performing water washing, then performing bonderizing treatment, and performing dry wire drawing. The wire drawing can be performed using a die made of WC-Co super hard alloy and having a shape with a die approach (entire) angle of 20° and a bearing length of approximately 0.3 times of the diameter. The wire drawing rate may be set to 50 m/min, and a dry wire drawing lubricant mainly composed of sodium stearate and calcium stearate may be used.

[0019] When no wire breaking has occurred, the die diameter is reduced so that the rate of decrease in cross-sectional area is 20%, and wire drawing is performed until wire breaking occurs. The evaluation is finished at the time point when the total number of times of wire breaking is 20, and the degree of wire drawing is found from the wire diameter (the wire diameter before the start of wire drawing) D0 of the test material and the die diameter D at which wire breaking occurs, using the following formula.

$$\text{Degree of wire drawing } (\varepsilon) = 2 \times \ln(D0/D)$$

[0020] At each degree of wire drawing, the number of times of occurrence of breaking is divided by 20 (the total number of tests), and thereby the rate of breaking is found; and the cumulative rate of breaking until then is added to that rate of breaking; thus, the cumulative rate of breaking at each degree of wire drawing is found. FIG. 2 is a test result of a wire rod coil that serves as the criterion for assessing the wire drawability as good. When the degree of wire drawing is

1.7, the number of times of breaking is 1, and the cumulative rate of breaking on the vertical axis is 0.05 (1/20). When the degree of wire drawing is 1.9, the number of times of breaking is 5, and the rate of breaking is 0.25; when the cumulative rate of breaking before then (the degree of wire drawing: 1.7), i.e. 0.05, is added, the cumulative rate of breaking is 0.3. When the degree of wire drawing is at the maximum in the 20 tests, the cumulative rate of breaking is 1.0.

[0021] In the present invention, the degree of wire drawing at which the cumulative rate of breaking is 0.5 is found from a graph, and is defined as the wire drawability. As shown in FIG. 2, the wire drawability of the wire rod coil serving as the criterion for assessing the wire drawability as good is 2.23. Further, the rate of wire drawing at which the cumulative rate of breaking is 0.9 is 3.0, and the rate of wire drawing at which the cumulative rate of breaking is 1.0 is 3.12. Thus, in the present invention, the wire drawability being 2.23 or more is evaluated as good, it is preferable that the wire drawability being 2.53 or more be evaluated as good, and it is more preferable that the wire drawability being 2.95 or more be evaluated as good.

(With regard to steel wire rod)

[0022] Next, the components of the steel wire rod of the present invention are described. Herein, "%" for the components represents mass%.

<With regard to components>

C

[0023] C is an element that turns the structure into pearlite and improves the strength. If the amount of C is less than 0.60%, a non-pearlite structure such as grain boundary ferrite is produced; consequently, wire drawability is impaired, and the tensile strength of an ultra-thin steel wire is reduced. On the other hand, if the amount of C is more than 1.10%, a non-pearlite structure such as pro-eutectoid cementite is produced, and wire drawability is degraded. Thus, the amount of C is limited in the range of 0.60 to 1.10%. The amount of C is preferably set to 0.65% or more.

Si

[0024] Si is an element used for the deoxidation of steel, and also contributes to solid solution strengthening. To obtain the effect, 0.02% or more Si is added. The amount of Si is preferably set to 0.05% or more. On the other hand, if the amount of Si is more than 2.0%, surface decarburization is likely to occur in a hot rolling process; thus, the upper limit is set to 2.0%. The amount of Si is set to preferably 1.0% or less, and more preferably 0.5% or less.

Mn

[0025] Mn is an element used for deoxidation and desulfurization, and the added amount is 0.1 % or more. On the other hand, if the amount of Mn is more than 2.0%, pearlite transformation is significantly delayed, and the time of patenting treatment is increased; thus, the amount of Mn is set to 2.0% or less. The amount of Mn is preferably 1.0% or less.

Cr

[0026] Cr is an element that makes the prior γ grain size fine and makes the pearlite structure fine, and also contributes to strength increasing. To obtain the effect, 0.3% or more of Cr is added. On the other hand, if the amount of Cr is more than 1.6%, pro-eutectoid cementite is precipitated, and wire drawability is reduced; thus, the upper limit is set to 1.6%. The upper limit is preferably set to 1.3% or less. The upper limit is more preferably set to 1.0% or less.

Al

[0027] Al is an element having deoxidation action, and is needed to reduce the amount of oxygen in steel. However, if the Al content is less than 0.001%, this effect is hardly obtained. On the other hand, Al is likely to form a hard oxide-based inclusion; in particular, if the Al content is more than 0.05%, the formation of coarse oxide-based inclusions is significant, and consequently the reduction in wire drawability is significant. Thus, the Al content is set to 0.001 to 0.05%. A preferred lower limit is 0.01% or more, and a preferred upper limit is 0.04% or less.

N

[0028] N is an element that, during wire drawing in cold working, adheres to a dislocation to improve the strength of the steel wire, but reduces wire drawability. In particular, if the N content is more than 0.008%, the reduction in wire drawability is significant. Thus, the N content is limited to 0.008% or less. The N content is preferably 0.005% or less.

P

[0029] P is likely to be segregated in steel; when P is segregated, eutectoid transformation is significantly delayed, and consequently eutectoid transformation is less likely to be completed and hard martensite is likely to be formed. To prevent this, the P content is limited to 0.02% or less.

S

[0030] When there is a large amount of S, it forms a large amount of MnS, and reduces the ductility of steel; thus, the S content is limited to 0.020% or less. The S content is preferably 0.01% or less.

Mo

[0031] The addition of Mo is optional. When Mo is added, there is an effect of enhancing the tensile strength of the steel wire rod. To obtain this effect, it is desirable to add 0.02% or more of Mo. However, if the Mo content is more than 0.20%, the martensite structure is likely to be produced, and wire drawability is reduced. Thus, the Mo content is preferably 0.02 to 0.20%. It is more preferably 0.08% or less.

V

[0032] The addition of V is optional. When V is added, the V forms a carbonitride in the steel wire rod, and reduces the pearlite block size and improves wire drawability. To obtain this effect, it is desirable to add 0.02% or more of V. However, if the V content is more than 0.20%, a coarse carbonitride is likely to be produced, and wire drawability may be reduced. Thus, the V content is preferably 0.02 to 0.20%. It is more preferably 0.08% or less.

Nb

[0033] The addition of Nb is optional. When Nb is added, the Nb forms a carbonitride in the steel wire rod, and reduces the pearlite block size and improves wire drawability. To obtain this effect, it is desirable to add 0.002% or more of Nb. However, if the Nb content is more than 0.05%, a coarse carbonitride is likely to be produced, and wire drawability may be reduced. Thus, the Nb content is preferably 0.002 to 0.05%. It is more preferably 0.02% or less.

Ti

[0034] The addition of Ti is optional. When Ti is added, the Ti forms a carbide or a nitride in the steel wire rod, and reduces the pearlite block size and improves wire drawability. To obtain this effect, it is desirable to add 0.002% or more of Ti. However, if the Ti content is more than 0.05%, a coarse carbide or nitride is likely to be formed, and wire drawability may start to decrease. Thus, the Ti content is preferably set to 0.02 to 0.05%. It is more preferably 0.03% or less.

B

[0035] The addition of B is optional. When B is added, the B forms BN out of solid solution N in the steel wire rod, and reduces the amount of solid solution N in the steel and improves wire drawability. To obtain this effect, it is desirable to add 0.0003% or more of B. However, if the B content is more than 0.003%, a coarse nitride is likely to be produced, and wire drawability may be reduced. Thus, the B content is preferably 0.0003 to 0.003%. It is more preferably 0.002% or less.

<With regard to metal structure>

[0036] Next, the metal structure of the steel wire rod of the present invention is described.

Area ratio

[0037] A non-pearlite structure such as pro-eutectoid ferrite or pro-eutectoid cementite is a cause of the occurrence of a crack during the final wire drawing. In an embodiment of the present invention, the area ratio of pearlite is set to 95% or more in order to enhance wire drawability. The balance is non-pearlite structures such as pro-eutectoid ferrite and pro-eutectoid cementite. The metal structure mentioned above can be identified by taking, as a sample, a cross section of the wire rod in the direction perpendicular to the wire rod longitudinal direction, mirror-polishing the cross section, and then observing the cross section with a scanning electron microscope. The area ratio of each metal structure can be found from the observation result obtained with a scanning electron microscope using the planar segmentation method or the point counting method. The observation magnification is preferably set to, for example, 1000 times or more, and the observation area is preferably set to, for example, 1000 μm^2 or more. In the case where the area ratio is identified by, for example, the point counting method, the number of measurement points is preferably set to 200 or more.

Block size of pearlite

[0038] As described in the above findings, if the block size of pearlite (hereinafter, occasionally referred to as a pearlite block size) is larger than 15 μm, wire drawability is reduced; thus, the pearlite block size is set to 15 μm or less. It is preferably 12 μm or less. Further, if the pearlite block size is 5 μm or less, the amount of non-pearlite structures is increased; thus, the lower limit is set to 5 μm.

Degree of accumulation of ferrite crystal orientations <110>

[0039] When ferrite crystal orientations <110> are accumulated in the outer peripheral portion of a cross section perpendicular to the wire rod longitudinal direction, orientation rotation during wire drawing can be suppressed, and void formation due to shear deformation is suppressed. In the present invention, the degree of accumulation of ferrite crystal orientations <110> at which this effect is significant is set to 1.3 or more. It is preferably 1.5 or more, and more preferably 1.7 or more.

[0040] The pearlite block size and the degree of accumulation of ferrite crystal orientations <110> can be identified by an EBSD method like that mentioned above.

Lamellar spacing

[0041] The metal structure in the present invention is mainly formed of pearlite; it is aimed to achieve, as the tensile strength of the steel wire rod, 1300 MPa or more, preferably 1350 MPa or more, and more preferably 1400 MPa or more. To obtain the strength, the average lamellar spacing of pearlite shown in Examples described later needs to be 100 nm or less. If the average lamellar spacing of pearlite is less than 50 nm, the bainite structure other than pearlite coexists, and the target strength is not obtained and the rate of wire drawing hardening is reduced; thus, the lower limit is set to 50 nm.

<With regard to method for producing steel wire rod>

[0042] Next, a method for producing a steel wire rod of the present invention is described using a specific example. The following description is only an example for describing the present invention, and does not limit the scope of the present invention.

[0043] A steel wire rod of the present invention is produced by smelting and casting steel containing the components mentioned above by the usual method and performing hot rolling on the resulting steel piece. The hot rolling is performed while the steel piece is heated to approximately 1150°C. The finishing temperature of hot rolling is 740 to 880°C. In order to produce pearlite transformation after finishing rolling, cooling (the primary cooling) is performed by a means such as air blast cooling, mist cooling, or water cooling at 25°C/sec to 40°C/sec until the temperature reaches 550°C to 650°C, the temperature is kept in the range of these temperatures for 30 seconds to 180 seconds, then cooling (the secondary cooling) is performed by a means such as air cooling or water cooling at 2°C/sec or more up to 300°C, and cooling is performed up to room temperature by a means such as allowing to cool. The diameter of the wire rod is not particularly limited as long as work hardening needed when the wire rod is made into a steel wire can be ensured.

[0044] For the finishing temperature of hot rolling, if it is higher than 880°C, the effect of making the prior γ grain size fine is reduced; thus, it is set to 880°C or less. Further, if rolling is performed at less than 740°C, pro-eutectoid ferrite may be precipitated during rolling; thus, the lower limit is set to 740°C.

[0045] For the cooling rate in the primary cooling, if it is less than 25°C/sec, the prior γ grain size is made coarse; thus, the lower limit is set to 25°C/sec. Cooling at more than 40°C/sec is difficult in the actual production; thus, the cooling rate is set to 40°C/sec or less.

[0046] For the holding temperature, if it is more than 650°C, the prior γ grain size is made coarse, and the strength is reduced; thus, the upper limit is set to 650°C. Further, if the holding temperature is less than 550°C, the amount of non-pearlite structures is increased; thus, the lower limit is set to 550°C.

[0047] For the holding time, if it is less than 30 seconds, pearlite transformation is not completed, and the amount of non-pearlite structures is increased; thus, the lower limit is set to 30 seconds. Further, holding for more than 180 seconds worsens productivity, and spoils the shape of lamellar pearlite and reduces the strength of the wire rod; thus, the upper limit is set to 180 seconds.

[0048] In the secondary cooling, if slow cooling at less than 2°C/sec, such as furnace cooling, is performed in the temperature range of 300°C or more, the strength is reduced; thus, the lower limit of the cooling rate of the secondary cooling up to 300°C is set to 2°C/sec. The cooling rate of the cooling from 300°C to room temperature is not limited.

[Examples]

[0049] The steel wire rod and the method for producing a steel wire rod according to an embodiment of the present invention will now be specifically described with reference to Examples. Examples shown below are only examples of the steel wire rod and the method for producing a steel wire rod according to an embodiment of the present invention, and the steel wire rod and the method for producing a steel wire rod according to the present invention are not limited to the examples described below.

[0050] In regard to high-carbon steel hot rolled wire rods of the component compositions shown in Table 1, wire rods that had the pearlite structure in common but in which the pearlite block size of the central portion, the degree of accumulation of ferrite crystal orientations <110> of the outer layer portion, and the tensile strength were variously different were produced by changing the hot rolling conditions shown in Table 2. These wire rods were evaluated with the wire drawing critical strain. The results are shown in Table 3.

[Table 1]

Steel type	C	Si	Mn	Cr	Al	Mo	B	Nb	V	Ti	
A	0.82	0.2	0.5	0.5	0.029	-	-	-	-	-	Invention steel
B	1.07	0.05	0.1	1.2	0.028	-	-	-	-	-	Invention steel
C	0.62	1.5	1.5	0.3	0.004	0.1	-	-	-	-	Invention steel
D	0.92	0.2	0.5	0.5	0.045	-	0.002	-	-	-	Invention steel
E	1.08	0.05	0.5	0.8	0.030	-	-	0.01	0.1	-	Invention steel
F	0.83	0.15	0.2	0.7	0.035	-	-	-	-	0.03	Invention steel
G	0.92	0.05	0.5	0.1	0.004	-	-	-	-	-	Comparative steel
H	0.82	0.2	2.5	0.5	0.018	-	-	-	-	-	Comparative steel
I	1.35	0.05	0.5	1	0.022	-	-	-	-	-	Comparative steel

[Table 2]

Production conditions	Heating temperature (°C)	Finishing rolling temperature (°C)	Primary cooling rate (°C/sec)	Holding temperature (°C)	Holding time (sec)	Secondary cooling rate (°C/sec)	
a	1150	770	35	575	40	7	Invention Example
b	1150	770	7	600	60	7	Comparative Example
c	1150	800	30	670	120	7	Comparative Example
d	1150	880	30	625	60	7	Invention Example
e	1150	760	30	550	5	7	Comparative Example
f	1150	900	25	600	40	7	Comparative Example

(continued)

Production conditions	Heating temperature (°C)	Finishing rolling temperature (°C)	Primary cooling rate (°C/sec)	Holding temperature (°C)	Holding time (sec)	Secondary cooling rate (°C/sec)	
g	1150	770	35	575	600	7	Comparative Example
h	1150	700	35	575	40	7	Comparative Example
i	1150	770	35	575	40	0.1	Comparative Example

[Table 3]

No.	Steel type	Production conditions	Structure and characteristics of steel wire rod					Steel wire characteristics	
			Pearlite area ratio (%)	PBS (μm)	Lamellar (nm)	Degree of accumulation of {110}	Tensile strength	Wire drawing critical strain (ε)	
1	A	a	98	9	72	1.4	1320	2.9	Present Invention
2	A	d	98	11	73	1.3	1316	2.4	
3	B	d	98	8	91	1.3	1356	3.1	
4	B	a	98	6	62	1.5	1456	4.0	
5	C	a	99	10	66	1.3	1306	2.9	
6	D	a	97	9	68	1.3	1423	2.9	
7	D	a	98	8	66	1.5	1411	3.4	
8	E	a	98	6	60	1.3	1523	3.7	
9	F	a	98	8	62	1.5	1484	3.2	
10	B	c	97	13	104	1.6	1269	3.4	Comparative Example
11	G	d	98	18	72	1.4	1311	1.5	
12	H	a	30	6	-	1.0	1623	0.4	
13	I	a	91	4	99	1.9	1326	2.0	
14	A	e	13	-	-	1.3	1271	1.5	
15	C	b	99	21	63	1.4	1317	2.0	
16	A	g	98	9	76	1.4	1193	2.9	
17	A	h	21	-	-	1.7	936	1.5	
18	A	f	99	26	72	1.4	1320	2.0	
19	A	i	98	10	71	1.4	1267	2.9	

[0051] A specific method for producing these high-carbon steel wire rods is described below. Smelting was performed with a converter so as to obtain the chemical components of the wire rod shown in Table 1, the resulting steel ingot was subjected to blooming to produce billets of a 155-mm square, and the billet was heated to approximately 1150°C and was then hot rolled in the range of the end temperature of rolling of 740°C to 880°C; thus, a wire rod with a diameter of 10 mm was obtained.

[0052] The wire rod after finishing the hot rolling mentioned above was subjected to the jetting of cooling water from nozzles in a cooling zone provided on a rolling-line, and was immediately cooled to a temperature in the range of 550°C to 650°C. At this time, the amount of water and the time of water cooling were changed to control the peak temperature. Further, the wire rod was subjected to air blast cooling to be cooled at a cooling rate of 5°C/sec to 25°C/sec to a temperature in the range of 650°C to 550°C. After that, the wire rod was held in the range of these temperatures for approximately 60 seconds to complete pearlite transformation, and was cooled by air cooling up to room temperature.

[0053] The pearlite area ratio (%), the pearlite block size, the lamellar spacing, the ferrite crystal orientation, and the tensile strength of these steel wire rods were measured.

[0054] The pearlite area ratio was found by cutting the wire rod and mirror-polishing a transverse cross section thereof to prepare a sample, etching the sample with a mixed liquid of nitric acid and ethanol, and observing a central portion between the surface and the center of the wire rod at a magnification of 2000 times.

[0055] The pearlite block size and the lamellar spacing were measured in an area of 62,500 μm^2 within 5 mm around the center of the steel wire rod. The degree of accumulation of ferrite orientations <110> was measured in an area of 62,500 μm^2 within 500 μm from the outer layer using an EBSD measuring apparatus manufactured by TSL Solutions K.K.

[0056] The tensile test was performed in accordance with JIS Z 2241. The wire drawability was evaluated by performing dry wire drawing in the above manner, plotting the relationship between the wire drawing true strain and the cumulative rate of breaking, with the total number of times of wire breaking set to 20, and taking, as the evaluation value, the wire drawing true strain at which the cumulative rate of breaking was 50%. The results are shown in Table 3. PBS represents the average of the pearlite block size.

[0057] In No. 10, the holding temperature is high; consequently, the lamellar spacing is large, and the tensile strength is insufficient.

[0058] In No. 11, the amount of Cr is low, and the fine-making of the pearlite block size is insufficient; consequently, the wire drawing critical strain is small.

[0059] In No. 12, the amount of Mn is large, and pearlite transformation is not finished and the pearlite area ratio is very small; consequently, the wire drawing critical strain is small.

[0060] In No. 13, the amount of C is high, and pro-eutectoid cementite is produced; consequently, the pearlite area ratio is small, and the wire drawing critical strain is small.

[0061] In No. 14, the holding time is short, and the secondary cooling is performed before pearlite transformation is completed; consequently, the pearlite area ratio is small, and the wire drawing critical strain is small.

[0062] In No. 15, the primary cooling rate is small, and the prior γ grain size is made coarse; consequently, the pearlite block size is large, and the wire drawing critical strain is small.

[0063] In No. 16, the holding time is long, and the shape of lamellar pearlite is spoiled and the tensile strength is insufficient.

[0064] In No. 17, the finishing rolling temperature is low; a large amount of pro-eutectoid ferrite is produced and the tensile strength is insufficient, and the wire drawing critical strain is small.

[0065] In No. 18, the finishing rolling temperature is high, and the prior γ grain size is made coarse; consequently, the pearlite block size is large, and the wire drawing critical strain is small.

[0066] In No. 19, the secondary cooling rate is small; the shape of lamellar pearlite is spoiled, and the tensile strength is reduced.

Claims

1. A high-carbon steel wire rod after hot rolling, having a steel composition comprising, in mass%,
C: 0.60% to 1.10%,
Si: 0.02% to 2.0%,
Mn: 0.1% to 2.0%,
Cr: 0.3% to 1.6%,
Al: 0.001% to 0.05%,
N: limited to 0.008% or less,
P: limited to 0.020% or less,
S: limited to 0.020% or less, and
a balance: Fe and unavoidable impurities, and

a structure containing 95% or more pearlite in an area ratio in a cross section perpendicular to a wire rod longitudinal direction,
wherein an average lamellar spacing of the pearlite is 50 to 100 nm, and
an average value of a pearlite block size of a central portion that is an area within a circle with a diameter of D/2 with respect to a diameter D of the wire rod from a center of a cross section perpendicular to a wire rod longitudinal direction is as follows, 5 μm < pearlite block size < 15 μm.

2. The high-carbon steel wire rod according to claim 1, wherein, in an outer peripheral portion that is an area within 500 μm from an outer layer of the cross section perpendicular to the wire rod longitudinal direction, a degree of accumulation of crystal orientations <110> of ferrite in the pearlite structure is 1.3 or more.

3. The high-carbon steel wire rod according to claim 1, further comprising, in mass%, Mo: 0.02% to 0.20%.

4. The high-carbon steel wire rod according to claim 1, further comprising, in mass%, one or two or more of
Nb: 0.002% to 0.05%,
V: 0.02% to 0.20%, and
Ti: 0.002% to 0.05%.

5. The high-carbon steel wire rod according to claim 1, further comprising, in mass%, B: 0.0003% to 0.003%.

6. The high-carbon steel wire rod according to claim 1, comprising Si: 0.02% to 1.0%.

7. The high-carbon steel wire rod according to claim 1, wherein the average value of the pearlite block size is specified by a following expression,

$$5\ \mu m < \text{pearlite block size} < 12\ \mu m.$$

FIG. 1

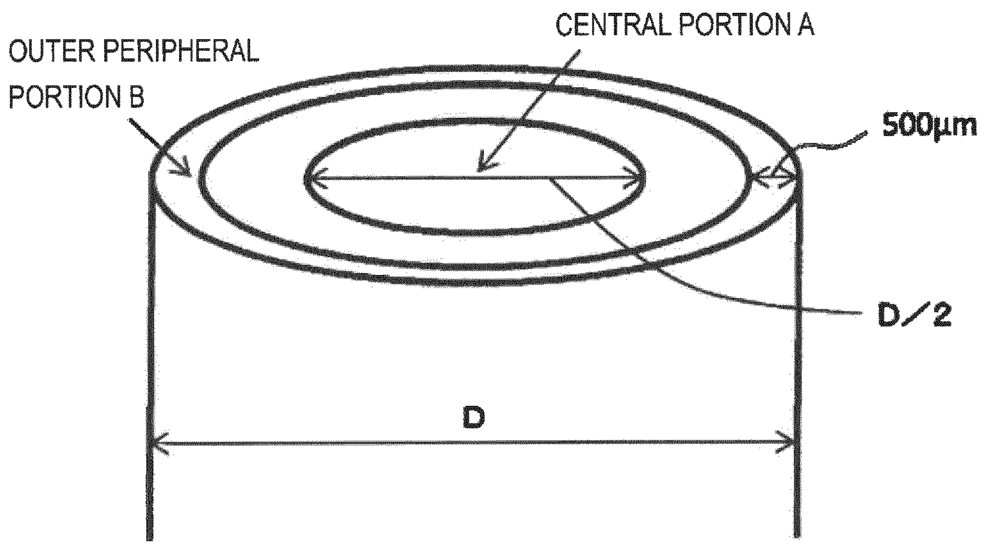
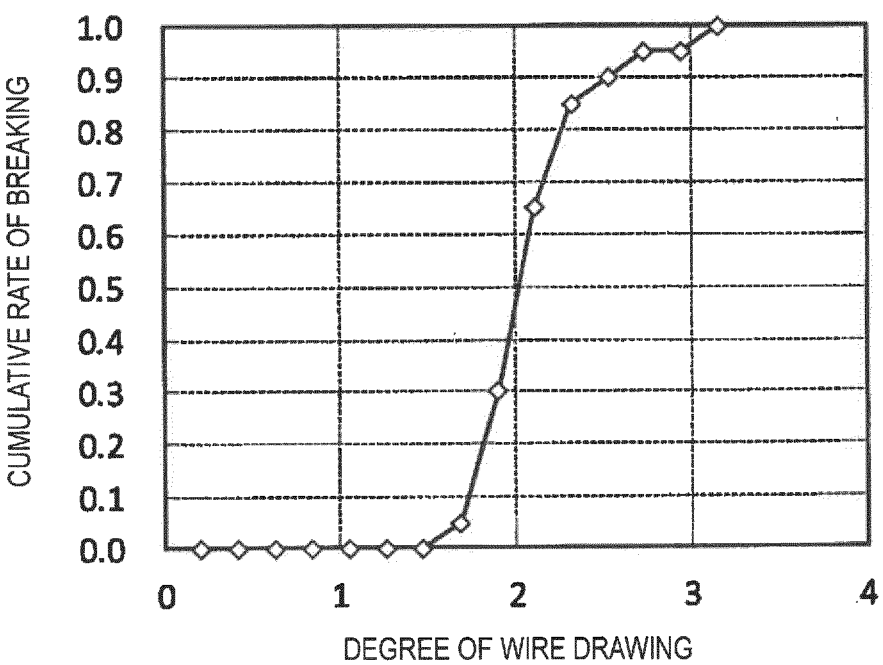

CENTRAL PORTION A
OUTER PERIPHERAL
PORTION B
500μm
D/2
D

FIG. 2


CUMULATIVE RATE OF BREAKING
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
DEGREE OF WIRE DRAWING

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2015/083879

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/38*(2006.01)i, *C21D8/06*(2006.01)n, *C21D9/52*(2006.01)n

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-C22C38/60, C21D8/06, C21D9/52

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2012/124679 A1 (Nippon Steel Corp.), 20 September 2012 (20.09.2012), claims; 0001 to 0011, 0014 to 0016, 0020 to 0023, 0029 to 0032, 0039, 0053 to 0059, 0062 to 0069, 0073; tables 1, 3; fig. 3 & US 2014/0000767 A1 claims; 0001 to 0014, 0021 to 0023, 0030 to 0033, 0043 to 0049, 0059 to 0060, 0086 to 0096, 0099 to 0106, 0112 to 0113; tables 1, 1-continued, 3, 3-continued; fig. 3 & JP 5224009 B2 & EP 2687619 A1 & CN 102959115 A & KR 10-2013-0034029 A	1,3-7 2

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

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 February 2016 (19.02.16)	08 March 2016 (08.03.16)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/083879

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	KR 10-2011-0047383 A (POSCO), 09 May 2011 (09.05.2011), claims; 0001 to 0005, 0010 to 0011, 0014, 0022, 0028, 0034, 0043; table 1; fig. 5 (Family: none)	1-7
A	JP 2010-229469 A (Nippon Steel Corp.), 14 October 2010 (14.10.2010), (Family: none)	1-7
A	JP 2008-7856 A (Nippon Steel Corp.), 17 January 2008 (17.01.2008), (Family: none)	1-7
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